2023 Lighting TPM

Final Report

ET23SWE0009

Prepared by:

Yao-Jung Wen Energy Solutions

October 6, 2023

Acknowledgments

This Lighting Technology Priority Map (TPM) was developed by the Lighting Subject Matter Expert (SME) Team of the CalNEXT Program, which is responsible for the production of this document, background research, stakeholder engagement of the Technical Advisory Committee (TAC), and management of the TPM development process. We thank the Lighting SME team members and our facilitation team for their contributions in this process as well as the guidance provided by the TPM TAC and other key advisors:

CalNEXT Lighting Team Members
(SMEs, Facilitators, & Supporting Staff)

Yao-Jung Wen, Energy Solutions	Jill O'Connor, VEIC
Zoe Mies, Energy Solutions	Adam Tower, VEIC
Greg Barker, Energy Solutions	Jae Yong Suk, U.C. Davis
Kyle Booth, Energy Solutions	Keith Graeber, U.C. Davis
David Ayoub, AESC/ASK Energy	Michael Mutmansky, TRC

We acknowledge the following individuals for serving as the CalNEXT Lighting TPM TAC members, spending time participating in the TAC meeting and providing valuable feedback to the TPM draft.

CalNEXT Lighting TPM TAC Members

Savannah McLaughlin, CPUC	Michael Myer, PNNL
Jenny Chen, SCE	Michael Poplawski, PNNL
David Rivers, SCE	Jes Rivas, ILLUME Advising
Kevin Lin, SCE	James Fay, Exelon
Chris Wolgamott, NEEA	

Finally, we thank the following stakeholders we engaged during the last part of the Lighting TPM development for providing insights based on their job functions and roles to further improve the 2023 Lighting TPM.

Albert Chiu, PG&E	Lake Casco, TRC

Van Do, TRC

Merry Sweeney, SDG&E

James Gingras, PG&E

Harpreet Singh, PG&E

Charles Kim, SCE

Tai Voong, PG&E

Jeff McDowell, PG&E

Kate Zeng, SDG&E

Thomas Mertens, PG&E

Disclaimer

Table of Contents

Abbreviations, Acronyms, and Glossary of Terms

Acronym	Meaning
AC	Alternating Current
ANSI	American National Standards Institute
API	Application Programming Interface
BESS	Battery-Energy Storage System
CA	California
CALCTP	California Advanced Lighting Controls Training Program
CASE	Codes and Standards Enhancement
CEC	California Energy Commission
CPUC	California Public Utilities Commission
C&S	Codes & Standards
DC	Direct Current
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management System
DLC	DesignLights Consortium
DOE	Department of Energy
EE	Energy Efficiency
EMS	Energy Management Systems
EPIC	Electric Program Investment Charge Program
ET	Emerging Technology
ETCC	Emerging Technology Coordinating Council
EV	Electric Vehicle
FTE	Full-time equivalent
GHG	Greenhouse Gas Emissions

Acronym	Meaning
HID	High Intensity Discharge
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air Conditioning
HVAC/D	Heating, Ventilation, and Air Conditioning / Dehumidification
IOU	Investor-Owned Utility
LCDs	Liquid Crystal Displays
LCF	Light Control Films
LED	Light Emitting Diode
M&V	Measurement and verification
NEEA	Northwest Energy Efficiency Alliance
PoE	Power-over-Ethernet
PNNL	Pacific Northwest National Laboratory
PPE	Photosynthetic Photon Efficacy
SCE	Southern California Edison
SME	Subject Matter Expert
TAC	Technical Advisory Committee
TLEDs	Tubular Lighting Emitting Diodes
TPM	Technology Priority Map
µmol/J	Micromoles per Joule
UV/UVGI	Ultraviolet/Ultraviolet Germicidal Irradiation
WH	Water Heating

Glossary	Meaning
Technology Category	One of six broad technology categories (e.g. Whole Building, HVAC, Water Heating (WH), Plug Loads, Lighting, Process Loads).
Technology Family	Functional grouping that provides description of program role, opportunities, barriers.
Subgroups	Common examples to further describe each technology family.
Definitions	Narrative to provide additional clarification on the technology family scope.
Opportunities	Description of potential impacts and potential research areas.
Barriers	Description of key barriers and potential barriers research.
CalNEXT Role	Describes general level of engagement by California's Statewide Emerging Technologies Program (CalNEXT) SMEs. *Note: Roles will change as research is completed.*
Lead Collaborate Observe	"Lead" – CalNEXT expects to take on most or all of the work and cost burden. "Collaborate" – CalNEXT is interested in collaborating and co-funding projects. "Observe" – CalNEXT will track progress but will encourage external programs to take the lead in unlocking these opportunities.
CalNEXT Priority	Communicates expected level of focus by CalNEXT SMEs. *Note: Priorities will change as research is completed.*
High Medium Low	"High" - CalNEXT SME team has highlighted this technology family as having high impacts within the Technology Category. "Medium" - CalNEXT SME team determined this technology family has moderate overall impacts within the Technology Category. "Low" - CalNEXT SME team has highlighted this technology family as having low relative impacts within the Technology Category.
Impact Factor	One of four broad impact areas (energy savings potential, demand flexibility potential, decarbonization potential, and other GHG impacts).
Impact Factor Ratings	A qualitative rating (High-Medium-Low) by the CalNEXT SME team on impact potential if technological advancements are made in key subgroups.
Knowledge Index	One of three types of knowledge areas (technical performance, market understanding, and program intervention) used to assess types of barriers studies necessary to obtain the stated impact potential.

Glossary	Meaning
Knowledge Index Rating	A qualitative rating (High-Medium-Low) by the CalNEXT SME team on the relative knowledge of most subgroups within a technology family. A higher rating means that the topic is well understood.

Introduction

The Technology Priority Maps (TPMs) provide the CalNEXT Program a framework to externally communicate the priorities of the program, clearly define the central focus areas of the program, and assist with project screening. They document the impact potential, programmatic research needs, and market readiness of all technology families across each of the end-use technology areas, driving product ideation, informing project selection, and determining eligibility for future focused pilot efforts. For the TPMs to provide this guidance, they require regular updates to reflect specific changes to technology, market, and policy. This Final Report documents the development of the 2023 Lighting TPM.

Background

The TPMs were originally developed by Southern California Edison's Emerging Technologies program in 2017. They have been incorporated as a key element of the CalNEXT program to provide clarity to the program on our priorities. They require frequent updates to reflect technical advancement, policy changes, and market developments in order to maintain their relevance. In 2022, the CalNEXT team did a thorough revision to the TPMs and published them on our website at https://calnext.com/resources/.

Objectives

The 2022 revision of the Lighting TPM, i.e., the current active Lighting TPM, included a significant reorganization of the technology families and subgroups to improve clarity and reflect notable changes in the market landscape compared to when the previous TPM was developed. This 2023 Lighting TPM revision aims to improve clarity to program priorities for prospective participants by making updates to the current technology families and adding new technology families as appropriate.

Methodology

The 2023 Lighting TPM revision began with multiple meetings of the CalNEXT lighting SMEs to review the existing 2022 Lighting TPM and identify key changes expected based on technology, market, and policy for different technology families. Common sources of research included published research papers or publicly available information from various California-based sources including the Emerging Technology Coordinating Council (ETCC), California Energy Commission-Electric Program Investment Charge program (CEC-EPIC), and California investor-owned utilities (CA IOU) Codes and Standards Enhancement (CASE) Team. The team also reviewed outside resources from other emerging technologies programs, national laboratories, national building codes and standards bodies, and Department of Energy (DOE) initiatives. Following this research, the SME team then drafted changes to the technology family definitions, subgroups, and opportunities and barriers narratives, which were presented in the Preliminary Findings Report (submitted on May 9, 2023).

