UC Berkeley

Energy Delivery Options
Executive Summary

Final Report

Rev A | December 1, 2015

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 243378

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1 Executive Summary

The goal of this study was to investigate suitable replacement and/or upgrade options for the existing University of California, Berkeley (UCB) campus energy delivery system. The motivation for such a replacement/upgrade came from the failing condition and the fast approaching (2017) third party operation contract expiration of the existing system. Given the complex nature of such a major overhaul, the study made use of a multi-criteria decision framework, and also considered sensitivities arising from various levels of building energy conservation measures (ECMs), and plausible future renewable energy supply (RES) scenarios.

This study makes separate cost-optimal and carbon-optimal recommendations for options to investigate further. Using the various combinations of the ECM and RES scenarios considered, these recommendations are based on the relative total cost of ownership (TCO) and relative total global carbon emissions of each option as compared to the baseline (BL) option which involves overhaul and continued use of the existing system.

The three options recommended for further study as a result of this framework include nodal heat recovery (NHR), centralized cogeneration (CCG), and centralized electric boilers (CEB). Each of these options involve a move away from campus steam distribution towards campus low-temperature heating hot water distribution. The NHR option also introduces chilled water distribution in two specific zones on campus. Additionally, each of these options entail a distributed/building level approach towards steam generation for process equipment such as autoclaves, dishwashers, and animal cage washing.

NHR: Nodal Heat Recovery

The NHR option was found to be the cost-optimal option under the enhanced RES future, regardless of the level of building level ECMs pursued. It was also found to be carbon-optimal under a base case RES future, regardless of the level of building ECMs pursued.

Under these ECM and RES scenarios, the NHR option reduces UCB buildings[1] carbon emissions between 38% and 59% below the BL scenario over 30 years. It was also found to reduce TCO by US$$_{2015}$ 98 - 159 million (or 11% - 18%) below the BL option over the same period.

The NHR option will require an estimated additional capital cost outlay of US$$_{2015}$ 70 million[2] (or 50%) above the BL option.

CEB: Centralized Electric Boilers

The CEB option was found to be carbon-optimal under the enhanced RES future, regardless of the level of building ECMs pursued. Under these scenarios it reduces carbon emissions by approximately 70% below the BL option over 30 years. However, it was found to increase TCO by US$$_{2015}$ 106 - 125 million (or 13% - 14%) above the BL option over the same period.

The CEB option will require an estimated additional capital cost outlay of US$$_{2015}$ 40 million (or 29%) above the BL option.

CCG: Centralized Cogeneration

The CCG option was found to be cost-optimal under a base case RES future, only if the deepest level of building ECMs are pursued[3]. Under this specific ECM and RES scenario, the CCG option increases carbon emissions by approximately 28% above the BL option, but reduces TCO by approximately US$$_{2015}$ 119 million (or 13%) below the BL option.

The CCG option will require an estimated additional capital cost outlay of US$$_{2015}$ 149 million (or 105%) above the BL option.

