U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Lighting Technologies for Grid-Interactive Efficient Buildings

Building Technologies Office

April 15, 2019

Agenda

1. Introduction
    a) Background
    b) Lighting Potential
    c) Flexibility Modes and Grid Services
    d) Report Approach
2. State-of-the-Art Technologies
3. Evaluation of Technologies
4. Attributes, R&D Challenges, and Opportunities

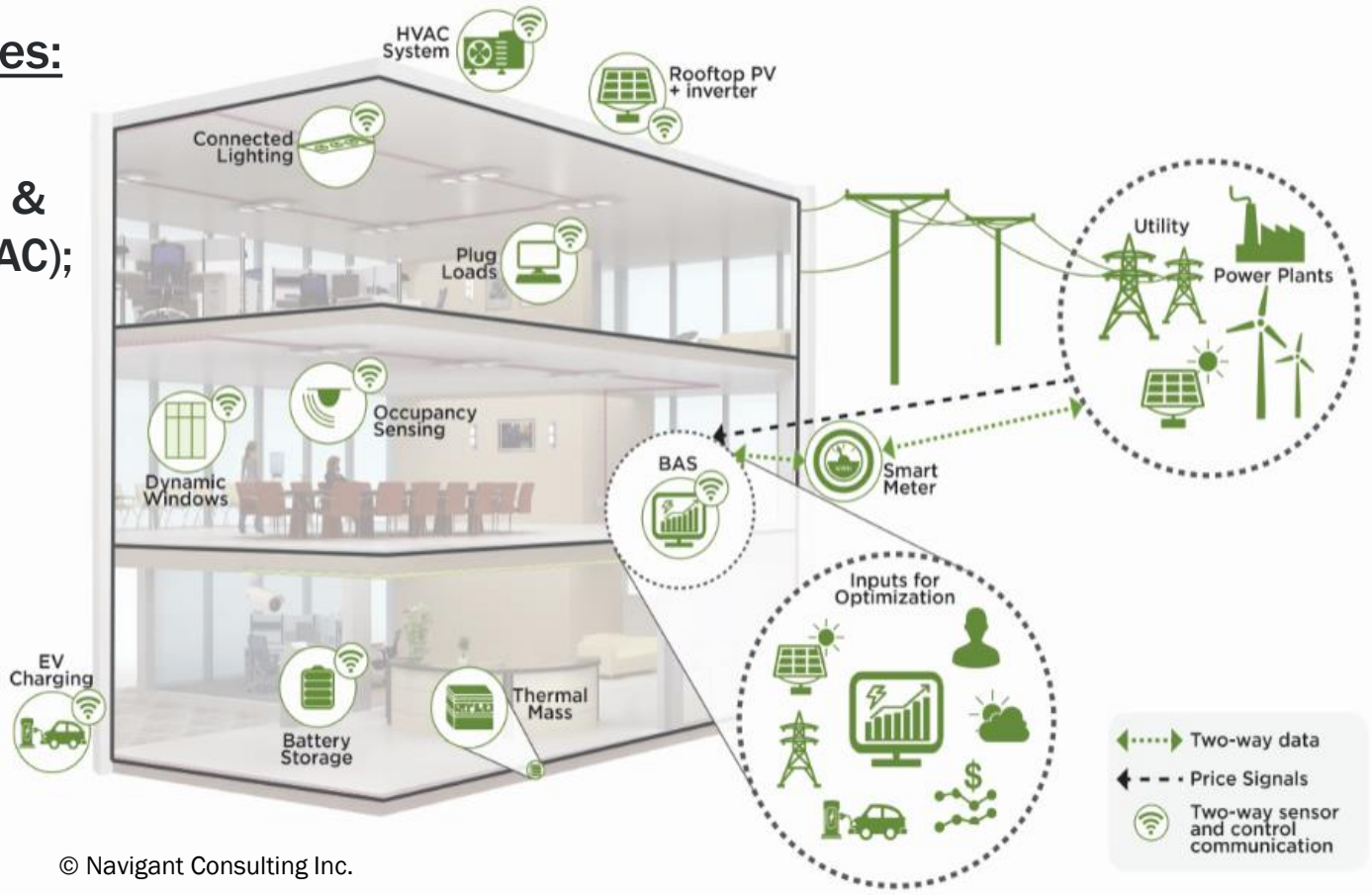
1. Introduction

GEB Technical Report Series Overview

The GEB Technical Report Series will help guide BTO's R&D portfolio and serve as a foundational resource for the larger building research community.

Technical Report Series:

- Overview
- Heating, Ventilation, & Air Conditioning (HVAC); Water Heating; and Appliances
- Lighting
- Building Envelope & Windows
- Sensors & Controls, Data Analytics, and Modeling