Following the development of the Preliminary Findings Report, the Lighting SME team was given digital ballots to provide guidance on potential changes to the program role and program priority, key factors, and knowledge indices through an online balloting platform. Concurrent with this activity, the initial narratives were presented to the Technical Advisory Committee (presented on May 30, 2023). The Technical Advisory Committee attendees received a presentation of key changes and access to a cloud-based draft to provide suggestions for each technology family's key factors, knowledge indices, and narratives for opportunities and barriers. This initial feedback was documented and incorporated into the Draft Report submitted on June 21, 2023.

The SME Team conducted additional targeted outreach to stakeholders who were either not able to attend the Technical Advisory Committee meeting or were not Technical Advisory Committee members. These stakeholders included California IOU resource program administrators, codes and standards groups, energy efficiency program implementors, and other emerging technologies program administrators. This effort was to ensure alignment with the IOU energy efficiency portfolio priorities and to inform opportunities for technology transfer.

The SME Team then refined the Lighting TPM based on stakeholder feedback for this Final Report. Note: any technology families that show potential for a Focused Pilot will be identified for further development under that effort.

Draft Report Feedback

Following submission of the Draft Report, the CalNEXT program team obtained additional feedback from SCE on June 26, 2023. A summary of each comment can be found in Table 1 with changes incorporated into this Final Report.

Table 1: Additional Draft Report Feedback & Resolution

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
N/A – Intro	Highlighted Priority Areas	Missing other 3 Technology Family's Priority status.	This section, to be consistent with the TPM reports for all other Technology Categories, is meant to highlight Technology Families that are rated "high" for the ETP Priority. Therefore, the other 3 Technology Families with low to medium priorities are not listed in this section. Readers can refer to Technology Family TPM sections for their respective ETP Priorities and other details.
Connectivity, Controls, and Integration	Action Taken & Justification column of the Advisory Committee Feedback & Resolution Matrix	What was the reason that it (referring to the Statewide CASE Team's attempt to incorporate networked lighting controls into Title 24 in the previous code cycles) wasn't successful in the previous code cycles? What are we doing differently here and now to address the gap?	The reasons were intricate and weren't included in the main text of the technology family content. The general approach to Title 24 is to be technology agnostic as much as possible, i.e., mandating functionalities (e.g., small-zone occupancy sensing controls, automatic daylighting controls, etc.) instead of specific technologies (e.g. NLC, LLLC, etc.). In other words, the approach to include NLC in Title 24 would be to require functionalities that either can only be implemented using NLCs or are otherwise very difficult to implement without using NLCs. All the basic controls that NLCs are capable of (occupancy sensing, daylight harvesting, etc.), though much easier to implement using NLCs, are already mandatory requirements in the current Title 24, so it would not generate meaningful above-code energy savings to prove cost-effectiveness and justify requiring NLCs in the previous code cycles. Advanced NLC capabilities and integrations specified as subgroups in this technology family are sources for additional energy

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
			savings and demand flexibility that have not been captured by the current Title 24 controls requirements. Quantifying their benefits would provide the pathway for NLCs to be included through the existing Title 24 regulatory framework.
Connectivity, Controls, and Integration	Action Taken & Justification column of the Advisory Committee Feedback & Resolution Matrix	Suggest providing explicit definition (referring to the advanced daylighting controls subgroup) and ET aspect of this specific technology. I was under the same impression as comment that CalNEXT was referring traditional daylight harvest technology.	This has been addressed in the Opportunities section (see the next row below). The added verbiage is designed to provide a more explicit description of the technologies of interest while not too specific to favor a particular product or manufacturer and prevent other innovative solutions from being considered.
Connectivity, Controls, and Integration	Opportunities	Again, I think this ET (referring to the opportunity description of the advanced daylighting controls subgroup) deserves to add a little bit more clarity.	Added verbiage in the Opportunities section to qualify the advanced daylighting controls as technologies using combinations of passive apparatus and active tracking and controls to bring natural light into spaces where daylight is not reachable through traditional architectural fenestration design.
Advanced Approaches to Exterior Lighting	Key Factors	Medium1? (Referring to the rating for the Other Emissions Impacts factor)	Thanks for catching the typo. It has been corrected.

A detailed list of feedback provided by the Technical Advisory Committee along with the Lighting TPM SME Team's responses was included in the Draft Report and is attached again in Appendix A: Advisory Committee Feedback & Resolution Matrix at the end of this document as a reference.

Feedback from Additional Stakeholder Outreach

The additional stakeholder outreach was conducted between August 17 and September 15, 2023 in the form of individual or small-group interviews. The stakeholders interviewed and their roles are listed in Table 2.

During the interviews, an overview of CalNEXT and Lighting TPM was presented to the stakeholders who have not been involved in CalNEXT, and the key discussions centered around the opportunities and barriers identified for each technology family. The stakeholders were asked if the opportunities and barriers were in line with what they had seen in their roles and functions, and if there were specific gaps that could be addressed through CalNEXT research activities. The stakeholders generally also recognized the identified opportunities and barriers, and their specific feedback is summarized in Table 3.

Table 2: Stakeholder Engaged through the Additional Targeted Outreach

Name	Organization	Role/Group
Charles Kim	SCE	Codes & Standards
Kate Zeng	SDG&E	Codes & Standards
Merry Sweeney	SDG&E	Codes & Standards
Thomas Mertens	PG&E	Code Readiness
Albert Chiu	PG&E	DR ET Lead
Van Do	TRC	Statewide Lighting Energy Efficiency Program Implementor
Lake Casco	TRC	Statewide Lighting Energy Efficiency Program Implementor
Jeff McDowell	PG&E	Custom Project Program Manager
James Gingras	PG&E	Custom Project Quality Control Project Review Engineer
Tai Voong	PG&E	Program Engineer
Harpreet Singh	PG&E	Customer Care Program Engineer

Table 3: Feedback from Additional Targeted Stakeholder Outreach

Technology Family	Feedback	Action Taken
Connectivity, Controls, and Integration	There are still significant gaps in making integrating lighting with HVAC and other building systems a standard practice.	Highlighted as a research focus in the Opportunities section.
Connectivity, Controls, and Integration	Put additional emphasis on "integration". Specifically, integrating lighting as part of the whole-building controls since demand flexibility and management from the utility's perspective is at the whole-building level as the utility's visibility to the building load is at the meter.	Highlighted as a research focus in the Opportunities section.
Connectivity, Controls, and Integration	Use the term "load management" to replace the occurrence of "DR" in the TPM since this should broadly refer to the opportunities for technologies to receive a signal and respond to that signal for all load management purposes, not just for DR.	Changed the use of "demand response" in the Opportunities section to "load management" to broaden the scope of the description.
Connectivity, Controls, and Integration	An opportunity is for technologies to help users simplify load management setup and execution. Systems need to have the capability to allow users to set their preferences and communicate correct (grid-intended) messages to the users.	Highlighted as a research focus in the Barriers section with a broader scope for both energy savings and demand flexibility.
Horticultural Lighting	Add considerations from the aspect of impact on the grid, specifically local T&D infrastructure as commercial production facilities create very high demand at the distribution level.	Added the consideration in the Opportunities section.
Horticultural Lighting	Spectral tunability, while might not be an energy savings feature, could facilitate the adoption of efficient lighting, thereby relieving grid stress. So it should not be completely discounted when considering projects.	Added a description in the Barriers section.
Horticultural Lighting	There is a lack of a unified metric that combines energy and yield for growers to make side-by-side comparisons when considering upgrades.	Added the need for such a unified metric as one of the research foci in the Barriers section.
Horticultural Lighting	Most field studies to date have been done at cannabis-growing facilities. It has been difficult to identify and identify growers of other crops, so additional studies focusing on non-cannabis facilities will fill the current gaps.	No additional action was taken. This need has already been included as one of the research foci.

