Berkeley Lab Site-Wide Interior Lighting Business Plan

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WORKING DRAFT

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This Berkeley Lab Site-Wide Interior Lighting Business Plan presents the context, planning assumptions, value proposition, and high-level implementation plan for conducting a site-wide lighting retrofit at Lawrence Berkeley National Laboratory (Berkeley Lab).

1 Executive Summary

1.1 Purpose

- **Reduce Greenhouse Gas Emissions (GHGs)**: This plan reduces greenhouse gas emissions from interior lighting in a site-wide building portfolio of 1.1 million square feet at the Berkeley Lab main site by about 70%.

- **Meet Federal and State Climate Targets:** This plan is part of an overall portfolio of energy management, commissioning, and deep energy efficiency retrofits at scale designed to support goals to:
  - Reduce greenhouse gas emissions from buildings and vehicle fleet 50% by 2025 from a 2008 baseline (required by Federal Executive Order 13693)
  - Reduce energy use intensity in buildings 25% by 2025 from a 2015 baseline (required by Federal Executive Order 13693)
  - Achieve zero net GHG emissions from buildings and vehicle fleet by 2025 (the University of California Carbon Neutrality Initiative goal)

- **Address Deficient Lighting Infrastructure:** The portfolio of lighting energy efficiency retrofits identified in this plan addresses significant deficiencies in the existing lighting infrastructure at Berkeley Lab and will modernize workspace conditions in the largest and most valuable scientific facilities across the Lab's main site.

1.2 Costs, Savings, and Financing

- The retrofit portfolio requires an investment of $7.3 million and generates an annual energy and maintenance cost savings of $450K, despite very low current electricity costs of $0.053/kWh. The retrofit portfolio generates electricity savings of 3,300 MWh/year and greenhouse gas emissions reduction of 990 MT CO_2e/year.

- The financial evaluation includes up-front and ongoing maintenance costs for materials and labor (both internally and externally sourced) compared to a baseline case of maintaining and replacing (like-for-like) existing lighting infrastructure over a 20-year period. Ongoing maintenance includes annual "short-cycle maintenance" and "long-cycle maintenance" required to replace failed or aging equipment. The analysis period is consistent with historical experience at the Lab (many fixtures are older than 20 years) and the long effective useful lives (EULs) of the retrofit luminaires (ranging from 7 to over 50 years depending on the application).

- The retrofit portfolio achieves annualized savings approximately 24% greater than annualized costs. Savings are much greater if networked lighting controls are leveraged to generate savings through control of mechanical systems and plug loads. Savings are estimated to be 43% greater than costs; 86% greater if mechanical and plug load controls are implemented.

- The project portfolio is most cost-effectively pursued using internal funds, and is modeled as such. The underlying analysis spreadsheets allow for inputs to be changed to easily reflect a cost of external financing.

1.3 Additional Benefits and Phased Approach

- Additional benefits of the retrofit portfolio include reduced maintenance costs, extended useful life of campus lighting systems, and improved lighting quality.

- The project portfolio is most prudently implemented in a phased approach in which the first year consists of pilot efforts to refine approaches and lower costs. Pilot efforts are intended to refine lighting specifications, lighting control sequences, control approaches, demonstrate solutions, verify savings, and validate costs. Subsequent years capture economies of scale.

2 Context

The Lab is pursuing a range of energy efficiency and renewable energy efforts at scale designed to support goals to:

- Reduce greenhouse gas emissions from buildings and vehicle fleet 50% by 2025 from a 2008 baseline (required by Federal Executive Order 13693)
- Reduce energy use intensity in buildings 25% by 2025 from a 2015 baseline (required by Federal Executive Order 13693)
- Achieve zero net GHG emissions from buildings and vehicle fleet by 2025 (the University of California Carbon Neutrality Initiative goal)

The Lab's efficiency efforts emphasize energy management and commissioning as well as deep energy efficiency retrofits at scale.

- Energy management and commissioning activities focus on a continuous improvement process that generates and maintains significant savings (energy, cost and GHG) with relatively limited capital investment.
- Retrofit projects require greater capital investment but also generate savings as well as significant co-benefits in terms of improving work environments and extending the lifetime of research assets.

The Lab is emphasizing energy efficiency retrofits that include both:

- Integrated, whole-building projects that address core building systems, often across multiple systems (mechanical, lighting, and plug)
- Lighting-driven projects that capitalize on improvements in LED lighting technology that can deliver savings exceeding 50% with improved lighting quality and control

Acknowledgements: This plan was developed by Sustainable Berkeley Lab, which holds overall responsibility for the composition and conclusions of the report. Sustainable Berkeley Lab would like to thank and acknowledge two entities that significantly shaped and contributed to this plan.

- kW Engineering, an energy engineering consultant, designed and prepared much of the underlying technical analysis. Portions of this report are taken directly from kW Engineering work products.
- Karl Brown of the California Institute of Energy and the Environment, through the “Deep Energy Efficiency—Getting to Scale” project sponsored by the UC Global Climate Leadership Council, conducted analysis of lighting reference projects across the UC system. Karl Brown developed a template lighting business plan on which this document was based. Also, some assumptions are drawn from the UC analysis.

