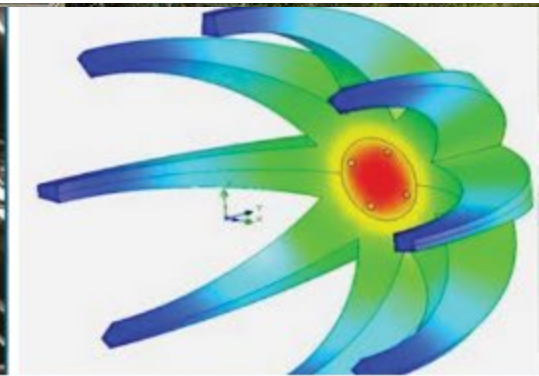# Connected Lighting Systems Stakeholders Research Study

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Acknowledgments

Disclaimer

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Note: All other interviewees and contributors requested to remain anonymous.

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1. Project Overview

Project Overview

The objective of this study is to better understand how users and stakeholders engage with connected lighting systems (CLS) and make decisions during each step in the supply chain process, from production to operation, in commercial buildings in the United States. CLS have seen slower than expected adoption and have faced many operational and installation challenges since they were first introduced in the market. The goal of this study is to provide an overview of:

- The decision-making process for CLS and how/why technologies and features are selected;
- The user experience in each step of the supply chain and the challenges faced;
- Barriers to adoption for CLS and opportunities to address these barriers; and
- Potential opportunities to improve the design of CLS to increase adoption and enhance usage.

Though important and influential to the CLS market, utility incentives, regulations, energy codes, and policy impacts are not a focus of the study and are largely out of scope.

This CLS project is the first in a series of three studies on building technologies users; the next two studies will cover residential smart thermostats and associated HVAC and residential envelope upgrades. These studies are intended to be used for internal DOE planning purposes.

CLS Definition and Project Scope

Definition

For the purpose of this study, CLS comprise solid-state lighting sources, interfaces, sensors, and controllers connected as a network, allowing for two-way communication and data sharing across devices and systems. CLS must have either occupancy, daylight, ,color tuning and/or task tuning capabilities, in addition to the ability to communicate with a BAS, HVAC, or other centralized platform. Connected lighting systems are also referred to as networked lighting control systems.

Scope

The study is focused on CLS used in interior spaces in commercial buildings and does not include residential or outdoor/municipal lighting systems and roadway lighting. Stand-alone, non-networked luminaire level sensors and controls are not considered CLS and are out of scope. Lighting controls are included in the scope of CLS.

Project Approach

1.. **Perform secondary research to identify existing research on CLS users and challenges**
- Develop detailed research questions and scope to focus research efforts
- Summarize findings and identify gaps/remaining questions

2. **Identify key CLS stakeholder types, organizations, and subject matter experts**
- Define various users from manufacturing to design through to operation

3. **Map out technology selection process and decision points CLS supply chain process**
- Identify market players, challenges, nuances, and opportunities in each step on the CLS selection process

4. **Identify stakeholder contacts and develop interview question guides**
- Determine gaps in research to inform interview questions
- Develop questions for each stakeholder type focusing on identifying challenges

5. **Complete stakeholder interviews with key stakeholder types and organizations**
- Interviews included: lighting designers, researchers, manufacturer reps, manufacturers, building operators, and utilities/consultants

6. **Summarize research findings for each process step**
- Summarize the key market players, challenges, and nuances
- Identify opportunities to address challenges
- Obtain feedback, make revisions, and perform additional interviews as needed to verify findings

Key Research Sources

We utilized a combination of primary and secondary data sources to gain insights on the CLS process, user experience, challenges, nuances, and opportunities. We conducted a total of 30 interviews with CLS stakeholders and utilized existing research studies on CLS. The full list of secondary sources is provided in the Appendix. The interview findings were aggregated, summarized, and kept anonymous.

Interviews

- Lighting Researchers
- Lighting Designers
- Manufacturer Reps
- Manufacturers
- System Operators
- Utilities/Consultants
- Electrical Contractors

Secondary Research Sources

- Pacific Northwest National Lab Next Generation Lighting Systems
- Integrated Lighting Campaign
- World Green Building Council
- Illuminating Engineering Society
- Building Case Studies

2. CLS Supply Chain Roles

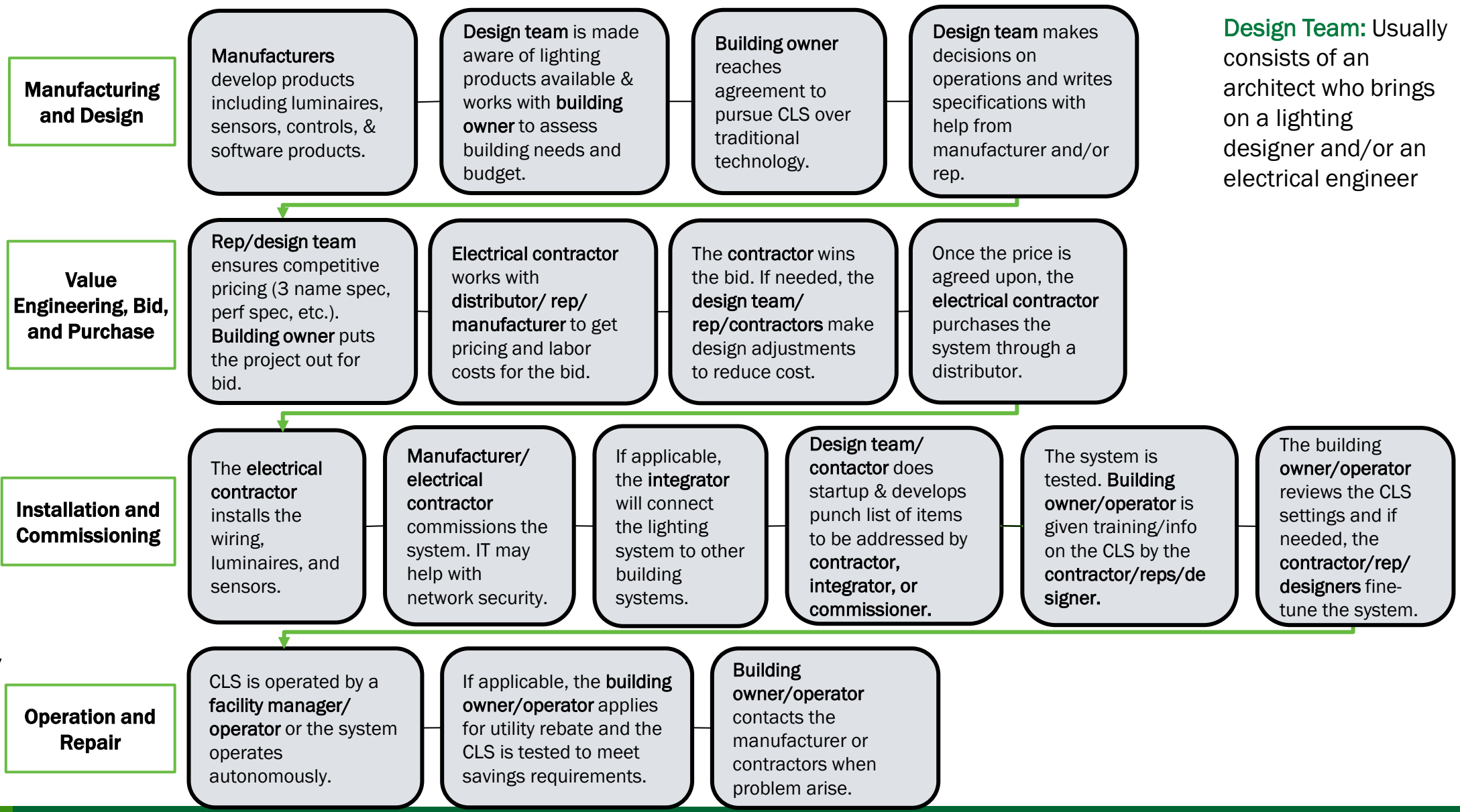# Definition of CLS Supply Chain Roles

Role	Definition
Manufacturer	Develops CLS products (luminaires, sensors, controls, and/or software systems) as well as training materials to aid in installation.
Building Owner	The client and key decision-maker, as well as the person whose budget pays for the installed product. **The building owner may rely on a construction manager, building manager, and/or contractor to make decisions on the connected lighting systems.**
Sales Rep	Works for an independent firm or a manufacturer and serves as a product consultant for CLS products, often helping with specifying, pricing, and commissioning system. Typically they represent multiple lighting/controls manufacturers.
Electrical Engineer	Can be independent or work for an electrical engineering firm. They are most often contracted by an architect or a contactor to design and/or specify the electrical systems.
Lighting Designer*	Can be independent or work for a lighting design firm. They are most often contracted by an architect to design a connected lighting system for a new building or renovation project.
Architect	Drives the design team on new construction projects or major renovation projects. May complete design and specifications or hire a team to do so. They ensure the building owner's design goals are met within budget.
Electrical Contractor	Usually contracted by the general contractor/construction manager and is on the construction team. Typically they must win the bid for the project (often with a manufacturer rep). They are responsible for purchasing and installing the CLS.
General Contractor*	Typically used to hire the electrical contractor and handle the bid process.
Integrator	Expert in integrating connected lighting systems with other building electrical systems (BAS, HVAC, AV system, etc.). They can do the integration themselves or train contractors on installation, start up, and commissioning the system.
Occupants	End-users who occupy the lit spaces in the building.
Building Operator	(Also called a facility manager, building manager, system operator) Operates and manages the CLS, as well as the person whose budget pays for the maintenance of the CLS. Depending on repair needs they will contact an electrician, manufacturer, and/or integrator.
Construction Manager	When involved they manage the entire construction process and may become decision-maker if the building owner is not heavily involved.
Third Party Commissioning Agent	May be required to have a third party do the commissioning and testing of the system.