Technology Family	Feedback	Action Taken
Horticultural Lighting	The interactive effect with HVAC/D and water level still needs more research. Related research is currently performed in the context of HVAC as the HVAC manufacturers need to ensure their equipment can handle the additional reheat and dehumidification needs.	No additional action was taken. The lack of research has already been pointed out in the Barriers section. Since related research is conducted in the context of HVAC/D, the Lighting TPM does not need to create a separate research focus.
Advanced Approaches to Exterior Lighting	Both occupancy/motion-based controls and grid-based controls are important and need research. There is a gap in how to incorporate exterior lighting into DERMS.	Highlighted as research foci in the Opportunities section.
Advanced Approaches to Exterior Lighting	The biggest opportunity for DERs-integrated exterior lighting and controls lies in microgrids. This is especially true for microgrids in locations with strategic importance, such as places near police stations, fire stations, libraries, and other public service and assembly areas – think of locations impacted by the Public Safety Power Shutoffs.	Added the opportunity and highlighted this as a research focus in the Opportunities section.
Advanced Approaches to Exterior Lighting	Specifically for the DERs-integrated exterior lighting, CPUC's non-IOU supplied energy sources guidance and the Energy Efficiency Policy Manual related to Decision 09-12-022 will likely have an impact on how savings can be determined.	Added the consideration as part of the recommended research focus areas in the Opportunities section.
All/Multiple	For developing deemed measures, a key barrier is the availability of pricing information, which is always considered proprietary by market actors and not willing to disclose.	This was noted but no explicit verbiage was added to the TPM as the TPM is not positioned to address this at the strategic level.
All/Multiple	Not seeing advanced lighting and control projects coming through the program pipeline. This has to do with how the state accounts for energy savings, making the incentives not worth the effort to pursue from the customer's perspective. So this is more of a process and regulatory barrier than a market barrier.	No additional action was taken. The comment is noted, but CalNEXT does not seem to be a good avenue for addressing this barrier.
All/Multiple	CPUC ISP is solely based on DLC QPL analysis, and the result could be skewed since many products have very high efficacy, and listed products are not necessarily available. It would be helpful to conduct market research to	While the comment was mostly for LED light sources, which is not a focus of the TPM, it was a good insight to avoid unrealistic ISP by providing strong field evidence.

Technology Family	Feedback	Action Taken
	understand the efficiency level of the products that are actually being sold and installed to help regulators establish a more realistic ISP.	Conducting market research to further inform the determination of ISP was added as one of the research foci for Horticultural Lighting and Advanced Approaches to Exterior Lighting technology families.
All/Multiple	Current Remaining Useful Life (RUL) programs are allowed to use is very short, e.g. only 3 years for BRO (behavioral, retro-commissioning, and operational) projects, which significantly limits cost effectiveness, specifically program cost, and often makes the program nonviable. It may be worthwhile to conduct a lifecycle study to help CPUC make more realistic RUL determinations.	While the comment was mostly for LED light sources, which is not a focus of the TPM, it was a good insight to avoid unrealistic RUL by providing strong field evidence. Conducting lifecycle studies to further inform the determination of RUL was added as one of the research foci for Horticultural Lighting and Advanced Approaches to Exterior Lighting technology families.

CalNEXT Website TPM Mock-up (2022 Lighting sample below)

The 2023 Lighting TPM webpage update will be in the same format as the 2022 Lighting TPM webpage update that can be seen below. An additional row will be added for the new technology family: Advanced Approaches to Exterior Lighting. The CalNEXT role and priority for each technology family will also be updated based on the revised roles and priorities documented herein. The link to the 2023 Lighting TPM Final Report will appear in the top right corner with the option to download.

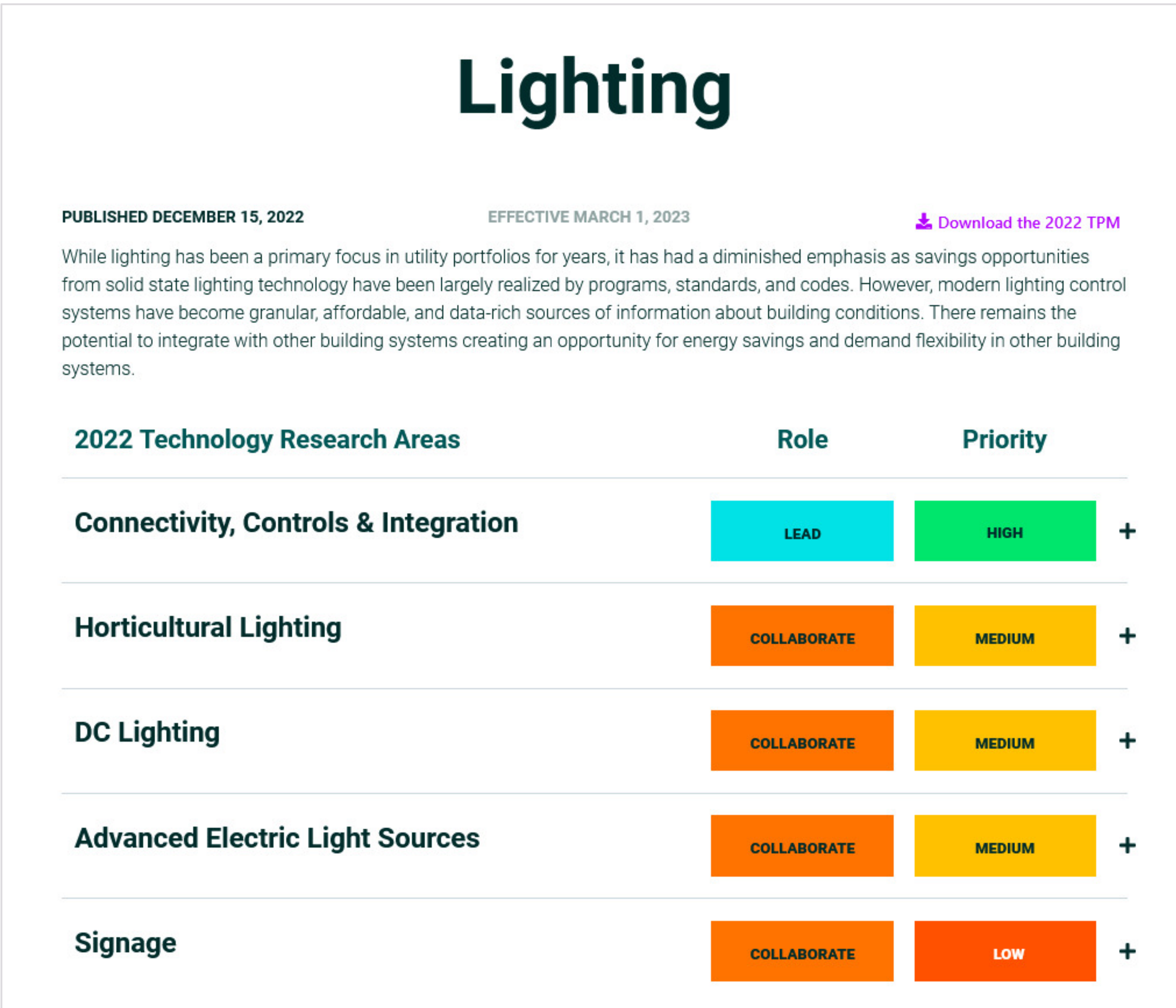

Figure 1: Lighting TPM webpage layout

2023 Lighting TPM

Lighting Technology Category Overview

This category covers an end use that has been a dominant player in efficiency programs for the past 10 to 20 years but is receiving less focus today due to stricter code requirements and the lack of direct relevance to decarbonization. Light Emitting Diode (LED) conversion has already contributed to significant energy savings across all technology categories. It has been viewed as “low-hanging fruit” and other potential savings from other lighting category technologies appear dwarfed in comparison.

