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Job number 243378

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# UC Berkeley Energy Delivery Options Executive Summary Final Report

Rev A | December 1, 2015



# **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 carbonoptimal 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<sup>1</sup> 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<sup>2</sup> (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<sup>3</sup>. 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\$<sub>2015</sub> 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

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<sup>&</sup>lt;sup>1</sup> For buildings connected to the campus steam distribution

<sup>&</sup>lt;sup>2</sup> Capital costs reported in this section have an average accuracy of +/- 40%

<sup>&</sup>lt;sup>3</sup> 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

### **Project Background** 1.1

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.

### **Current System** 1.2

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<sup>4</sup>). 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<sup>5</sup>. 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.

### 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 <sup>6</sup> (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

<sup>6</sup> 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 °F. Distribution diameters and costs estimated in this study reflect this assumption. See inset on page 58 for more detail on low-temperature HHW systems.

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<sup>&</sup>lt;sup>4</sup> See the "Steam Plant Alternatives Assessment" final report

<sup>&</sup>lt;sup>5</sup> See the "Phase 1 Existing Conditions Report"

the optimal balance of investment between demand-side and supply-side interventions. The energy, carbon, cost, and feasibility of three incremental<sup>7</sup> 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

### **Evaluation Methods** 1.4

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

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

### Table 2: Evaluation Methods

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

#### 1.4.1 **Oualitative**

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

U ST	JC Berkeley - Energy Delivery Options STRATEGY SCORING CUMMING Energy Delivery Options STRATEGY SCORING											
C	ORE STRATEGIES <sup>1,2,3</sup>											
		Carbon	Initial Cost	Viability	Energy Cost	Disruption	Water	O&M Cost	Reliability and Resilience	Future Technology		
		5	4	3	3	2	3	3	4	1	d S	Sco
		Total	Total	Total	Total	Total	Total	Total	Total	Total	Total Unweighte	Total Weighted
		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)		3	4	5	4	4	5	3	3	37	119
2	Centralized cogeneration with combustion turbines (HHW + P)		3		5			4	6	3	36	114
3	Nodal electric chillers and gas boilers (HHW + CHW)		3		5			5	3	3	36	114
4	Nodal cogeneration with combustion turbines (HHW + P)		3		5			3	6	3	35	109
5	Nodal cogeneration with fuel cells (HHW + P)		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	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

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 scorin

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

#### 1.4.2 **Ouantitative**

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.

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<sup>&</sup>lt;sup>7</sup> 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<sup>8</sup> 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.

### **Operational Costs** 1.4.2.2

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.

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<sup>9</sup>.

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<sup>&</sup>lt;sup>8</sup> Per AACE international recommended practices. <u>http://www.aacei.org/resources/rp</u>



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.

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Baseline Loads (5 Years)

Baseline Loads (30 Years)

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

Building ECMs & Overhauls

Building ECMs & Overhauls

	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%					
$\Delta$ \$ TCO / Ton Reduction	-137					
$\Delta$ \$ Capital / Ton Reduction	66					

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%			
$\Delta$ \$ TCO / Ton Reduction	-135			
$\Delta$ \$ 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		

127

761

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%			
$\Delta$ m\$ TCO / Ton Reduction	-117			
$\Delta$ 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 -	F
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	COST BASED REC	OMMENDA <sup>®</sup>	TION	
BASELINE LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF OWNERSHIP	CARBON
Coro Stratomi	Nodal Hast Passwork	2015 m\$	2015 m\$	Tons
Core strategy	Nodal Heat Recovery	188	882	1,082,000
Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 3	2 MWe roottop PV	7	-4	-12000
Ennancement 4	I www.parking.shade.PV	4	-2	-6000
Subtotal		211	892	1,645,000
Reduction Over Baseline		-70	147	1,067,000
% Carbon Reduction	39%			
$\Delta$ \$TCO/Ton Reduction	-137			
$\Delta$ \$ 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%			
$\Delta$ \$ TCO / Ton Reduction	-135			
$\Delta$ \$ 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%			
$\Delta m$ \$ TCO / Ton Reduction	N/A			
$\Delta$ 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		

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## Base Case Renewable Energy Supply