* indicates an ESCO could also play this role

3. Connected Lighting System Project Process

Connected Lighting Supply Chain Diagram

While the connected lighting process varies, this diagram shows the typical steps involved from production to operation for a new construction or major renovation project, where connected lighting is more commonly installed. The 16 steps are divided into 4 key phases of a connected lighting systems project. *Detailed information on each step is provided in the Appendix on page 31.*

Design Team: Usually consists of an architect who brings on a lighting designer and/or an electrical engineer

Manufacturing and Design

Manufacturers develop products including luminaires, sensors, controls, & software products.

Design team is made aware of lighting products available & works with **building owner** to assess building needs and budget.

Building owner reaches agreement to pursue CLS over traditional technology.

Design team makes decisions on operations and writes specifications with help from manufacturer and/or rep.

Value Engineering, Bid, and Purchase

Rep/design team ensures competitive pricing (3 name spec, perf spec, etc.). **Building owner** puts the project out for bid.

Electrical contractor works with **distributor/ rep/ manufacturer** to get pricing and labor costs for the bid.

The **contractor** wins the bid. If needed, the **design team/ rep/contractors** make design adjustments to reduce cost.

Once the price is agreed upon, the **electrical contractor** purchases the system through a distributor.

Installation and Commissioning

The **electrical contractor** installs the wiring, luminaires, and sensors.

Manufacturer/ electrical contractor commissions the system. IT may help with network security.

If applicable, the **integrator** will connect the lighting system to other building systems.

Design team/ contactor does startup & develops punch list of items to be addressed by **contractor, integrator, or commissioner.**

The system is tested. **Building owner/operator** is given training/info on the CLS by the **contractor/reps/designer.**

The building **owner/operator** reviews the CLS settings and if needed, the **contractor/rep/ designers** fine-tune the system.

Operation and Repair

CLS is operated by a **facility manager/ operator** or the system operates autonomously.

If applicable, the **building owner/operator** applies for utility rebate and the CLS is tested to meet savings requirements.

Building owner/operator contacts the manufacturer or contractors when problem arise.

3.1 Manufacturing and Design

Key Roles

- Lighting/Controls Manufacturers
- Manufacturer/Controls Rep
- Design Team
- Building Owner/Manager or Construction Manager

Step 1

Manufacturers develop products including luminaires, sensors, controls, & software products

Step 2

Design team is made aware of lighting products available & works with **building owner** to assess building needs and budget

Step 3

Building owner reaches agreement to pursue CLS over traditional technology

Step 4

Design team makes decisions on operations and writes specifications with help from manufacturer and/or rep.

Manufacturing

Overview	Manufacturers develop a wide array of products to fit any CLS design requirements. These products include lighting fixtures, controls/sensors, software, and interfaces. These products are sold though representatives and distributors, who establish relationships with designers, contractors, and engineers. Product designs are influenced by end-user needs such as a wireless communication, ease of configuration and usability, flexibility and adaptability. Some manufacturers/ESCOs also offer ongoing service contracts with their products. Lighting designers are made aware of new manufacturer products through reps, advertisements, and trade shows.
Key Decision Makers	*The manufacturer* conducts research or utilizes available research on end-user needs and efficiency to develop CLS products optimized for both energy and lighting needs, and profit. Manufacturers may develop only fixtures or sensors/controls products or may develop the entire CLS and software/interfaces.
Greatest Challenges	*Designing Products* It can be difficult designing for the end-user because there are no 'standard occupants needs' and there is no standard building, so they must design them to be as flexible/adaptable as possible. Also, it can be difficult to meet utility requirements for data reporting, as it decreases the profit margin for manufacturers. Products need to be designed with a clear value proposition to the customer as well as meeting certain requirements (e.g., DLC), that can incur additional costs and effort. Many customers desire short-term ROIs. However, due to their high cost and their marginal energy savings, most CLS do not have short payback periods. This requires manufacturers to develop value propositions that go beyond simple ROI calculations. *Supply Chain Relationships* Products are sold through reps and distributors who establish longstanding relationships with contractors, which can be a great benefit to some manufacturers while also a major hurdle for others. Many are unwilling to take a risk on a new product or a manufacturer they haven't worked with. It can be difficult and time-consuming to develop trust and build the relationships needed to sell new CLS products. Further, even if a manufacturer's system wins a bid, it may still be substituted for cheaper products at a later stage in the project. *Interoperability* Manufacturers often develop proprietary products that don't easily integrate with other systems/products made by other manufacturers.

Design and Specification

Overview	Most often the design team recommends a CLS to the building owner based on their needs. However, in some cases the building owner has already decided on a CLS and then they hire an architect (more tech savvy building owners and/or creating a specific occupant experience). First, this step involves making design recommendations and finding out what features meet the building owner's needs, depending on the building type, usage, size, and other determining factors, while also considering budget constraints and code requirements. Afterwards, the design team contacts a manufacturer/rep to develop specifications and chose products for the design. The lighting design is done first, and controls design follows to determine how best to service function of the space for the building occupants.
Key Decision Makers	*The building owner* approves and pursues the CLS over traditional technology and the *design team* designs the system based on their needs. The design team could consist of a lighting designer, architect, and/or electrical engineer. *Manufacturers/reps* typically influence/assist with the products and specifications for the design.
Greatest Challenges	*Complexity* Many building owners prefer a simple, set it and forget it lighting system. Even if designers recommend advanced features in the CLS, many building owners are reluctant to use complicated systems, fearing operational and maintenance issues or complex systems that they don't understand. *Lack of Pricing Transparency* Because of the lack of pricing transparency and budget constraints, a system may have to be specified multiple times, wasting time/efforts and ultimately costing more. *Lack of Standardization* Manufacturers may use different communication protocols, configuration methods, and wall controls. This can make specifying systems with different manufacturer products difficult. *Choice of Products* Contractors and designers tend to use reps that they have worked with in the past based on familiarity and/or regional availability. These reps may have limited choice of products to specify or may be biased or incentivized to specify certain manufacturers. *Product/Package Compatibility* Making a substitution to a lighting controls package can cause incompatibility issues. Also, there is often an incentive to have the luminaires and controls from the same manufacturer in the package to improve compatibility, but compatibility issues still arise. *Prior Bad Experiences* Some building owners have had prior bad experiences with earlier CLS (installation/implementation issues, maintenance issues, shorter lifetime, etc.) which makes them reluctant to purchase a new CLS.

3.2 Value Engineering, Bid, & Purchase

Key Roles

- Manufacturer/Controls Rep
- Electrical Contractor
- Distributor
- Design Team
- Building Owner/Manager or Construction Manager

Step 5	Step 6	Step 7	Step 8
Rep/design team ensures competitive pricing (3 name spec, perf spec, etc.). **Building owner** puts the project out for bid.	**Electrical contractor** works with **distributor/ rep/ manufacturer** to get pricing and labor costs for the bid.	The **contractor** wins the bid. If needed, the **design team/ rep/contractors** make design adjustments to reduce cost.	Once the price is agreed upon, the **electrical contractor** purchases the system through a distributor.

Value Engineering and Purchasing

Overview

Following specification, the design team often provides a 3-name spec or performance spec and the building owner (could also be architect, construction manager) puts the project out for bid. In other cases, the manufacturer product might already be decided. The electrical contractor reads the building plan and specifications to get a price based on labor, and then a rep/distributor would price out the system. After, determining their price, an electrical contractor will bid on the project and the building owner selects one of the bids. Sometimes the cost of the designed system turns out to be more than budgeted or the lighting budget is reduced, and certain features/products may be substituted out or the design team may be forced to redesign the system. Once the owner, general contractor, and/or architect agrees to the price and the design team approves the submittals/shop drawings, the electrical contractor purchases the system from the distributor.

Key Decision Makers

The building owner puts the project out to bid and decides on the winner.
The design team must substitute products and/or redesign the system if it is no longer in budget.
The electrical contractor prepares pricing information for bid and ultimately purchases the CLS from a distributor.

Greatest Challenges

Budget Constraints Because lighting is often the last part of the building construction process, the lighting system budget may be reduced, forcing substitutions for cheaper products. In this case, the design team/rep must go back and find less expensive design options to reduce overall cost. When this occurs, it can be difficult to maintain the original design intent and the CLS quality may suffer.
3-Name Spec It is often difficult to develop equivalent 3-name specs for unique or emerging CLS products, so the products chosen may not be equivalent. Most systems are already budgeted around the lowest cost solution, which might compromise lighting system performance.
Contractor Unfamiliarity Contractors are often unfamiliar with CLS installation and bidding, which can lead to increased premiums for labor cost estimations. In some cases, contractors may push to substitute the original design with products they are familiar with to try to avoid future issues.
Lack of Pricing Transparency Contractors prices are given for the entire package without any detail of how they arrived at that price.
Redesign If the cost of the bid is higher than anticipated (labor, overhead, etc.) or there are other budget constraints.

3.3 Installation and Commissioning

Key Roles

- Lighting/Controls Manufacturers
- Manufacturer/Controls Rep
- Electrical Contractor
- Design Team
- Integrator
- Building Owner/Manager or Construction Manager

Step 9	Step 10	Step 11	Step 12	Step 13	Step 14
The **electrical contractor** installs the wiring, luminaires, and sensors.	**Manufacturer/ electrical contractor** commissions the system. IT may help with network security.	If applicable, the **integrator** will connect the lighting system to other building systems.	**Design team/ contactor** does startup & develops punch list of items to be addressed by **contractor, integrator, or commissioner.**	The system is tested. **Building owner/operator** is given training/info on the CLS by the **contractor/reps/ designer.**	The building **owner/operator** reviews the CLS settings and if needed, the **contractor/rep/ designers** fine-tune the system.

