Ice-based Thermal Energy Storage for Permanent Load Shifting

Guru Navaneetham, Lincus Inc.
Akhilesh R. Endurthy, Solaris-Technical LLC.
Nicholas W. Fette, Solaris-Technical LLC.
Emrah Ozkaya, Southern California Edison Co.

ABSTRACT

Ice-based Thermal Energy Storage (I-TES) technologies stores thermal energy by cooling a storage medium (ice) so that the stored energy can be used later for cooling applications. Refrigerant based and Chilled Water based I-TES technologies have been traditionally used for shifting the cooling demands from the on-peak to the off-peak utility periods. Even though the overall energy storage market has grown by 46% over the last 3 years, adoption rates for I-TES, especially within the small-medium commercial segments have been lower.

The current paper will focus on the benefits/costs of an optimized partial storage I-TES system in top two (2) small-medium commercial segments (Retail and Restaurants) and a residential segment (Single Family) in three (3) representative Climate Zones of the IOUs in California with an emphasis on smoothening out the duck curve. The current simple payback period of I-TES installations based on the existing IOU TOU rates were noted to be between 10 and 42 years. The energy rate discounts IOUs should consider offering to make I-TES attractive to customers for a 7-year payback period varies widely from 28% to 90%. However, by choosing the appropriate off, mid and on peak pricing, IOUs could achieve a revenue neutral rate structure. The paper discusses the technical potential of I-TES for unitary cooling equipment in the (3) segments and the grid impact with I-TES market adoption assuming a reasonable penetration. With increased market adoptions, I-TES has potential to mitigate the solar energy curtailment and alleviate the steeps in the “duck curve”

Introduction

Energy storage systems are essential solutions to addressing the growing concerns of capacity and resiliency of our energy grids while being transitioned from predominantly fossil fuel powered to clean energy fuels. These systems ensure continuity of energy supply and improve the operational reliability of the power grid by addressing the intermittency associated with renewable power supplies (such as solar and wind) whose output is reliant on weather and season. Given the large proliferation of solar photovoltaic power in California in the recent years coupled with legislations requiring the state to get 60% of its electricity from renewable sources by 2030, and 100% by 2045 (SB 100 2018), there has been a growing interest in systems that have the capability to store excess energy from renewable resources.

Energy storage systems come in many forms and sizes depending on the form of stored energy – such as potential (pumped storage hydropower), electromechanical (flywheels, compressed air energy storage), chemical (Lead-acid/Lithium type batteries, flow batteries and fuel cells), electrochemical (electrochemical capacitor), electromagnetic (super conducting magnetic storage systems), thermal (chilled water, ice-based and molten salt storage), etc. Pumped storage hydropower (PSH) is by far the most popular form of energy storage, accounting for about 95 percent of utility-scale energy storage capacity as of September 2019

(DOE 2017). However, there are numerous studies that suggests that the investment in the PSH technology has stalled since the late 1990s due to non-availability of new sites (Medina et al. 2014), environmental concerns, and financial uncertainties (Yang and Jackson 2011). Between 2010 – 2017, the PSH energy storage systems had increased by only ~2 GW while the large-scale battery storage system had added about 708 MW into the U.S energy grid.

The California Public Utility Commission (CPUC) has imposed energy storage procurement targets for each of the Investor Owned Utilities (IOUs) in California, totaling 1,325 MW to be completed by 2020 and implemented by 2024 (AB 2514 2010). The regulation mandates IOUs to procure energy storage in three distinct grid domain targets, with some flexibility, among the grid domain targets of customer sited, distribution-connected, and transmission connected. Following this, the State also passed AB-2868 (AB 2868 2016) regulation, which required the three IOUs to propose programs and investments to accelerate the deployment of customer sited and distribution-connected storage systems with the total capacity not to exceed 500 MW. This total capacity goal of 500 MW was recommended to be equally distributed amidst the (3) CA-IOUs per CPUC decision D.17-04-039 in 2017. To date, the CPUC has approved procurement of more than 1,600 MW of new storage capacity across all domain targets to be built in the State. Although the three major IOUs have together exceeded the AB 2514 target goal of 1,325 MW cumulatively, not all the IOUs (with the exception of SCE) could meet their recommended distributed energy storage capacity (customer sited plus distribution-connected) target goals set by CPUC. Figure 1 below shows a bar graph representation of the initial goals from AB2514 and the current storage contracted for each of the IOUs, as of this current date. Figure 2 shows the distribution of the various energy storage system technologies installed in the three distinct grid domain targets within each of the IOUs. As can be seen from the pie charts below, chemical (more specifically, the lithium ion battery technology) energy storage systems represent the large majority of the energy storage system installations (about 88.2% of the total) within each IOU while thermal energy storage system technology only accounted for about 2.1% of the total.