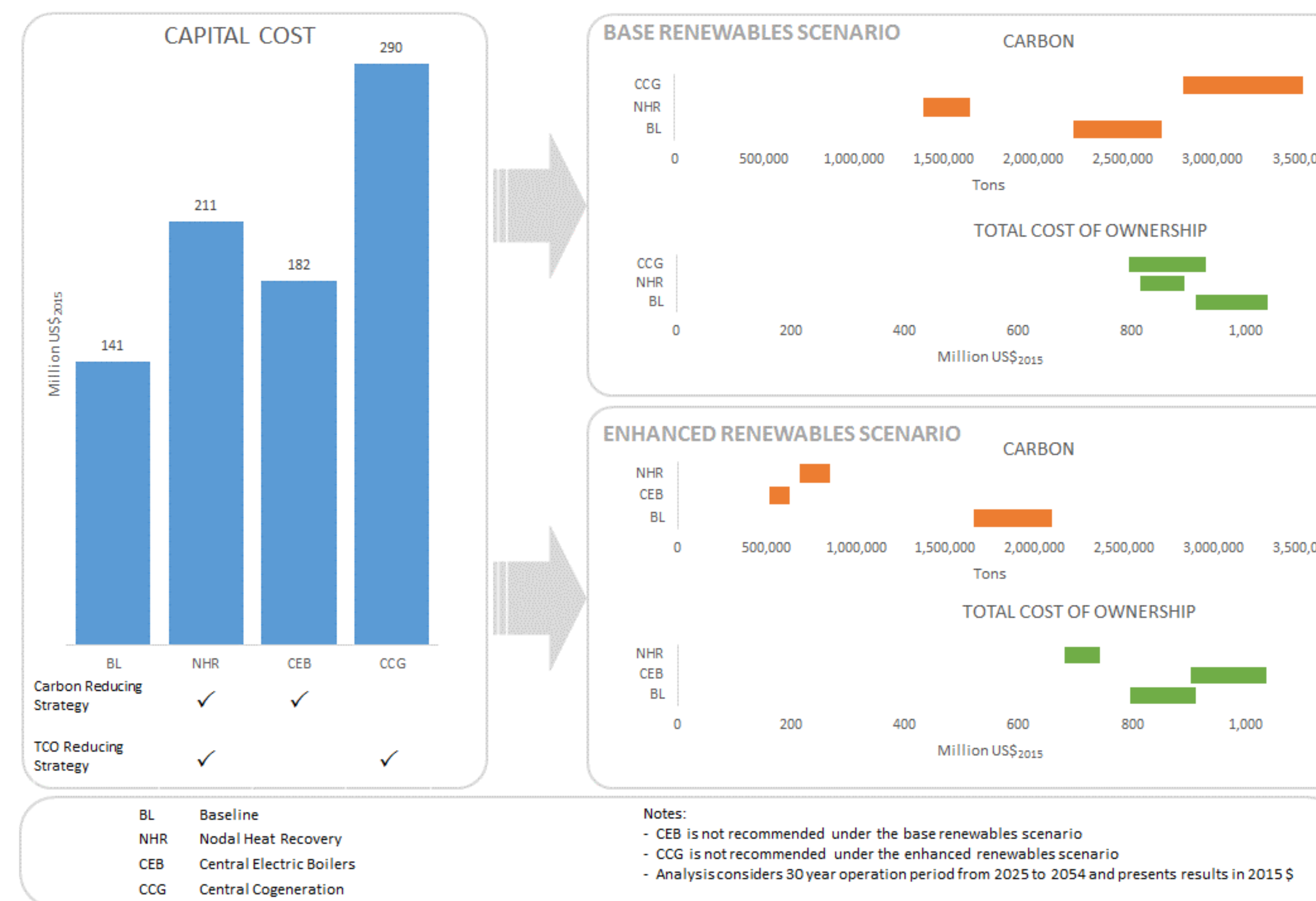

Figure 1: Executive Summary

[1] For buildings connected to the campus steam distribution
[2] Capital costs reported in this section have an average accuracy of +/- 40%
[3] The cost-optimal option at less aggressive levels of building ECMs under a base case RES future was again found to be the NHR option

1.1 Project Background

This project was primarily motivated by the increasingly deteriorating state of the existing UCB campus energy delivery system. With a growing deferred maintenance program and a fast approaching expiration of the current contract between UCB and the third party system operator, UCB recognized the need for a holistic and long-term study of the future of the campus energy delivery system.

In 2013, the University of California (UC) also announced its Carbon Neutrality Initiative, under which all UC campuses are required to eliminate greenhouse gas emissions from their buildings and vehicle fleets by 2025.

Given this context, UCB contracted the Arup team (the team) to perform a study with the intent of identifying the best method of delivering heat and power to the UCB campus in the long term under the "UCB Energy Delivery Options Analysis" project (the project).

Specifically, UCB wanted to explore whether the existing central steam system or some other energy delivery system would better serve the campus. The final report summarizes the recommendations for UCB's energy delivery in the future, as well as the process leading to those findings.

1.2 Current System

The campus currently receives heat from a cogeneration system in the form of high-pressure steam. The cogeneration system is owned and operated by PE Berkeley, and is located in a central plant building on the UCB campus. This central plant also contains 3 auxiliary steam boilers that are owned by UCB but operated by PE Berkeley.

PE Berkeley sells electricity to Pacific Gas & Electric (PG&E) and sells steam to UCB for building heating, cooling (using absorption chillers), and process equipment. UCB in turn purchases electricity directly from PG&E. The current energy services contract between UCB and PE Berkeley is set to expire at the end of 2017.

The existing cogeneration and boiler system is approximately 28 years old and sees significant distribution losses (on the order of 20% water losses and 37% thermal energy losses[4]). A portion of these losses are a result of one-pass process loads in buildings (such as glass wash and cage wash systems) but a significant amount of losses also occur due to excessively corroded steam and condensate piping, uninsulated steam piping, and leaking building heat exchangers[5]. Ongoing repairs are difficult due to a low maintenance budget and poor manhole conditions.

The energy and resource inefficiency of the system also results in a high carbon emission intensity compared to modern day campus and/or district systems.