Installation and Commissioning

For more detail, please see Appendix page 44-47

|	
Overview	After buying the system, the electrical contractor and team members install the wiring, luminaires, sensors, and controllers. They rely on installation materials, especially videos, from manufacturers and in some cases may contact the manufacturer/rep for additional support. Documentation of installation is very important for operation and maintenance of the system by the operators. After installation, the commissioning is done to make sure all pieces of the CLS work together as specified. The manufacturer, design team, or contractor do the commissioning and set up. The design team provides a sequence of operations.
Key Decision Makers	*The electrical contractor* completes the installation typically with a team of electricians. *The manufacturer and/or rep* may provide a field service team to train, educate and assist the contractor with installation. They are often involved in control system commissioning. The *contractor* may also commission or assist with commissioning the system. *A third-party commissioner* is typically necessary for larger projects and sometimes for code compliance.
Greatest Challenges	*Installation Materials/Tools* With limited first-hand experience in CLS, most contractors must rely on installation and configuration guides to a much a greater extent than they do when installing luminaires; often the information provided isn't sufficient, and contractors end-up contacting manufacturers directly for help, which can be a time-consuming and frustrating process. *Communication* Installation manuals can be too long and use unfamiliar/inconsistent terminology *Manufacturer Support* When contractors have questions for manufacturers, wait times can be exhausting and some are not responsive. *Configuration Tools* Many app interfaces are glitchy and not intuitive to use. Most contractors need assistance from manufacturers to configure/commission the CLS. *Complex Commissioning* Streamlined commissioning processes are needed through improved app interfaces and/or self-commissioning systems.

Integration and Testing

Overview

If necessary, an integrator would connect the CLS to another building system such as HVAC, AV controls, window blinds, and/or a BAS system. Today, this is not common, but is an emerging opportunity in CLS. Next, the design team does a thorough review and walk-through of the system and creates a punch list to ensure that the system operates as it was intended in the original design. The contractor then addresses the punch list, and the system is tested to ensure everything is working as it should. Finally, the building owner ensures that the final product meets their original ideas and needs. Fine-tuning of the system may be necessary if the design did not translate through after it was installed or if the owner has new requests. On major projects, the rep or contractor may offer system training for handoff to the end users and/or building operators.

Key Decision Makers
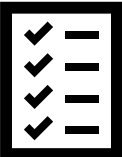
The design team provides a sequence of operations and then verifies the system is working and creates a punch list of final changes to address.
The contractor/integrator will address the problems listed on the punch list and help with handoff.
The building owner does a final review of the system and requests fine-tuning.
The manufacturer/rep offers may help with system training for handoff to the end users and operators.

Greatest Challenges

Interoperability Lack of interoperability between CLS and other building systems can make integrating CLS with other systems challenging.
Lack of communication or issues during the configuration process can make the testing, reconfiguring, and fine-tuning a time-consuming process. Then, troubleshooting issues during testing can be very challenging and time-intensive, and may require assistance from manufacturers.
Integration with Building IT Complications can arise in connecting a CLS to the owner's building operations and internet. Security implications are drastic. Also, the need for firmware and software upgrades can be daunting immediately upon installation as well as afterward to eliminate potential bugs.

3.4 Operation and Repair

Key Roles

- Manufacturer/Controls Rep
- Electrical Contractor
- Facilities Manager/Operator
- Building Owner/Manager or Construction Manager

Step 15
CLS is operated by a **facility manager/ operator** or the system operates autonomously.

Step 16
If applicable, the **building owner/operator** applies for utility rebate and the CLS is tested to meet savings requirements.

Step 17
Building owner/operator contacts the manufacturer or contractors when problem arise.

Operation and Repair

Overview

Finally, the day-to-day management is passed over to the facility manager/operator, or whoever is responsible for maintaining the system. Facility manager/operators also assist building occupants with controlling the lighting, as needed. Many manufacturers, reps, and contractors provide resources and support for CLS operation when needed, typically through a warranty and/or service contract. If applicable, after the system is installed the building owner could apply for a utility rebate, typically contingent on demonstrated energy savings.

Key Decision Makers

The facility manager/operator is responsible for ensuring the system is operating as it should and scheduling maintenance/repairs if problems arise.

The manufacturer is responsible for system repairs or helping to reconfigure the system.

The electrical contractor is often responsible for electrical repairs and may help with ongoing system maintenance as an ongoing fee.

Greatest Challenges

Troubleshooting Issues If a problem arises with the system, it can be very difficult to troubleshoot and figure out what is wrong with the system; further, it may be difficult for an operator to figure out who to contact to fix the issue. Often issues with the CLS go unfixed for long periods of time.

Training Often, not all the CLS capabilities are utilized either because of lack of training or issues with the configuration. Facilities personnel often lack experience, documentation and training to troubleshoot problems, as well as the time to learn. CLS are only one of many responsibilities and not generally the highest priority.

Repairs Sometimes manufacturers have limited staff and can take longer to get someone out to help due to scheduling and ongoing building usage needs. Contractors/manufacturers may also pass blame for issues to others, making the process more time-consuming and difficult. Also, many CLS products have a short shelf life, since products are constantly updated, which results in difficulty finding replacement options.

Software Upgrades In order to keep up with IT security protocols, software updates are needed for the CLS. These updates can at times create problems (i.e., wiping out prior settings).

Utility Rebates Depending on location and project type, utility rebate programs can be difficult/costly to comply with.

4. Key Challenges & Opportunities

Summary of Key Challenges

Complexity and Variability There is so much variability in almost every aspect of a CLS from products to roles to regional nuances. While variance is often inevitable, it can also lead to overcomplication and can be a barrier to CLS adoption.

➢ **Roles:** So many different roles are involved in the process. This can lead to disagreements and miscommunication. Each person that touches the process (manufacturer, distributor, rep) adds anywhere from 5-300% markup on the system.

➢ **Technologies:** Every manufacturer's CLS system is different, which can lead to challenges for training, installation, and operation

➢ **Regional nuances:** The designers and reps working in multiple regions have to keep up to date with different energy codes and utility incentive programs

Experience and Relationship-Based Market Established relationships, past experiences, and familiarity with certain manufacturers and products take precedent over the actual capability of the system and strongly bias the decision-making process. Reliance on relationships can be a barrier because contractors/designers are more inclined to stick with products they know or have used previously, which may not always be the best products. New advanced products or systems thus have a high barrier to entry in the market.

Contractor Apprehension and Reluctance Many first-generation lighting controls faced operational and maintenance issues, not operating as intended or being difficult to repair. Since then, systems have improved and costs have declined, but many contractors still base their opinion of CLS on negative prior experiences. This includes misconceptions on complexity and cost, fear of installation and maintenance issues, as well as uncertainty on labor costs with installing and programming a new system.

Summary of Key Challenges

Consumer Lack of Perceived Value Many CLS stakeholders cited a lack of perceived value as the greatest barrier to adoption. Building owners generally do not see the need for advanced features and tend to want simpler, consistent, low-cost, minimum code level lighting systems. Tech-savvy building owners, tech companies, or businesses that create a unique user experience (museums, entertainment, hospitality, etc.) see more value in CLS. Also, the longer and uncertain payback periods of CLS present a challenge as energy savings can be highly variable.

Embedded Sensors & Controls In general they have low adoption, and their complexity can be intimidating. However, luminaire level lighting controls have the potential to enhance control/sensor granularity, accuracy, and efficiency of systems and simplify installation and configuration. These capabilities offer a better lighting experience and enhanced energy savings, as well as expand business applications and other non-energy benefits.

Cost Transparency Cost transparency is one of the largest challenges facing for CLS and commercial lighting in general. First, many building owners assume CLS will cost more than it actually does and shy away from adoption. Also, cost transparency becomes an issue during the value engineering process, if the system ends up being higher than expected and the design/specification process must be repeated. With lighting being the last piece of construction, it can also be difficult to stay on budget with initial designs. Cost of CLS can also be highly variable, depending on the project.

Interoperability Manufacturers often develop proprietary products that don't easily integrate with other systems/products made by other manufacturers. Lack of interoperability between CLS and other building systems (and standardization in communication protocols) can make integrating CLS with other systems challenging.

Greatest Barriers in CLS Process

We identified **5 steps** in the CLS process as the greatest barriers to connected lighting adoption, as highlighted below.

Building owner reaches agreement to pursue CLS over traditional technology.	**Rep/design team** ensures competitive pricing (3 name spec, perf space, etc.). **Building owner** puts the project out for bid.	**Electrical contractor** works with **distributor/ rep/ manufacturer** to get pricing and labor costs for the bid.	The **contractor** wins the bid. If needed, the **design team/ rep/contractors** make design adjustments to reduce cost.	**Building owner/operator** contacts the manufacturer or contractors when problem arise.
Step 3	*Step 5*	*Step 6*	*Step 7*	*Step 17*
The building owner's lack of education and/or perceived value of CLS, fear of increased maintenance, and/or prior bad experiences act as barriers in the decision to adopt a CLS. Most building owners want a simple system that they can "set and forget", and when they are faced with the complexities of a CLS it can be intimidating. Many feel the value of CLS is unproven and even when a CLS is recommended they can push back.	This step represents the beginning of the value engineering process, which is a detrimental barrier to CLS adoption. With lighting being last in building construction, the budget can often be decreased, thus eliminating certain CLS capabilities. In addition, a 3-name spec can be difficult due to variability in manufacturer products. Often the lowest-cost technology option is substituted for the original, which can cause operational/installation issues.	This step begins to highlight issues with cost transparency, another detrimental barrier to CLS adoption. Because manufacturer reps don't tend to break up pricing, contractors will often give a higher premium for their labor and then try to find cheaper options. Also, contractors can be unfamiliar with the products and installation/commissioning process, and this lack of familiarity can also increase their premium (resulting in a higher bid).	If the system is over budget, the design team, reps, and/or contractors must adjust the system to reduce costs. This also highlights the issue of cost transparency, which can complicate staying on budget and make if difficult for the design team to continue with initial design intent. If redesign is needed, the additional time and labor will also increase the cost, restricting everyone involved. This can also cost the lighting designer time and money. Making cheaper product substitutions can also cause issues with system operating as intended and reduce the overall quality.	The complexity of a CLS acts as a barrier to adoption and reconfiguring a CLS can be just as difficult as installation. For example, if a problem arises with a CLS, troubleshooting the issue can be a daunting task. Depending on the operator and manufacturer support, figuring out who to contact and getting someone to help fix it can be time-consuming and disruptive to the building occupants. Maintenance and operational issues remain a barrier to CLS adoption.