Grid Services

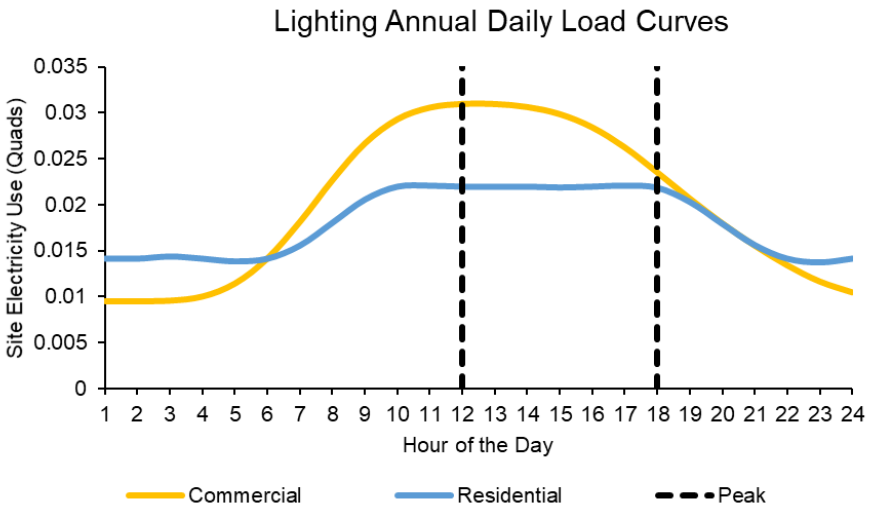
We identified 7 grid services that can be provided by building technologies.

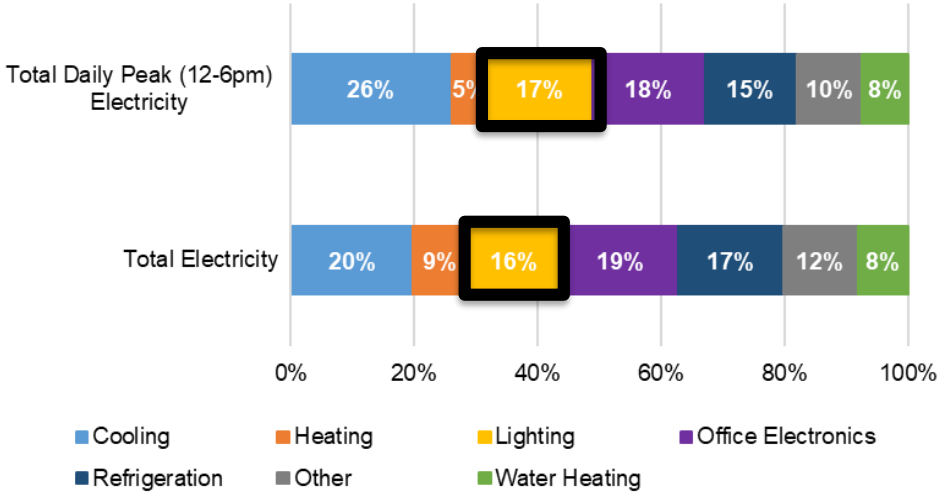
Grid Services		Potential Avoided Cost
Generation Services	Generation: Energy	Power plant fuel, operation, maintenance, and startup and shutdown costs
	Generation: Capacity	Capital costs for new generating facilities and associated fixed operation and maintenance costs
Ancillary Services	Contingency Reserves	Power plant fuel, operation, maintenance, and opportunity costs associated with providing contingency reserves
	Frequency Regulation	Power plant fuel, operation, maintenance, and opportunity costs associated with providing frequency regulation
	Ramping	Power plant fuel, operation, maintenance, and startup and shutdown costs
Delivery Services	T&D: Non-wires Solutions	Capital costs for transmission & distribution equipment upgrades
	Voltage Support	Capital costs for voltage control equipment (e.g. capacitor banks, transformers, smart inverters)

Lighting Potential

Lighting is an untapped resource in grid service markets, but potential exists.

- **The vast majority of lighting systems are not connected or DR responsive**
- **Lighting contributes to building peak energy use**
  - Lighting constitutes approximately 16% of total energy and 17% total daily peak energy use

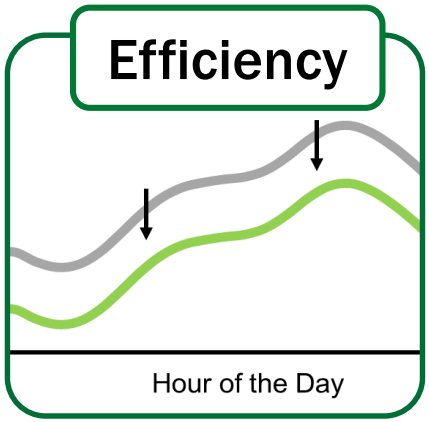


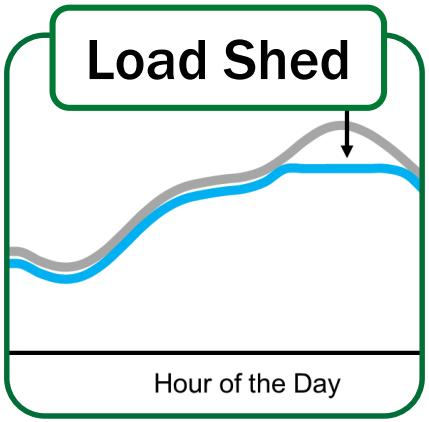


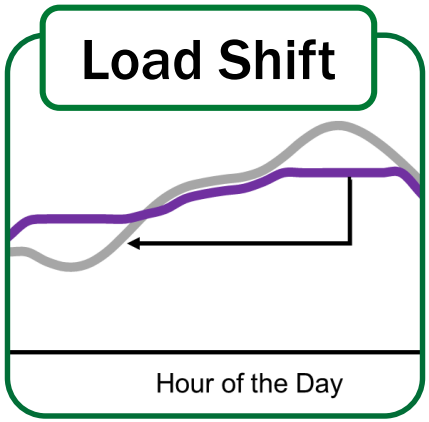
Data are generated using the Scout time-sensitive efficiency valuation framework, which attributes annual baseline energy use estimates from the U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO) across all hours of the year using energy load shapes from the Electric Power Research Institute (EPRI).