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

### CARBON BASED RECOMMENDATION

BASELINE LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF	CARBON
		2015 mŚ	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%			
$\Delta$ \$ TCO / Ton Reduction	85			
<b>△\$ Capital / Ton Reduction</b>	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%			
$\Delta$ \$ TCO / Ton Reduction	86			
$\Delta$ \$ 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		

#### TOTAL COST OF ECM TIER 2 LOADS STRATEGY CAPITAL COST CARBON OWNERSHIP 2015 m\$ 2015 m\$ Tons Core Strategy Central Electric Boilers 158 890 528,000 Enhancement 1 10 MWe battery storage 13 19 0 2 MWe rooftop PV 7 -4 -12,000 Enhancement 2 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% $\Delta m$ TCO / Ton Reduction 93 $\Delta$ 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

COST BASED RECOMMENDATION           BASELINE LOADS         STRATEGY         CAPITAL COST 2015 m5         TOTAL COST OF 2015 m5         CARBON 2015 m5         CA		-			
BASELINE LOADS         FTRATEGY         CAPITAL COST         TOTAL COST OF QUISTING         CARBON QWREISHIP           Core Strategy         Hodal Heat Recovery         158         712         R87,000           Enhancement 1         Hodal Heat Recovery         158         712         R87,000           Enhancement 2         0         -2         -1,000         10,0We backing shade PV         4         -2         -20,000           Enhancement 3         10,WWe backing shade PV         4         -2         -20,000         10,0We backing shade PV         4         -2         -20,000           Enhancement 4         10,0We backing shade PV         4         -2         -20,000         10,0We backing shade PV         4         -2         -20,000           Stobtal         2015 mS         TOTAL COST		COST BASED RECO	MMENDAT	ION	
BASELINE LOADS         STATEOr         CAPITAL Cost         OWNERSHIP         CARDIN           Core Strategy         Nodal Heat Recovery         138         732         887,000           Enhancement 1         Hot and chilled water TES         0         -2         -15,000           Enhancement 3         13         19         0           Enhancement 4         10 MWe battery storage         13         19         0           Subtral         211         74         -2         -6000           Subtral         211         74         90,000         Reduction           Subtral         211         74         850,000         Reduction         -370         188         1,243,000         % Carbon Reduction         -355         State Reduction         -356         State Reduction         -355         State Reduction         -356         State Reduction         -356         State Reduction         -356         State Reduction         -356         State Reduction         -370         188         1,243,000         % Carbon Reduction         -356         Reduction /2015 m5         Toris         Reduction /2015 m5         -3015 m5         701 ms         2015 m5         Toris         Reduction /2015 m5         701 ms         2015 m5         700 ms		CTD LTCCV	010/711 00/7	TOTAL COST OF	61000H
2015 mS         2015 mS         2015 mS         Tons           Rodal Heat Recovery         188         772         887,000           Enhancement 1         10 MWe battery storage         13         19         0           Inhancement 2         10 MWe battery storage         13         19         0           Subtotal         211         741         850,000           Reduction Over Baseline         -70         168         1,243,000           % Carbon Reduction         -135         -         -           A St CO / Ton Reduction         -315         -         -           St Cor / Ton Reduction         -315         -         -           St Cor / Ton Reduction         -315         -         -           St Cor / Ton Reduction         -315         -         -           Baseline Loads (B Years)         Building ECM/Overhauls         127         -           Baseline Loads (S Years)         Building ECM/Overhauls         13         19         0           Core Strategy         Nodal heat recovery chillers         188         718         861,000           Enhancement 1         Hot and chilled water TS         0         -         2         -         000	BASELINE LOADS	STRATEGY	CAPITALCOST	OWNERSHIP	CARBON