Summary of Findings: Regional Differences

The CLS processes, challenges, and trends can differ by state, city, and region in the country. Primary differences include utility programs/incentives, building energy codes, code compliance, state/local energy and sustainability policies. *The below section shows some examples of some regional differences gathered from interviews but is not meant to be a comprehensive list.*

General Trends
- CLS is much more common in urban areas
- Middle of the country tend to want simpler systems
- Every state with IECC energy codes requires third party commissioning
- Cybersecurity and privacy inconsistencies across the country and differences between what gets written in legislation and what gets enforced
- Outside of certain regions (like New England and California), the contractors don't know the codes well so they don't keep up to date Regions with higher electricity rates have higher efficiency program budgets and can offer more incentives for CLS

Pacific Northwest
- Regional focus on LLLC, though region's 145 utilities offer a variety of incentives for broader CLS category
- Regional LLLC program working with manufactures, reps and distributors to bring more focus on these products
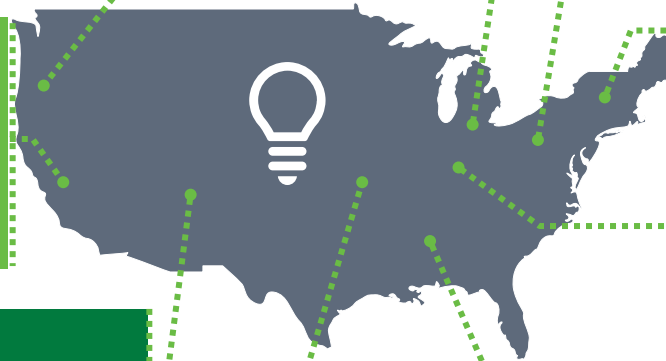
California
- One of the most advanced building energy codes and state energy policies in the country
- Title 24 requires some lighting systems to have ADR capabilities
- **Offers a training program to contractors on how to install CLS**

Colorado
- Contractors are usually the decision-maker

Missouri
- St. Louis does have energy codes, but the rest of the state does not

Michigan
- Utilities have CLS programs and incentives, but adoption has still been slow
- Networked controls are new for Michigan and utilities are working to make it more affordable

New York
- Known to be a specifier-focused market
- Strict code compliance

New England
- The design team has more control
- Lucrative utility incentive market (in Vermont, about 100% of projects are pushed by incentives)

Illinois
- Mostly a new construction market
- In Chicago, contractors have more control

Southern US
- Some states have low energy code compliance, so contractors/reps have less knowledge of the energy codes in general
- Manufacturer reps and distributors have more control
- Florida has very strict energy codes but lower enforcement

Potential Opportunities to Address Challenges

Workforce Development

- Use pre-installation meetings to help reduce errors during installation and configuration
- Promote better and frequent communication between construction management, installation, and commissioning teams
- Utilize more visual instructions with diagrams and videos; provide both a quick guide and detailed instructions as well as better default sets and documentation to make installation easier out-of-the-box
- Develop trainings and educational materials for technical support to mitigate issues as they arise
- Support manufacturers in developing training, educational materials, and certification courses on CLS, installation, and commissioning
- Create educational materials/resources/trainings for operators on how to operate CLS

Technical Research and Development

- Develop standard user interfaces to be more intuitive
- Improve configuration tools and instructions to become more intuitive
- Create better ways to identify and troubleshoot issues when they occur (improved automated fault detection and diagnostics)
- Identify/ develop software workflows that provide simple/automated performance validation and verification as designs proceed from conceptual, to bid documents, to product selection, to configuration and operation
- Develop self-commissioning CLS

Data Collection/Field Validation

- Analyze and quantify the benefits of integrations with other building systems
- Analyze and quantify the value of non-energy benefits of CLS, particularly color tuning and human centric lighting
- Analyze/share documentation on lessons learned from projects that do not run smoothly
- Collect/analyze feedback from facility operators to better understand common problems the systems face to decipher what is and is not working
- Increase understanding of variability in energy savings to improve predictions of energy savings and modeling
- Expand current field validation efforts to include longer-term remote monitoring more building types/sizes, especially CLS for smaller-scale buildings

Potential Opportunities to Address Challenges

Market

- Increase pricing transparency through more projects with publicized anonymized CLS costs
- Perform market research to better understand and improve utility incentive programs and rebates for CLS
- Create more innovative design/bid approaches and incentivize adding lighting controls pre-bid to avoid pricing and value engineering issues

Education

- Provide educational materials/resources for building owners and contractors to help prove the value of CLS. First generation systems had issues, which resulted in skepticism from building owners and contractors in terms of maintenance issues and complexities in general. These resources could eliminate the fear of CLS being too complex and/or having operational and maintenance issues
- Increase understanding of CLS cost, maintenance cost, and payback periods; some people perceive CLS to be more expensive than they are

Stakeholder Engagement

- Encourage more standardization of utility incentives including: how energy savings are calculated, metrics, what products qualify, and the rebate application process
- Support interoperability standards for connected lighting products and HVAC/whole-building control systems
- Support consistent terminology and clear communication for CLS

Potential Opportunities: Stakeholder Specific

Manufacturers

- Provide a quick setup guide with detailed installation and configuration instructions
  - Use images that show what installers will see
  - Include a glossary of terms and use consistent language (support development of consistent controls terminology)
- Assure accessibility to helplines across all time zones
- Provide a streamlined process from design to commissioning
- Collect regular feedback from building operators, particularly for newer systems
- Provide an installation/programming video for contractors

Design Team

- Provide a detailed narrative describing the intended performance of the control system
- Clearly designate control zones and locations on drawings
- Stay consistent with language and terminology (that of the specified product)
- Support the development of consistent controls terminology
- Develop mechanisms to learn how well previous designs are performing, and integrate lessons learned into future designs

Contractors/Installers

- Make sure the contractor feels comfortable with installation instructions as they tend to be too general and not descriptive enough
- Team leaders and project managers should read materials in advance to ensure they are clear
- Support installers with industry and manufacturer education on controls (trainings)
- Provide operation videos to building owners to access at any time
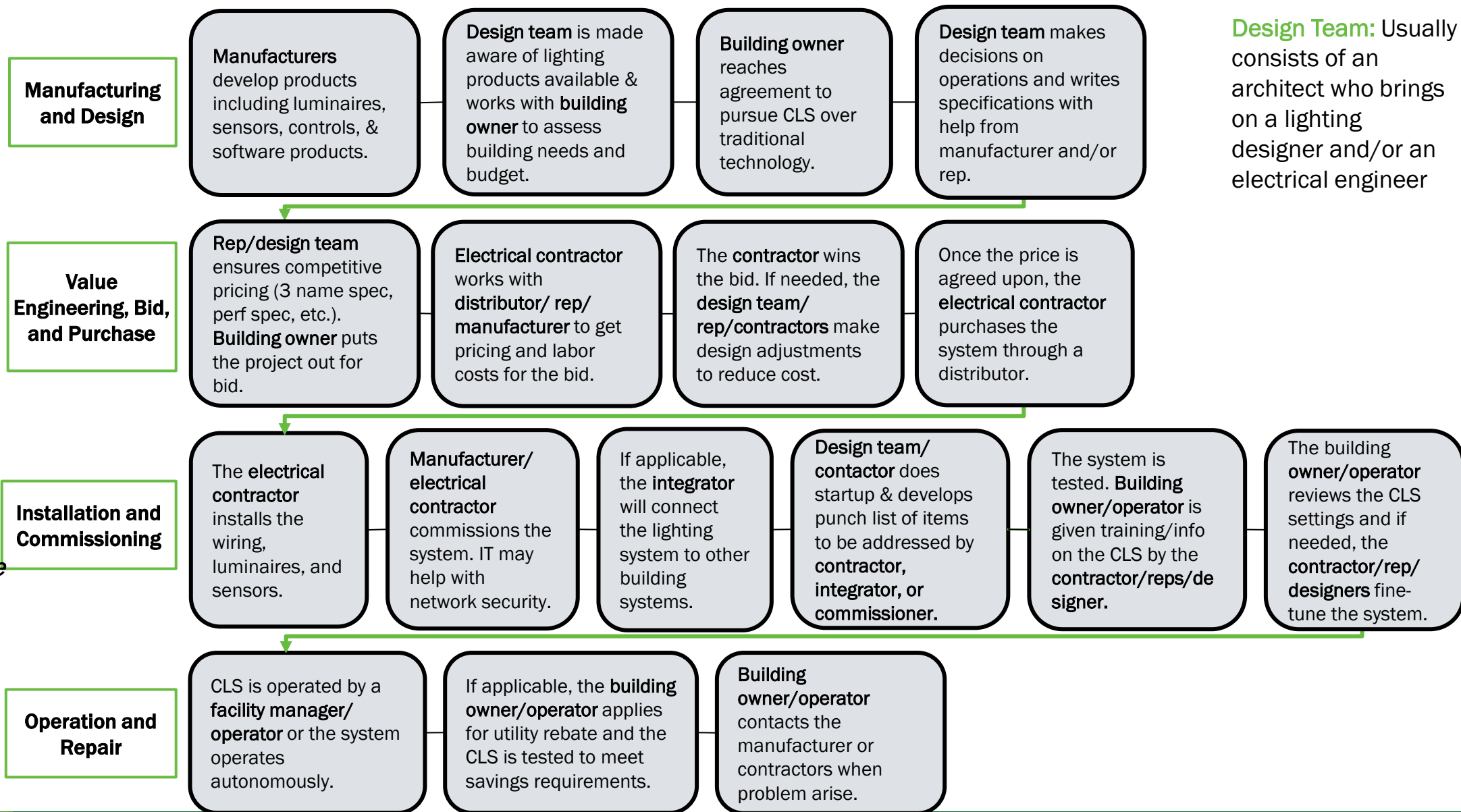
Building Owners

- Require clear labeling or function identification on manual controls
- Provide control systems training for facilities personnel and all new personnel
- Learn about CLS and the capabilities to ensure all needs are met and the system is utilized to its maximal potential
- Develop mechanisms to allow designers to learn how well their designs are performing, and integrate lessons learned into future designs

5. Appendix

Connected Lighting Supply Chain Diagram

While the connected lighting process varies, this diagram shows the typical steps involved from production to operation. The 16 steps are divided into 4 key phases of a connected lighting systems project. Connected lighting is generally installed for new construction and major renovation projects. *Detailed information on each step is provided in the following section.*

Design Team: Usually consists of an architect who brings on a lighting designer and/or an electrical engineer

Manufacturing and Design

Manufacturers develop products including luminaires, sensors, controls, & software products.

