

# Application Specific Lighting: Outdoor Area and Horticultural/Agricultural



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# Project Summary

## Timeline: New scope/continuing work

Start date: 10/1/2018

Planned end date: 9/30/2021

### Key Milestones – FY19

1. Outdoor lighting & resiliency recommendations for National Park Service 3/31/2019
2. Horticultural lighting literature review 6/30/2019 (pt 1) and 9/30/19 (pt 2)

## Budget:

### **Total Project \$ to Date:**

- DOE: \$946k
- Cost Share: \$0

### **Total Project \$:**

- DOE: \$3946k
- Cost Share: \$0

## Key Partners:

National Park Service
Illuminating Engineering Society
Delaware Valley Regional Planning Council
VA Tech Transportation Institute
Adler Planetarium

## Project Goals and Outcomes:

- Decrease outdoor lighting energy use at least 75% by 2030 through increased luminaire and application efficiency, including optimized intensity, distribution, spectrum and connected controls
- Develop and support new metrics, methods of measurement, and recommended practices for horticultural and animal production lighting using SSL systems that optimize spectrum, intensity, distribution, timing and duration
- Contribute to BTO goal to decrease overall lighting energy use intensity 30% by 2030, relative to 2010

# Team



**Bruce Kinzey**  
Principal Investigator  
Chair, IES Sky Glow  
Calculations Committee  
Former Director MSSLC  
MS Ag & Industrial  
Engineering



**Kelly Gordon**  
Program Manager  
Adv Lighting Team  
Lead  
Masters Public  
Policy



**Naomi Miller**  
Pedestrian-scale  
outdoor lighting design  
Glare metrics  
Lighting designer  
Fellow of IES, IALD  
MS Lighting



**Alp Durmus** (Post-Doc)  
Analysis of light at night  
spectral content  
Lighting spectrum for  
horticulture lighting  
Spectral optimization  
PhD Architecture  
BSEE, MS Arch Lighting



**Jason Tuenge**  
Outdoor lighting  
specifications &  
standards  
BS Arch Eng  
Masters Data Science  
(in progress)



**Michael Poplawski**  
PI Connected Lighting  
City of Chicago Smart  
Lighting Program advisor  
BSEE, MSEE



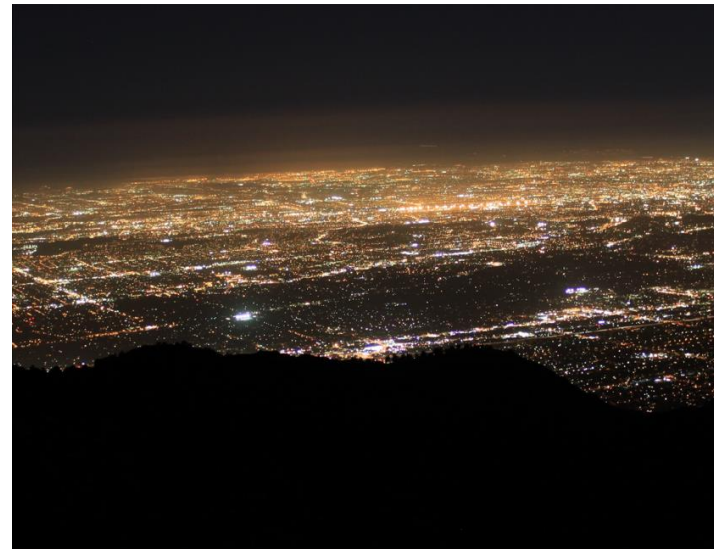
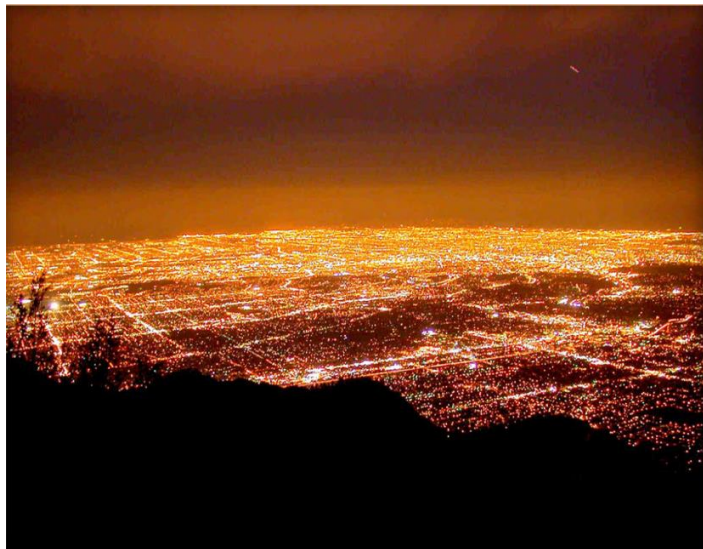
**Anay Waghale**  
Horticultural lighting  
technology & metrics  
Electrical engineer  
BSEE, MSEE