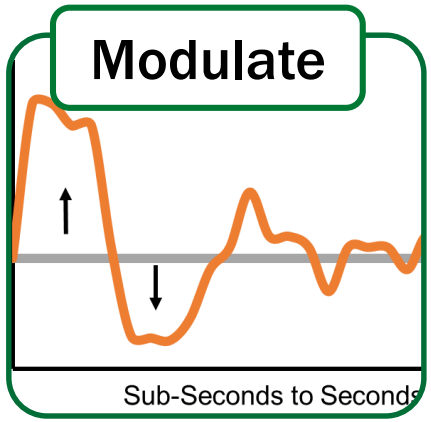
Mapping Flexibility Modes and Grid Services

Lighting can provide grid services through 4 demand flexibility modes.









Grid Services Provided

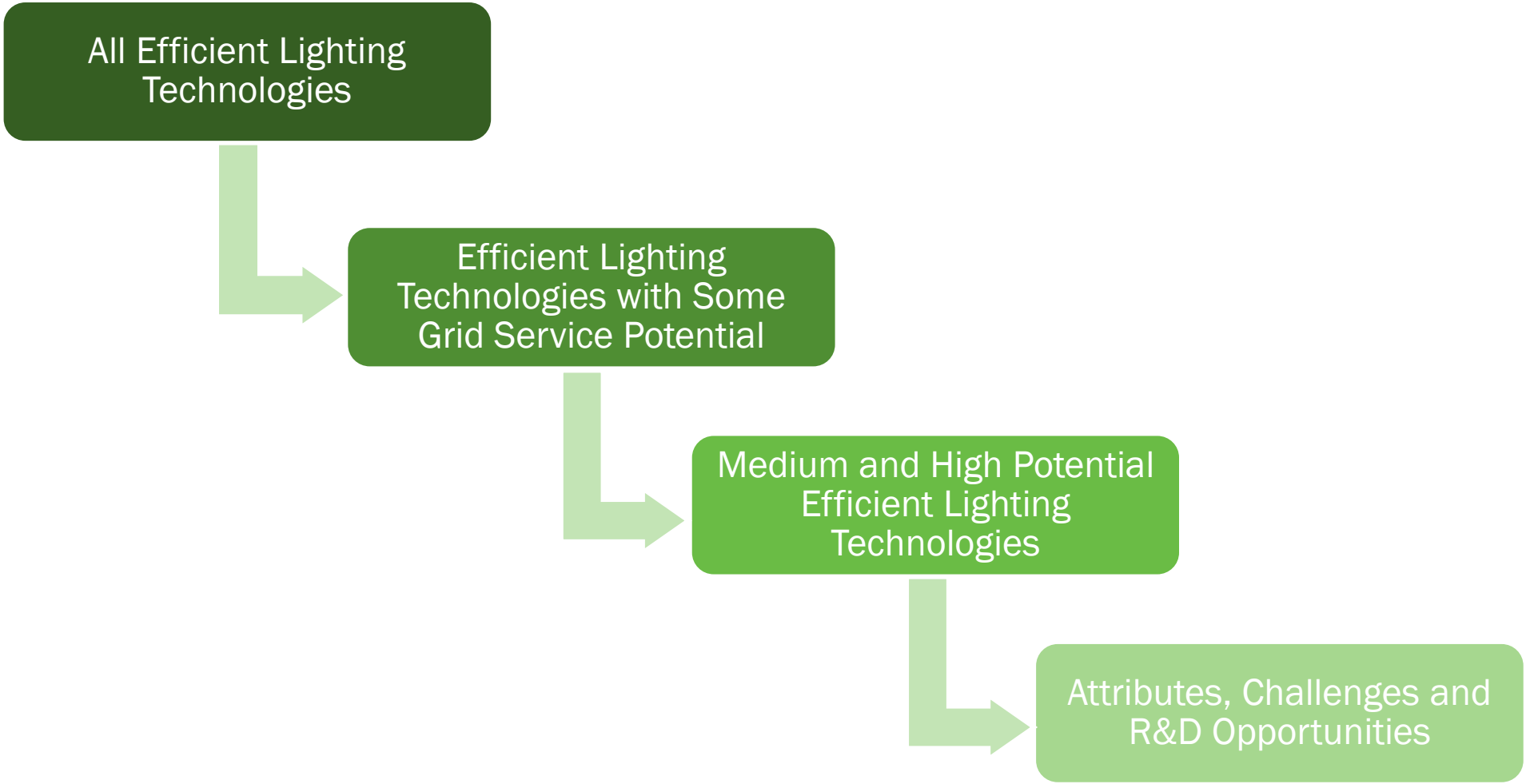
• Generation: Energy & Capacity • T&D: Non-Wires Solutions	• Con. Reserves • Generation: Energy & Capacity • T&D: Non-Wires Solutions	• Generation: Capacity • T&D: Non-Wires Solutions	• Frequency Regulation • Ramping

Examples

• Daylighting S&C	• Dimming by preset amounts	• Lighting + batteries	• Rapid dimming

Report Approach

This is the approach we took to identify lighting technologies that could provide grid services and what R&D is needed to provide them.