Core Strategy         Nodal Heat Recovery         188         772         887,000           Enhancement 1         Hot and chilled water TES         0         -2         -19,000           Enhancement 2         10 MWe battery storage         13         19         0           Enhancement 3         11 MWe parking shade PV         4         -2         -6000           Subtotal         211         743         850,000           Reduction Ver Baseline         -70         168         1,243,000           % Carbon Reduction         -315         -55         -56           Baseline Loads (5 Years)         Building ECM/Overhauls         127         -           Baseline Loads (5 Years)         Building ECM/Overhauls         127         -           Baseline Loads (10 Years)         215 m5         2015 m5         Total COST of CoMWERSHIP           Core Strategy         Nodal heat recovery chillers         138         718         861,000           ECM TIER 1 LOADS         STRATEGY         CAPITAL COST         Total COST of ComWERSHIP         CARBON           Inhancement 1         Hot and chilled water TES         0         -2         -15,000           Io Mwe battery storage         13         15         0         -2         -5			2015 m\$	2015 m\$	Tons
Enhancement 1         Hot and chilled water TES         0         -2         -19,000           Enhancement 2         10 MWe battery storage         13         19         0           Enhancement 3         10 MWe battery storage         13         19         0           Enhancement 4         11 MWe parking shade PV         4         -2         -6000           Subtotal         211         743         850,000           Reduction Over Baseline         -70         168         1,243,000           Scarbon Reduction         -35         -         -           AS toptal / ton Reduction         -35         -         -           Baseline Loads (10 Years)         Building ECM/Overhauls         127         -         -           Baseline Loads (10 Years)         STRATEGY         CAPTTAL COST         TOTAL COST OF OWERESHIP         CABBON           Core Strategy         Financement 1         10         0         -2         -19,000           Enhancement 3         10         0         2         -2         -2000           Subtal         211         729         82,000         Reduction         -33         19         0           Scarbon Reduction         -33         19         0	Core Strategy	Nodal Heat Recovery	188	732	887,000
Enhancement 2 Enhancement 3 Enhancement 4 2 MWe prototop PV 7 4 2 MWe prototop PV 7 2 MWE prototop PV 7 4 2 MWE prototop PV 7 4 2 4 2 4 2 4 4 2 4 4 2 4 4 4 2 4 4 4 4 4 4 4 4 4 4 4 4 4	Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 3         2 MWe rooftop PV         7         4         1.2000           Enhancement 4         1 MWe parking shade PV         4         -2         -6000           Subtotal         211         743         850,000         86           Reduction Over Baseline         -70         168         1,243,000         8           SCarbon Reduction         -55         -70         168         1,243,000         8           Scapital / Ton Reduction         -55         -70         168         1,243,000         8           Baseline Loads (5 Years)         Building ECM/Overhauls         127         -<	Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 4 Enhancement 5 ECM TIER 1 LOADS Enhancement 1 Enhancement 1 Enhancement 2 Enhancement 4 Subtotal ECM Tier 1 Loads (5 Years) ECM Tier 1 Loads (5 Years) ECM Tier 2 LOADS ECM Tier 2 LOADS ECM Tier 2 LOADS ECM Tier 2 LOADS ETM Tier 2 LOADS ECM Tier 1 Loads (19 Years) ECM Tier 1 Loads (19 Years) ECM Tier 2 LOADS ECM Tier 2 LOADS ECM Tier 1 Loads (19 Years) ECM Tier 2 LOADS ECM Tier 2 LOADS ECM Tier 2 LOADS ECM Tier 1 Loads (19 Years) ECM Tier 1 Loads (19 Years) ECM Tier 2 LOADS ECM Tier 1 Loads (19 Years) ECM Tier 2 LOADS ETH Tier 2 LOADS	Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Subtotal       211       743       #50,000         Reduction Over Baseline       -70       168       1,243,000         % Carbon Reduction       59%       -70       168       1,243,000         