Specialized expertise  
necessary for  
atmospheric spectral  
measurements and  
horticulture and  
agriculture lighting  
topics to be addressed  
through subcontracts  
with key researchers.

# Challenge – Outdoor Lighting

- LED outdoor lighting conversions well underway
- Concerns about spectrum: sky glow/light pollution, blue light
  - Has delayed conversions in some cities
  - Pressure to install 2700K LEDs ~ 10% less efficient compared to 4000K
  - Some calls for amber LEDs ~40% less efficient
- More effective solutions: decrease output, eliminate uplight, use controls
- Project goal: decrease outdoor lighting energy use at least 75% by 2030 through increased luminaire and application efficiency, including optimized intensity, distribution, spectrum, and connected controls

Los Angeles from Mt. Wilson, 2008 and 2012 (~1/2 way through conversion)



# Approach – Outdoor Lighting

- Focus on application efficiency: directing light where and when it is needed
- Computer model: sky glow impact of LED relative to high pressure sodium
  - Variables: spectrum, light output, uplight, viewing location
  - Light output and distribution had the biggest effect
- Validate modeled results with real-world data
  - Collaborate with recognized experts in atmospheric light measurement and astronomical observation impacts

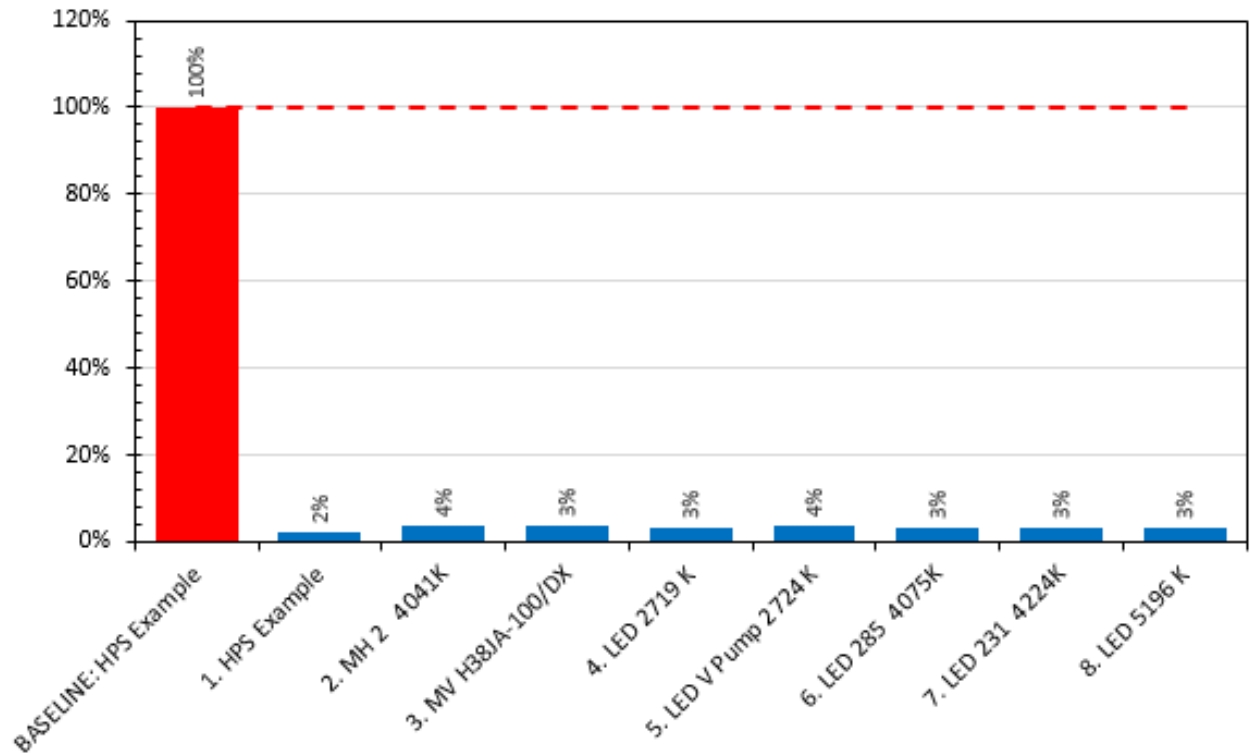


# Progress – Outdoor Lighting Modeling

## Sky Glow Comparison Tool

- Tutorial webinar conducted November 2018

Relative Sky Glow with Specified Conditions  
Percent of baseline



Shows impact of eliminating uplight and decreasing total lumen output 50%

INPUT CONDITIONS

**1. Scenario Parameters**

Observer location:

Atmospheric condition:

Weighting function:

**2. Baseline Light Source Characteristics**

Percent uplight:

Baseline source:

**3. Comparison Light Source(s) Characteristics**

Percent uplight:

Lumen output (% of baseline):

RESULTS

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

Source Label	Relative Sky Glow
BASELINE: HPS Example	1.00
1. HPS Example	0.02
2. MH 2 4041K	0.04
3. MV H38JA-100/DX	0.03
4. LED 2719 K	0.03
5. LED V Pump 2724 K	0.04
6. LED 285 4075K	0.03
7. LED 231 4224K	0.03
8. LED 5196 K	0.03

# Progress – Outdoor Lighting Lumen Equivalency

## Real-world experience

Location	Lumens Pre (HPS)	Lumens Post (LED)	Reduction