2. State-of-the-Art Technologies

Connected Lighting Systems

For this report, we have focused on technologies associated with *connected lighting systems (CLS)*.

CLS is being defined as:

- Comprised of LED lamps and/or luminaires, network communication interfaces, and sensors/controllers.
- Can communicate with the grid, BAS, and other DERS
- Can respond automatically and in aggregate to grid signals

PNNL Connected Lighting Testbed. https://www.energy.gov/eere/ssl/connected-lighting-systems

Identifying State-of-the Art Technologies

We utilized SSL and connected lighting experts to narrow our initial list of efficient lighting technologies down to five.

- **The following were selected based on those conversations:**
  - Advanced Lighting Controls
  - Integrated Batteries
  - DC Lighting Systems
  - Hybrid Sunlight LED Systems
  - SSL Displays

Advanced Lighting Controls

CLS that utilize embedded advanced controls and algorithms to modulate lighting levels, spectrum, or other power-consuming lighting features in response to external grid signals.

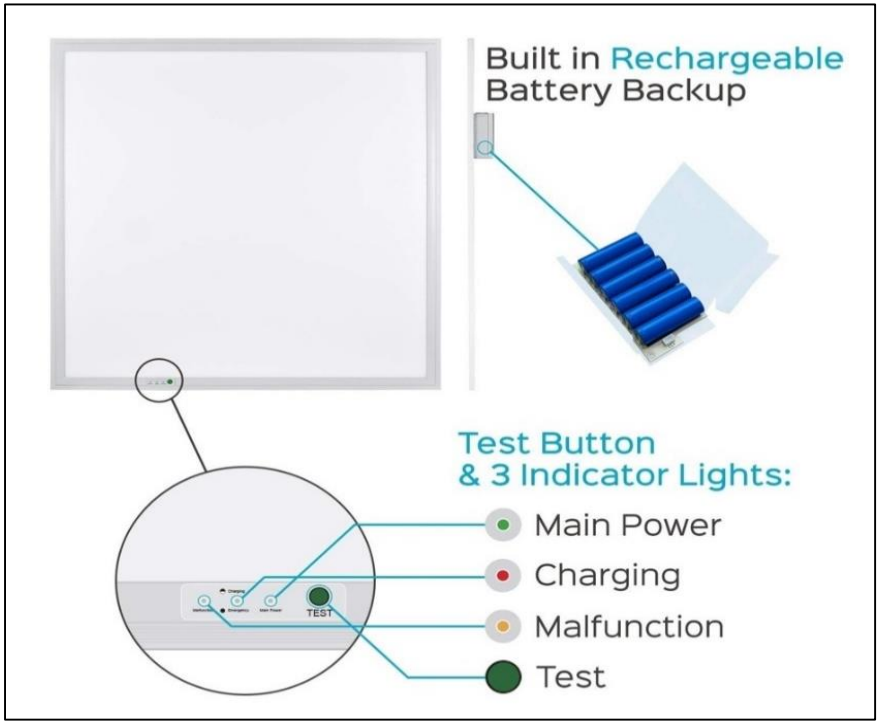
- Go beyond standard lighting controls
- Include adaptive algorithms for controls, APIs for DR, etc.
- Lighting controls market expected to see rapid growth

Bonneville Power Administration, "Luminaire Level Lighting Controls" [Online]. Available: https://www.bpa.gov/EE/Technology/EE-emerging-technologies/Projects-Reports-Archives/Pages/Easily-commissioned-Lighting-Controls-.aspx

Integrated Batteries

CLS utilizing an integrated rechargeable battery to provide off-grid lighting power that automatically recharges when needed.

- Battery could be integrated into the luminaire or somewhere else in the lighting system
- Currently exist but are used to provide emergency lighting during power outages
- Market mostly non-existent in the U.S.