A Strot / Ton Reduction       58       -70       168       1,243,000         Baseline Loads (S Years)       Building ECM/Overhauls       127	Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Reduction Over Baseline     -70     168     1,243,000       % Carbon Reduction     59%     -35     5       A \$ TCO / Ton Reduction     59     5       Baseline Loads (\$ Years)     Building ECM/Overhauls     127       Baseline Loads (\$ Years)     Building ECM/Overhauls     761       Core Strategy     Nodal heat recovery chillers     188     718     861,000       Enhancement1     Hot and chilled water TES     0     -2     -150,000       Enhancement3     2MWe rooftop PV     7     -4     -12000       Enhancement4     2MWe parking shade PV     4     -2     -6000       Subtotal     2015 mS     2015 mS     100     128       Care Strategy     IMWe battery storage     13     19     0       Enhancement4     ZMWe rooftop PV     7     -4     -12000       Subtotal     -70     158     1,190,000       % Carbon Reduction     59%     -70     158     1,190,000       % Carbon Reduction     59%     2015 mS     705     100       StrOt / Ton Reduction     59%     2015 mS     705     100       Core Strategy     Building ECM/Overhauls     1,169     1,169     110       ECM Tit Loads (30 Years)     Building ECM/Overhauls <td>Subtotal</td> <td></td> <td>211</td> <td>743</td> <td>850,000</td>	Subtotal		211	743	850,000
% Carbon Reduction       59%         Δ\$ Tco / Ton Reduction       -135         Δ\$ Capital / Ton Reduction       56         Baseline Loads (SV Fars)       Building ECM/Overhauls       127         Baseline Loads (30 Years)       Building ECM/Overhauls       761         ECM TIER 1 LOADS       STRATEGY       CAPITAL COST       TOTAL COST OF OWERSHIP       CABBON         Core Strategy       Nodal heat recovery chillers       188       718       861,000         Enhancement 1       Hot and chilled water TES       0       -2       -13,000         Enhancement 3       ZMW erooftop PV       7       -4       -12000         Subtotal       211       729       824,000         Reduction Over Baseline       -70       158       1,190,000         % Carbon Reduction       59%       59%       -70       158       1,190,000         % Carbon Reduction       59%       59%       2015 m\$       Tons         Core Strategy       Building	Reduction Over Baseline		-70	168	1,243,000
ΔS Copital / Ton Reduction       -135         Solution / Ton Reduction       56         Baseline Loads (S Years)       Building ECM/Overhauls       761         ECM TIER 1 LOADDS       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         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       211       729       824,000         Subtotal       211       729       824,000         Sc Carbin Reduction       59%       -70       158       1,190,000         Sc Carbin Reduction       59%       -2       -5000       -5000         Subtotal       211       729       824,000       -133       -52       -5000         Sc Carbin Reduction       59%       -70       158       1,190,000       %       -56       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5000       -5	% Carbon Reduction	59%			
S6       Baseline Loads (5 Years)     Building ECM/Overhauls     127       Baseline Loads (30 Years)     STRATEGY     CAPITAL COST     TOTAL COST OF OWNERSHIP     CARBON       Core Strategy     Nodal heat recovery chillers     188     718     8651,000       Enhancement 1     Hot and chilled water TES     0     -2     -19,000       Enhancement 3     2015 mS     Tons       Subtotal     211     729     824,000       Reduction Over Baseline % Carbon Reduction     -70     158     1,190,000       Sch Terr 1 Loads (5 Years)     Building ECM/Overhauls     135       ECM TIER 2 LOADS     STRATEGY     CAPITAL COST     TOTAL COST of OWNERSHIP     CARBON       Stoto Reduction     -133     55       ECM TIER 2 LOADS     STRATEGY     CAPITAL COST     TOTAL COST of OWNERSHIP       Core Strategy     Building ECM/Overhauls     135       ECM TIER 2 LOADS     STRATEGY     CAPITAL COST     TOTAL COST of OWNERSHIP     CARBON       Core Strategy     Building ECM/Overhauls     135     Strategy     Canseline     Capital COST of OWNERSHIP     CARBON       Core Strategy     STRATEGY     CAPITAL COST     TOTAL COST of OWNERSHIP     CARBON       Diading ECM/Overhauls     1,159     Strategy     100     Canseline	△\$ TCO / Ton Reduction	-135			