Figure 1. Goals vs Contracted energy storage capacities for CA-IOUs

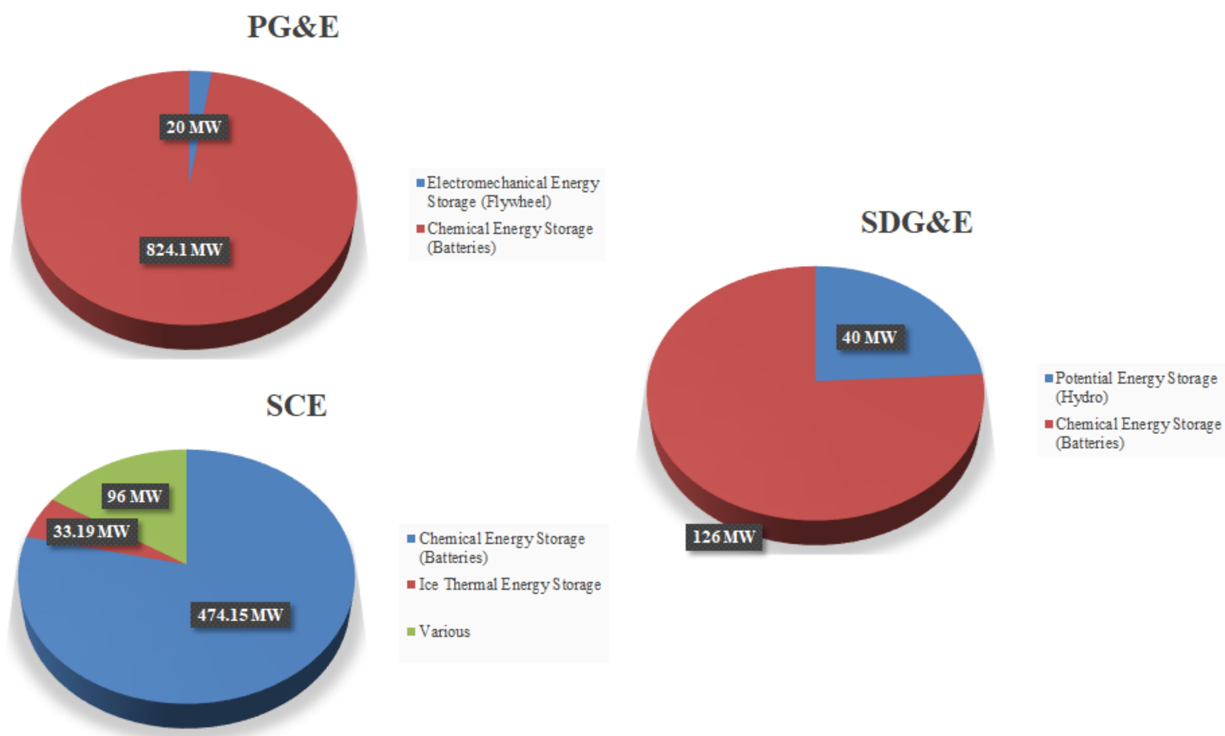

Figure 2. Energy Storage technology distribution for CA-IOUs

Although battery energy storage systems (BESS) have come a long way since its inception in the 1990's from the lead-acid battery days, thermal energy storage systems are better suited as distribution energy storage systems at customer sites primarily due to its usage of storage mediums (such as ice) which are readily available, extremely effective for storing and releasing large amounts of energy with minimal wastes, relatively lower initial costs, longer useful times and safe disposal capability in comparison with the BESS technologies. Furthermore, the storage of energy in the thermal form enables a more direct use of the stored energy for later use, resulting in lower losses than associated with the BESS. In spite of these obvious advantages, adoption rates for thermal energy storage systems have been considerably lower due to lack of beneficial Time Of Use (TOU) utility rates that would result in continued costs savings benefits for the customers installing I-TES.

The remainder sections of this paper will focus on the current situation in the state of California for the adoption of Ice-based Thermal Energy Storage Systems (I-TES), technical potential of I-TES for unitary cooling systems in light commercial and residential market segments, cost benefits analysis of I-TES implementation using a simplified engineering tool across representative climate zones in each IOU territory and propose beneficial Time Of Use (TOU) utility rate structures that can favor these I-TES installations. We will also evaluate the impact of these potential I-TES installations as a Permanent Load Shifting (PLS) technique to help manage the CA grid operations to alleviate the negative impacts of the "duck curve" associated with the high levels of solar energy input into the CA grid.