[4] See the "Steam Plant Alternatives Assessment" final report
[5] See the "Phase 1 Existing Conditions Report"

1.3 Project Scope

The scope of the project was to determine the optimal system choices for heat and energy delivery on the UCB campus. Following an initial brainstorming session that documented 129 strategies, the team performed a high-level qualitative analysis to filter and reduce the energy delivery options to study in further detail to those summarized in **Table 1**.

Table 1: Core Energy Delivery Options

Option	Abbreviation	Generation System	Distribution
0	BL	Overhaul and continued operation of the existing system (Centralized gas-fired cogeneration)	Steam
1	NHR	Nodal heat recovery chillers, electric chillers, and gas-fired boilers	Chilled water (CHW) and heating hot water[6] (HHW)
2	CCG	Centralized cogeneration with combustion turbines	HHW and power
3	NHC	Nodal electric chillers and gas fired boilers	CHW and HHW
4	NCG	Nodal cogeneration with combustion turbines	HHW and power
5	NCG-F	Nodal cogeneration with fuel cells	HHW and power
6	CGB	Centralized gas-fired boilers	HHW
7	DGB	Fully distributed condensing boilers	No campus distribution
8	CEB	Centralized all electric boilers	HHW
9	DEB	Fully distributed all-electric boilers	No campus distribution
10	CEB-S	Centralized all-electric boilers	Steam

In addition to the 11 holistic and unique (termed "core") campus strategies, the team also considered several "enhancement" strategies that could be added to any number of attractive "core" strategies. Examples of these enhancements include but are not limited to the following:

- battery storage
- chilled water storage
- hot water storage
- distributed solar photovoltaics (PV)
- all-electric fuel cells

Though the focus of the study was on supply-side energy delivery, the impact of demand-side load reduction on the cost and scale of each energy delivery option was also explored to address

[6] All HHW systems considered in this study were assumed to be medium-to-low-temperature systems, with a supply/return differential temperature of approximately 30 ºF. Distribution diameters and costs estimated in this study reflect this assumption. See inset on page 58 for more detail on low-temperature HHW systems.

the optimal balance of investment between demand-side and supply-side interventions. The energy, carbon, cost, and feasibility of three incremental[7] tiers of load-reducing building ECMs were studied:

- Baseline ECMs: simplest and least disruptive to sensitive buildings; low end of cost
- Tier 1 ECMs: more aggressive and disruptive to sensitive buildings; medium-cost
- Tier 2 ECMs: most aggressive and highly disruptive; high-cost

Lastly, each energy delivery option was studied under two renewable energy supply scenarios:

- Base Case: a scenario representing a baseline state of renewable energy policy, availability, and competitiveness with purchased electricity and gas from PG&E
- Enhanced Case: a scenario representing a more optimistic future state of renewable energy policy, availability, and competitiveness with direct purchase renewables and (direct or directed) biogas

1.4 Evaluation Methods

Two methods were used sequentially to evaluate energy delivery options as summarized in **Table 2**.

Table 2: Evaluation Methods

	Method	Purpose	Inputs
1	Qualitative	High level qualitative filtering	• qualitative decision factors • multiple decision criteria • relative decision criteria scores • relative decision factor weighting
2	Quantitative	Detailed quantitative analysis	• capital costs • operations and maintenance costs • utility and fuel costs • life-cycle costs • energy, water, and carbon performance

The following sections provide brief descriptions for each of these evaluation methods.

1.4.1 Qualitative

The team developed a strategy categorization and qualitative assessment framework in order to perform an initial high-level evaluation of the 129 strategies identified at the workshop. The strategies were categorized into "campus energy delivery options", "enhancements", and "water strategies." This categorization resulted in an initial set of 13 unique campus energy delivery strategies requiring further assessment. The team then filtered the initial options further from 13 to 11 "core" strategies (see **Table 1**) using logical screening criteria (or "gates") as described in section 10.3.2.

This was an important first step to help narrow down the number of technical energy supply options that could then be considered using a more detailed and quantitative methodology.

Each decision factor in the qualitative framework was assigned a definition, maximum point allocation, and weight. **Figure 2** shows the summarized application of the final decision criteria framework to the initial 11 "core" campus energy delivery options.