Baseline Loads (5 Years)     Building ECM/Overhauls     127       Baseline Loads (10 Years)     STRATEGY     CAPITAL COST     TOTAL COST OF 0.2015 m\$     CARBON 2015 m\$     CARBON	△\$ Capital / Ton Reduction	56			
Baseline Loads (30 Years)     Building ECM/Overhauls     761       ECM TIER 1 LOADS     STRATEGY     CAPITAL COST     TOTAL COST OF OWNERSHIP     CARBON       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%     3     -0       AS TCO/Ton Reduction     59%     2015 mS     Tons       Core Strategy     Building ECM/Overhauls     195     ELM TIER 2 LOADS     STRATEGY     CAPITAL COST     TOTAL COST OF       Core Strategy     Itad chilled water TES     0     -2     -19,000       Enhancement 1     Hot and chilled water TES     0     -2     -19,000       Enhancement 2     10 MWe battery storage     13     19     0       Enhancement 3     10 MWe battery storage     13     19     0       Enhancemen	Baseline Loads (5 Years)	Building ECM/Overhauls	127		
ECM TIER 1 LOADS       STRATEGY       CAPITAL COST       TOTAL COST       OULL COST OF OWNERSHIP       CARBON OWNERSHIP       CARBON OWNERSHIP       CARBON OWNERSHIP       CARBON OWNERSHIP       CARBON OWNERSHIP         Core Strategy       Nodal heat recovery chillers       188       718       861,000         Enhancement 1       Het and chilled water TES       0       -2       -19,000         Enhancement 3       DMWe battery storage       13       19       0         Enhancement 4       DMWe parking shade PV       4       -2       -6000         Subtotal       211       729       824,000         Reduction Over Baseline       -70       158       1,190,000         % Carbon Reduction       59%       -       -       -         AS TCO/Ton Reduction       59%       -       -       -       -         Building ECM/Overhauls       195       -<	Baseline Loads (30 Years)	Building ECM/Overhauls	761		
ECM TIER 1 LOADS     STRATEGY     CAPITAL COST OWNERSHIP     CARBON OWNERSHIP       2015 m\$     2015 m\$     Tons       Core Strategy     Nodal heat recovery chillers     138     718     881,000       Enhancement 1     Hot and chilled water TES     0     -2     -19,000       Enhancement 3     10     Model heat recovery chillers     13     19     0       Enhancement 4     10 MWe battery storage     13     19     0       Subtotal     211     729     824,000       Reduction Over Baseline     -70     158     1,190,000       % Carbon Reduction     59%     -70     158     1,190,000       % Carbon Reduction     59     -70     158     1,190,000       ECM TIER 2 LOADDS     STRATEGY     CAPITAL COST OF OWNERSHIP     CARBON       Core Strategy     Nodal Heat Recovery     188     671     719,000       Enhancement 1     Hot and chilled water TES     0     -2     -12,000       Enhancement 3     2 MWe rooftop PV     7     -4     <					
2015 m\$     2015 m\$     Tons       Core Strategy     Nodal heat recovery chillers     188     718     861,000       Enhancement 1     10 MWe battery storage     13     19     0       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%     .45 (Co) / Ton Reduction     .45 (Co) / Ton Reduction       A\$ (Co) Ton Reduction     59     .169	ECM TIER 1 LOADS	STRATEGY	CAPITAL COST	TOTAL COST OF	CARBON
Core StrategyNodal heat recovery chillers188718861,000Enhancement 1Hot and chilled water TES0-2-19,000Enhancement 210 MWe battery storage13190Enhancement 32 MWe rooftop PV7-4-12000Enhancement 41 MWe parking shade PV4-2-6000Subtotal211729824,000Reduction Over Baseline-701581,190,000% Carbon Reduction59%			2015 m\$	2015 m\$	Tons