Cambridge, MA	54 million	22.4 million	59%
Tucson, AZ	450 million	160 million	64%
Portland, OR (PNNL est.)	362 million	165 million	54%

Source: PNNL

$$\phi_{LED} = \frac{\phi_{HID} * LLF_{HID}}{1.35 * LLF_{LED}}$$

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$$\phi_{LED} = \frac{15,800 \text{ lumens} * 0.64}{1.35 * 0.78}$$

Examples

$$\phi_{LED} = \frac{37,900 \text{ lumens} * 0.50}{1.35 * 0.78}$$

$$\phi_{LED} = 9,603 \text{ lumens}$$

$$\phi_{LED} = 18,047 \text{ lumens}$$

LED: 60% of HID lumens

LED: 48% of HID lumens



Metrics in Motion: Lumen Equivalency  
April 2, 2019 - Webinar



# Impact – Outdoor Lighting

- PNNL modeling and field validation data support high application efficiency while decreasing light pollution
- Project goal: enable higher energy savings for outdoor lighting
  - 76-79% energy savings in 2030 if SSL program goals are met
  - Additional 216 tBTU annual savings; ~2m homes equivalent energy use

Area and Roadway Lighting		2017	2020	2025	2030	2035
Current SSL Path	Source Energy Savings (tBTU) <sup>3</sup>	89	161	248	283	303
	Source Energy Savings (%)	21%	37%	55%	61%	63%
DOE SSL Program Goals	Source Energy Savings (tBTU)	94	182	302	356	380
	Source Energy Savings (%)	22%	42%	67%	76%	79%

Parking Lighting		2017	2020	2025	2030	2035
Current SSL Path	Source Energy Savings (tBTU) <sup>3</sup>	259	483	660	692	710
	Source Energy Savings (%)	26%	47%	64%	66%	66%
DOE SSL Program Goals	Source Energy Savings (tBTU)	268	531	770	835	860
	Source Energy Savings (%)	26%	52%	74%	79%	80%

Energy Savings Forecast. DOE. 2018. *Preliminary.*

# Stakeholder Engagement – Outdoor Lighting

- **ANSI/IES Sky Glow Calculations Committee**

- Scope: Committee is tasked with developing recommended calculations, procedures and tools for estimating contributions to nighttime skyglow from various end-uses of general illumination

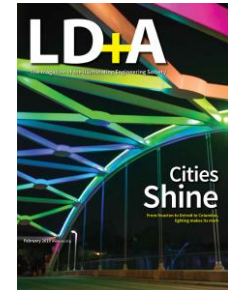


- **Public presentations of DOE research**

- 2018 IES Street and Area Lighting Conference (SALC)
- 2018 Artificial Light at Night (ALAN) Conference
- 4<sup>th</sup> International Street Lighting + Smart Controls Conference
- Regular requested participation or input to municipal public hearings; small (e.g., Bend, OR) to large (e.g., Chicago, IL)
- Feature article Lighting Design + Application (LD+A), Apr 2019