Code-readiness efforts are one aspect of lighting efficiency that has received some attention in recent years. These efforts focused on the advanced capabilities of networked lighting control and horticultural lighting. Exterior lighting has increased relevance in influencing peak demand on the California grid, which has shifted towards evening and night hours. This may be a candidate for further study under future pilots.

Unique Opportunities and Barriers

Lighting control systems have, thanks to rapidly dropping costs in sensor components and network connectivity technologies, become the most granular and data-rich sources of information about building conditions. Integration with other building systems creates an opportunity for energy savings and demands flexibility in other building systems and end uses. Lighting has the unique ability to contribute to demand flexibility in both directions: for the grid and within the building. While ramping down demand is still the predominant use, demand response (ramping up demand when renewable generation is experiencing over-generation) is in the realm of possibility for lighting end use. The potential exhibited in exterior lighting is increasing as the California grid peak shifts towards the evening hours. The interconnectedness and variable settings of lighting control systems make setup and installation complex and have potential to result in occupant dissatisfaction. Education of and communication among parties involved, from the specifier to contractor to the customer, can help avoid poorly executed controls and integration.

Lighting systems have capabilities to deliver a variety of non-energy benefits. This includes serving as the power and communication backbone for granular and often luminaire-integrated sensors, creating non-visual biological effects, and performing germicidal functions. There continue to be opportunities to ensure high-energy savings while delivering non-energy benefits.

Horticultural lighting is on the cusp of experiencing large-scale LED conversion similar to that which took place in architectural lighting. There are tremendous opportunities for deeper savings by ensuring controls and LED luminaires are deployed at the same time, through proper system design and integration. Unclear return-on-investment and the perception of uncertain impact on crop production remain the major barriers.

Highlighted Priority Areas

Technology Family	Definition	ETP Role	ETP Priority
Connectivity, Controls, and Integration	Sensors, communication systems, control algorithms, advanced diagnostics and analytics, and integration capabilities that reduce energy consumption in lighting, and other building systems and appliances, enhance occupant comfort and wellness, or provide data to feed into systems in other technology families, including Envelopes, Integrated Systems, Scalable HVAC Controls, and Plug Load Optimization & Management.	1-Lead	1-High
Horticultural Lighting	Systems producing light and non-visible electromagnetic radiation for plant growth and horticultural production in indoor commercial production facilities or for supplemental lighting in commercial production greenhouses, including specific design strategies, lighting technologies and control systems for optimizing productivity, energy efficiency, and resource conservation. High-efficiency fixtures, lamps, and controls for in-home growing.	1-Lead	1-High
Advanced Approaches to Exterior Lighting	Products, design strategies and components that improve the efficiency of exterior lighting in commercial and public sectors while also considering best practices for the nighttime lighting environment (human health, visual comfort, public safety, and environmental impacts).	1-Lead	1-High

Connectivity, Controls, and Integration

CalNEXT Role: Lead | CalNEXT Priority: High

Key Factors

Energy Savings: Medium
Decarbonization: Not Applicable
Demand Flexibility: High
Other Emissions Impacts: Low

Knowledge Index

Technical Performance: Medium
Market Understanding: Low
Program Intervention: Low

Example Technologies

Examples for commercial and industrial applications: advanced monitoring, diagnostics, analytics, and integration capabilities in lighting control systems and lighting energy management systems (EMS); use of integrated sensor information to enhance building EMS performance and for other energy and non-energy uses; daylighting controls that coordinate with fenestration design and other building systems.

Example for residential applications: home automation.

Definition

This technology family includes sensors, communication systems, control algorithms, advanced diagnostics and analytics, and integration capabilities that reduce energy consumption in lighting. It can encompass other building systems and appliances, enhance occupant comfort and wellness, or provide data to feed into systems in other technology families, including Envelopes, Integrated Systems, Scalable HVAC Controls, and Plug Load Optimization and Management.

Note: See the Whole Buildings TPM for details of the Envelope and Integrated Systems technology families, the HVAC TPM for the Scalable HVAC Controls technology family, and the Plug Loads and Appliances TPM for the Plug Load Optimization and Management technology family.

Opportunities

In commercial and industrial applications, lighting controls and inter-system integration can reduce energy consumption of both lighting and other end uses all while incorporating increasingly important demand flexibility. Energy benefits from controls may be increased by simplifying on-site commissioning and enabling control features with more aggressive settings by default. Interconnection with HVAC controls can enable reduction of both HVAC and lighting energy consumption during unoccupied and partially occupied periods. Greater sensitivity and more sensor nodes can enhance sophisticated controls programming and reduce uncertainty in the commissioning process, saving time and lowering energy consumption.

Advanced daylighting technologies using combinations of passive apparatus and active tracking and control can bring natural light into spaces within buildings that are traditionally unreachable through architectural fenestration design. Introducing daylight in buildings can result in both health benefits for building occupants and energy savings, being careful to consider both lighting and HVAC energy.

Lighting system native metering and reporting features may be used to quantify actual energy savings as opposed to the current, expensive practice of third-party verification. It may enable more streamlined measurement and verification, accurate energy usage trending, improved continuous commissioning strategies, efficient facility management workflow, and advanced integration use cases. The native metering capability with dashboard visibility and real-time communication with other building systems or the grid may also help energy managers develop more sophisticated load management strategies.

Integration should be a research emphasis for commercial and industrial applications to incorporate lighting into part of the whole building load as a standard practice. This would allow the inclusion of lighting as one of a building's dispatchable and controllable load when the building responds to both utility and intra-building load management needs, achieving higher demand flexibility at the whole-building level.

Lighting controls in residential applications currently provide mostly amenities, allowing light level or color to change based on voice commands or triggers from other smart home devices. Smart lamps and light fixtures are increasingly moving away from requiring a proprietary hub, so adding a focus on energy, such as energy-focused "skills" or "recipes" in the smart home apps or smart home hub could promote higher energy savings. There are also opportunities to address this through the Whole Buildings technology category, where lighting controls are incorporated as an element of home automation to achieve a deeper level of whole-home integration.

Barriers

In commercial and industrial applications, lighting control strategies are well-understood at a high level, but they still carry a stigma from the past of not working when they were implemented in legacy systems and light sources. Controls would be disabled, and owners and contractors would only install the bare minimum to avoid getting complaints from occupants. The system complexity, especially when accessing advanced features like native metering, diagnostics, analytics, and integration, as well as continually evolving options of system architecture poses a challenge for field implementation. Modern systems are more software- than hardware-based; contractors may not be fully trained, and most will not know the proper programming and start-up process for advanced system features and capabilities. Even with the most sophisticated lighting systems, they are often only configured for code compliance, leaving the advanced capabilities underutilized and deeper savings untapped due to contractor or owner unfamiliarity. Systems integrated with other building end-uses have increased complexity, adding cost and coordination barriers to projects. Research focusing on simplifying and standardizing the access, setup, and utilization of advanced lighting system capabilities would help break down the barriers of lighting control systems not being used to their full potential to achieve the highest energy savings and demand flexibility.

The customers' lack of education for requesting advanced controls and capabilities creates a barrier to adoption from the inception of the project. As modern lighting control systems move towards being software-centric in the face of an aging workforce, contractor education is essential to address complexity barriers and avoid poor occupant satisfaction. Specifier and architect education can avoid poorly executed controls integration, often stemming from unclear intent, vague specification, and inefficient communication among the multidisciplinary actors involved. Knowledge sharing from successful projects can address resistance to complex controls from facility managers.