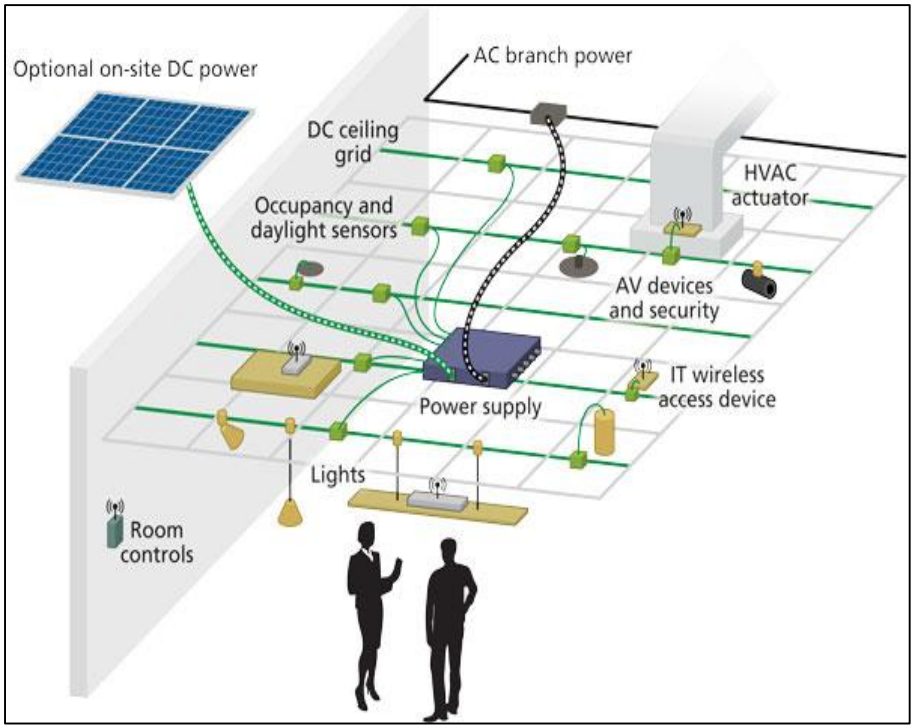


Luxrite, "Luxrite LED Products – Winer 2018" [Online]. Available: http://www.allstarlighting.com/media/Luxrite_Brochure_Winter_2018_LR.pdf

DC Lighting Systems

CLS that are powered by direct current (DC) rather than alternating current (AC) electric generation/storage sources.

- Eliminate the need to convert AC to DC within each LED luminaire or lamp
- Provides additional energy efficiency gains
- Well-suited for DER integration
- Market is in infancy, but growth is expected



EMerge Alliance, "DC Power Distribution Systems," Strategies in Light, Feb-2015 [Online]. Available: https://www.emergealliance.org/Portals/_default/Knowledgebase/1/150225%20Strategies%20in%20Light_The%20LED%20Show_BTP.pdf

Hybrid Sunlight LED Systems

CLS that are enhanced by the integration of technology to collect and re-distribute zero energy sun-lighting.

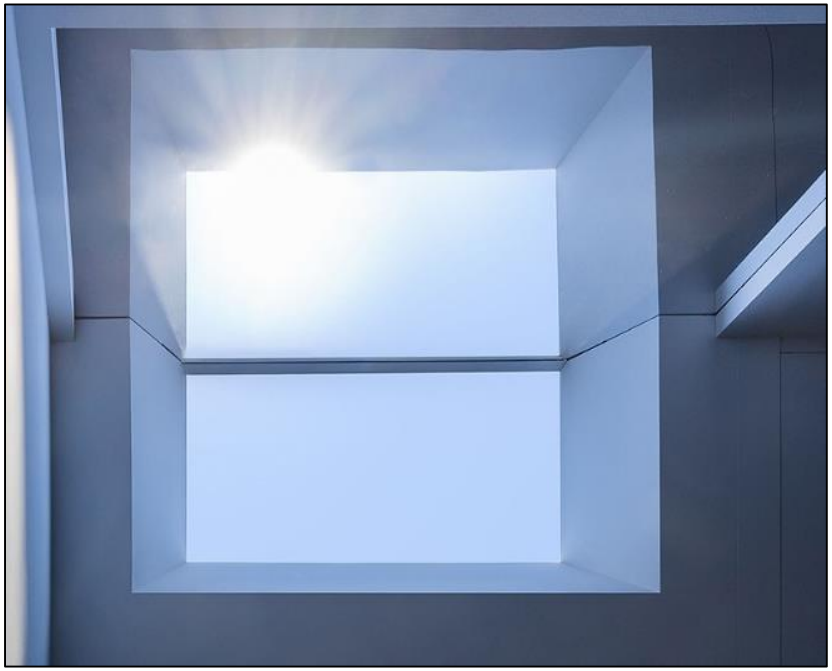
- Include optimization of window and skylights as well as sunlight concentrating systems (fiber optic cables, piping, mirrors)
- Photosensors and controllable LEDs are used to ensure real-time and automatic light modulation
- Exist today, but market adoption is very slow.

Mohammed S. Mayhoub, "Hybrid Lighting Systems: Performance, Application and Evaluation," July 2011. [Online]. Available: https://www.researchgate.net/publication/262933734_Hybrid_Lighting_Systems_Performance_Application_and_Evaluation

SSL Displays

CLS displays leveraging either LED or organic-LED (OLED) technology to eliminate the need for windows and skylights as sources of day lighting.

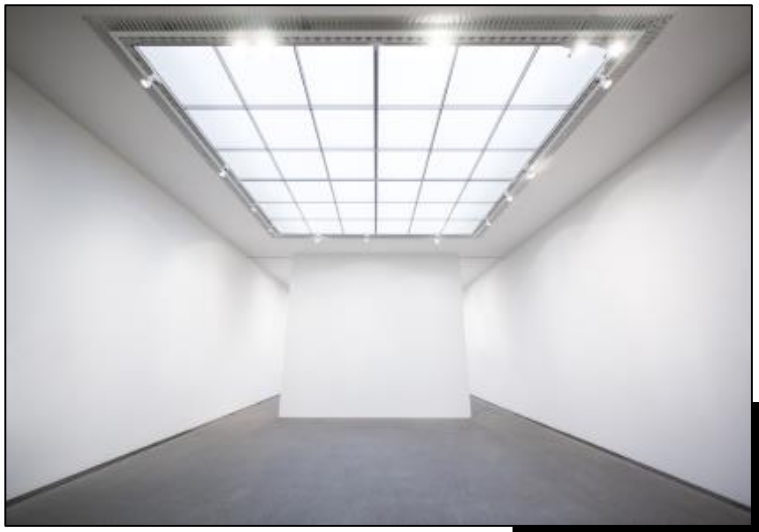
- Consists of energy efficient SSL displays that mimic day lighting and sun exposure
- Provide necessary lighting while eliminating heating/cooling losses
- Exist today, but used for lighting basements or other spaces without windows.