INTERNATIONAL DARK-SKY ASSOCIATION



- **Collaboration with National Park Service on lighting efficiency, resiliency in hurricane-affected areas**

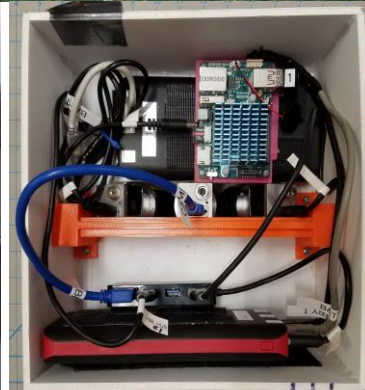
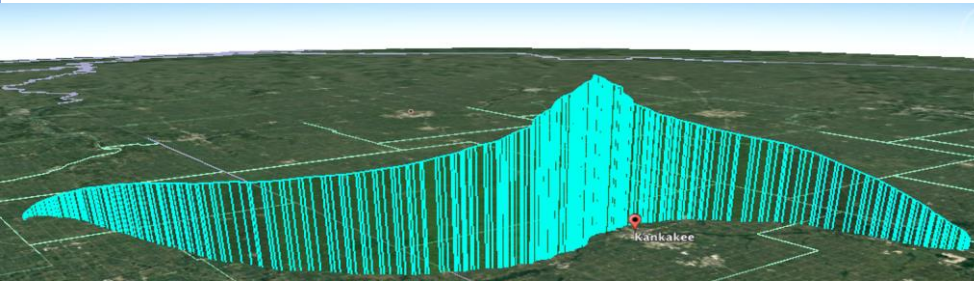
- Report: *Lighting and Power Upgrade Recommendations for U.S. National Park Service Caribbean Units*
- PNNL, City of Seattle, NPS Natural Sounds and Night Skies



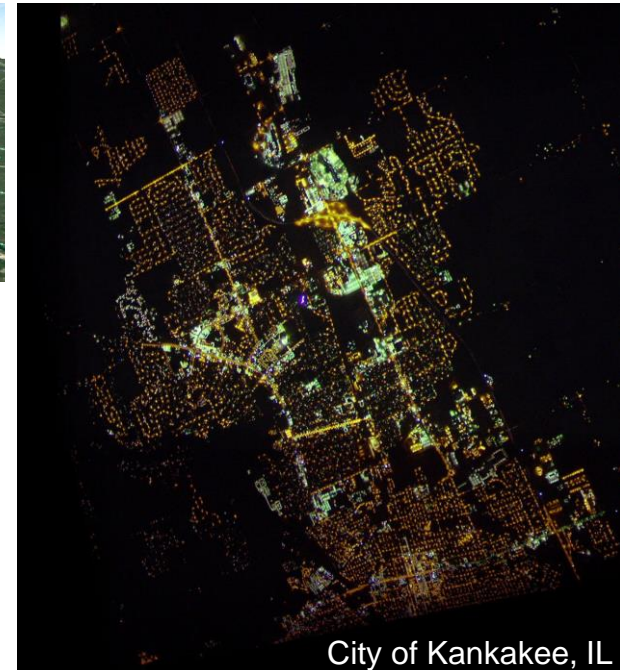
# Remaining Work – Field Validation of Uplight

Collaboration with Adler Planetarium to study changes in Chicago night sky from street lighting conversion

- On-going conversion of 270,000 high pressure sodium streetlights to connected LED system
- Weather balloon imaging measurements at 90,000+ feet
- Additional data from ground measurements, product settings
- Real time photo documentation of dimming changes
- Unique dataset from astronomical experts



**ADLER**  
PLANETARIUM



City of Kankakee, IL

# Remaining Work: Light Measurement & Crash Statistics

- Statistical analysis of actual pre- and post-conversion crash data in several municipalities in Philadelphia region
- DVRPC already analyzes crash statistics for PennDOT
- VTTI will document luminance and illuminance maps of several select locations, under existing high-pressure sodium and replacement LED systems
- This study will test the hypothesis that the superior visual acuity afforded by the broader-spectrum LEDs results in fewer crashes