Accessing the advanced capabilities continues to command a high premium, reserving these capabilities for only the most well-budgeted large projects. The lack of a clear line between code requirements for controls and incentive program eligibility also creates a barrier to the adoption of advanced controls.

In residential applications, the adoption of lighting connectivity and controls is particularly low among HUD-assisted renter households due to affordability constraints, a substantial barrier to adoption. Addressing this sector, as well as the rest of the residential sector, solely from the energy efficiency angle is not sufficient due to cost-effectiveness considerations of the energy efficiency measures. Innovative intervention strategies, possibly leveraging non-utility programs, initiatives, or campaigns that focus on other non-energy benefits, will need to be explored.

Horticultural Lighting

CalNEXT Role: Lead (increased) | CalNEXT Priority: High (increased)

Key Factors

Energy Savings: High (increased)
Decarbonization: Not Applicable
Demand Flexibility: Medium
Other Emissions Impacts: Medium

Knowledge Index

Technical Performance: High (increased)
Market Understanding: Medium (increased)
Program Intervention: Low

Example Technologies

Examples for commercial applications: high-efficiency horticultural luminaires for grow facilities; lighting controls and system design for horticultural grow facilities in a wide variety of building types.

Examples for residential applications: high-efficiency fixtures and lamps for in-home, personal horticultural growing.

Definition

Horticultural Lighting systems produce light and non-visible electromagnetic radiation for plant growth and horticultural production in indoor commercial production facilities or for supplemental lighting in commercial production greenhouses, including specific design strategies, lighting technologies and control systems for optimizing productivity, energy efficiency, and resource conservation. This technology family includes high-efficiency fixtures, lamps, and controls for in-home growing.

Note: Non-lighting technologies intended for horticulture such as dehumidification (HVAC/D), envelopes, or irrigation controls are handled under the Indoor Agriculture technology family in the Process Loads TPM.

Opportunities

The most significant, proven opportunities for this technology family are for energy savings, and other standards and programs are already in place. Demand flexibility benefits can be added via scheduling-based system designs and powering the lighting system from renewable energy or embedded electrical energy storage. Increased demand reduction and demand flexibility from this technology family would have a significant impact on relieving the grid stress at the distribution level.

Key drivers of energy savings include increasing the efficacy and productivity of horticulture through optimization of system designs, controls, light source innovations, and reducing negative impacts from light pollution. The California Building Energy Standards, Title 24, Part 6, requires a minimum photosynthetic photo efficacy (PPE) of 1.9 and 1.7 micromoles per joule (μmol/J) for luminaires and lamps used in indoor grow facilities and greenhouses, respectively. The code change proposal for 2025 Title 24, Part 6 is looking to increase the minimum PPE requirements to 2.3 and 1.9 μmol/J for the two applications. While code requirements and efficiency standards are catching up on light source efficacy, the focus of horticultural lighting as an emerging technology should be on system design and controls to unlock largely untapped savings. Innovations in sensor and control strategies can maximize energy performance and demand flexibility by leveraging spectral tunability and harvesting daylight. Efficient and productive indoor growing enabled by horticultural lighting could also have both direct and indirect greenhouse gas reduction advantages over the open-field growing practices. Another non-energy benefit includes the potential of reducing light pollution when lighting is deployed with thermal blocking curtains in greenhouses.

Recreational indoor plant growing in the residential sector is still a niche market compared to commercial production. There are energy savings opportunities as the energy performance and effectiveness of these light sources are not well-characterized, and their efficiency is not currently governed by building codes, appliance standards, or voluntary certification programs.

Barriers

Rapid expansion of indoor agriculture has resulted in inefficient system designs, a lack of targeted efficiency programs, and the need for systems with higher efficacy and greater power quality.

Technical barriers are largely related to system design. There is a lack of clarity for designers and trusted tools for optimizing productivity and efficacy of horticultural lighting systems as well as limited understanding of the interactive impacts of schedule, space conditioning, HVAC/D, and water level. Lighting control strategies, including automatic spectral tuning and daylight harvesting, are still new concepts to most growers, and their performance is not well-quantified. As such, controls are yet to be as widely built into horticultural lighting systems as their counterparts in architectural lighting. Spectral tuning, while not likely to generate additional energy savings, could serve as a catalyst to breaking down growers' hesitancy in adopting efficient light sources and controls by offering promising potential for higher crop yield. Market barriers include the lack of confidence due to uncertain cost-effectiveness, limited in-field evaluation of innovative lighting technologies and controls, and lack of best-practice lighting designs from experienced practitioners, considering both performance and cost. For the residential or small seasonal commercial customer, the cost of certified efficient products such as those listed by the DesignLights Consortium (DLC) may be more expensive than energy savings can justify. Requirements for certifying products typically require a minimum of a five-year warranty on products, rendering many three-year-warranty products that meet the same technical qualifications at a lower cost ineligible for consideration and program support.

Efficiency programs have yet to identify high-priority program opportunities for targeted horticulture applications and sectors with reliable, low-carbon intensity, cost-effective solutions. Code requirements related to horticultural lighting and systems in different applications and building types also lack consistency.

Research should focus on activities that help build knowledge for the industries (both growers and utilities), including:

- Investigate how changes in lighting affect the overall economics for growers, including growth, energy savings, and production value in various types of facilities, and design effective knowledge transfer approaches to present comprehensive side-by-side results in terms of yield versus the cost of energy in different crops, different light sources, and different building types.

- Develop a quantitative metric that can simultaneously characterize the energy performance and crop yield of a solution to allow growers the ability to make true side-by-side comparisons across different lighting solutions.
- Develop guidelines based on studies of difference in yields achieved with high intensity discharge (HID) lighting versus. LED lighting and how PPE from the different lighting types may affect the overall cost/gram achieved.
- Study how controlling the light intensity and spectral distribution to match a daily cycle and crop growth cycle can help growers develop strategies to adjust production and increase energy savings.
- Study financial benefits and additional production values regarding the thermal curtains on the HVAC/D and lighting needs.
- Conduct market research and lifecycle study to further inform the determination of industry standard practice and claimable program savings.

Outputs from research would help alleviate growers' hesitancy in trying different technologies or growing practices for fear of lower yields and income. Additionally, research findings from the indoor agriculture technology family under the Process Loads technology category should be incorporated to highlight considerations, such as the need for additional heating or watering rates, that would need to be part of a facility upgrade plan.

DC Lighting

CalNEXT Role: Collaborate | CalNEXT Priority: Medium

Key Factors

Energy Savings: Low (decreased)
Decarbonization: Not Applicable
Demand Flexibility: Medium
Other Emissions Impacts: Low

Knowledge Index

Technical Performance: Medium (increased)
Market Understanding: Low
Program Intervention: Low

Example Technologies

Power-over-ethernet (PoE) lighting systems; low-voltage direct current (DC) lighting (<60VDC); higher-voltage DC lighting; off-grid lighting.

Definition

Any lighting appliance for commercial and industrial applications that operates on a DC power distribution network fits the DC Lighting technology family.

Note: Depending on the project scope, prospective projects in the DC Lighting technology family may also have relevance to the Electrical Infrastructure technology families (Whole Building TPM).

Opportunities

DC lighting has the potential for improved electrical efficiency, primarily through the consolidation of AC/DC conversion, with proper design and deployment. DC lighting may also support easier battery-energy storage system integration, and as a result, greater load flexibility. The potential impact on energy savings, demand flexibility, and operational efficiency is especially promising when integrated with distributed energy resources (DERs) as a part of the pure DC infrastructure within a building.

PoE and other DC lighting systems with data communication functionality can support a highly integrated and adaptive lighting system.