Design team is made aware of lighting products available & works with **building owner** to assess building needs and budget.

Building owner reaches agreement to pursue CLS over traditional technology.

Design team makes decisions on operations and writes specifications with help from manufacturer and/or rep.

Value Engineering, Bid, and Purchase

Rep/design team ensures competitive pricing (3 name spec, perf spec, etc.). **Building owner** puts the project out for bid.

Electrical contractor works with **distributor/ rep/ manufacturer** to get pricing and labor costs for the bid.

The **contractor** wins the bid. If needed, the **design team/ rep/contractors** make design adjustments to reduce cost.

Once the price is agreed upon, the **electrical contractor** purchases the system through a distributor.

Installation and Commissioning

The **electrical contractor** installs the wiring, luminaires, and sensors.

Manufacturer/ electrical contractor commissions the system. IT may help with network security.

If applicable, the **integrator** will connect the lighting system to other building systems.

Design team/ contactor does startup & develops punch list of items to be addressed by **contractor, integrator, or commissioner.**

The system is tested. **Building owner/operator** is given training/info on the CLS by the **contractor/reps/designer.**

The building **owner/operator** reviews the CLS settings and if needed, the **contractor/rep/ designers** fine-tune the system.

Operation and Repair

CLS is operated by a **facility manager/ operator** or the system operates autonomously.

If applicable, the **building owner/operator** applies for utility rebate and the CLS is tested to meet savings requirements.

Building owner/operator contacts the manufacturer or contractors when problem arise.

Step 1: Manufacturers develop products including luminaires, sensors, controls, & software products.

Overview	• Typically, manufacturers develop a wide array of products to fit any design requirements. Custom products may be developed for specialized projects, but this is less common as it increases the system cost • It is common to include a service contract with the purchase and a warranty to cover any repairs or assist in modifying the system. Some manufacturers also sell ongoing services such as energy management services through subscriptions • Manufacturers generally sell products though representatives and distributors, who establish relationships with designers, contractors, and engineers; in some cases, they may approach building owners directly to sell a CLS, but this is not common • Product designs are influenced by end-user needs such as a wireless system, ease of control, flexibility and adaptability
Market and Players	• The U.S. market consists of 100s of luminaire manufacturers, around 20 sensor/control manufacturers, and around 10 connected lighting system manufacturers. A few major HVAC manufacturers offer connected lighting products that are integrated with HVAC systems • Some of the major industry players in CLS include: Acuity, Osram, Signify, GE Current, Lutron, and Cree
Challenges	• The market is fragmented, and manufacturers develop their own proprietary systems that are not interoperable with other systems and products • As every system is different, it is also challenging to develop trainings for installation, configurations, and commissioning • Manufacturers are not directly connected to the end-users using the products as there are so many market players in the supply chain • It is difficult to design for the end-user because there are no 'standard occupants' and needs can differ greatly • Manufacturers developed CLS in anticipation of market demand, and adoption has been slower than expected • Manufacturers have to tune their systems to match utility rebates and they usually don't like putting data reporting in their dashboards • Interoperability is an issue as some manufacturer control systems do not work well with other manufacturer's luminaires, or it may require additional programming to use them in the same system
Nuances	• Manufacturers may create customized software in some cases, generally for larger projects/buildings • Some manufacturers may offer 24/7 service to handle repairs and issues as they arise. In some cases, building owners can negotiate for maintenance to be included, but it is not common • Several manufacturers offer complete solutions for lighting and controls where they embed controls into luminaires, which streamlines the entire process and reduces installation complexities
Opportunities	• Develop voluntary interoperability standards with manufacturer input • Develop transparent pricing or a central database of product prices • Communicate with utilities to make sure products meet their rebate requirements

Step 2: Design team is made aware of lighting products available & works with building owner to assess building needs and budget.

Overview	• Often, building owners don't know exactly what they want, so this step involves probing them to make recommendations and finding out what features meet the building owner's needs. Depending on the building/project type priorities vary between safety, productivity, ease of use, flexibility/adaptability, and energy savings while balancing for the needs of the building occupants. In some cases, the building owner may provide little guidance and/or delegate this to someone else (building manager, operator, etc.). • The lighting design is done first, and controls design follows to determine how best to service function of the space for the building occupants. • Daylight harvesting and occupancy sensing is most common and is usually code required. Task tuning is also commonly used. • Emerging but less popular CLS capabilities include: color tuning/human centric lighting, tunable white in healthcare and education, and scheduling in terms of ADR support, integration with other building systems, and energy reporting
Market and Players	• The architect is hired by the building owner and then often hires a design team consisting of themselves, lighting designers, and/or electrical engineers. For lower budget project, there is often not a lighting designer involved, in which case a manufacturer and/or rep would be more involved in the design process. • The architect lays out the building, the lighting designer or electrical engineer lays out the lighting as it relates to the furniture/user needs • The lighting designer/engineer acts as a translator, turning building owner needs into products and specifications, as well as determining how occupants want to use the space and translate that into a control standpoint (do occupants want time-based sensors, occupancy sensor, etc.) • A controls designer can also be involved at this step following the lighting designer
Challenges	• Building owners are often afraid of complicated controls; they want to "set it and forget it" and not have to continually manage it • Too much diversity among products creates a challenge and the lack of commonality acts as a barrier to adoption and designing • Designers must balance many needs, priorities, and code requirements; they must ensure lighting controls must have the right amount of light at the right location during the right timing
Nuances	• When the design team is discussing features with building owners, younger or more tech savvy building owners (tech companies, start-ups, sustainably focused companies) tend to be more comfortable with complex controls, while older and less tech savvy tend to be less comfortable with advanced or complex controls • In retrofit projects, ESCOs are often involved instead of a design team to make recommendations and propose efficiency measures • Building size: for small-to-mid size projects, especially retrofit applications, simple system may better fit the needs and budget • Sometimes the design team meets the building owner to discuss needs, which is helpful in developing a plan of how they want their building to operate; other times the building owner is not available • Regional design and code requirements differ. Some regions like Florida has very strict codes, but a very low enforcement. California and New England have stringent building codes and generally better enforcement. • Larger manufacturer rep agencies often have reps to assist in design, smaller agencies usually outsource to the manufacturer for help
Opportunities	• Building owners tend to get excited by the possibility of control via iphone/ipad/tablet • Open communication between the design team and building owner help ensure all needs are met • Involving and working with the specifiers (manufacturer reps) earlier in the design process can help to ensure design needs are met

Step 3: Building owner reaches agreement to pursue CLS over traditional technology.

Overview	• The majority of CLS projects are done to meet the local energy codes, and it is uncommon to add addition networked controls that go beyond code requirements
	• There are various reasons aside from meeting the energy code a building owner could decide to adopt a CLS, including but not limited to:
	    • The building owner is trying to create a user experience (ex: theater, hotels, theme parks, conference centers)
	    • Some building owners might be more tech-savvy or interested in receiving LEED certification, tax credits and so on
	    • The building owner might have a desire for more flexibility (buildings turn into open-office spaces with flexible uses), increased control and personalization, ability to make changes to the system as needed, as well as future-proofing zoning and programming (no physical rewiring needed in the future)
	    • The building owner might want ease of maintenance and management (set it and forget it capability)
	    • The building owner is approached by a utility or incentivized by a utility program rebate or discount
	    • An emerging opportunity is to utilize CLS occupancy sensors to enforce COVID-19 social distancing protocols

Market and Players	• The building owner is the decision maker and motivation varies depending on individual owner characteristics as well as building type (ex: schools/universities, hospitals, commercial buildings, hotels, restaurants, theaters, warehouses, municipal offices and more) • Building owners may delegate decision making on CLS to a contractor/construction manager or rely on input from building operators • Real-estate developers can often be the drivers of CLS
Challenges	• It can be difficult for building owners to see the value in CLS due to increased costs and longer payback periods; in addition, many building owners have negative associations with CLS from past experiences with earlier systems that had operational issues • Many building owners shy away from complexity in a lighting system and prefer a simple, set it and forget it capability • COVID-19 presents a challenge for occupancy sensors, as they need to be 100% accurate to account for social distancing measures • The return on investment remains the largest hurdle for projects that go beyond required energy code • Many customers are not aware of the non-energy benefits (asset tracking, safety, health, etc.) or additional energy savings from integrating with other building systems like HVAC

Step 3 Continued: The building owner is recommended a CLS and/or agrees to pursue a CLS over traditional technology

Nuances	• CLS are more commonly installed in new construction buildings or for deep renovations. In new construction buildings, the building owner or construction manager usually makes this decision or is required to purchase a CLS. A design team then recommends a CLS based on building owner needs. In retrofit buildings, a contractor or engineer may recommend a CLS based on building owner needs; in some cases, they may also be approached by a sales rep or may be motivated by a utility program • Building energy codes vary by state and region. Also, some states may not have building energy codes and cities/local jurisdictions may enact codes instead. IECC 2018 and ASHRAE 90.1 codes are adopted in many states and require occupancy and daylighting controls. California's Title 24 code also requires demand response capabilities in lighting systems • Motivation depends on building type (ex: hospitals and airports want to make sure lights are always on). Larger buildings more commonly install CLS over smaller buildings, as the greater energy savings help to justify the system costs for a larger footprint
Opportunities	• Increase education (for building owners and contractors in particular) to show the value of connected lighting, additional benefits and capabilities (non-energy benefits, flexibility, system integration, etc.) • Reduce risk by simplifying the CLS and by manufacturers providing warranties and maintenance/service contracts. • Increase education on utility incentives to reduce capital costs of the system. Utility incentive programs could also benefit from increased consistency and clarity on what qualifies for rebates • Increased use of embedded controls (luminaire level lighting controls) to simplify the CLS design process and increase precision and accuracy of sensors

Step 4: Design team makes decisions on operations and writes specifications with help from manufacturer and/or rep.