Example illuminance map of freeway interchange. VTTI



# Challenge – Horticultural Lighting

- Population and technology driving trend of indoor/vertical farming
- Plant growth requires higher light levels and different spectra than visual tasks
- Energy use forecast to grow 15-25% per year over next ten years
- LEDs offer several potential advantages with direct energy implications:
  - Ability to change spectrum, intensity, and distribution to match plant needs at different stages of their growth
  - Alternative lighting system configurations for more efficient light delivery
  - Lower heat loads advantageous in some climates and seasons
- **Project goal: develop and support new metrics, methods of measurement, and recommended practices for horticultural lighting using SSL systems that optimize spectrum, intensity, distribution, timing and duration**



# Approach – Horticultural Lighting

- Literature review of currently available metrics and plant science to identify gaps and opportunities
  - Additional metrics
  - Optimized lighting system design based on improved metrics
  - Lab testing of lighting prototypes for data validation
- Identify new target goals incorporating yield, quality, and associated characteristics
  - Optimal lighting characteristics for each plant type at each growth stage
- Field evaluations/case studies of new, optimized lighting systems

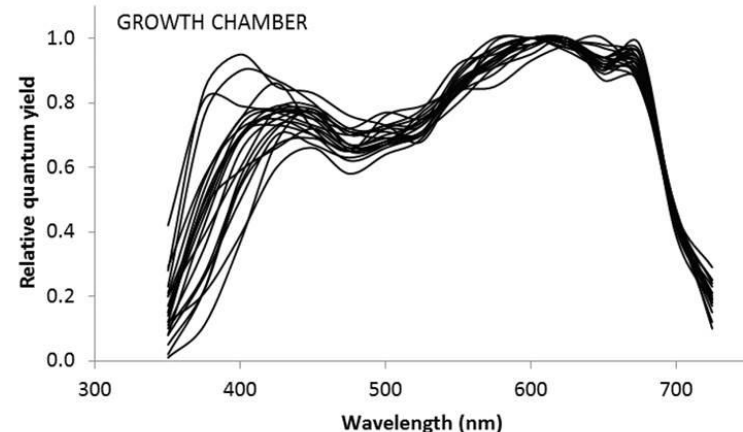
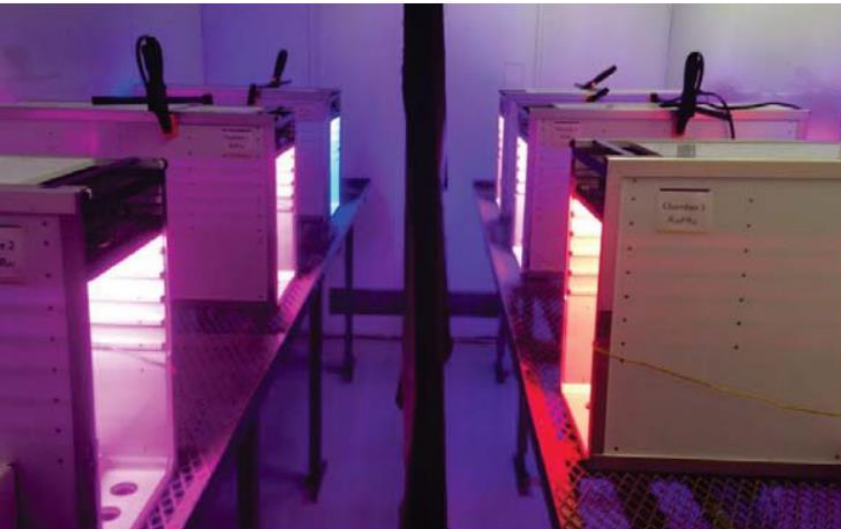


Figure 1 – This figure shows the individual responses of the 22 plants investigated by McCree for plants grown in the field (top) and in climate chambers (bottom). (See Figure 13 in Reference 1.)