Low-voltage DC lighting systems may benefit from different construction requirements that will lower installation costs in new construction compared to line-voltage systems.

Off-grid lighting can result in energy savings when replacing mains-powered alternatives and avoid distribution infrastructure costs in new construction.

Barriers

Technical barriers to DC lighting adoption include the lack of interoperability between manufacturers, lack of standard design practices addressing specific DC requirements (e.g., system architecture, switch power supply sizing), and unproven and unquantified system-level efficiency improvements over traditional alternating current (AC) lighting systems. Existing DC lighting systems still largely rely on upstream AC-to-DC conversion. The benefits — both energy and non-energy — of a pure DC lighting system are not well-characterized as use of a DC infrastructure is almost nonexistent in buildings.

Market actors lack an understanding of the use cases and the associated value propositions of DC lighting. Contractors lack the familiarity to confidently and correctly install them or the labor force needed to realize installation cost savings for low voltage. Confusion regarding appliance repair responsibility within the facility management, cyber-security concerns, and atypical user interfaces are also major market barriers.

DC lighting currently has no significant incremental energy savings or other energy benefits in retrofitting AC lighting for efficiency programs to leverage for accelerated and large-scale deployment.

Market studies focusing on understanding the current landscape of DC lighting technologies, clarifying the value propositions for different DC lighting technologies, and examining how DC lighting integrates with other building systems are critical research needs to help overcome market barriers. Demonstrations of DC lighting on a pure building DC infrastructure, including direct integration with DERs, will help clarify the technology performance and benefits of the technology family.

Advanced Electric Light Sources

CalNEXT Role: Collaborate | CalNEXT Priority: Medium

Key Factors

Energy Savings: Medium
Decarbonization: Not Applicable
Demand Flexibility: Low
Other Emissions Impacts: Low

Knowledge Index

Technical Performance: Medium (increased)
Market Understanding: Low
Program Intervention: Low

Example Technologies

Examples for commercial and industrial applications: Network-connected linear lamps, retrofit kits, and luminaires; tubular lighting emitting diodes (TLEDs), retrofit kits, and luminaires with embedded sensors and controls; spectrally tunable light sources and spectrally engineered LED for peak melanopic sensitivity in offices, schools, and healthcare settings; disinfecting luminaires in offices, schools, healthcare, and public settings; laser diodes for industrial high bay applications.

Examples for residential applications: network-connected lamps and downlights; lamps and fixtures with embedded sensors and controls; spectrally tunable or engineered LED for sleep/wake cycle improvement.

Definition

Advanced Electric Light Sources have two primary functions: energy-focused and non-energy-focused. For energy-focused functions, advanced electric light sources provide high-efficiency illumination and offer additional functionality such as network communication, sensors, or built-in intelligence for enhancing the effectiveness of light delivery. Advanced electric light sources also provide disinfection and/or light benefiting human health.

Opportunities

Advanced Electric Light Sources have the potential to continue to drive energy savings beyond LED conversions through built-in sensors and controls. Light sources with built-in sensors, connectivity, and intelligence have the potential to enable demand flexibility for lighting systems as well as other building systems and appliances.

The current architectural and lighting research trends show that there is potential for improving occupant health and well-being (circadian rhythm or disinfection) by using Advanced Electrical Light Sources. Units designed for impacting circadian rhythm are beneficial in the office, education, and healthcare settings as well as residential buildings. Advanced Electrical Light Sources with disinfection functionality are most impactful in office, healthcare, and public assembly buildings.

Barriers

Higher costs and unproven energy and non-energy benefits are generally the key market barriers of this technology family. Cost and simplicity are particularly important factors for increasing the penetration of retrofit light sources with onboard sensing and connectivity capabilities that can reduce energy consumption from illumination.

For Advanced Electric Light Sources that can deliver non-energy benefits, the technical performance is not well-quantified as the supporting science may not be fully developed. Non-visual lighting simulation tools and metrics have been developed, but validation research is still required.

Signage

CalNEXT Role: Collaborate | CalNEXT Priority: Low

Key Factors

Energy Savings: Medium
Decarbonization: Not Applicable
Demand Flexibility: Low
Other Emissions Impacts: Low

Knowledge Index

Technical Performance: High
Market Understanding: High
Program Intervention: Low

Example Technologies

LED) billboards, channel letter signs, back-lit graphics; light control films (LCF); liquid crystal displays (LCDs), and other display signage; LED replacements for neon signs; signage controls.

Definition

This technology family covers illumination for the display of visual information in interior or exterior environments.

Opportunities

Progress in illumination technologies offers the opportunity for more energy-efficient, durable, and long-lasting signage lighting. Higher energy savings and demand flexibility can be achieved through signage controls. Newer technologies offer better lighting quality and the potential to reduce light pollution compared to incumbent technologies. The new program measure opportunities may exist to incentivize lower energy consumption through controls, advanced light source technology, and product design details to ensure lower energy consumption.

Barriers

California code requirements for indoor and outdoor signage are based on older technologies such as metal halide and fluorescents light sources. Recent code update proposals have faltered as industry adoption of LED signage is above code baselines, casting doubt on the benefits of stricter code.

The basis for programs will need to be detailed knowledge of industry standard practice (ISP) for the energy consumption and controls strategies in modern signage products and signage retrofit approaches.

ENERGY STAR® currently has a Signage Display category, but it only covers displays that are similar to modern LED-style televisions. Large LED billboards, channel letter signs, static cabinet signs, and other common sign types do not have any guidance or performance targets to establish ISP or better levels. No recent utility program is specifically targeted at signage lighting and controls.

Advanced Approaches to Exterior Lighting

CalNEXT Role: Lead | CalNEXT Priority: High

Key Factors

Energy Savings: Medium
Decarbonization: Not Applicable
Demand Flexibility: High
Other Emissions Impacts: Medium

Knowledge Index

Technical Performance: High
Market Understanding: Medium
Program Intervention: Medium

Example Technologies

DERs-integrated exterior luminaires (grid-powered)[1]; networked controls; exterior-specific occupancy sensing technologies; emerging design practices; high-efficiency light sources or optics.

Definition

This technology family encompasses products, design strategies and components that improve the efficiency of exterior lighting in commercial and public sectors while also considering best practices for the nighttime lighting environment (human health, visual comfort, public safety, and environmental impacts).

Opportunities

There are significant energy savings and demand flexibility benefits if the entire exterior lighting stock is transformed by this technology family. Streetlights managed by the public sector stakeholders and area lighting managed by commercial sector stakeholders are the primary focus. With the peak demand on the California grid moving toward the early evening hours, this technology family could shift a significant portion of exterior lighting demand while also delivering meaningful energy savings. As utility tariffs continue to evolve, advanced network controls and DERs integration for exterior lighting will become more cost-effective and increased adoption should drive additional innovation. DERs-integrated exterior lighting also has the potential to serve as part of the essential infrastructure in locations with a high likelihood of power outage, such as areas impacted by the Public Safety Power Shutoff events.

Additional opportunity lies in developing occupancy-sensing technologies that enable deep savings for installations where the dimensions or other site-specific conditions, such as vegetation or weather, prohibit the deployment of existing occupancy sensing technologies. Projects focused on refining the definition of idealized visual environments through human factors studies can further reduce energy usage. Advanced exterior lighting, particularly roadway or parking lot lighting, also has the potential to incorporate electric vehicle (EV) chargers into the existing infrastructure for non-energy benefits (equity and low-income sector).

Research should focus on the following areas:

[1] Existing related project: “Demonstrate Smart Exterior Solid-State Lighting in Low-Income or Disadvantaged Communities”, project number ET21SCE0014.