CoeLux, “CoeLux® 45 SQUARE.” [Online]. Available: https://www.coelux.com/en/p/coelux-45-square-en-11

Discussion

Are there other lighting technologies available or that could be developed that should also be considered?



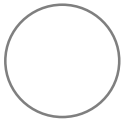
R-Display and Lighting. “OLED Display” http://www.r-displayandlighting.com/oled-lighting
J. Hecht, “Lessons on Laser Diodes,” *Archit. Light.*, 2017 [Online]. Available: https://www.archlighting.com/technology/lessons-on-laser-diodes_o

3. Evaluation of Potential

Evaluation Criteria

We used 3 basic criteria to evaluate the technologies.

1. **Capability Rating for Each Flexibility Mode**
   - Based on Grid Services Technical Requirements

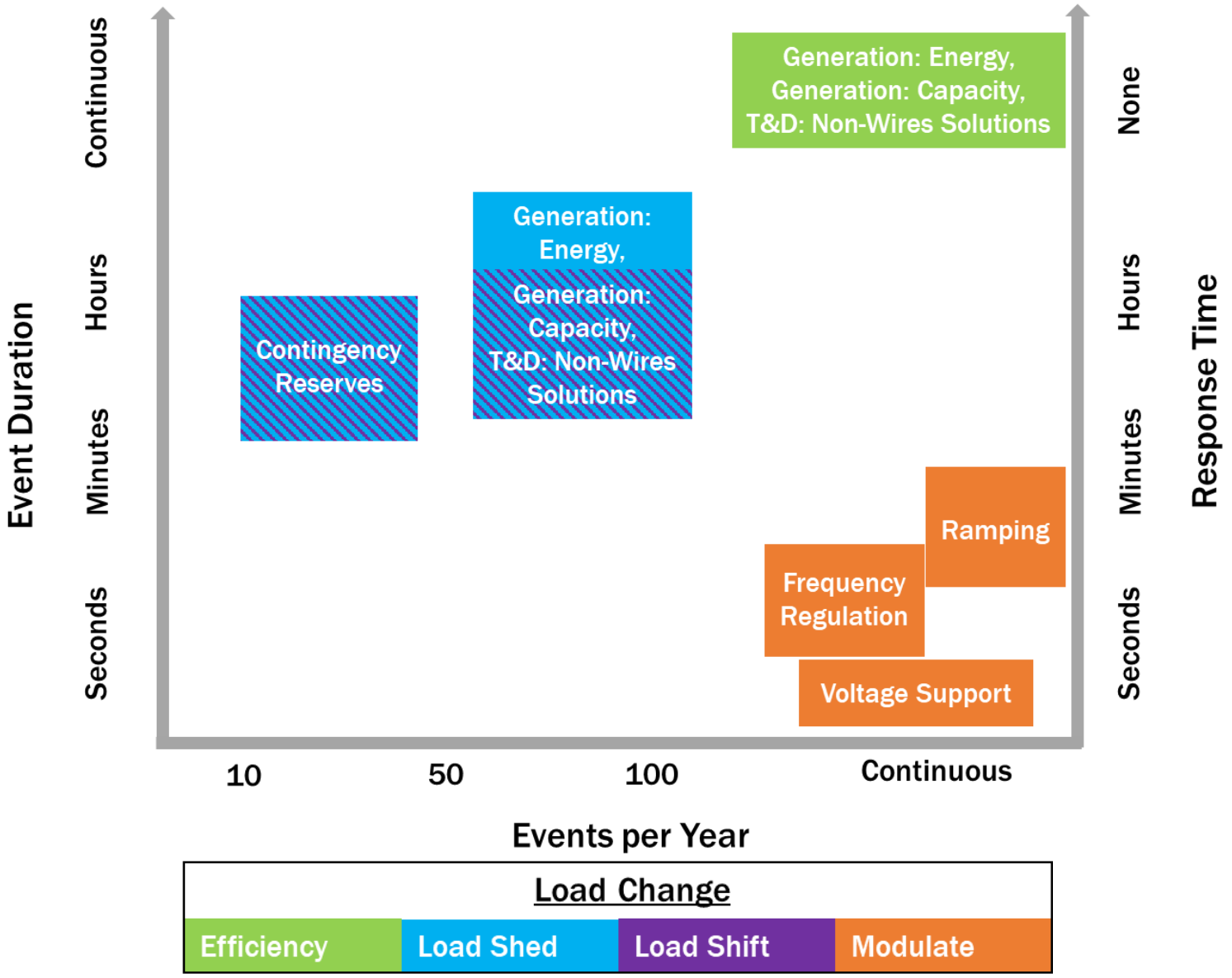
Capability Ratings							
	Not Applicable		Low Capability		Medium Capability		High Capability

2. **Number of Flexibility Modes provided**
   - I.e., Efficiency, Load Shed, Load Shift, Modulate
3. **Weighting of Flexibility Modes**
   - Efficiency and peak reductions (shed/shift) higher value than frequency regulation, voltage support, ramping (modulate)