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         1MWe parking shade PV         4         -2         -6000           Subtotal         211         729         824,000           Reduction Over Baseline         -70         158         1,190,000           % Carbon Reduction         59%         -         -           Δ\$ Capital / Ton Reduction         59         -         -           ECM Tier 1 Loads (5 Years)         Building ECM/Overhauls         195         -           ECM TiER 2 LOADDS         STRATEGY         CAPITAL COST         TOTAL COST OF OWNERSHIP         CARBON           Core Strategy         188         671         719,000           Enhancement 1         Hot and chilled water TES         0         -2         -19,000           Enhancement 3         10 MWe battery storage         13         19         0           Enhancement 4         10 MWe battery storage         13         19         0           Subtotal         21         682 <td>Core Strategy</td> <td>Nodal heat recovery chillers</td> <td>188</td> <td>718</td> <td>861,000</td>	Core Strategy	Nodal heat recovery chillers	188	718	861,000
Enhancement 2 Enhancement 310 MWe battery storage13190Enhancement 3 Enhancement 42 MWe rooftop PV7-4-12000Subtotal211729824,000Reduction Over Baseline % Carbon Reduction Δ\$ TCO / Ton Reduction 5 Carbon Reduction Δ\$ Carbon Reduction 4 S Capital / Ton Reduction 5 Straters)-701581,190,000Building ECM/Overhauls and 13 S195ECM Tier 1 Loads (5 Years) ECM Tier 1 Loads (30 Years)Strategy195ECM Tier 1 Loads (30 Years)STRATEGYCAPITAL COST OWNERSHIP 2015 m\$TOTAL COST OF OWNERSHIPCARBONCore StrategySTRATEGYCAPITAL COST OWNERSHIPTonsCore StrategyNodal Heat Recovery188671719,000Enhancement 1 Enhancement 2 SubtotalHot and chilled water TES 10 MWe battery storage0-2-19,000Enhancement 3 Subtotal2MWe rooftop PV7-4-12000-Subtotal211682682,000Reduction Over Baseline % Carbon Reduction59%Subtotal211682682,000Reduction Over Baseline % Carbon Reduction59%Subtotal211682682,000Reduction Over Baseline % Carbon Reduction59%Subtotal59%Core Strategy10 Segital / Ton Reduction59%	Enhancement 1	Hot and chilled water TES	0	-2	-19,000
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%       -       -         Δ\$ Carbon Reduction       59%       -       -         Δ\$ Capital / Ton Reduction       59       -       -         ECM Tier 1 Loads (5 Years)       Building ECM/Overhauls       195       -         Building ECM/Overhauls       1,169       -       -       -         Core Strategy       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         Core Strategy       INdal Heat Recovery       188       671       719,000         Enhancement 1       Hot and chilled water TES       0       -2       -19,000         Enhancement 3       10 MWe battery storage       13       19       0         Enhancement 4       1MWe parking shade PV       4       -2       -6000         Subtotal       211       682       682,0000         Reduction Over Baseline       -70       114       975,00	Enhancement 2	10 MWe battery storage	13	19	0
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%     -70     158     1,190,000       % Carbon Reduction     59%     -70     158     1,190,000       % Carbon Reduction     59%     -70     158     1,190,000       ECM Tier 1 Loads (5 Years)     Building ECM/Overhauls     195     -70     2015 m\$     CARBON       ECM TIER 2 LOADS     STRATEGY     CAPITAL COST     TOTAL COST OF OWNERSHIP     CARBON       Core Strategy     IModal 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       Canker of PV     7     -4     -12000       Enhancement 4     1MWe parking shade PV     4     -2     -6000       Subtotal     682     682,0000       Carbon Reduction     59%     -70     114     975,000       Subtotal     Starting shade PV     4     -2     -6000       Subtotal     Say     -70     114     975,000	Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Subtotal211729824,000Reduction Over Baseline % Carbon Reduction $\Delta \S$ TCO / Ton Reduction $\Delta \S$ Capital / Ton Reduction SS Capital / Ton Reduction ECM Tier 1 Loads (30 Years)Building ECM/Overhauls Building ECM/Overhauls195 Building ECM/Overhauls195 Building ECM/OverhaulsECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,169ECM TIER 2 LOADSSTRATEGYCAPITAL COST OWNERSHIPTOTAL COST OF OWNERSHIPCARBONCore StrategyIstante Recovery188671719,000Enhancement 1 Enhancement 2 Enhancement 3 Enhancement 4Hot and chilled water TES 10 MWe battery storage0-2-19,000Subtotal211682682,000Reduction Over Baseline % Carbon Reduction Am§ Capital / Ton Reduction Com Statery-70114975,000SubtotalECM Tier 1 Loads (5 Years)Building ECM/Overhauls327 ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327 ECM Tier 1 Loads (50 Years)Building ECM/Overhauls327 ECM Tier 1 Loads (50 Years)	Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Reduction Over Baseline       -70       158       1,190,000         % Carbon Reduction       59%       -70       158       1,190,000         Δ\$ TCO / Ton Reduction       59%       -70       158       1,190,000         Δ\$ Capital / Ton Reduction       59%       -70       158       1,190,000         ECM Tier 1 Loads (5 Years)       Building ECM/Overhauls       195	Subtotal		211	729	824,000