UC Berkeley - Energy Delivery Options
STRATEGY SCORING

	CORE STRATEGIES[1,2,3]	Carbon	Initial Cost	Viability	Energy Cost	Disruption	Water	O&M Cost	Reliability and Resilience	Future Technology	Total Unweighted Score	Total Weighted Score
		5	4	3	3	2	3	3	4	1		
		Total	Total	Total	Total	Total	Total	Total	Total	Total		
		0 - 6	0 - 6	0 - 6	0 - 6	0 - 6	0 - 6	0 - 6	0 - 6	0 - 6		
1	Nodal heat recovery chillers, electric chillers, and gas fired boilers (HHW + CHW)	6	3	4	5	4	4	5	3	3	37	119
2	Centralized cogeneration with combustion turbines (HHW + P)	3	3	4	5	3	5	4	6	3	36	114
3	Nodal electric chillers and gas boilers (HHW + CHW)	5	3	4	5	4	4	5	3	3	36	114
4	Nodal cogeneration with combustion turbines (HHW + P)	3	3	4	5	5	3	3	6	3	35	109
5	Nodal cogeneration with fuel cells (HHW + P)	3	3	4	5	3	5	3	5	3	34	107
6	Centralized gas fired boilers (HHW)	3	4	5	3	3	5	6	2	2	33	104
7	Fully distributed condensing boilers in buildings, grid power	4	4	4	4	4	4	4	2	1	31	101
8	Centralized all electric boilers (HHW)	3	3	4	1	3	5	6	3	3	31	96
9	**Centralized natural gas fired cogeneration with combustion turbines (Steam, BAU)**	**2**	**6**	**6**	**0**	**6**	**1**	**1**	**6**	**1**	**29**	**95**
10	Fully distributed all electric boilers	3	4	4	1	5	4	4	3	0	28	92
11	Centralized all electric boilers (Steam)	1	5	6	0	6	1	3	3	2	27	81

NOTES
1. All core strategies can be enhanced by use of biogas and/or increasing levels of future grid embedded renewables (CA Renewable Portfolio Standard)
2. Fuel enhancements are not considered as part of the core strategies or enhancements at this stage in the process
3. All centralized core strategies can be delivered using a third party own/operate model, similar to the existing agreement with PE Berkeley Inc. Carbon implications of such models not considered in scoring

Figure 2: Qualitative Scoring of Shortlisted "Core" Campus Strategies

1.4.2 Quantitative

Once a manageable number of attractive energy supply options were identified using the qualitative assessment framework, the team performed an "all-in" comparative economic and environmental cost assessment of all options. This involved developing rough order of magnitude capital, operational, and life-cycle costs for each option, as well as modeling their relative energy and resource (electricity, gas, steam, water, and carbon) performance.

[7] Incremental here means that ECM tier 1 includes the Baseline tier measures, and ECM tier 2 includes the Baseline and ECM tier 1 measures

1.4.2.1 Capital Costs

Rough order of magnitude capital costs were estimated in a bottom-up fashion using conceptual cost-driving design parameters developed for each option in the following categories:

- central plant buildings
- generation and transmission systems
- distribution systems
- building interconnection systems
- building level plant and in-building work
- point steam for process equipment
- phasing and temporary heating

Soft costs, owner's costs, contingencies, and all construction-related markups were added as percentage markups of total direct cost of work.

An initial level 5[8] capital cost estimate was generated for the 11 core strategies with an average estimated accuracy of +/- 50%. The results of this initial cost estimate were used as a basis for selecting the "final" 6 strategies for further detailed analysis.

A subsequent capital cost estimate was performed for these final 6 strategies with a level of detail that exceeded the minimum standards of a level 5 estimate. As such, the capital cost estimates for the final 6 campus energy delivery strategies have an estimated average accuracy of +/- 40%.

Capital cost estimation details can be found in section 10.5.

1.4.2.2 Operational Costs

Operational costs for each of the final 6 options were estimated using a combination of energy and resource modeling to determine utility (electricity, gas, steam, and water) and carbon emission costs. A bottom-up staffing and labor rate analysis was used to determine operations and maintenance costs associated with each option.

Operational cost estimation details can be found in section 10.6.

1.4.2.3 Life-Cycle Costs

The capital and operational costs for each of the 6 final options were combined in a life-cycle cost analysis that incorporated appropriate escalation factors to manage the time value of money associated with the future construction and operation of each option.

[8] Per AACE international recommended practices. http://www.aacei.org/resources/rp

To identify energy supply strategies that are less sensitive to future energy policy and/or campus load uncertainty, the team carried out the analysis for each of the six final strategies under the following input combinations (as introduced in section 1.3):

- three building load tiers
- two future renewable energy supply scenarios

Life-cycle cost estimation details can be found in section 10.7.

The team also studied the feasibility of supplemental energy generation and storage technologies that could enhance the performance of each of the final 6 options. Capital, operational, and life-cycle costs for each of these "enhancements" were calculated using the same methodology described in this section for campus energy deliver strategies.