- Develop a standardized approach to incorporate exterior lighting as grid dispatchable and controllable loads and connecting to the utility's Distributed Energy Resource Management Systems (DERMS).
- Quantify the total benefits of DERs-integrated exterior lighting and controls in microgrid use cases, especially in areas prone to power outage (e.g. due to Public Safety Power Shutoff), and clarify measure design to account for potential interaction with California self-generation policies.
- Increase and demonstrate the performance reliability of occupancy-sensing technologies at a wider range of mounting heights and terrain and weather conditions.
- Conduct market research and lifecycle study to further inform the determination of industry standard practice and claimable program savings.

Barriers

Exterior lighting consists of a wide array of applications (roadway, hardscape/area, façade, landscaping, and more), each of which may have more than one accepted design practice that depends on site-specific conditions. Because of this, the performance of advanced exterior lighting technology is understood for some of the example technologies for a range of limited applications but never broadly across the entire breadth of possible deployments. The diversity and scale of exterior lighting applications is a significant barrier to justifying programs for technologies covered under this family. Workforce training related to installation and commissioning and adoption/acceptance by operations and maintenance staff remains a significant barrier to the adoption and deployment of advanced approaches to exterior lighting. Also, the conventional design practice of maintaining nighttime visibility for public safety significantly limits the wide adoption of occupant-based control technology.

Next Steps

Following submittal of the 2023 Lighting TPM Final Report, the Program Team will do the following:

1. Update CalNEXT website with new 2023 Lighting TPM.
2. Launch email announcement through email outreach.
3. Develop and submit 2023 Lighting TPM Distribution Report.

Appendix A: Advisory Committee Feedback & Resolution Matrix (Incorporated in the Draft Report)

Table 4: Advisory Committee Feedback & Resolution Matrix

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Connectivity, Controls, and Integration	Subgroups	Codes and Standards (C&S) and existing energy efficiency (EE) measures already cover some much of this effort.	Provided qualifiers to specify the capabilities of the subgroups that are not covered by current control requirements in codes and standards. The Statewide CASE Team has attempted to incorporate networked lighting controls into Title 24 in the previous code cycles but wasn't successful. Savings from these additional capabilities could ultimately help justify requiring networked lighting controls in building energy codes. Also, the additional savings from Certain subgroups are covered by existing EE measures, but continued advancement of the subgroups should still be encouraged to realize deeper savings, higher operational efficiencies, and better market penetration.
Connectivity, Controls, and Integration	Subgroups & Opportunities	Home automation is not new. Recommend expand in Opportunities maybe where it is today…Alexa, smart speaker, etc.	Expanded the related narratives in the Opportunities section.
Connectivity, Controls, and Integration	Definition	Highly recommend combining both paragraphs in the section.	Incorporated the mentioning of other technology families into the definition as recommended. Modified the notes to point the readers to the TPMs of those technology families.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Connectivity, Controls, and Integration	Opportunities	Advanced daylighting controls have been researched and maybe in code. How far does the range benefit from daylight at the window to the center of the room? There is a lot of research on this already. Is this really an Emerging Technology effort?	Advanced daylighting controls here are not referring to traditional daylight harvesting but novel daylighting control technologies, which may be combined with passive devices and apparatuses, to increase daylight penetration into and/or down the building. A good example is the technology that mechanically tracks the sun and collect and direct the light to spaces without direct access to daylight through a medium capable of transmitting light in a long distance with minimum losses.
Connectivity, Controls, and Integration	Opportunities	Though recently, ultraviolet/ultraviolet germicidal irradiation (UV/UVGI) lighting is known to support health benefits.	Agreed with the statement. The capability and benefit of UV/UVGI lighting, however, are not delivered through Connectivity, Controls, and Integration (although they do play a role), but primarily through light sources. For this reason, UV/UVGI lighting is covered in the Advanced Electric Light Sources technology family.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Connectivity, Controls, and Integration	Opportunities	This (referring to lighting system native metering and reporting) really treads on the line of (ISP). A lot of this is being or has been incorporated into code. How is this an emerging technology? Users use this to relieve in-house full-time equivalent (FTEs) or third parties to measure and report. There are several dashboard offerings on the market.	The emphasis of this paragraph is the self-energy metering and reporting capability built into the lighting systems, and in some cases, lighting components (e.g., drivers). The description was slightly modified. However, the SME team does not believe this has become an industry standard practice nor has it already been incorporated into the code. A recent advancement is the new American National Standards Institute (ANSI) standard (ANSI C137.5-2021 Energy Reporting Requirements for Lighting Devices) governing the accuracy of lighting system/device metering accuracy. This enables lighting systems to self-report trustworthy energy data that can be used for M&V, energy usage trending, code compliance (in the future outcome-based code scenario), continuous commissioning, or other advanced integration use cases. While the lighting system's native metering and reporting capability is currently available with supporting accuracy standards, its utilization is still low and has not yet been incorporated into the facility management workflow or other applications, and enabling such capability still commands a high premium. Therefore, the SME team believes there is significant untapped potential for this capability.
Connectivity, Controls, and Integration	Barriers	The Barriers section should be enhanced seeking additional stakeholder(s) SME's input on the topics presented here.	Additional thoughts and insights were collected from the SMEs and external stakeholders and incorporated into the section.