3 Planning Assumptions

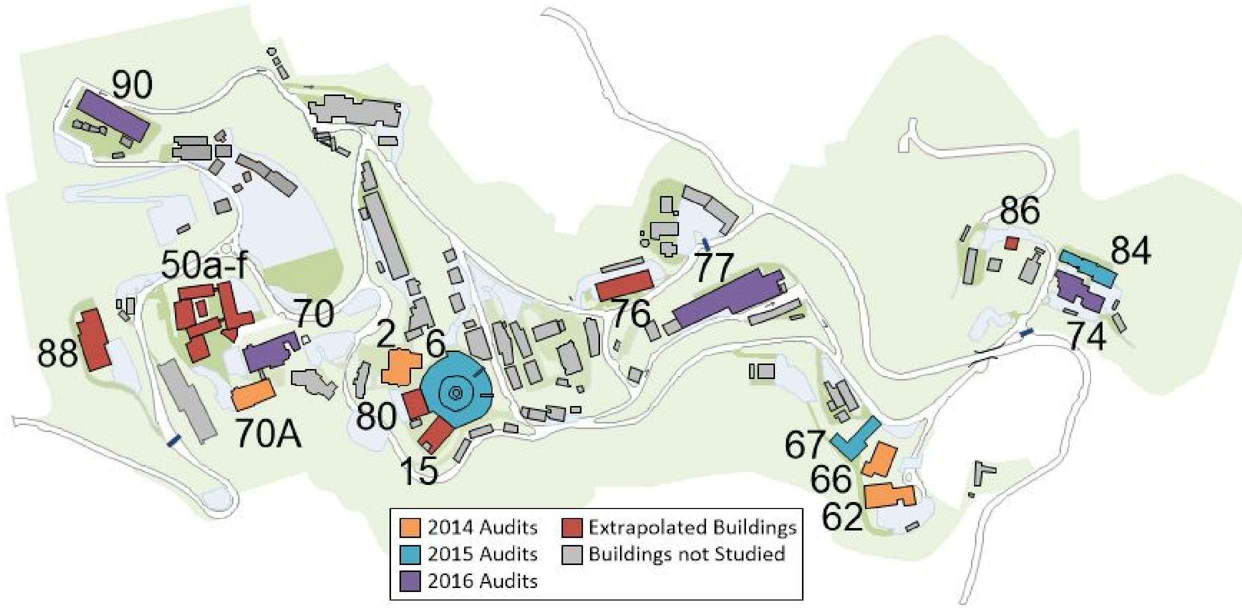
3.1 Scope

Key Buildings: This lighting business plan is limited to the Berkeley Lab main site and to 23 “key buildings” representing the largest facilities with the greatest energy use (and also housing the Lab’s key research assets). The key buildings (2, 6, 15, 30, 33, 34, 37, 50A-F, 59, 62, 66, 67, 70, 70A, 74, 76, 77, 78, 80, 84, 86, 88, 90) account for 1,463,708 gross square feet of built space and represent approximately 90% of building-related greenhouse gas emissions at the main site.

Exclusions: The square footages corresponding to the key buildings represent gross square footages and total 1,407,322 square feet. By count, the key buildings are a small subset of buildings at the Lab, which includes more than 140 buildings and structures. Of the key buildings, six buildings accounting for 303,981 internal square feet were excluded from the analysis because they are newly constructed and occupied since 2015 (30, 33, 59), are mechanical support structures that enclose chilling plants (34, 37), or received a lighting retrofit in 2016 (78). The remaining study buildings totaled 1,103,341 gross square feet.

Audits: The plan is informed by scoping energy audits conducted over the last three years in 11 buildings, that account for about 62% of the studied building area. These energy audits are required by the Federal government as part of the 2007 Energy Independence Security Act.

Figure 3.1: Berkeley Lab Main Site Map and Study Buildings



<u>3.2 Space Types</u>

The study area was mapped into six space types, assigned based on more than 60 different space categories provided in the Lab's space inventory system of record. Some support spaces were excluded from the analysis based on their low-operating hours, assuming that these spaces would not yield sufficient savings for energy saving retrofits. In practice, these areas should be analyzed during detailed design to validate this assumption. Within areas, the number of included lighting control spaces was identified to inform assumptions about daylighting and control designs. For unvisited areas, typical values were extrapolated based on average values collected during the scoping energy audits. The table below provides information about the six space types and excluded areas. Each space type was further disaggregated in up to 8 different analysis groups, informed by the scoping energy audits. Assumptions were varied to best reflect each analysis group.

Table 3.2: Space Type Descriptions

Space Type	**Included Spaces**	**Area [sq ft]**	**Number of Individual Spaces**
Office & Office Support Areas	Private Offices, Open Offices, Open Office Support, Conference Rooms, Computer Rooms, Break Rooms	351,101	2,449
Laboratories	Wet labs, Dry Labs, Laser Labs, Other Labs	231,397	537

Hallways	Lobby, Circulation Separate for Open Offices	168,685	262
Restrooms	Restrooms, Locker Rooms, Shower Areas, Lactation Rooms	24,771	164
Highbays	Highbay, Mechanical Shops	148,799	64
Cleanrooms		6,382	2
Excluded	Atriums, Chemical Storage, Electrical Rooms, Elevators, Custodial Closets, Storage Areas, IT Rooms, Mechanical Rooms, Trash Collection Areas, Loading Areas, Under Construction Areas	171,207	1,005
Total		1,103,341	4,483

3.3 Lighting Power Densities and Fixture Counts

Lighting power densities were assumed for each analysis category based on observations collected during the scoping energy audits. For unvisited areas, typical values were extrapolated based on average values collected during the scoping energy audits. Fixture counts were estimated by dividing the total lighting power density by the luminaire power of a design-basis luminaire selected for each retrofit analysis group. Ranges and average lighting power densities for each space type are provided in the table below.

Table 3.3: Baseline Lighting Power Density Assumptions by Space Type

Space Type	**Range of LPD [W/ft^2]**	**Average LPD [W/ft^2]**	**Typical LPD [W/ft^2]**
Office & Office Support Areas	0.74 - 1.79	1.21	1.13
Laboratories	0.65 - 1.95	1.42	1.39
Hallways	0.34 - 2.31	0.68	0.65

Restrooms	0.32- 2.37	0.57	0.94
Highbays	0.42 - 2.48	1.25	1.25
Cleanrooms	1.95	1.95	1.95

3.4 Baseline Assumptions

Baseline luminaire power assumptions were developed by a consultant (kW Engineering). To calculate the baseline luminaire power, fixture technologies and nominal lamp wattages were visually verified during the scoping energy audits where possible. If this was not possible, a reasonable assumption based on the luminaire size and application was made.[1]

Interior lighting at the Lab is predominantly 3,000K or 4,100K fluorescent. The lamps used are either 700-series T8 or 800-series T8/T5, with color rendering index (CRI-Ra) values of 70 and 80 respectively. Many zones have minimal controls, usually just a manual switch and some kind of occupancy sensor (usually wall-mounted or incorporated in a wall switch). There are a few open-loop photocells in hallways and lobbies with significant daylighting potential.