1.5 Results

Of the 129 strategies initially considered, the following three are recommended for further study under the various combinations of energy policy and building load conditions:

- NHR: nodal chilled water and heating hot water using heat recovery chillers, gas-fired boilers, and electric chillers combined with hot and chilled water thermal energy storage, battery storage, and distributed solar PV (referred to in study as option 1)
- CCG: central heating hot water using gas-fired cogeneration with distributed solar PV (referred to in study as option 2)
- CEB: central heating hot water using electric boilers and battery storage, with distributed solar PV (referred to in study as option 8)

Additionally, each of the above options entail a distributed/building level approach towards steam generation for process equipment such as autoclaves, dishwashers, and animal cage washing.

All alternate strategies considered were compared against a baseline scenario entailing overhaul and continued operation of the existing cogeneration and steam distribution systems. Due to the failing condition of these systems, this baseline scenario requires not only central plant building and system overhauls, but also distribution and building interconnection upgrades. The capital cost requirement to implement this baseline option was estimated at US$$_{2015}$141 +/- 40%.

The three energy delivery options recommended for further study are illustrated in **Figure 4**, **Figure 5**, and **Figure 6**. A legend for these figures is provided in **Figure 3**[9].

[9] Note: Zones illustrating plant on these maps do not reflect the footprint of each plant; rather the footprint of the site that was identified as suitable to locate the plant. Placement of solar PV is indicative only. Shapes illustrating thermal energy storage tanks or battery storage systems are not to scale.