Grid Services Technical Requirements

Technical Requirements

1. Event Duration
2. Response Time
3. Event Frequency
4. Load Change

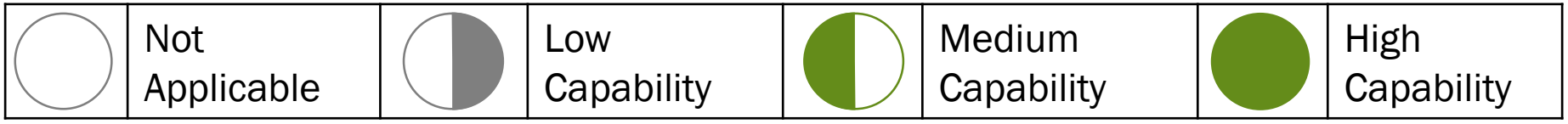


Advanced Lighting Controls

High potential

- Provides both efficiency gains and demand responsiveness
- Has the capability to provide fast response grid services, though in limited capacities due to the necessity of lighting in occupied spaces

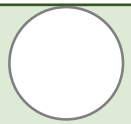
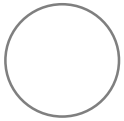
Flexibility Mode	Capability	Overall Potential
Efficiency		High
Shed Load		
Shift Load		
Modulate Load		

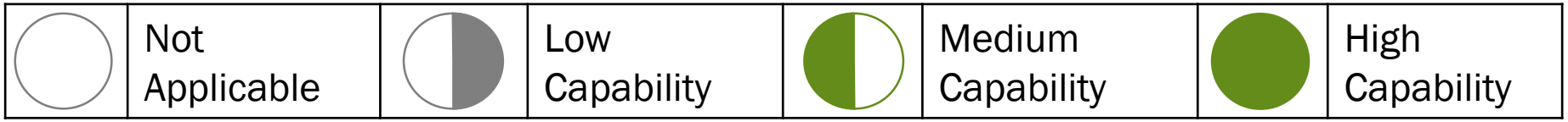


Integrated Batteries

High potential

- Provides the capability to shift loads to off-peak periods and the capability to provide fast response grid services while maintaining nominal lighting service
- Would not reduce/shed the overall lighting load as batteries are recharged during off-peak periods

Flexibility Mode	Capability	Overall Potential
Efficiency		High
Shed Load		
Shift Load		
Modulate Load		

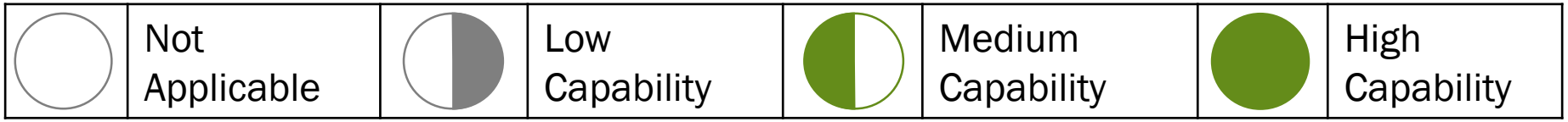


DC Lighting System

Medium potential

- Provides moderate efficiency gains and, when combined with controls, demand response can be used to shed loads
- By itself has low potential to modulate loads, but when combined with distributed generation/storage, it increases the potential to provide fast response grid services

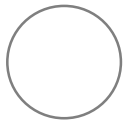
Flexibility Mode	Capability	Overall Potential
Efficiency		Medium
Shed Load		
Shift Load		
Modulate Load		

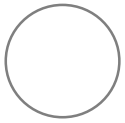


Hybrid Sunlight LED System

Medium potential

- Despite greatly reducing lighting loads when sunlight is available, it does not perform load shedding or shifting
- Could potentially be used to modulate lighting loads between sunlight and LED lighting as needed

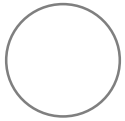
Flexibility Mode	Capability	Overall Potential
Efficiency		Medium
Shed Load		
Shift Load		
Modulate Load		

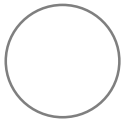
	Not Applicable		Low Capability		Medium Capability		High Capability

SSL Displays

Low potential

- Only provides grid benefits via reduction of heating and cooling loads
- Increases the electricity consumption from electric lighting sources
- Could provide only limited demand response capabilities (shedding load) as the magnitude would be minimal

Flexibility Mode	Capability	Overall Potential
Efficiency		Low
Shed Load		
Shift Load		
Modulate Load		

	Not Applicable		Low Capability		Medium Capability		High Capability

Discussion

Within the technologies included in the report, are there any that have potential we have understated or overstated?

High Potential	Medium Potential	Low Potential
• Advanced Lighting Controls • Integrated Batteries	• Hybrid Sunlight LED Systems • DC Lighting Systems	• SSL Displays

R&D Challenges & Opportunities

Attributes Considered

We also considered these 7 attributes of each technology which can serve as additional benefits or barriers to implementing the technologies.