Based on discussions with occupants and observations gathered while performing walk-through audits, only about 60% of occupancy sensors may be functional, and the vast majority of the daylighting controls are no longer functional. Baseline assumptions regarding hours of operation are likely conservative: they likely under represent the occupancy controls that are not functioning but likely do reflect the daylight controls that are not not functioning.

Underlying assumptions for baseline hours of operation are listed in the table below.

Table 3.4.1: Underlying Assumptions for Baseline Hours of Operation

	Utilization (% of 24 hours daily)				Daily Operating Hours (hours/day)				Days Per Week (days)			
Building	Lab	Off	Hall	Other	Lab	Off	Hall	Other	Lab	Off	Hall	Other
B02	0.775	0.7	1	0.8	18	12	24	24	6	5	7	7
B06	0.83	0.73	0.96	0.84	19.5	12.63	24	23	6.25	5	7	6.5
B62	0.7	0.7	1	0.8	24	14	24	24	7	5	7	7

[1] The California statewide incentive program estimates of the total ballast power were used. See AESC. 2015. 2013-15 Statewide Customized Offering Procedures Manual for Business, Appendix B. Sacramento, CA: Pacific Gas & Electric. http://www.aesc- inc.com/download/spc/2013SPCDocs/PGE/App%20B%20Standard%20Fixture%20Watts.pdf

B66	0.775	0.7	1	0.8	18	12	24	24	6	5	7	7
B67	0.85	0.775	0.7	0.7	24	12	24	24	5	5	7	5
B70A	0.7	0.7	1	0.8	24	12	24	24	7	5	7	7
B74	0.7	0.7	1	1	18	14	24	24	5	5	7	7
B77	0.9	0.8	1	1	16	12	24	16	7	5	7	5
B84	1	0.775	1	1	18	13	24	24	7	5	7	7
B90	0.9	0.65	1	0.8	14	14	24	24	5	5	7	7
B15	0.83	0.73	0.96	0.84	19.5	12.63	24	23	6.25	5	7	6.5
B50a-f	0.83	0.65	0.96	0.84	19.5	12.63	24	23	6.25	5	7	6.5
B76	0.83	0.73	0.96	0.84	19.5	12.63	24	23	6.25	5	7	6.5
B86	0.83	0.73	0.96	0.84	19.5	12.63	24	23	6.25	5	7	6.5
B88	0.83	0.73	0.96	0.84	19.5	12.63	24	23	6.25	5	7	6.5
Average	0.82	0.72	0.96	0.85	19.40	12.72	24.0	23.1	6.2	5	7	6.5

Assumed baseline annual hours of operation were chosen to best represent the analysis group and are provided in the table below. These calculations take into account the factors from Table 3.4.1 -- operating hours, days per week, and utilization rate, and assume 52 weeks per year.

Table 3.4.2: Baseline Hours of Operation Assumptions by Space Type

Building	Lab [hrs/yr]	Office [hrs/yr]	Hallway [hrs/yr]	Other [hrs/yr]
B02	4,352	2,184	8,736	6,989
B06	5,260	2,397	8,387	6,530
B62	6,115	2,548	8,736	6,989
B66	4,352	2,184	8,736	6,989
B67	5,304	2,418	6,115	4,368
B70A	6,115	2,184	8,736	6,989
B74	3,276	2,548	8,736	8,736

B77	5,242	2,496	8,736	4,160
B84	6,552	2,620	8,736	8,736
B90	3,276	2,366	8,736	6,989
B15	5,260	2,397	8,387	6,530
B50a-f	5,260	2,134	8,387	6,530
B76	5,260	2,397	8,387	6,530
B86	5,260	2,397	8,387	6,530
B88	5,260	2,397	8,387	6,530
Average	5,076	2,378	8,422	6,675

For comparison, planning assumptions for different space types developed based on various UC reference projects, along with the range encountered, are presented below in the table below.

Table 3.4.3: Reference Planning Assumptions for Baseline Hours of Operation by Space Type

Space Type	**Baseline Planning Assumption (reference range) [hrs/year]**
Circulation (e.g., corridors)	8,423 (2,182-8,760)
General (including Laboratory)	5,598 (3,276-7,919)
Private	3,600 (992-4,554)

3.5 Project Design

For each analysis category, a representative retrofit project was identified. Typically:

- **Newer linear fluorescent fixtures** (troffer, surface mount, and pendant) are retrofit with new LED drivers and LED strips. This includes elimination of existing ballasts and lamp holders and installation of new optics if required.
- **Old linear fluorescent fixtures** are typically replaced with new LED fixtures.
- **Compact fluorescent lamp-based downlight fixtures** are fully re-built with LED technology including elimination of existing ballasts and lamp holders and installation of new optics. In some limited cases, existing compact fluorescent ballasts and ballasts are retained.