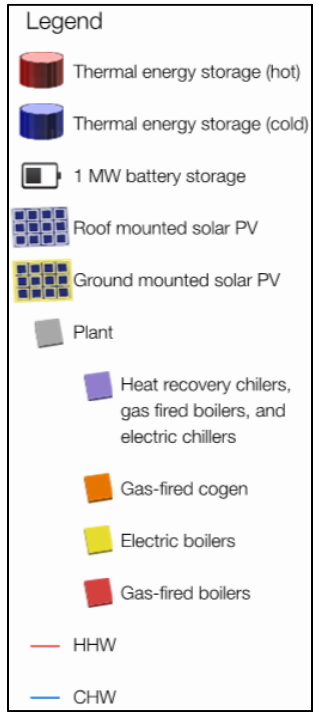

Figure 3: Legend for Figures 3, 4, and 5

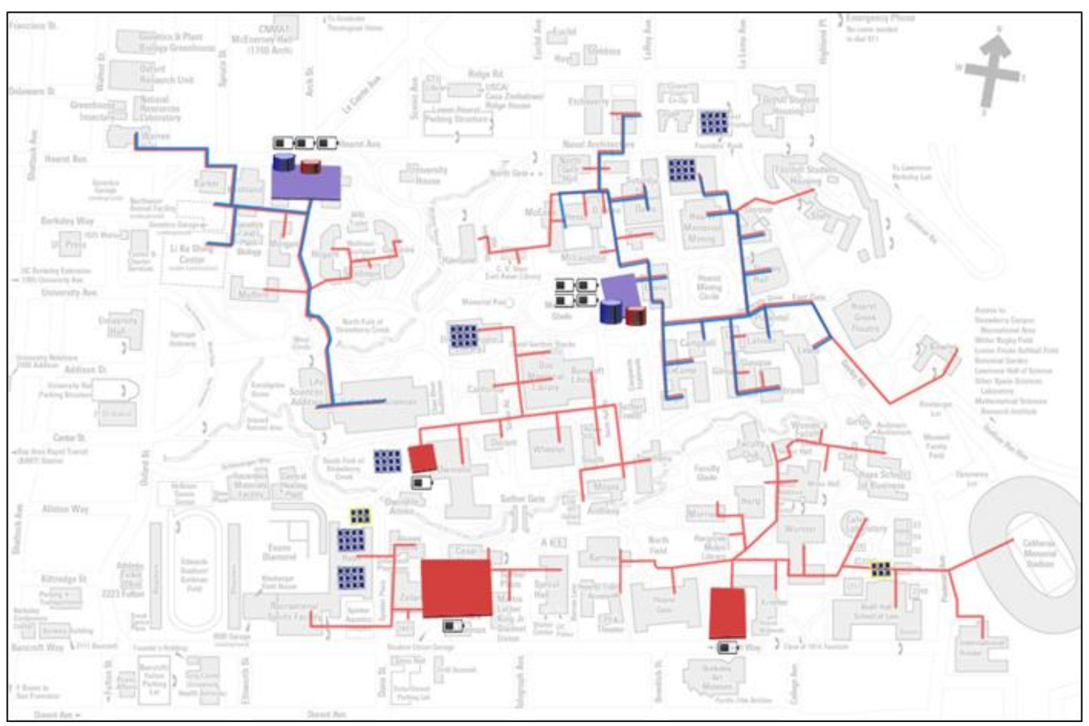

Figure 4: Study Option 1: NHR

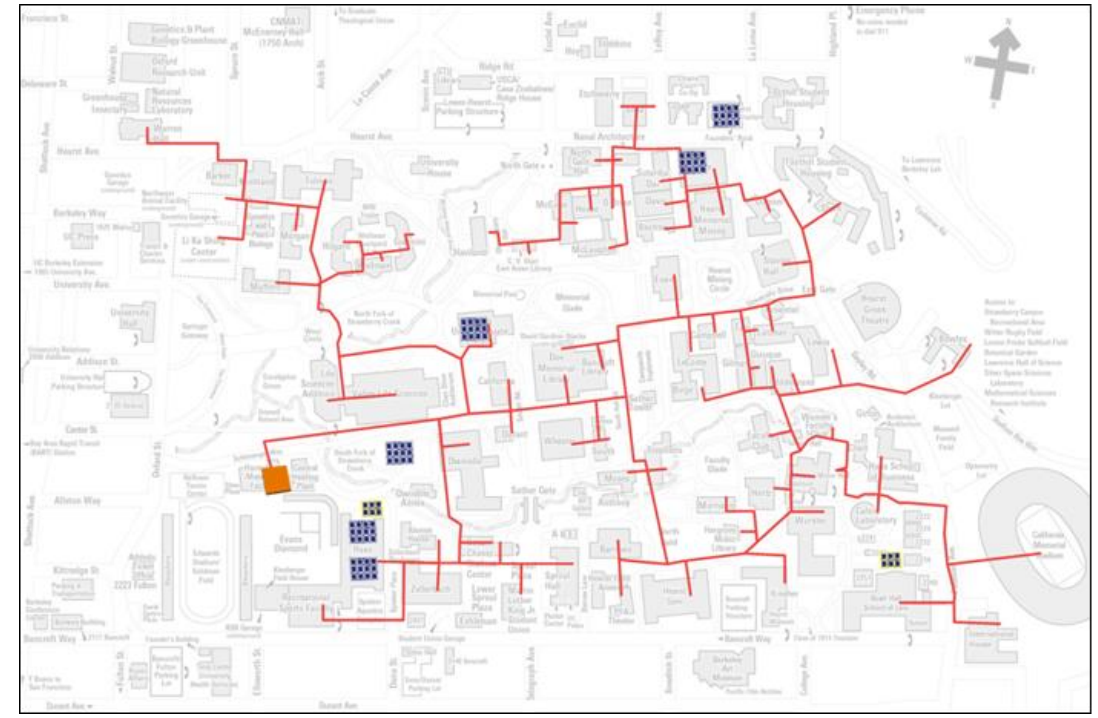

Figure 5: Study Option 2: CCG

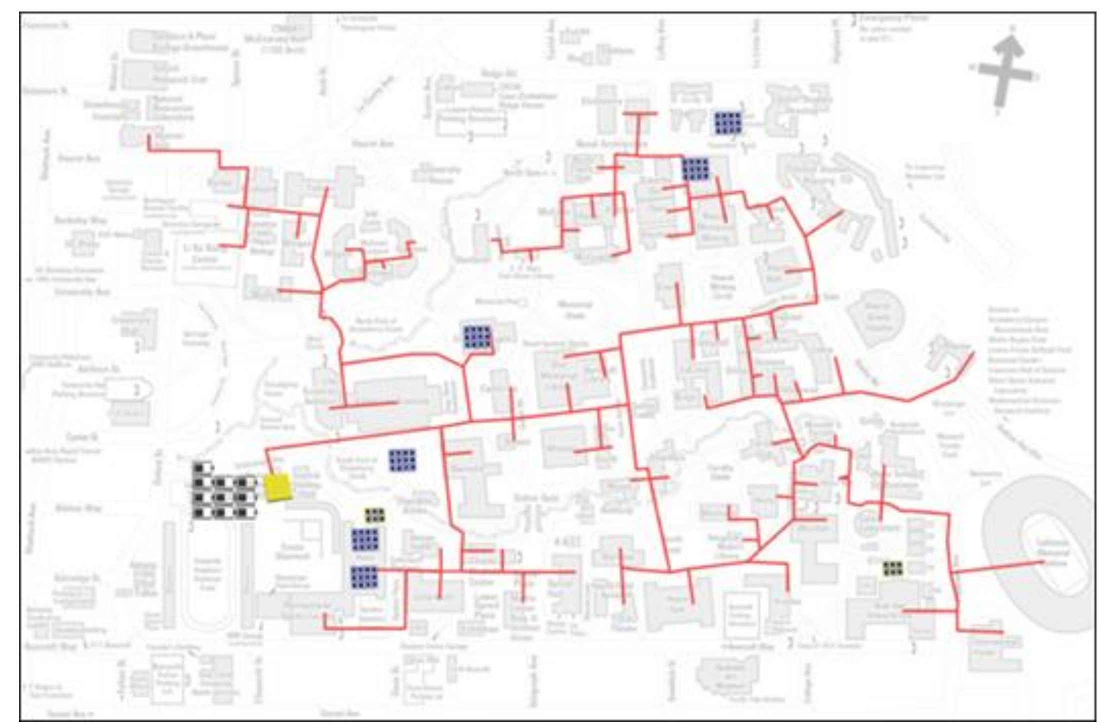

Figure 6: Study Option 8: CEB

The synthesized results of the detailed quantitative analysis are summarized in **Table 3**, **Table 4**, **Table 5**, and **Table 6**. These tables are also included in Appendix A in larger format, along with an overview of how they are laid out.

Table 3: Carbon-Based Recommendations – Base Case Renewable Energy Supply

	CARBON BASED RECOMMENDATION			
BASELINE LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**882**	**1,682,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12,000
Enhancement 4	1 MWe parking shade PV	4	-2	-6,000
Subtotal		**211**	**892**	**1,645,000**
Reduction Over Baseline		**-70**	**147**	**1,067,000**
% Carbon Reduction	**39%**			
∆$ TCO / Ton Reduction	**-137**			
∆$ Capital / Ton Reduction	**66**			
Baseline Loads (5 Years)	Building ECMs & Overhauls	127		
Baseline Loads (30 Years)	Building ECMs & Overhauls	761		
ECM TIER 1 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**863**	**1,634,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12,000
Enhancement 4	1 MWe parking shade PV	4	-2	-6,000
Subtotal		**211**	**874**	**1,597,000**
Reduction Over Baseline		**-70**	**137**	**1,019,000**
% Carbon Reduction	**39%**			
∆$ TCO / Ton Reduction	**-135**			
∆$ Capital / Ton Reduction	**69**			
ECM Tier 1 Loads (5 Years)	Building ECMs & Overhauls	195		
ECM Tier 1 Loads (30 Years)	Building ECMs & Overhauls	1,169		
ECM TIER 2 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**805**	**1,422,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12,000
Enhancement 4	1 MWe parking shade PV	4	-2	-6,000