# Impact – Horticultural Lighting

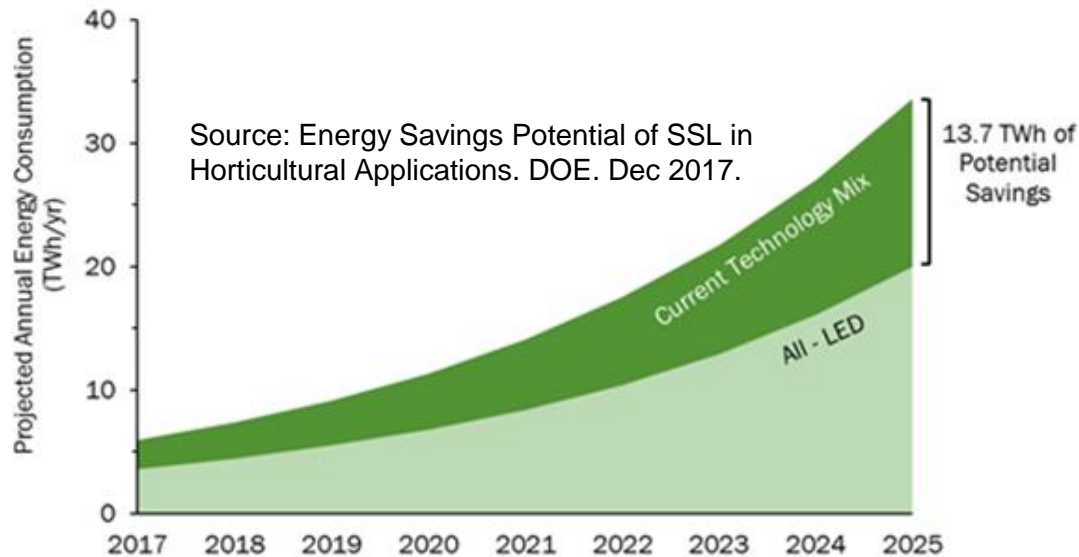


Figure 5.1 Estimated Growth Horticultural Lighting Energy Consumption

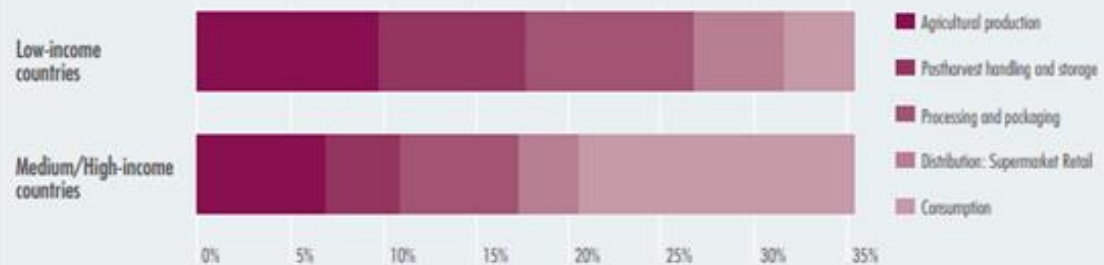
## Direct energy savings from LED replacing HPS

- 40% “all LED” savings
- 13.7 TWh per year by 2025 in all LED scenario
  - Assumes grow area increases 19% per year average

## Indirect energy savings potential from more indoor, local production of high-value produce

- Transportation
- Water
- Pesticides
- Food loss/waste (FLW)

FIGURE 2. FLW AT EACH STEP OF THE FOOD SUPPLY CHAIN IN MEDIUM/HIGH AND LOW-INCOME COUNTRIES



Source: author, based on information from FAOSTAT figures for 2010 and FAO. 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome. Annex 1-4, pp.26-27.

\*Grouping of world regions is based on the classification from FAO. 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Rome. Annex 1, p.23. Medium/High-income countries include world regions 1 (Europe), 2 (United States of America, Canada, Oceania) and 3 (Industrialized Asia) while low-income countries include regions 4 (sub-Saharan Africa), 5 (North Africa, West and Central Asia), 6 (South and Southeast Asia) and 7 (Latin America).

# Progress/Remaining Work – Horticultural Lighting

- **Review existing industry committees and metrics for horticultural lighting**
  - ANSI/ASABE S640 Quantities and Units of Electromagnetic Radiation for Plants (Photosynthetic Organisms) July 2017 - metrics
  - ANSI/ASABE S642 Quantities and Units of Electromagnetic Radiation for Plants (Photosynthetic Organisms) September 2018 – test method
- **Identify additional metrics and methods of measurement needed for evaluating horticultural lighting products and systems**
- **Review scientific research on spectrum, intensity, and distribution optimization by plant type, growth stage, product objectives (nutrition, appearance, size)**
  - Scope developed for subcontract with university researchers