Overview	• Once the design team decides how they want the system to operate, they reach out to the manufacturer directly or a manufacturer rep who helps to develop the specifications • The usability of a lighting system and how it meets the occupant needs is an important part of project success, and is critical for CLS project acceptance • Sometimes the design team is partnered with a manufacturer; in this case, system support is usually guaranteed • During this step, the decision for wired or wireless is made by the electrical engineer or contractor
Market and Players	• The lighting designer looks for the "wow factor" • Lighting designers create the initial sequence of operations and zoning and contact local manufacturers/reps for specification • Manufacturer reps often have a close relationship with one or many manufacturers. • Manufacturer reps typically work closely with the design team (designers, architects, and/or engineers) to help specify the system
Challenges	• Manufacturer reps and distributors often have a built-in incentive to change the specification on many projects; they also tend to give a lump sum price instead of breaking it up • Because of lack of pricing transparency and/or miscommunications between the design team and specifier, a system may have to be specified multiple times with multiple product substitutions, wasting time and efforts • Lack of standardization and interoperability between different manufacturers can make specifying systems with different products difficult; manufacturers may use different language, configuration methods, wall controls, etc. • Ongoing maintenance savings is a big selling point, but if the upfront cost is too high, it still will not be chosen • Data sheets do not easily convey product capabilities and market brochures are not always helpful, making system selection more difficult • A manufacturer rep is typically limited to the manufacturers they represent, which may not always be the optimal system for the design needs • It can be difficult for manufacturer reps to keep up to date with new products coming to the market; some reps may be more inclined to specify or recommend simpler products that they are more familiar with rather than newer advanced products

Step 4 Continued: Design team makes decisions on operations and writes specifications with help from manufacturer and/or rep.

Nuances	• Depending on location and design team, they can often make a specific manufacturer a basis of design and building CLS specifications around a specific product • Decisions on manufacturers and reps often depend on building/project type; different manufacturers develop products • In the Northeast, lighting designers have a lot more control and the design team in general has more say • When the project is controls focused, the design team works with a manufacturer rep throughout. If it is luminaire focused, the lighting designers own the decisions • Some regions of the country such as rural areas and the middle of the U.S. tend to favor simpler lighting systems • Sometimes specifying is done in one region and the project is in another
Opportunities	• Develop voluntary interoperability standards with manufacturer input • Develop transparent pricing or a central database of product prices • Standardize terminology and increase market knowledge to overcome CLS misperceptions • Increase communication between the design team and specifiers and allowing specifiers to be involved earlier in the process to provide input on product recommendations

Step 5: Rep/design team ensures competitive pricing (3 name spec, perf space, etc.). Building owner puts the project out for bid.

Overview	• Following specification, the building owner usually puts the project out for bid • Depending on location and project type, the rep and design team are often required to give a 3-name spec, meaning they must offer 3 equivalent products according to the specifications • The design team and building owner usually go with the lowest package number from the 3-name spec • Most of the time the bids are based on specification drawings • Most of the time, more expensive products lose out because there is no equivalent
Market and Players	• If the lighting designer keeps the project open to different manufacturers, they can bid on the project • The building owner will put the project out for bid and then select reps from the bid
Challenges	• Lighting is often the last part of the building construction process so cost cutting can occur if budget is too tight • Product pricing is a "black box" and can vary widely from initial estimates (manufacturers do not publicize pricing) • It's difficult to do a 3-name spec with 3 equivalent products for CLS because of complexity of systems and differences/variability in manufacturer product lines • The design team must go through and ensure all pieces meet requirements once the value engineering process starts • The specification team and contracting team often don't work together, resulting in missed/misleading information
Nuances	• The 3-name spec depends on the building owner and how much the architect/design team values quality of good lighting • If the motivation for a CLS adoption comes from the building owner directly, it will usually make it through the value engineering process • Retrofit projects do not usually follow a 3-name spec, value engineering, or going out for bid • In some cases, designers may have more control over products specified and may be able to forego the 3-name spec process
Opportunities	• Increase pricing transparency potentially through publicizing project costs • Standardize terminology and increase market knowledge to overcome CLS misperceptions

Step 6: Electrical contractor works with distributor/ rep/ manufacturer to get pricing and labor costs for the bid.

Overview	• The building owner ultimately selects the bid and tells electrical contractor • The electrical contractor reads the building plan and specifications to get a price based on labor. Afterwards, they contact a manufacturer rep and/or a distributor to ask how much the control system costs
Market and Players	• The distributor obtains the pricing for the fixture and controls packages that the design team specifies, and then they provide it to the contractor and handle the ordering/staging of equipment. They are not involved in the design process or other advanced services • The electrical contractor chooses products within the price (sometimes going outside of budget) • The design team tends to lose control of decisions once an electrical contractor gets involved
Challenges	• Sometimes the contractor will try to find cheaper options to substitute products from the original specification, which drags out the design and construction processes; this may also cause issues with the installation and operation of the system and compromise the original system design • Many contractors don't know how to bid or install a CLS, which makes it more difficult to estimate labor costs; in response they often increase their labor costs significantly for installing CLS • Distributors often push toward one manufacturer, which can influence cost • There is little pricing transparency in the market and prices can be highly variable
Nuances	• In California, there is a program that teaches contractors how to install CLS • Some electrical contractors are more technical savvy, which can ultimately save on installation costs • In urban areas, electrical contractors are more likely to be familiar with CLS than in rural areas • Retrofit projects no not usually follow a 3-name spec, value engineering or going out for bid
Opportunities	• Increase product pricing transparency would help to simplify this step • Increase data on installation labor costs and installation time for CLS • Education and training programs for CLS purchasing and installation

Step 7: The contractor wins the bid. If needed, the design team/ rep/contractors make design adjustments to reduce cost.

Overview	• The lighting system design is almost complete, but remains fluid until configuration is complete • Sometimes the cost of the designed system turns out to be more than budgeted, and if the building owner does not agree to the price, certain features/products may be negotiated and substituted out. This means the design team, rep, and possibly contractor must go back and find less expensive design options to reduce overall cost. • Sometimes value engineering has nothing to do with cost but fear of complexity and over-complication
Market and Players	• The lighting designer helps the building owner understand pricing and they work with the contractor to ensure the design is properly implemented and control manufacturers to make sure all sequences are working properly • Lighting consultants may be hired by an architect to help substitute items and reduce cost
Challenges	• Pricing is always a challenge due to the lack of transparency, which makes it hard for projects to stay on budget and for designers to design projects to stay within the budget • Adjustments can cost the lighting designers can be time-consuming and push the project off track
Nuances	• Cost and budgeting vary depending on building type, size and location • Retrofit projects do not usually follow a 3-name spec, value engineering or going out for bid
Opportunities	• Develop transparent pricing or a central database of product prices • Involve reps earlier in the design process to help obtain more accurate pricing estimates of the system

Step 8: Once the price is agreed upon, the electrical contractor purchases the system through a distributor.

Overview	• Once the price is agreed upon the project moves forward, and the electrical contractor can purchase the system from the distributor and prepare for installation • Sometimes the project might be eligible for a utility rebate. If so, the building owner or electrical contractor applies for the rebate and works with the utility to ensure they meet the requirements. Many utilities require substantial energy reporting to validate energy savings from the CLS so the rebate would not be issued until after the testing period.
Market and Players	• CLS can still be unfamiliar to utilities so they often have to hire a consultant to assist in developing and implementing CLS programs
Challenges	• Contractors often include premiums because of unfamiliarity with a CLS installation labor needs (this can push the building owner back to doing minimum code requirements) • Contractors sometimes intentionally underbid the project, knowing they will substitute lighting products to make up for it; they might also do last minute substitutions in attempt to stay in budget
Nuances	• Regionally, electrical contractor input varies. For example, in Chicago contractors tend to have more say in the projects
Opportunities	• Focus on networked lighting systems that can be upgraded easily later on, potentially adding in additional capabilities and energy management features over time.

Step 9: The electrical contractor installs the wiring, luminaires, and sensors.