% Carbon Reduction       59%         \$\Delta\$ StrCo / Ton Reduction       -133         \$\Delta\$ So capital / Ton Reduction       59         ECM Tier 1 toads (5 Years)       Building ECM/Overhauls       195         Building ECM/Overhauls       1,169         ECM TIER 2 LOADS       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         Core Strategy       STRATEGY       188       671       719,000         Enhancement 1       Hot and chilled water TES       0       -2       -19,000         Enhancement 3       2MWe rooftop PV       7       -4       -12000         Enhancement 4       1MWe parking shade PV       4       -2       -6000         Subtotal       59%       -70       114       975,000         % Carbon Reduction       59%       -70	Reduction Over Baseline		-70	158	1,190,000
Δ\$ TCO / Ton Reduction       -133         Δ\$ Capital / Ton Reduction       59         ECM Tier 1 Loads (5 Years)       Building ECM/Overhauls       195         Building ECM/Overhauls       1,169         ECM Tier 1 Loads (30 Years)       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         Core Strategy       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         Particle 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       2MWe rooftop PV       7       -4       -12000         Enhancement 4       1MWe parking shade PV       4       -2       -6000         Subtotal       59%       -70       114       975,000         % Carbon Reduction       59%       -117       -114       975,000         % Carbon Reduction       59%       -117       -114       975,000         % Carbon Reduction       59%       -114       975,000       % Carbon Reduction       -117         Am§ Capital / Ton Reduction       72	% Carbon Reduction	59%			
∆\$ capital / Ton Reduction       59         ECM Tier 1 Loads (5 Years)       Building ECM/Overhauls       195         Building ECM/Overhauls       1,169         ECM Tier 1 Loads (30 Years)       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         Core Strategy       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         Enhancement 1       Hot and chilled water TES       0       -2       -19,000         Enhancement 3       10 MWe battery storage       13       19       0         Enhancement 4       1MWe parking shade PV       4       -2       -6000         Subtotal       59%       -70       114       975,000         % Carbon Reduction       59%       -710       114       975,000         % Carbon Reduction       72       -       -       -       -         ECM Tier 1 Loads (5 Years)       Building ECM/Overhauls       327       -       -       -         ECM Tier	△\$TCO / Ton Reduction	-133			
ECM Tier 1 Loads (5 Years)       Building ECM/Overhauls       195         Building ECM/Overhauls       1,169         TOTAL COST OF OWNERSHIP         CAPITAL COST         TOTAL COST OF OWNERSHIP         CAPITAL COST         TOTAL COST OF OWNERSHIP         CARBON         Odd Heat Recovery         Bail ding ECM/Overhauls         TOTAL COST OF OWNERSHIP         CAPITAL COST         TOTAL COST OF OWNERSHIP         OWNERSHIP         OUTS m\$ 2015 m\$ TOTS         CAPITAL COST         TOTAL COST OF OWNERSHIP         OUTS m\$ 2015 m\$ TOTS         TOTAL COST OF OWNERSHIP         OWNERSHIP         TOTAL COST OF OWNERSHIP         OWNERSHIP         TOTAL	<b>△</b> \$ Capital / Ton Reduction	59			
ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,169ECM TIER 2 LOADSSTRATEGYCAPITAL COSTTOTAL COST OF OWNERSHIPCARBON2015 m\$2015 m\$2015 m\$TonsCore StrategyNodal Heat Recovery188671719,000Enhancement 1Hot and chilled water TES0-2-19,000Enhancement 210 MWe battery storage13190Enhancement 32 MWe rooftop PV7-4-12000Enhancement 41 MWe parking shade PV4-2-6000Subtotal211682682,000Reduction Over Baseline-70114975,000% Carbon Reduction59%-70114975,000MS Carbon Reduction72-70114975,000ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961	ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	195		