Subtotal		**211**	**815**	**1,385,000**
Reduction Over Baseline		**-70**	**98**	**836,000**
% Carbon Reduction	**38%**			
∆m$ TCO / Ton Reduction	**-117**			
∆m$ Capital / Ton Reduction	**84**			
ECM Tier 1 Loads (5 Years)	Building ECMs & Overhauls	327		
ECM Tier 1 Loads (30 Years)	Building ECMs & Overhauls	1,961		

Table 4: Cost-Based Recommendations – Base Case Renewable Energy Supply

	COST BASED RECOMMENDATION			
BASELINE LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**882**	**1,682,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Subtotal		**211**	**892**	**1,645,000**
Reduction Over Baseline		**-70**	**147**	**1,067,000**
% Carbon Reduction	**39%**			
∆$ TCO / Ton Reduction	**-137**			
∆$ Capital / Ton Reduction	**66**			
Baseline Loads (5 Years)	Building ECM/Overhauls	127		
Baseline Loads (30 Years)	Building ECM/Overhauls	761		
ECM TIER 1 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**863**	**1,634,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Subtotal		**211**	**874**	**1,597,000**
Reduction Over Baseline		**-70**	**137**	**1,019,000**
% Carbon Reduction	**39%**			
∆$ TCO / Ton Reduction	**-135**			
∆$ Capital / Ton Reduction	**69**			
ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	195		
ECM Tier 1 Loads (30 Years)	Building ECM/Overhauls	1,169		
ECM TIER 2 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Central Cogeneration**	**279**	**799**	**2,853,000**
Enhancement 1	2 MWe rooftop PV	7	-4	-12,000
Enhancement 2	1 MWe parking shade PV	4	-2	-6,000
Enhancement 3				
Enhancement 4				
Subtotal		**290**	**794**	**2,835,000**
Reduction Over Baseline		**-149**	**119**	**-614,000**
% Carbon Reduction	**-28%**			
∆m$ TCO / Ton Reduction	**N/A**			
∆m$ Capital / Ton Reduction	**N/A**			
ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	327		
ECM Tier 1 Loads (30 Years)	Building ECM/Overhauls	1,961		