- **Lighting Controls Functionality**: Most fixtures will get new, networked lighting controls enabling the full tuning capabilities of LED lighting and native capabilities to leverage the same sensor network used for lighting to control mechanical systems and plug loads. In some cases local controls with less capability are deployed in order to lower project costs (and result in less avoided electricity use and GHG emissions). [check - Not accurate currently, but likely true in final draft].
- **Powering Lighting Controls (Wired vs. Batteries):** Networked lighting control components installed above ladder height are assumed to be installed in a wired configuration, even if the hardware can be installed wireless. Wireless components require batteries. While the batteries on these devices can last 10 years, they will ultimately require maintenance to replace the batteries. Given the Lab's limited experience with battery-powered wireless lighting controls, this analysis assumes that the higher first cost associated with installing a wireless component in a wired configuration (using a wireless adapter) above ladder height is preferred over the ongoing cost and effort of battery replacement. Below ladder height (for example, at the height of a wall switch) wireless, battery-powered, networked controls are assumed.
- **Daylighting** in office and hallways is generally open loop, which holds off lighting when the sensor is triggered under bright conditions. Daylighting in laboratories is closed loop, which continually adjusts to changing lighting conditions.
- **Correlated Color Temperature**" New LED hardware has a CRI-Ra of at least 80 and a positive CRI-R9 value. CRI-R9 evaluates color rendering of a highly saturated red, which is not captured in the CRI-Ra index.
- **Task lighting** is excluded from the analysis, with the exception of some laboratory space types where task lighting already exists.
- **Project light levels** are assumed to remain generally the same as baseline light levels.

Coordination with Other Projects: Note that any space that will have major renovations —that will replace or substantially upgrade lighting systems—should be identified and coordinated with retrofit efforts. In this plan, only building 70 has been identified as a potential demolition due to seismic concerns. However, since the Lab has firm plans to demolish or substantially renovate building 70, it has been retained in the analysis.

Also note that project designs are representative, developed at a granularity to support a business case. **Detailed surveys and space-specific project designs should be completed as a part of project development during implementation.**

3.6 Effective Useful Life

In this study, luminaire effective useful lives (EULs) ranged from 7 to 50 years. Note that, outside of the small percentage of LED chip failures or driver failures, most LED luminaires do not typically have a burn-out failure mode like conventional light sources. LEDs will continue to operate provided electric power; however, the total light output will drop over time. In this study, a hardware life expectancy was evaluated in each retrofit application at either a set number of lifetime operating hours or the time to reach 70% light output, whichever occurs first. LED luminaire lifetime operating hours were assumed to be 100,000 hours for new luminaires, 70,000 hours for full retrofit kits, and 50,000 hours for retrofit strips and lamps.

The control components associated with the LED luminaire are expected to last 8 years according to the California Energy Commission; however, use of networked lighting controls will allow facilities staff to perform adequate preventative maintenance to extend the EUL well beyond the state-expected EUL. Therefore, control hardware replacement was assumed using a 4% annual failure rate.

3.7 Lighting Savings

For the proposed luminaires, typical manufacturer data for the total input power was used. For all bi-level luminaires, bi-level controls were assumed to reduce the input power by 50%. The factors used to estimate controls savings for advanced lighting controls are provided in the table below.

Table 3.7: Advanced Lighting Control Assumptions

Daylighting								
	Fixture Locations			Lab	Office	Hallway	Other	
			Primary Daylit Zone	10%	20%	50%	10%	of Fixtures
			Secondary Daylit Zone	10%	20%	0%	10%	of Fixtures
	Dimming Assumptions							
		Primary Daylit Zone						
			Primary Full Brightness	60%	40%	20%	60%	of the Time
			Primary 50% Brightness	40%	60%	80%	40%	of the Time
		Secondary Daylit Zone						
			Secondary Full Brightness	80%	70%	0%	80%	of the Time
			Secondary 50% Brightness	20%	30%	0%	20%	of the Time
Occupancy Factors								
			Occupied, Normal Operation	60%	80%	20%	60%	
			Unoccupied, Bi-level	0%	0%	40%	0%	
			Unoccupied, Off	40%	20%	40%	40%	
Top Trimming								
			TT % Full Load	85%	85%	85%	85%	

Manual Dimming								
			MD % Full Load	90%	70%	100%	100%	

3.8 Mechanical System Savings

Mechanical system savings were estimated assuming that the networked lighting control sensors are leveraged to control mechanical systems. In general, the savings results from use of zone-by-zone occupancy information to dynamically control minimum airflow requirements and zone temperature setbacks, which saves ventilation, cooling, and heating energy. The savings estimate should be considered preliminary. Savings were estimated as follows:

- **Overall calculations**: The average yearly ventilation, cooling, and heating energy usage directly related to minimum ventilation requirements, per square foot of office and per square foot of lab space was estimated based on energy balances developed during the scoping energy audits.
- **For each building**, the average energy savings values, total laboratory and office space areas, occupancy hours, as well as an HVAC integration score, were used to determine the achievable heating, ventilation and air conditioning (HVAC) savings related to the integration of the occupancy information and the programming of dynamic minimum ventilation controls and zone temperature deadbands.
- **The HVAC integration score** (for each building that received a scoping audit) between 0 and 1 is based on the existing systems and controls in place. For example, using occupancy information dynamically would not be practical in buildings that have Barrington or old Johnson HVAC controls, and therefore buildings with such controls received an HVAC integration score of zero. Buildings 67 and 74 are the only two buildings with a score of 1 because they have recent DDC VAV controls throughout. Other buildings have partial scores between 0 and 1 based on their mix of existing HVAC systems. For buildings we have not audited, HVAC integration score is set at 0.5, which is the average of the scores of audited buildings.
- **No/low Savings in Labs:** For the labs, at the air handler unit (AHU) level, variable-volume controls are assumed (e.g. VFD with duct static pressure controls), all supply systems are 100% OA, supply air temperature setpoint resets are in place, and operation is continuous (24/7). No ventilation savings were assumed on the exhaust side, because advanced controls are needed to fully take advantage of airflow reductions on the exhaust side (variable volume exhaust fans, and plume height controls), and these advanced controls are not yet present in any of the buildings included in this study, which results in much lower exhaust-side savings potential.
- **Offices:** In the simplified proposed case for offices, ventilation requirements were lowered to 0 cfm, resulting in zero energy usage during unoccupied hours (i.e. generated in the building automation system via large setbacks), and ventilation requirements for laboratories are lowered to 4 air changes per hour (ACH). Based on these minimum ventilation scenarios, average energy savings per square foot and per hour of unoccupancy were calculated.