ECM TIER 2 LOADS       STRATEGY       CAPITAL COST       TOTAL COST OF OWNERSHIP       CARBON         2015 m\$       2015 m\$       Tons         2015 m\$       2015 m\$       Tons         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         Subtotal       211       682       682,000         Reduction Over Baseline       -70       114       975,000         % Carbon Reduction       59%       -117       -117         Δm\$ Capital / Ton Reduction       72       8uilding ECM/Overhauls       327         ECM Tier 1 Loads (30 Years)       Building ECM/Overhauls       1,961       114	ECM Tier 1 Loads (30 Years)	Building ECM/Overhauls	1,169		
ECM TIER 2 LOADSSTRATEGYCAPITAL COSTTOTAL COSTTOTAL COSTOWNERSHIPCARBON2015 m\$2015 m\$2015 m\$Tons2005 m\$2015 m\$2015 m\$TonsCore Strategy188671719,000Enhancement 1Hot and chilled water TES0-2-19,000Enhancement 210 MWe battery storage13190Enhancement 32 MWe rooftop PV7-4-12000Enhancement 41 MWe parking shade PV4-2-6000Subtotal211682682,000Reduction Over Baseline-70114975,000% Carbon Reduction59%-70114975,000% Carbon Reduction59%-7014975,000% Carbon Reduction59%ZECM Tier 1 Loads (5 Years)Building ECM/Overhauls327ECM Tier 1 Loads (30 Years)ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961-				TOTAL COST OF	
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Enhancement 210 MWe battery storage13190Enhancement 32 MWe rooftop PV7-4-12000Enhancement 41 MWe parking shade PV4-2-6000Subtotal1 MWe parking shade PV4-2682,000Reduction Over Baseline-70114975,000% Carbon Reduction59%-117-117\Deltam S Capital / Ton Reduction72-1200ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961	Enhancement 1	Hot and chilled water TES	0	-2	-19,000
Enhancement 32 MWe rooftop PV7-4-12000Enhancement 41 MWe parking shade PV4-2-6000Subtotal211682682,000Reduction Over Baseline-70114975,000% Carbon Reduction59%\Deltampi CO / Ton Reduction-1117\Deltampi Capital / Ton Reduction72ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327-ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961	Enhancement 2	10 MWe battery storage	13	19	0
Enhancement 41 MWe parking shade PV4-2-6000Subtotal211682682,000Reduction Over Baseline-70114975,000% Carbon Reduction59%\Deltamp TCO / Ton Reduction-117\Deltamp Capital / Ton Reduction72ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327-ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961	Enhancement 3	2 MWe rooftop PV	7	-4	-12000
Subtotal211682682,000Reduction Over Baseline-70114975,000% Carbon Reduction59%\Deltam\$ TCO / Ton Reduction-117\Deltam\$ Capital / Ton Reduction72ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327-ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961	Enhancement 4	1 MWe parking shade PV	4	-2	-6000
Reduction Over Baseline-70114975,000% Carbon Reduction59% $\Delta m$ TCO / Ton Reduction-117\Delta m$ Capital / Ton Reduction72ECM Tier 1 Loads (5 Years)Building ECM/Overhauls327ECM Tier 1 Loads (30 Years)Building ECM/Overhauls1,961$	Subtotal		211	682	682,000
% Carbon Reduction     59%          \Deltamp TCO / Ton Reduction       \Deltamp Capital / Ton Reduction       T2      -117           \Deltamp Capital / Ton Reduction       72      72           ECM Tier 1 Loads (5 Years)       Evil ding ECM/Overhauls       327      327           ECM Tier 1 Loads (30 Years)       Building ECM/Overhauls       1,961      1,961	Reduction Over Baseline		-70	114	975,000
Am\$ TCO / Ton Reduction     -117       Am\$ 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	% Carbon Reduction	59%			
∆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	△m\$ TCO / Ton Reduction	-117			
ECM Tier 1 Loads (5 Years)     Building ECM/Overhauls     327       ECM Tier 1 Loads (30 Years)     Building ECM/Overhauls     1,961	<b>△m\$ Capital / Ton Reduction</b>	72			
ECM Tier 1 Loads (30 Years) Building ECM/Overhauls 1,961	ECM Tier 1 Loads (5 Years)	Building ECM/Overhauls	327		

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

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.

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