Table 5: Carbon-Based Recommendations – Enhanced Case Renewable Energy Supply

CARBON BASED RECOMMENDATION

BASELINE LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Central Electric Boilers**	**158**	**1,022**	**643,000**
Enhancement 1	10 MWe battery storage	13	19	0
Enhancement 2	2 MWe rooftop PV	7	-4	-12,000
Enhancement 3	1 MWe parking shade PV	4	-2	-6,000
Enhancement 4				
Subtotal		**182**	**1,035**	**625,000**
Reduction Over Baseline		**-40**	**-125**	**1,468,000**
% Carbon Reduction	**70%**			
∆$ TCO / Ton Reduction	**85**			
∆$ Capital / Ton Reduction	**27**			
Baseline Loads (5 Years)	Building ECM/Overhauls	127		
Baseline Loads (30 Years)	Building ECMs & Overhauls	761		

ECM TIER 1 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Central Electric Boilers**	**158**	**995**	**620,000**
Enhancement 1	10 MWe battery storage	13	19	0
Enhancement 2	2 MWe rooftop PV	7	-4	-12,000
Enhancement 3	1 MWe parking shade PV	4	-2	-6,000
Enhancement 4				
Subtotal		**182**	**1,008**	**602,000**
Reduction Over Baseline		**-40**	**-121**	**1,412,000**
% Carbon Reduction	**70%**			
∆$ TCO / Ton Reduction	**86**			
∆$ Capital / Ton Reduction	**29**			
ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	195		
ECM Tier 1 Loads (30 Years)	Building ECMs & Overhauls	1,169		

ECM TIER 2 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Central Electric Boilers**	**158**	**890**	**528,000**
Enhancement 1	10 MWe battery storage	13	19	0
Enhancement 2	2 MWe rooftop PV	7	-4	-12,000
Enhancement 3	1 MWe parking shade PV	4	-2	-6,000
Enhancement 4				
Subtotal		**182**	**903**	**510,000**
Reduction Over Baseline		**-40**	**-106**	**1,147,000**
% Carbon Reduction	**69%**			
∆m$ TCO / Ton Reduction	**93**			
∆m$ Capital / Ton Reduction	**35**			
ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	327		
ECM Tier 1 Loads (30 Years)	Building ECMs & Overhauls	1,961		

Table 6: Cost-Based Recommendations – Enhanced Case Renewable Energy Supply

COST BASED RECOMMENDATION

BASELINE LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**732**	**887,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Subtotal		**211**	**743**	**850,000**
Reduction Over Baseline		**-70**	**168**	**1,243,000**
% Carbon Reduction	**59%**			
∆$ TCO / Ton Reduction	**-135**			
∆$ Capital / Ton Reduction	**56**			
Baseline Loads (5 Years)	Building ECM/Overhauls	127		
Baseline Loads (30 Years)	Building ECM/Overhauls	761		

ECM TIER 1 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal heat recovery chillers**	**188**	**718**	**861,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Subtotal		**211**	**729**	**824,000**
Reduction Over Baseline		**-70**	**158**	**1,190,000**
% Carbon Reduction	**59%**			
∆$ TCO / Ton Reduction	**-133**			
∆$ Capital / Ton Reduction	**59**			
ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	195		
ECM Tier 1 Loads (30 Years)	Building ECM/Overhauls	1,169		

ECM TIER 2 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
		2015 m$	2015 m$	Tons
Core Strategy	**Nodal Heat Recovery**	**188**	**671**	**719,000**
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Subtotal		**211**	**682**	**682,000**
Reduction Over Baseline		**-70**	**114**	**975,000**
% Carbon Reduction	**59%**			
∆m$ TCO / Ton Reduction	**-117**			
∆m$ Capital / Ton Reduction	**72**			
ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	327		
ECM Tier 1 Loads (30 Years)	Building ECM/Overhauls	1,961		

Despite the uncertainty in loads and future energy policy, this study has identified two interesting trends as illustrated in **Table 3**, **Table 4**, **Table 5**, and **Table 6**.

First, the optimal energy delivery strategies do not vary with load across three of the four recommendations; i.e., each of the carbon-based and cost-based energy delivery strategy recommendations remain unchanged regardless of the level of load reduction achieved through building level ECMs.

The exception is the cost-based recommendation under the base renewable energy supply scenario, under which the optimal energy delivery strategy is different under the ECM Tier 2 loads (CCG with distributed solar PV) than under baseline and ECM Tier 1 loads (NHR with battery storage, and distributed solar PV). The change in the cost-optimal strategy from NHR to CCG is a function of the closing gap in cost savings between the two options as simultaneous building heating and cooling loads are minimized through aggressive ECMs.

Second, the NHR option was found to be an attractive strategy under all three load tiers, both renewable energy supply scenarios, and each of the carbon-based and cost-based recommendations, making it an attractive option despite compounding uncertainty in future conditions.