- **Operating Hours**: Laboratories were assumed to be occupied 50 weeks per year, 6 days a week, 12 hours per day, with an occupancy factor of 80%, i.e. 2,880 hours per year. Offices were assumed to be occupied 50 weeks per year, 5 days a week, 12 hours per day, with an occupancy factor of 80%, i.e. 2,400 hours per year. These assumptions differ from those used for lighting and presented in Table 3.
- **Costs**: assumed that each occupancy point will take approximately 10 minutes to map via BACnet into the HVAC control system. For each office zone, 30 minutes of programming for the VAV box was assumed. Since laboratories have two zone devices (generally a VAV box for supply air and an exhaust box for lab exhaust), the programming was assumed to require 60 minutes. A control technician labor rate of $100 per hour was assumed.

3.9 Plug Load Savings

Plug load savings were estimated assuming that the networked lighting control sensors are leveraged to control plug loads. While the potential for savings was evident in all spaces during the scoping energy audits, the savings estimate should be considered preliminary. Plug load savings should be verified through pilot activities. Savings were estimated as follows:

- Plug loads were estimated based on energy balances developed during the scoping energy audits.
- Each office area was assumed to be able to schedule approximately 2.6 kWh/yr/ft^2 in plug loads (or equivalent to 0.4 W/ft^2 during unoccupied hours). Each laboratory area was assumed to be able to schedule 5.0 kWh/yr/ft^2 (or equivalent to 0.86 W/ft^2 during the unoccupied hours).
- Costs were based on a Daintree plug-load device using the manufacturer's suggested retail device ($109 per receptacle pair) and 5 minutes of installation time. The scheduling effort was assumed to take 30 minutes. Each office was assumed to have two receptacle pairs for control and each lab would have four receptacle pairs.

3.10 Project Evaluation and Costs

Project savings take into account materials, installation labor (both internally and externally sourced), maintenance, and energy costs, and are evaluated based on levelized annual costs and savings in comparison to a baseline case. Costs include up-front and ongoing maintenance costs over a 20-year period. Baseline costs include ongoing maintenance (ballast and lamp replacement) and changing out luminaires and controls, like-for-like, as equipment fails. Retrofit project costs involve full retrofit with new LED luminaires and controls with maintenance necessary to maintain systems. Cost components for baseline and retrofit projects are presented in the table below.

Table 3.10.1: Baseline and Retrofit Project Cost Components

Costs	General Description	Description for Baseline Project	Description for Retrofit Project
Energy	Annual energy costs associated with luminaire and controls configuration	Annual energy costs for existing luminaires and controls	Annual energy costs for new luminaires and controls

Project	Materials, installation labor, and project management	Not applicable	Total retrofit project cost
Short-Cycle Maintenance	Recurring maintenance activities, generally conducted on an annual cycle.	Relamping and re-ballasting costs	System licensing or support costs
Long-Cycle Maintenance	Equipment maintenance that is required over a 30-year project planning horizon	Costs for replacement of luminaires and controls at the end of their useful life	Costs for replacing, after expiration of warranty, failed lamps or drivers

Luminaire materials and installation cost assumptions are listed in the table below. Cost assumptions are based on consultant input and reference projects on UC campuses as indicated.

Table 3.10.2: Luminaire Materials and Installation Costs

Luminaire Cost Details							
				Unit Price		Cost Sources	
Luminaire Materials Costs & Installation				Material Cost	Install Time (min)	Material	Labor
	Proposed Luminaires						
		New Hardware					
			LED Light Bars	$103	20	UC Avg.	Estimate
			LED 2x4 Retrofit	$122	20	UC Avg.	Estimate
			LED 4' Pendant	$330	30	A19LED	Estimate
			LED SM Luminaire	$280	20	Shine Retrofits	Estimate
			LED 4' Pendant (Nice)	$330	30	TBD	Estimate
			LED CFL Retrofit Lamp	$20	3	Lunera	Estimate
			LED Downlight Retrofit	$120	20	Goodmart	Estimate

			LED High Bay	$436	40	Zoro.com	Estimate
		Demolition of Existing					
			Luminaires				
			Ballast Recycling	$1.00	5	Facilities.net	Estimate
			Lamp Recycling	$0.50	2	Facilities.net	Estimate
		Relocate Luminaires					
	Like-for-Like Luminaires						
		New Hardware					
			Recessed Troffer Fixture	$180	60	RS Means	Estimate
			T8 Lamps	$6	3	Goodmart	Estimate
			T8 U-bend Lamps	$10	3	Goodmart	Estimate
			T5 Lamps	$12	3	Goodmart	Estimate
			CFL Lamp	$5	3	Goodmart	Estimate
			200W Induction Lamp	$788	20	Rexel	Estimate
			400W Metal Halide Lamp	$35	20	Grainger	Estimate
			T8 Lamp Ballast	$29	10	1000 bulbs	Estimate
			T5 Lamp Ballast	$40	10	1000 bulbs	Estimate
			CFL Ballast	$29	10	Goodmart	Estimate
			Induction Ballast	$912	20	Rexel	Estimate
			400W Metal Halide Ballast	$203	20	Grainger	Estimate
		Demolition of Existing					
			Luminaires				
			Ballast Recycling	$1.00	5	Facilities.net	Estimate
			Lamp Recycling	$0.50	3	Facilities.net	Estimate

	LED Panel Replacement	$62	10		
	LED Driver Replacement	$41	10		

Networked lighting control materials and installation cost assumptions are listed in the table below Cost assumptions are based on consultant and vendor input.