Overview	- After buying the system, the electrical contractor and team members install it relying on installation materials from manufacturers - Installations vary widely depending on controls, sensors, building type and other factors - Documentation of installation is very important for operation and maintenance of the system by the operators - The installer often works with the manufacturer during this step to ensure metering equipment is capturing 3 post-project data collection periods: - Lighting technology change (fluorescent to LED) separate from control energy savings, - Light-level tuning (initial light-level setting that is different from active occupant dimming) to meet occupant or programmatic needs, and - Occupancy sensor control - Installers have noted a few differences when installing CLS compared to more standard LED and fluorescent products - Support wires and fixtures themselves are often a tight fit - More time is required to install separate controls
Market and Players	- The electrical contractor does the installation (typically a team of electricians) - The manufacturer and/or rep may provide a field service team to train, educate and assist the contractor with installation
Challenges	- Contractors often rely on experience rather than printed instructions; with limited first-hand experience in CLS, most contractors must rely on installation and configuration guides to a much a greater extent than they do when installing luminaires - Installation manuals can be too long and use unfamiliar/inconsistent terminology (ex: zone, channel, scene) - When contractors have questions for manufacturers, wait times can be exhausting and some are not responsive - Out of date software and faulty firmware can impede the installation process - Unreliable communication: sometimes information conveyed during preconstruction does not get communicated to the contractor - If the space is occupied, fine-tuning can be disruptive to occupants so it would need to be done slowly over time - The physical location of controls on a wall can slow down the installation process - Because every manufacturer develops unique CLS, each manufacturer provides different trainings; a contractor trained in one system may not be able to install another manufacturer's system

Nuances	• Younger contractors tend to be more comfortable with installing CLS and have more electronics/wireless systems knowledge • Cybersecurity and privacy – inconsistency across the country and differences between what gets written in legislation and what gets enforced • In some regions such as Colorado and Illinois, contractors have more influence in the project and act as the decision-maker • A large percentage of customers want to stick with a wired solution, but wireless capabilities are becoming more reliable • Some contractors offer ongoing support and maintenance, while others will hand issues over to the manufacturer rep • Simpler systems tend to have an easier and faster installation

Opportunities	• Improvements are needed on installation instruction, training, materials, and contractor support
	    • Training for contractors prior to installation can reduce errors and speed up the process
	    • Visual instructions such as videos and drawings are easier for contractors to follow than written instructions
	    • A system that requires anything more than an app download becomes complicated for contractors
	• A pre-installation meeting could help the installation process run smoother and help with planning/scheduling
	• With a networked system, it is crucial to pre-scope what the scope of work looks like
	• Increase use of embedded controls (luminaire level lighting controls) to simplify the CLS installation process

Step 10: Manufacturer/ electrical contractor commissions the system. IT may help with network security.

Overview	• After installation, the commissioning and programming is done to make sure all pieces of the CLS work together as specified. • The manufacturer or the design team take care of the programming. The design team provides a sequence of operations. • Commissioning processes vary widely as well depending on the devices and building type
Market and Players	• The manufacturer or rep is often involved in control system commissioning and some might provide equipment as well as an integrator • A third-party commissioner is typically necessary for larger projects and sometimes for code compliance • Electrical contractors may also be very involved in the commissioning process • The building's IT department will typically assist with security for the CLS
Challenges	• Often the software and firmware are not compatible with each other, or do not meet the building's IT security requirements. Cybersecurity and privacy issues can cause delays. • Pairing wall controls with luminaires and programming is not always intuitive and can be time consuming • Specification can be misinterpreted, which could result in faulty controls • Interoperability can be an issue when different manufacturer products (luminaire and controls) are used in the CLS that use different communication protocols • There is considerable diversity among wall control designs, with no single design approach; this can lead to confusion and impeding the ability of installers to adapt to new systems
Nuances	• The commissioning process can vary by region and building type/size. For instance, in some regions like California, a third-party commissioning and test is required by the building code. • Larger companies generally want enterprise control and are more willing to standardize on a platform, while smaller companies want wireless capability and products that are easy to configure or require no commissioning
Opportunities	• Simpler systems tend to configure more reliably • Developing easy-to-use self-commissioning systems is an emerging area • Clear communication with the building IT to ensure the software/firmware is accepted • Interoperability standards/common communication protocols

Step 11: If applicable, the integrator will connect the lighting system to other building systems

Overview	• In more complex systems, lighting control system integrators show up once everything has been installed • CLS integration with other building systems is rare today, but is an emerging area • Integrating lighting controls can increase energy savings. In a recent PNNL study, integrating lighting controls with HVAC showed an additional 26% savings from the mechanical system • The integrator would connect the CLS to another building system such as • HVAC, AV controls, window blinds, and/or a BAS system
Market and Players	• The manufacturer can help train the integrator • Integrators are only used in less than 10% of projects • Active coordination between the integrator and the mechanical teams or whoever manages the connected system is critical to success
Challenges	• CLS integrators are rare and difficult to find, but it is a growing field • Integration can be a very messy process • Integrators are a growing field and can be difficult to find • Firmware and software (if available) usually have to be updated for integrations to work
Nuances	• CLS integrators are much more common in urban building projects and smart building projects • Integrators are usually involved when electrical current polarity is an issue in the systems • Lighting system integrations would vary based on building types; for example, office building may integrate lighting occupancy sensors with meeting scheduling or AV systems and schools may want to integrate with other plug loads.
Opportunities	• Develop integrator training materials • Increase interoperability and establish standardization in communication protocols for increased ease of integration

Step 12: The design team does start-up and develops a punch list of items to be addressed by either the contractor, commissioner, or integrator

Overview	• The design team does a thorough review and walk-through of the system and creates a punch list to ensure that the system operates as it was intended in the original design • Then the contractor/commission/integrator goes through to fine-tune the system to address the items on the punch list to fit the design
Market and Players	• Lighting designers provide a sequence of operations/description of how the system works and then they verify the system is working • The contractor, commissioner or integrator will address the problems listed on the punch list, depending on what the issue relates to
Challenges	• If the contractor does not follow the specs and design precisely, the system may not operate way it was intended. In this case, the design team would request adjustments. In some cases, the issues can be related to the programming and require the manufacturer/commissioner to make adjustments. • If the punch list is long, this could be a time consuming and frustrating process • Lack of clear communication and direction can exasperate the process even further
Nuances	• Some lighting designers will do system programming, but it is not common
Opportunities	• Simpler systems tend to operative more intuitively • A separate device for each zone is often the most effective. Too many devices can be overwhelming and too few can complicate things • Consistent and clear labels for wall control buttons across all zones are most effective and should be put on after installation. They need to be more descriptive than just up and down arrows

Step 13: The system is tested and building owners/operators are given training and/or information on the CLS by the contractors, reps, and/or designers

Overview	• After the punch list is addressed, the system is tested to ensure everything is working as it should. • Usually during commissioning, the manufacturer/rep offers system training for handoff to the end users and/or building operators. This could be written training materials, pictures, and/or a video.
Market and Players	• Lighting designers are often involved in the system programming and testing • Contractors, manufacturers or reps provide training- usually in person and sometimes through videos or booklets; then the building owner/operator is then left in charge of managing the system
Challenges	• If building staff move/leave, the training is not usually passed down and it can be difficult and time consuming for them learn the system on their own. • Software and training on reparation is free, but it is usually not documented or not passed along to others • Building operators/ facility managers manage other systems within the building so they don't want to spend a large portion of their time on lighting • Response times can be slow (ex: dimming response), which can confuse end users • Control choices (ex: buttons) can be very confusing to end users • Kinetic switches can require a firmer press, which can frustrate end users • Users often complain about inaccurate occupancy sensors and/or daylighting systems not providing enough light • Testing the system, debugging, and troubleshooting can be very disruptive to the building occupants; they also cannot be tested until everything is installed
Nuances	• Some manufacturers offer ongoing support, while others do not. Ongoing support is usually at a subscription cost that is either offered in a lump sum price or a monthly contract
Opportunities	• Including operating controls directions next to each control • Simpler wall controls are easier for end users • Consistent and clear labels for wall control buttons across all zones are most effective and should be put on after installation. They need to be more descriptive than just up and down arrows • Controls through an app are usually preferred to a handheld device. Apps are easier to install, are not easily lost, and can be accessed by multiple people

Step 14: The building owner/operator reviews the CLS settings and if needed, the contractor/ rep/ designers may fine-tune the system

Overview	• The building owner ensures that the final product meets their original ideas and needs. Fine-tuning of the system may be necessary if the design did not translate through after it was installed or if the owner has new requests. • Manufacturers may take feedback from customers to help educate the market
Market and Players	• Building owner would be testing the CLS with the end-users (occupants) in mind • Contractors, manufacturers and designers help fine-tune the system to meet the needs of the building owner
Challenges	• Replacement parts are not always available as they are not usually available at your local distributor/retailer, so it can take a long time to get a system back to full operation • Users often find controls too confusing and do not utilize them to the full capabilities of visual enhancements and energy savings • General stigma that controls have poor operational performance and don't offer benefits beyond LEDs • Energy savings vary widely; usually 20-80% on commercial offices. If the system isn't meeting the expected energy savings, additional fine-tuning may be necessary.
Nuances	• Younger building owners tend to be more technological savvy and accepting of changes than older ones • Regardless of age, a building owners' interest in technology and having access through their phone could increase their perceived benefit in controls • Geography in terms of available day light, climate, and weather to influence sensor settings
Opportunities	• Including operating controls directions next to each control • Simpler wall controls are easier for end users • Consistent and clear labels for wall control buttons across all zones are most effective and should be put on after installation. They need to be more descriptive than just up and down arrows

Step 15: CLS is operated by a facility manager/operator or the system operates autonomously

Overview	• Day-to-day management is passed over to the facility manager/operator
	• The usability of a CLS and how it meets the occupants' needs is an important success factor
	• CLS can help create other efficiencies, such as:
	   • Providing faster response times to BAS issues
	   • Increase occupant safety
	   • Maintenance diagnostic capabilities to help ensure the latest security protocols

Market and Players	• The facility manger/operator oversees managing the system and sharing knowledge of CLS to other users • Some facility managers/operators may spend a great amount of time fixing/improving systems to optimize them for the building needs
Challenges	• Maintenance of a CLS can be as difficult as initial configuration *NGLS* • Facilities personnel often lack relevant experience, documentation and training to troubleshoot problems, as well as the time to learn • Often, not all the CLS capabilities are utilized either because of lack of training or issues with the configuration. • When controls are connected to a smart app, it can be more difficult/time consuming to figure out the app • Energy savings from controls are variable and can be difficult to predict • Facility managers and operators often leave or change jobs and the knowledge is not always passed on • Smaller/average buildings generally do no facility/energy managers to ensure the system is running properly. • Operators want simplicity and dependability and don't want something proprietary; they think of lighting as an afterthought and don't want to be locked into anything • Human reaction to change and having to learn something new when the cost effectiveness is not always drastic
Nuances	• CLS operation varies by building size/type and location; some may operate completely autonomously with very little changes needed while others may be more involved for operators, particularly if they need to assist or train building occupants to use the controls. • Younger facility managers/operators tend to be more technologically savvy and more accepting of the changes than older generations
Opportunities	• Clear instructions either in binder, booklet, video form can help ensure proper function of the CLS • Quantifying and valuing non-energy benefits from lighting systems. For example, there is currently no way to capture data to support increase in productivity. If insurance companies could offer a health discount and tie it to circadian rhythms, employers/building owners might be more interested in CLS adoption. • For facility mangers, these projects offer a chance to incorporate additional technology advancements that create efficiencies