System Attribute	Definitions
Reliability	The ability of the technology to consistently perform grid services as intended over the lifetime of the product.
Resiliency	The ability of the technology to improve the resistance of the building to electric power outages and/or natural disasters by providing energy, services, occupant comfort, protection, and/or damage resistance.
System readiness	The ability of the technology to interoperate with other technologies, networks, and systems while maintaining cybersecurity.
Usability	The ease of use of the technology to the customer including ease of installation, ease of implementation, ease of operation, and ease of maintenance.
Manufacturability	The ability of the technology to be manufactured at a large scale; this includes the environmental sustainability of the raw materials, the manufacturing costs, and the final capital cost of the technology.
Human Health	The extent to which the technology contributes to a healthy and safe living environment for the building occupants.
Energy and Emissions	The estimated energy savings and environmental CO_2 emission savings from implementing the technology at scale.

Attributes: Advanced Lighting Controls

Benefits

- Energy and emissions savings
- Human health impacts

Barriers

- Usability difficulty
- Interoperability/ Cybersecurity
- Manufacturability/High capital costs
- Technical limitations (modulation levels)
- Few utility programs

Advanced Lighting Controls: High Potential

DR Protocols and Control Algorithms

- Quantify the DR potential of lighting manipulations
- Determine the optimal control algorithms and communication architecture for maximizing grid services provided (shedding and modulating) and minimizing occupant impact
- Novel control algorithms that leverage machine learning capabilities to customize strategies

Sensors Integration

- Design and techniques for optimal sensor integration in lighting devices

If R&D solutions achieve the opportunities outlined above, advanced lighting control systems will have greater capability to provide: 1) energy efficiency, 2) load shedding, and 3) load modulation.

Attributes: Integrated Batteries

Benefits

- Resiliency

Barriers

- Usability difficulty
- Interoperability/ Cybersecurity
- High capital costs

Integrated Batteries: High Potential

Load Modulation Benefit Quantification

- Develop integrated battery lighting prototypes that are designed to autonomously respond to grid signals within seconds
- Identify the use cases and measure/verify the potential load modulation benefits

DR Protocols

- Develop DR protocols, integrated controllers, as well as drivers and power supplies that enable the LED lighting system to switch power sources seamlessly in response to grid signals
- Determine the optimal charging strategies for the batteries to minimize efficiency losses and the impact on the grid

If R&D solutions achieve the opportunities outlined above, connected lighting systems with integrated batteries will have greater capability to provide: 1) load shifting and 2) load modulation. However, market challenges must be overcome to increase manufacturing and market adoption.

Attributes: DC Lighting Systems

Benefits

- Energy and emissions savings
- Reliability
- Manufacturability/Low capital costs
- Usability

Barriers

- Interoperability/ Cybersecurity

DC Lighting Systems: Medium Potential

Electric Current Transport Efficiency

- Determine improved cabling, drivers, switches, gateway devices, and system designs for DC LEDs that minimize electricity losses

If R&D solutions achieve the opportunities outlined above in DC lighting systems, they will have greater capability to provide: 1) energy efficiency, 2) load shedding, and 3) load modulation.

Attributes: Hybrid Sunlight LED Systems

Benefits

- Energy and emissions savings
- Resiliency
- Human health impacts

Barriers

- Usability difficulty
- Interoperability/ Cybersecurity
- Manufacturability/High capital costs
- Technical limitations (light transfer)

Hybrid Sunlight LED: Medium Potential

Efficiency of Light Guiding Materials

- Improve design of hybrid sunlight LED systems and materials to minimize efficiency losses

Cost

- Develop higher efficiency light transmitting systems at lower costs and technology payback periods

Integration with SSL

- Optimize the design of hybrid sunlight LED systems to ensure they are seamless and consistent

Load Modulation Benefit Quantification

- Develop hybrid sunlight LED system protypes that are designed to autonomously respond to grid signals within seconds
- Identify the use cases and measure/verify the potential load modulation benefits

DR Protocols

- Develop DR protocols, integrated controllers, as well as drivers and power supplies that enable the LED lighting system to between sunlight and electrical lighting seamlessly in response to grid signals

If R&D solutions achieve the opportunities outlined above, hybrid sunlight LED systems will have greater capability to provide: 1) energy efficiency and 2) load modulation.

Discussion

Are there any additional challenges and/or R&D opportunities that we missed here? Is there anything that should not be included?

Technology	Challenges and Gaps
Advanced Lighting Control Systems	Demand Response Protocols and Control Algorithms
	Sensors Integration
Integrated Batteries	Load Modulation Benefit Quantification
	Demand Response Protocols
DC Lighting Systems	Electric Current Transport Efficiency
Hybrid Sunlight LED Systems	Efficiency of Light Guiding Materials
	Cost
	Integration with SSL Systems
	Load Modulation Benefit Quantification
	Demand Response Protocols

Acknowledgements

Authors

- Mary Yamada, Navigant Consulting, Inc.
- Valerie Nubbe, Navigant Consulting, Inc.

Contributors

- Julie Penning, Navigant Consulting, Inc.
- Clay Elliott, Navigant Consulting, Inc.
- KyungHen Lee, Navigant Consulting, Inc.
- Ed Barbour, Navigant Consulting, Inc.
- Michael Poplawski, Pacific Northwest National Laboratory
- Jason Tuenge, Pacific Northwest National Laboratory
- Morgan Pattison, SSLS, Inc.
- Jeffrey Tsao, Sandia National Laboratory
- Jared Langevin, Lawrence Berkeley National Laboratory
- Monica Neukomm, U.S. DOE

End of Presentation