Table 3.10.3: Controls Materials and Installation Costs

Control Cost Details							
				Unit Price		Cost Sources	
Luminaire Materials Costs & Installation				Material Cost	Install Time (min)	Material	Labor
	New Control System						
		Occupancy Sensors					
			Wall Mount, PIR 24V	$85	45	Prolighting.com	Estimate
			Wall-Mount, Dual Tech 24V	$140	45	Prolighting.com	Estimate
			Ceiling Mount, PIR 24V	$58	45	P78 Pilot	Estimate
			Ceiling Mount, Dual Tech 24V	$140	45	Prolighting.com	Estimate
			Fixture Mount	$75	5	Glued Solutions	Estimate
		Daylighting Controls					
			Closed Loop	$185	50	Grainger	Estimate
		Dimmers/Switches					
			Wireless Wall Switch	$52	5	P78 Pilot	Estimate
			Wall-Switch, 0-10V	$94	15	Grainger	Estimate
		Networking Hardware					
			Wireless Sensor Adapter	$69	10	P78 Pilot	Estimate
			Wireless Fixture Adapter	$69	10	Estimate	Estimate
			Wireless Fixture Adapter, PM	$75	15	P78 Pilot	Estimate
			WAC (assume 1/100 spaces)	$449	45	P78 Pilot	Estimate
			Additional WAC Nodes	$25	5	P78 Pilot	Estimate

	Like-for-Like Controls						
		Occupancy Sensors					
			Wall Mount	$163	45	Grainger	Estimate
			Ceiling Mount, PIR 24V	$229	45	Grainger	Estimate
			Ceiling Mount, Dual Tech 24V	$263	45	Grainger	Estimate
			Fixture Mount	$75	5		
		Daylighting Controls					
			Closed Loop	$185	50	Grainger	Estimate
		Dimmers/Switches					
			Wall-Switch, 0-10V	$94	15	Grainger	Estimate
	Lighting Zone Sensor Replacement			$119	39.2		

Additional project cost assumptions are provided in the table below.

Table 3.10.4: Project Cost Assumptions

Installation Labor Type	Rate	Source
Assumed Electrician Labor Rate	70	RS Means 2016 Labor Rate, Union Bay Area Average
Cost Component Markup	Material	Labor
New Luminaires	11%	30%
New Controls	11%	30%
Like-for-Like Luminaire Replacement	11%	30%
Like-for-Like Controls Replacement	11%	30%
Luminaire Maintenance	0%	30%

Controls Maintenance	0%	30%
Escalation Rates	Annual Rate	Source
Labor Cost Escalation Rate	1.7%	Employment Cost Index for State & Local Government Works in Service Occupations, 10-year average ending December 2015 - Bureau of Labor Statistics
Materials Cost Escalation Rate	2.5%	Purchaser's Price Index for Hardware, building materials, and supplies retailing, 7-year average through Feb 2016 - Bureau of Labor Statistics
FY15 Baseline Average Hill Electricity Cost	$0.053/kWh	See Project Financial Thresholds for further information about the financial analysis
FY15 Baseline Average Hill Natural Gas Cost	$0.5324/therm	See Project Financial Thresholds for further information about the financial analysis
Annual Electricity Cost Escalation Above Inflation	3.15%	See Project Financial Thresholds for further information about the financial analysis
Maximum Annual Inflation	2.2%	See Project Financial Thresholds for further information about the financial analysis
Project Management	Cost as a Percentage of Material and Installation Labor Costs	
Overhead, Mobilization	0.0%	

Overhead, Project Management	5.0%	
Overhead, Design	5.0%	
Overhead, Commissioning	2.0%	
Overhead, Contingency	2.0%	
Total Overhead	14.0%	

4 Project Performance

The threshold assumed for financial viability is a portfolio annualized ratio of savings to cost of 1.18. In this plan, in which projects are assumed to be funded internally, the ratio is called an "investment coverage ratio." The requirement that annualized savings exceed costs by 18% reflects potential uncertainty in the analysis and a buffer to ensure net savings.

An investment coverage ratio of 1.18 is analogous to a maximum annual debt service to energy savings ratio of 0.85 when financing is used. This 0.85 threshold is used in the UC system to evaluate financing of energy efficiency projects through bond financing (see the following Financing section).

Note that financial performance is generally best in hallway and high-bay space types where baseline operating hours are greatest. Project economic performance by space-type and per fixture is summarized in Table 4.1, assuming lighting control only. Table 4.2 includes costs and savings for lighting and mechanical system control. Table 4.3 includes costs and savings for lighting, mechanical system and plug load control.

Table 4.1: Project Performance by Space Type - Lighting Control Only

	Costs				Savings				
Retrofit Space Type	Project Cost	Luminaire Material and Install per Fixture	Controls Material and Install per Fixture	Total Project Per Fixture	Annualized Energy Cost	Annualized Maintenance Cost	Total Annual-ized Cost	Annual-ized per Fixture	Annualized Ratio of Savings to Cost
Laboratory	$2,333,043	$300	$46	$419	$101,370	$35,412	$136,781	$25	1.17
Office	$3,099,381	$275	$123	$453	$68,020	$28,720	$96,739	$14	0.62
Hallway	$478,718	$109	$31	$160	$67,369	$9,751	$77,120	$26	2.97
Restroom	$149,226	$190	$86	$316	$7,664	$1,103	$8,767	$19	1.14

Highbay	$1,111,724	$561	$167	$830	$83,348	$42,174	$125,521	$94	2.26
Cleanroom	$86,796	$157	$3	$183	$2,964	$659	$3,623	$8	0.83
Total	**$7,258,887**				**$330,735**	**$117,818**	**$448,552**		**1.24**
Average		**$271**	**$82**	**$410**				**$25**	

Notes: Cost are annualized over a 20-year period. Initial electricity cost is $0.053/kWh

Table 4.2: Project Performance by Space Type - Lighting and Mechanical System Control

	Costs				Savings				
Retrofit Space Type	Project Cost	Luminaire Material and Install per Fixture	Control Material and Install per Fixture	Total Project per Fixture	Annualized Energy Cost	Annualized Maintenance Cost	Total Annual-ized Cost	Annual-ized per Fixture	Annualized Ratio of Savings to Cost
Laboratory	$2,395,692	$300	$46	$430	$143,812	$35,412	$179,223	$32	1.50
Office	$3,262,648	$275	$123	$477	$96,001	$28,720	$124,721	$18	0.76
Hallway	$478,718	$109	$31	$160	$67,369	$9,751	$77,120	$26	3.22
Restroom	$149,226	$190	$86	$316	$7,664	$1,103	$8,767	$19	1.14
Highbay	$1,111,724	$561	$167	$830	$97,664	$42,174	$139,838	$104	2.52
Cleanroom	$86,796	$157	$3	$183	$2,964	$659	$3,623	$8	0.83
Total	**$7,484,803**				**$415,474**	**$117,818**	**$533,292**		**1.43**
Average		**$271**	**$82**	**$423**				**$30**	