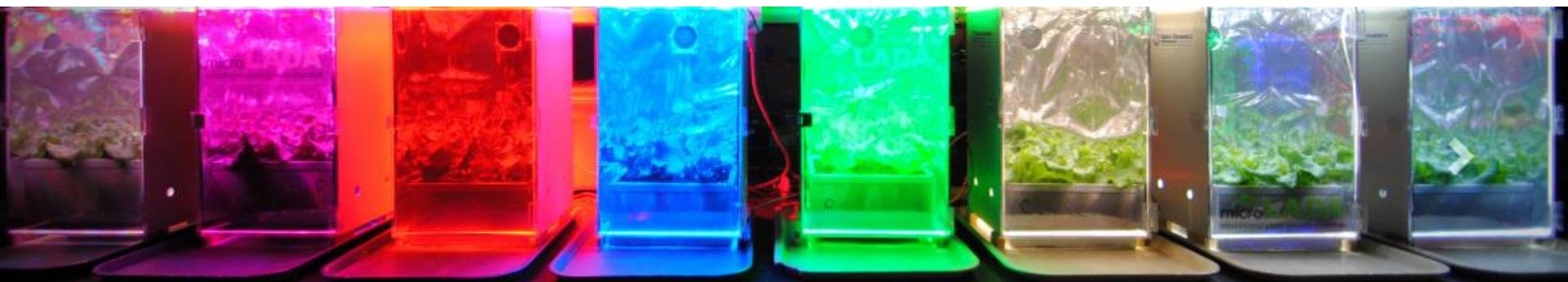


Photo: Fluence Lighting at Utah State University

# Stakeholder Engagement – Horticultural

University  
researchers and  
plant science  
experts

Horticultural  
lighting technology  
developers

Horticultural sites  
for pilot testing

Industry standards  
organizations



Voluntary  
performance  
qualification  
programs



# Remaining Project Work – Agricultural Lighting

- **Year 2: Optimizing SSL systems for horticultural and animal agriculture lighting applications**
  - Lab assessments of emerging horticultural lighting metrics and measurement methods
  - Field evaluations of pilot installations of emerging SSL horticultural systems
  - Research plan for animal agriculture lighting
- **Year 3:**
  - Optimizing SSL systems for animal agriculture lighting applications
  - Additional field evaluations of pilot installations for horticultural and animal agriculture applications



# Abbreviations

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- **ANSI – American National Standards Institute**
- **ASABE – American Society of Agricultural and Biological Engineers**
- **DLC – Design Lights Consortium**
- **DVRPC – Delaware Valley Regional Planning Council**
- **FLW – food waste/loss**
- **HID – high intensity discharge**
- **HPS – high-pressure sodium**
- **IES – Illuminating Engineering Society**
- **NPS – National Park Service**
- **VTTI – Virginia Tech Transportation Institute**

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# Thank You

Pacific Northwest National Laboratory

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# REFERENCE SLIDES

# Project Budget

**Project Budget:** Original planned budget was \$1500k per year for 3 years

**Variiances:** In year 1, budget was decreased due to:

- Removed energy impact study from scope, per DOE
- Lower than projected costs for FY19 scope
- Budget shifted to Emerging Lighting Science project

**Cost to Date:** as of March 2019 month end: \$273k cumulative cost to date

**Additional Funding:** National Park Service paid for FY18 travel to hurricane-affected parks. Potential NPS interest in funding future pilot projects based on recommendations developed in PNNL report.

## Budget History

FY 2018 (past)		FY 2019* (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
n/a	\$15,000	\$945,810		\$3,000,000	

\*Note: Includes FY2018 carry-over funds

# Project Plan and Schedule

Project Schedule												
Project Start: 10/1/2018	Completed Work											
Projected End: 9/30/2021	Active Task (in progress work)											
	◆ Milestone/Deliverable (Originally planned) use for missed											
	◆ Milestone/Deliverable (Actual) use when met on time											
	FY19				FY20				FY21			
	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Application Specific Lighting												
<b>Past Work</b>												
Outdoor lighting energy & resiliency report for NPS		◆										
<b>Current/Future Work</b>												
Literature review on metrics for horticultural lighting			◆									
Review of horticultural lighting technical literature				◆								
<i>Go/no-go decision based on projected energy impact</i>				◆								
Research plan for livestock facilities lighting					◆							
Final report on sky glow modeling						◆						
Lab evaluations of test methods for horticultural lighting							◆					
Status of research on lighting for livestock facilities								◆				
Report on pilot field installation of SSL horticultural lighting									◆			
Evaluation report on next-gen SSL exterior lighting system										◆		