Step 16: If applicable, building owner/operator applies for a utility rebate and the CLS is tested to meet energy savings requirements

Overview	• Sometimes the project might be eligible for a utility rebate. If so, the building owner or electrical contractor applies for the rebate and works with the utility to ensure they meet the requirements. Many utilities require substantial energy reporting to validate energy savings from the CLS so the rebate would not be issued until after the testing period. • The influence of utility programs on CLS adoption can vary depending on local utility programs and the incentive amount. For example, in Vermont utilities are very involved in CLS projects and are the primary driver of adoption. Other regions in the U.S. have still seen low adoption of CLS products despite utility incentives and rebate programs.
Market and Players	• Utility incentives and involvement vary by location (ex: Efficiency Vermont is involved from the start and can have input in design) • Applications for utility rebates can be done by various roles including the business owner and electrical contractor • CLS can still be unfamiliar to utilities so they often have to hire a consultant to assist in developing and implementing CLS programs
Challenges	• Utility rebate programs can be difficult and expensive to comply with and requirements are highly variable by utility and change frequently. • In many regions of the country, utility rebate programs are usually an afterthought, not a substantial market driver • Complexity of the systems makes the implementation and applying for rebates difficult • Utilities want customers to add networked controls, but this is not happening everywhere

Nuances	• Utility rebates can depend on location and project type (ex: public school vs private hotel)
	   • In Vermont, utility rebates are one of the largest market drivers for CLS, in addition to sustainability.
	   • Rebate calculation metrics varies as well. $/sq ft in Wisconsin, $/kWh in Michigan, $/fixture in one Vermont utility
	   • In MA, RI, VM, NY, and CA utility rebates are more influential and lucrative than elsewhere in the country. In markets where electricity rates are lower, utilities have less funding for efficiency programs and cannot offer lucrative incentives.
	• In general, utility rebates are a larger market driver in the retrofit space rather than new construction.

Opportunities	• Increase standardization for utility rebate programs that control system manufacturers can engineer toward and standardize energy savings calculation methodologies and metrics

Step 17: A facility manager/operator or building owner contacts the manufacturer or contractors for repairs when problems arise or to request changes to the system

Overview	• In general, many manufacturers, reps, and contractors provide resources and support for CLS operation when needed • Some buildings have facility managers trained to monitor fixtures usage and the CLS • In general, customers don't want to pay an annual commitment for manufacturer services, but they will pay a 5 year bundle up front • Repairs are needed for failed hardware, wiring issues, occupancy sensor issues, presence detection issues and gateway communication issues
Market and Players	• Electrician or electrical contractor usually does not come back for maintenance unless problems are strictly electrical • Troubleshooting connected lighting systems is essentially an IT exercise with multiple devices, software/firmware updates, system versions, and connectivity all playing a role
Challenges	• If a problem arises with the system, it can be very difficult to troubleshoot and figure out what is wrong with the system; further, it may be difficult for an operator to figure out who to contact to fix the issue. • Reconfiguring a system can be as difficult as initial configuration. Often a specific sequence is required to delete or add new equipment, and any deviation from the sequence can throw off the entire system. • Sometimes there is a lack of urgency on dealing with certain issues and/or end-users do not care enough to report a problem • Service agreements with manufacturers are often very expensive • Sometimes manufacturers have limited staff and can take longer to get someone out to help due to scheduling and ongoing building usage needs • Sometimes an operator does not want to be restricted to one manufacturer and this brings up issues of interoperability and proprietary systems • Manufacturers feel that service contracts are not utilized to the degree they should be
Nuances	• Smaller/average buildings don't tend to have facility/energy managers • Some manufacturers may offer 24/7 service to handle repairs and issues as they arise. In some cases, building owners can negotiate for maintenance to be included, but it is not common
Opportunities	• Clear communication of service contracts and clear instructions either in binder, booklet, video form can help ensure proper function of the CLS • Collecting additional feedback on a regular ongoing basis from facility managers/operators on the system operation

5.2 Secondary Sources

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5.3 Interview Questions

Manufacturer Reps

- How do you typically become **involved** in a connected lighting project? Do you work with designers/architects? Do you work with building owners directly?
- What are the main reasons you've seen or **biggest selling points** for CLS? How big of an influence does utility rebates have in the purchasing decisions?
- How do you typically work with lighting designers, distributors, manufacturers, contractors?
- How involved are you in the **design, specifying, commissioning,** etc.?
- What challenges and issues have you seen during the **specification** process?
- What challenges and issues have you seen during the **commissioning** process?
- How do you make **decisions/recommendations** on what manufacturer products to specify in a system?
    - How big of an influence do relationships play? Do past projects play a role?
- What **challenges** do you face in the value engineering process and related to the cost of the system?
    - Why do you think **cost transparency** is so difficult?
- Overall, what do you think are they **largest barriers** to connected lighting adoption, other than cost?
- After a system is installed, how do you **support** customers who have issues or questions? Do you collect **feedback** from them? If so, how is it used?

Utility Programs/Consultants

- Can you **describe the utility programs** you have worked on in connected lighting?
- What goes into the **design of the programs**? How are decisions made on what qualifies for a rebate and what does not?
- How closely do you work with building owners/construction managers etc.? Who is typically applying for a rebate?
- What **types of building owners or projects** are typically using utility incentives?
- Have you worked directly on demonstration projects for CLS? What challenges have you seen on these projects?
- In general, do you think utility incentives are a **major driver** for adoption of connected lighting systems? Why or why not?
    - How has it changed as building codes have changed?
- How popular are the utility connected lighting system programs? How often do building owners use them? Do they incentive buildings to go beyond code requirements?
- What **challenges** have you seen related to the purchasing and applying for rebates?
- Overall, what do you think are the biggest challenges **hindering the adopt**ion of connected lighting systems, other than cost?

5.3 Interview Questions

Manufacturers

- Could you describe the **role of the manufacturer** in the design and installation process? (aside from making the individual products that go into the system)
  - Maintenance and repair? Operation? Potential for ongoing services?
  - What information or services do you provide to assist with the installation and commissioning? What issues have you seen?
- What **challenges** do you face when manufacturing and designing the products?
- What goes into **the design of products** and lighting system features?
  - How does research affect designs? Are they being designed with occupant needs/comfort in mind?
- What products/features of CLS are the **most popular/best selling products**? What do customers really like vs dislike?
- How common is it to provide **customized control systems/custom programming**?
  - How common is it to provide ongoing maintenance services or other ongoing energy management services?
- Do **existing relationships** between reps and distributors impact decisions? Can you describe how the manufacturer works with the rep and distributors and how they make recommendations on products to choose?
- What do you think are they **largest barriers** to connected lighting adoption, other than cost?
  - What improvements, if any, could be made to the product/system design?
- After a system is installed, how do you **support** customers who have issues or questions? Do you collect **feedback** from them? If so, how is it used?

Lighting Designers

- On the connected lighting projects you've worked on, what is **the typical motivation** to install a connect lighting system? What types of buildings install it? How often are they for new construction vs retrofit? How much influence do utility incentives have?
- How are decisions made around what **features/capabilities** to include in the CLS in the design process? Are systems designed with the end-user in mind? Are they designed for optimal energy savings? How do building codes/lighting standards influence the design process?
- Can you describe the **CLS process** and how you work with manufacturer reps, building owners, architects, distributors, etc. How does the connected lighting process differ in your region?
- Who make decisions and how are decisions made on what manufacturers/reps/contractors will be used in the project and what products are used in the CLS?
- What **issues** do you encounter during the design and value engineering processes?
- What do you think are they **largest barriers** to connected lighting adoption, other than cost?
- After a system is installed, do you continue offering **support** to the building owners or operators? Do you ask for **feedback** on the system and the design?

5.3 Interview Questions

Operators/ Building Engineers

- Can you describe the lighting system and the **controls capabilities**. Do you know why these features were selected?
  - Are all the features and controls in the system typically used on a daily basis?
  - Have you had **issues** with the system operating as intended?
  - Are there any **features/sensors** that were disabled or that have malfunctioned?
- After installation, were you provided any **training, videos, materials, etc.** on the lighting system?
  - If so, did you think this training was helpful? Adequate?
- Has anyone (manufacturer or sales rep) **contacted** you or the building owner since installation to ask for feedback? If so, how was this **feedback** used?
- Since installation, have you had any opportunities to request changes in the system or fine-tuning?
- Does the system generally operate as expected? How autonomous is the operation?
- Have you heard or received any **positive or negative feedback** on the lighting system from the building occupants?
- Do you receive any **ongoing maintenance or support services**?
  - If you had an issue, would it be easy to get in touch with the manufacturer/contractor for a repair?

Electrical Contractors

- Can you describe the types of connected lighting systems you have installed?
  - Can you describe your involvement with the installation? What challenges did you face?
- Was the actual installation time much different than what was expected?
- What information were you provided?
- Were you given training from manufacturers or reps? Is this common?
- We have heard in other interviews that in some regions or on some projects the contractor may have more power/control over the products/specification of the system. Is this something you have seen?
- How often do contractors make replacements to the original design to cut costs? Are the building owner/designers involved in this decision?
- How closely do you work with the reps, distributors, and 3rd party commissioners?
- We have heard there is a lack of cost transparency for lighting products. Why do you think this is so challenging?
- After the system is installed and tested, what types of issues have you seen in the punch list that must be addressed. How common are these issues?
- After a system is installed, how do you support customers who have issues or questions?