Notes: Cost are annualized over a 20-year period. Initial electricity cost is $0.053/kWh

Table 4.3: Project Performance by Space Type - Lighting, Mechanical System and Plug Load Control

	Costs				Savings				
Retrofit Space Type	Project Cost	Luminaire Material and Install per Fixture	Control Material and Install per Fixture	Total Project per Fixture	Annualized Energy Cost	Annualized Maintenance Cost	Total Annual-ized Cost	Annual-ized per Fixture	Annualized Ratio of Savings to Cost
Laboratory	$2,648,080	$300	$46	$476	$254,093	$35,412	$289,504	$52	2.19
Office	$3,815,021	$275	$123	$558	$183,723	$28,720	$212,443	$31	1.11
Hallway	$478,718	$109	$31	$160	$67,369	$9,751	$77,120	$26	3.22
Restroom	$149,226	$190	$86	$316	$7,664	$1,103	$8,767	$19	1.14
Highbay	$1,111,724	$561	$167	$830	$136,744	$42,174	$178,918	$134	3.22
Cleanroom	$86,796	$157	$3	$183	$2,964	$659	$3,623	$8	0.83

Total	**$8,289,564**				**$652,558**	**$117,818**	**$770,376**		**1.86**
Average		**$271**	**$8**	**$469**				**$44**	

Notes: Cost are annualized over a 20-year period. Initial electricity cost is $0.053/kWh

5 Financing

Two primary financing options available to Berkeley Lab are internal financing and external financing. For this business plan, financial performance is presented using internal financing.

At this time, retrofits projects will be pursued with internal funding in order to minimize overall costs. If external financing is deemed necessary to complete the retrofit portfolio at scale, the underlying analysis spreadsheets allow for inputs to be changed to easily reflect a cost of external financing.

The Lab in general does not have access to bond financing which have been used to finance the majority of UC campus energy efficiency retrofits to-date. The planning parameters are 5% interest rate for 15-years with a maximum annual debt service to energy savings ratio of 0.85. The UC is also exploring the use of longer-term, 30-year debt financing.

The Lab has almost no ability to carry over funds from one fiscal year to the next, which prevents practical implementation of a typical revolving loan fund model. However, it should be noted that “spin up investment” model could be quantified from this analysis in which initial project savings are quantified to support subsequent project investments.

6 Implementation Plan

6.1 Project Management and Staffing

- Projects will be managed jointly by Berkeley Lab Facilities Division and Sustainable Berkeley Lab. This process has been working well since the start of FY 2015.

6.2 Project Staffing

- Detailed staffing plans will be developed by Berkeley Lab Facilities Division and Sustainable Berkeley Lab. Evaluation of staffing from projects across the UC system indicate necessary staffing to be 0.3 FTE per million gsf of buildings for interior lighting retrofits (within a range of 0.2 to 0.4). This is typically in the context of an overall retrofit portfolio for all end-uses requiring 0.9 FTE per million gsf of buildings (within a range of 0.6 to 1.2). Variability within the range can depend on the amount of survey work that is done in house and the amount of documentation required (e.g., for incentives). The effort required includes project development that typically draws from energy management staff, as well as project management that may also draw from other campus staff (e.g., capital projects). These staffing estimates are based on: (a) surveys of energy management staff at higher education universities including UC, (b) 7-16% of overall project costs needed for project development and management (8-20% adder to materials and installation costs), and (c) an eight-year timeframe to implement the portfolio in conjunction with the 2025 carbon neutrality goal.

6.3 Project Phasing

- **Pilot Projects**: Initial projects will be selected to minimize disruption, support the Lab's scientific mission, facilitate understanding and training for Operations staff (Facilities and Environment/Health/Safety), and confirm implementation details for key space types.
- **Site-Wide Project**: Once the Lab has developed a consensus project approach and has a strong set of specifications and sequence of operations for lighting, the remainder the site-wide lighting projects will be bid for implementation.
- **Phasing**: Phasing of a site-wide will be based on staffing availability and completion of the full retrofit portfolio before 2025. Assuming internal funding, phasing should consider the ability of early projects to validate the business case. If the project portfolio is debt financed, phasing can be optimized to consider integration into whole-building retrofit projects covering multiple end-uses capturing GHG reduction and cost reductions net of debt service as early as possible.

6.4 Procurement

- **Project Support**: All projects will be supported by a competitively bid engineering contractor (Project Support Contractor). The Project Support Contractor will provide services related to project scoping, owner's representation, solicitation support, third-party commissioning, support for ongoing operability and maintenance of energy savings, and project evaluation. The Project Support Contractor will be retained with an option for renewal across multiple projects and multiple years to provide continuity and knowledge accretion across all projects.
- **Project Implementation**: Work will be conducted by external, competitively-sourced design-build contractors with internal project and construction management.
- **Economies of Scale for Materials:** Much of the available economies of scale for materials are already captured from typical building-scale projects, or from installation vendor aggregation of purchases. Still, there are several opportunities to control mark-ups by different players in the lighting retrofit market and encourage competitive materials costs. Berkeley Lab plans to pursue request for quotes on materials in two separate bid cycles: (1) pricing for luminaires and controls by lighting product vendors based on performance specifications (2) pricing for a selected set of luminaire and controls products by distributors. A third solicitation would select installation contractors based on the identified luminaire and controls pricing.
- **Economies of Scale for Installation**: Economies of scale, continuity, and competition are achievable for to control installation costs. One approach consistent with campus-wide scale, that can capture all of these economies, is a multiple vendor process. Multiple (e.g., three) vendors are qualified to operate on campus simultaneously, then bid against each other for increments of project scope. Mobilization (scale) and familiarization (continuity) costs are limited while still reducing costs through competition.
- **Rebates**: In general, Berkeley Lab is not eligible for electricity PG&E rebates. Some lighting equipment incentives, specifically recess mount LED rebuild kits or replacement fixtures are,

at least in the short term, being shifted by some utilities to distributors (mid-stream). This requires further inquiry and should be considered in the request for quote process.