Connectivity, Controls, and Integration	Barriers	Sounds like this (referring to the first two paragraphs) is not really about Emerging Technology and more of training. The California Advanced Lighting Controls Training Program (**CALCTP**) is a statewide initiative aimed at increasing the use of lighting controls in commercial buildings and industrial facilities. Through proper installation, advanced lighting controls improve energy efficiency in commercial facilities and save significant dollars. This is supported by the electrical unions who have established training facilities across the state. On top of CALCTP, it is well known the majority of manufacturers also provide training. Some of which is targeted to Specifiers & Architect firms. Then there is the OEM sales and engineering teams that provide the same starting at the OEM to the Sales agents to the Distribution channels.	These paragraphs are about both the complexity of the technologies as well as training. Cost is another barrier that was mentioned twice in the paragraphs. The description has been improved to better reflect this. The scope is not just about basic control strategies but about accessing advanced capabilities to unlock deeper savings and improve operational efficiency. The SME team understands California Advanced Lighting Controls Training Program (CALCTP) is a great training program. Our understanding is that it is centered around basic (code-required) controls – dimmers, occupancy sensors, photosensors, relay modules, and communication-based control devices as stated on the CALCTP website. The same can be said for other current training programs. The advanced capabilities related to connectivity, controls, and integrations, such as native metering, advanced controls (such as high-/low-end trim), analytics, and integration (often through an application programming interface or application programming interface (API)), will require a different level of understanding to visualize their possibilities and incorporate them into the design and specification. At the moment, the difficulty lies in these advanced capabilities still evolving, and different manufacturers have different flavors of these features. It's not yet at a stage where programs like CALCTP can readily incorporate them. An emerging technology without well-trained installers and without its full capacity recognized, valued, and utilized by the stakeholders will have little chance to succeed. The SME team sees a lack of training and deep technology understanding as a market barrier.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Connectivity, Controls, and Integration	Barriers	Not sure this (referring to the third paragraph) is a factual statement. There is a clear line where individuals need to read them both. This is not a barrier to adoption. Advance Controls are not low hanging fruit for easy selling and installs. It is a harder sell with a higher price.	The SME team believes this is a factual statement. The control performance levels are not binary and can be compared against the code in the same way the lighting power density (LPD) can be compared. While some basic controls requirements are binary (e.g., you must use occupancy sensors in certain spaces), this doesn't automatically result in a known level of performance. For example, the delay time for occupant sensing controls is not absolutely dictated in code (although there is a 20-minute maximum), and the shorter the time delay, the higher the savings. However, designing a program to encourage/promote aggressive controls is often seen as infeasible because there is already a related code control requirement.
Connectivity, Controls, and Integration	Barriers	Sounds like the research is done. Where is the Emerging Technology here? How will the cost be overcome? Higher incentives, then what will be the cost effectiveness. Increased incentives may not be cost effective at the program level. What EE measures are available?	This description is related to the technology subgroup “home automation” with an emphasis on connected lighting and lighting controls. The description has been revised. The paragraph intends to point out the cost barrier and to call for innovative intervention strategies as it would not be possible to rely on traditional program intervention.
Connectivity, Controls, and Integration	Barriers	Please consider adding the Department of Housing and Urban Development (HUD) into the acronym list.	It has been added to the list of acronyms.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Horticultural Lighting	All	What is in code, as a measure and recently being considered for code? Overall is there a need for further research as an Emerging Technology… specify	Specified the current code requirements and the upcoming code change proposals for energy efficiency level in the Opportunities section. Revised the narrative to make clear that the savings opportunities are related to system design and controls. The research and development of control strategies and system design are significantly lagging compared to light source efficacy. Overall, it appears horticultural lighting is on a similar (and accelerated) trajectory as architectural lighting, where the advent and regulation of light source are much faster than design and controls. This is likely to make deploying advanced controls costly and economically prohibitive when they are not put in place at the same time as the efficient light sources.
Horticultural Lighting	All	The research has been done. Convincing the grower to just use LEDs vs. high intensity discharge (HID) is the barrier.	Agreed that the research on light source efficacy and the comparison of LEDs vs. HIDs are done. The emphasis of this technology family is on system design and controls. Also agreed that convincing the growers to adopt LEDs is the barrier. A large body of research is ongoing, though not directly related to energy efficiency, that investigates the effect of light source spectral distribution on different stages of plant growth and how the grower can manipulate the light source spectral distribution to achieve the desired production (speed, size, quality, etc.). The outcome of the research is likely to be the key driver that convinces the growers to adopt LEDs.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Horticultural Lighting	All	Replacement of luminaire often is not a one-for-one replacement but a 2-for-1 or 3-, 4-for-1 replacement.	Noted. This could mean the energy savings potential could be higher if one high-efficiency luminaire is replacing multiple low-efficiency luminaires.
Horticultural Lighting	All	Be aware of the plugged-in supplemental HID fixtures (plugged into the junction boxes only as needed) to supplement LED lighting.	This was noted as an existing practice but was not explicitly addressed in the TPM since there is more about program implementation and inspection.
Horticultural Lighting	Key Factors	Will the savings be predominately coming from deemed measures or custom measures?	The SME team did not assess the energy savings potential down to different program types. However, the savings captured are less about light source efficacy (due to the already-stringent requirement of codes and voluntary certification programs) but more about improved design practices and controls. In this regard, the savings are likely to initially come from custom measures until more data is available to create deemed measures.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Horticultural Lighting	Subgroups	Has the SME team considered adding clarification on how to differentiate commercial horticultural luminaires from residential horticultural luminaires?	The team is not aware of a straightforward way to differentiate between commercial and residential horticultural luminaires. The key difference is that commercial horticultural luminaires are currently governed by both building energy codes (Title 24) and voluntary certification programs (DesignLights Consortium (DLC) Hort v3.0). There are, however, no equivalent requirements or programs for luminaires designed for residential recreational growing. As a result, there may be additional energy savings opportunities in residential grow lights even though this is currently still a niche market. This point was added to the Opportunities narrative. The warranty period may be another common differentiator. Commercial products often have a five-year warranty, as dictated by the DLC Hort v3.0 requirements. Residential products (and non-DLC listed commercial products) typically offer a three-year warranty. These products are often more affordable because the manufacturers don't have to bake in the risk of a long warranty period.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Horticultural Lighting	Barriers	Is this (referring to the first two bullets of the recommended research activities) saying there needs to be further technology studies or a design to transfer the knowledge to the user? All these technologies have been researched, EE measures established and new Code in development including the review of it as an ISP. The technical aspect unknown is the growers' formula or methodology (Recipe) or change in accelerated production.	These recommended research activities would be more of a design to transfer this knowledge to end-users. The perceived performance of LEDs is still somewhat of a barrier, so breaking that perception with data will be useful. The recommended research intends to emphasize the need for solid documentation showing the production value of similar crops – one using HID and one using LED – and comparing the overall yield rates as well as the economic realities of both products. Many existing studies are only looking at one or the other without providing a convincing and straightforward A/B testing comparison. While a grower may see a slight decrease in yield with LED, it may be more than made up for in terms of energy cost savings. There is also an important control aspect to this point. How adjusting the lighting levels throughout the day or grow cycles can improve the yields using LEDs - something that's often not able to be done with HID fixtures. Advanced growers are using LEDs to emulate "sunrise/sunset" cycles where the lights slowly come up to a set output over the first/last 15-30 minutes of the day. They are also adjusting the light output based on the growth cycle the crops are in, e.g., the first two weeks may be at 60 percent light output then the next 3 at 70 percent, and the last 2 weeks back down to 60 percent, etc. Learning how this can affect the yield rate on different crops could not only help increase the acceptance of LEDs among growers but also further increase energy savings. The language has been revised to better reflect the original intent.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Horticultural Lighting	Barriers	Is this an Emerging Technology research need or more of training or market transformation?	Providing scientific research showing the performance of LEDs in relation to other light sources would benefit both the technology and end users. Horticultural lighting efficiency still has fewer scientific studies than other technologies, and the industry would benefit from better documentation of LED grow light performance.
DC Lighting	All	This is a good technology area when coupled with distributed energy resources (DERs).	Agreed. The Opportunities and Barriers narratives have been revised to explicitly point this out.
Signage	Key Factors	Savings could potentially be higher due to the new LCD screen test procedure Northwest Energy Efficiency Alliance (NEEA) is pushing for federal adoption after the success of getting the TV test procedure adopted by DOE.	Noted. In the context of CalNEXT, this could actually translate to diminished savings potential because the baseline efficiency will increase if the new test procedure is adopted. The current rating for energy savings still seems appropriate.
Advanced Approach to Exterior Lighting	Technology Family Name	The name “advanced exterior lighting” is misleading as it suggests advanced light sources, but the definition and subgroups are more about controls and design.	The name has been changed to “advanced approaches to exterior lighting”. This technology family intends to include all promising emerging technologies for outdoor lighting applications. As such, it does not discriminate against light sources. However, current promising emerging technologies are indeed more about design and controls. The new name should provide a clearer indication of what this technology family encompasses. Additionally, “high-efficiency light sources or optics” is added as a subgroup to ensure advanced light sources are not excluded.
Advanced Approach to Exterior Lighting	All	California had many prior projects, but the measure never took off.	Noted. This likely shows that there are other specific barriers that need to be overcome.

Technology Family	Section	Suggestion or Comment	Action Taken & Justification
Advanced Approach to Exterior Lighting	Subgroups	Clarify what we mean by "grid-connected" (in reference to the DER integrated exterior luminaires). Is it dispatchable or simply connected to grid power?	Changed the verbiage to "grid-powered" to signify the primary intent for this subgroup is hybrid luminaires that connect to grid power while equipped with self-generation and storage capability. These luminaires can potentially be also dispatchable, but such capability is captured in the "networked controls" subgroup.
Advanced Approach to Exterior Lighting	Subgroups	Reference: ET21SCE0014 (in reference to the DER integrated exterior luminaires)	Added a footnote to reference this project.
Advanced Approach to Exterior Lighting	Barriers	Outdoor lighting stakeholders might have even more concerned about load shedding compared to interior lighting stakeholders.	Agreed. This is already included in the barrier's narrative.