6.5 Detailed Project Design

- Projects will be developed sufficiently to procure a design-build implementation contractor and to minimize information risk for that contractor. Standard approaches will be captured in master design guidelines and master specifications. Project-specific information will be packaged up for the design-build solicitation.

6.6 Ongoing Operation

- **Project Operation**: Project operation will be conducted by the Facilities Division.
- **Project Monitoring**: Project monitoring will be conducted by Sustainable Berkeley Lab and Facilities using Skyspark or similar systems (to be piloted in fiscal year 2017).
- **Project Maintenance**: Integrate upgraded lighting controls into operations:
    - Shift maintenance resources from re-lamping to operations management
    - Integrate surplus into financial planning

6.7 Project Evaluation

- **Project Evaluation**: Project evaluation will be conducted by an external contractor. As much as practical, project savings will be verified on an ongoing basis through periodic checks and monitoring-based commissioning.
- **Scope**: Project measurement and verification will include:
    - Analysis for portfolio investment performance
    - Documentation for incentives (if applicable), and
    - Improvement of project design for subsequent phases.

6.8 Next Steps

To refine this business case and prepare for implementation at scale, the Lab plans near-term work to:

1. **Document Completed Pilot Results**: Document the results of the pilot installation of Daintree networked lighting controls in Building 78.
2. **Define Expanded Pilot**: Define a second lighting retrofit pilot that includes (compared to the B78 project) a wider variety of luminaire/retrofit solutions (such as laboratory spaces) and can serve as a showcase to engage other user groups and occupants of the Lab. The pilot should also be scoped to allow validation of assumptions that have the greatest impact on savings and costs.
3. **Refine Networked Lighting Control Designs:** This analysis indicates that networked lighting controls costs are sensitive to choices regarding the occupancy sensing technology (dual tech or PIR), the sophistication of daylighting control (open or closed loop), and the extent to which battery-powered wireless devices are deployed. Development of more detailed materials lists for specific representative space types from multiple vendors would help refine networked controls costs. Designs might also be differentiated between open offices and closed offices. The current analysis evaluates all offices together.

4. **Identify Lower Cost Options for Offices:** Additional efforts should be made to identify options for lowering retrofit costs in offices.
5. **Identify LED Upgrades Applicable to Routine Maintenance**: In some areas, lower expense upgrades could be more cost-effective than the complete retrofit projects modeled in this business plan. For example, during routine relamping, 4' fluorescent lamps could be replaced with LED replacements and existing ballasts retained. If fluorescent ballasts were to fail, then the entire luminaire could be upgraded to LED. These upgrades would achieve a transition to LED over time with lower material and labor costs.
6. **Document Approaches**: Incorporate lessons learned into an Owner's Project Requirements (OPR) and/or specification. All the decisions and thoughts should be summarized and documented for inclusion in a future bid document. These documents should precisely spell out requirements for Lab projects and specific unknowns that will affect implementation, for inclusion in a future bid document. These documents will serve as a key piece of information not only for the bidders, but for the various stakeholders at the Lab. Good documentation will ensure that key considerations are not forgotten or misunderstood in the future. The OPR should be easily accessible and maintained as a living document.
7. **Gather Documents for Bidding Process**: The bid documents are a critical part of the bid process with potential contractors. Anything that can be documented ahead of time increases the potential pool of bidders by reducing their risk and making it easier for them to bid. The following list of items could contribute to lower bid costs.
    a. Verify all fixture counts. This report used a rough metric (lighting power density) to estimate luminaire counts. Using actual luminaire counts would reduce uncertainty.
    b. Identify all asbestos abatement issues and sources in scope.
    c. Identify predominant ceiling types by building and space type.
    d. Identify predominant lighting voltage (120V or 277V) by building.
    e. Identify any known lighting deficiencies (e.g. not enough light) and consider rolling into project.
    f. Identify network infrastructure connectivity and barrier issues for controls.
    g. Identify and document all permitting requirements.
    h. Identify and document "attic" or maintenance stock percentage/quantity required.
    i. Identify desired warranty resolution approach (e.g. should the contractor include parts and labor for the entire fixture warranty period, versus just parts).
    j. Identify where shift work is and is not required.
    k. Document required commissioning process (e.g. design review, submittal review, contractor/vendor prefunctional tests, consultant functional tests, O&M manual contents required, training required, etc.).
    l. Document measurement and verification plans required. Decide whether to use stipulated power or whether to install temporary electrical submeters. If electrical submeters are desired, outline safety/permitting requirements for electrical contractor.
    m. Identify and document training or background checks required for contractor staff.
    n. Identify and document how change orders are handled moving forward, especially if indefinite luminaire and control quantities are used.

8. **Review Unknown Elements with Stakeholders**: Reviewing the unknown elements with key stakeholders (EH&S, Facilities Lighting Team, Facilities Engineering Team, Facilities Controls Team, Permitting Department, IT Department, SBL, Utility, Consultant, etc.) will provide an opportunity to brainstorm possible solutions. This brainstorming can take place in small groups, rather than large ones, to make better use of everyone's time. Sources of information should be documented if future clarification is necessary. Upon completion, all information should be captured in a revised OPR and/or Project Specification.
9. **Solicit Other Internal Experts**: Coordinate with researchers at the Lab to review this business plan and provided input through the process. See if they would like to conduct research using the retrofit process as a living laboratory.