Current Situation

CA-IOU programs catering to I-TES

California has a statewide program called Self-Generation Incentive Program (SGIP) which provides incentives to energy storage systems installed at customer sites. SGIP program is administered by all the IOUs (SCE, PG&E, SDG&E and SoCalGas) in their respective territories and by Center for Sustainable Energy in a few other areas. The incentives for SGIP are offered in 5 steps with $ 40 million reserved in each step. The incentive rate decreases by 5 cents for the subsequent steps which will begin once the previous step's budget is extinguished. Currently, the incentive program is in step 3 and the incentive rate for TES for commercial/residential customers is $0.35/Wh (SGIP Handbook 2020). In addition to SGIP program, SCE also has a Local Capacity Requirements (LCR) contract in Johanna-Santiago substations where the HVAC system with I-TES are installed at no cost to commercial and industrial customers[1].

Other municipal utilities such as City of Riverside and Los Angeles Department of Water and Power (LADWP) also offer programs for promoting I-TES installations in their regions offering incentives of $200 to $700/peak kW shifted onto the off-peak periods.

Grid Operations in California

Grid operations involves the act of constantly monitoring and managing the electric supply and demand to ensure reliable power to the end users whilst maintaining the required mix of renewable and conventional energy. The CAISO forecasts electrical demand and dispatches the lowest cost generator to meet demand whilst ensuring enough transmission capacity for delivery of power to all end-users. Figure 3 below shows the hourly total demands as extracted from CAISO (shown as hashed lines) on the CA grid system on an average summer and spring[2] day in a year. As can be seen, the maximum and minimum total demands on the grid is typically about ±25% to the mean value. These deviations during the day are typical and grid operators are adept at managing such demand variations with their supplies. However, the requirements to manage the electric grid are changing rapidly due to the introduction of renewable energy resources with intermittent supplies such as solar.

Impact of growing solar market on California grid

The state of California has a long history of establishing and achieving ambitious renewable energy goals. Solar Photovoltaics (PV) is one of the major technologies that has contributed to achieving the renewable energy goal targets and has been growing rapidly in the state. The solar industry has had an exponential growth over the last 10 years and based on the most current statistics, the total solar installed capacity in CA till date is over 27,405 MW. The industry anticipates growing this solar capacity from its existing levels by another 57% over the course of next 5 years (SEIA 2020).

Given that the power generation from all these solar installations occurs only during the day when the sun is out, this creates a huge imbalance between the time that the solar produces

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[1] This LCR is different than the SGIP and are mutually exclusive programs offered by SCE.

[2] The current paper uses 'Spring' day in lieu of 'Non-Summer' days typically referenced in CA-IOU rate tariffs, consistent with the representative hot/warm climate zones being used for evaluations. The effect of 'duck curve' is also more pronounced on such spring days which the paper primarily focuses on addressing.

its largest power and the peak demand during the day. Such scenarios where the net demand in the grid system sharply increases and decreases resembling a duck is referred to as the 'duck curve' as coined by CAISO. Figure 3 below shows the coincident net demand curve superimposed onto the hourly demand curve.

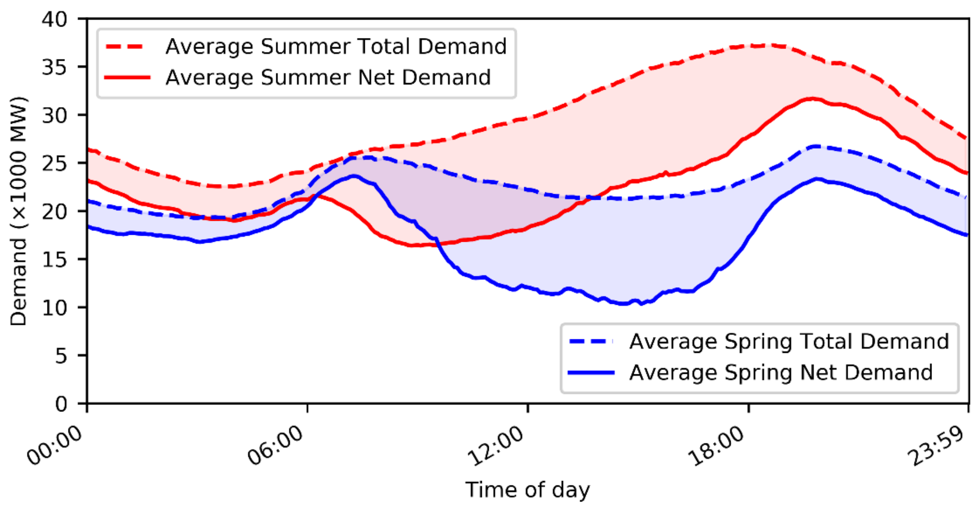

Figure 3. Hourly total and net demand profiles for a typical summer/non-summer day. Source CAISO

To ensure reliability under these changing grid conditions, the grid operators will require resources with rapid ramping flexibility and the ability to start and stop multiple times each day. This flexibility in power production comes at a very steep cost due to the nature of operation of the load-following and peak power plants that are very expensive to operate. To alleviate this issue, the grid operators automatically 'curtail' the generated energy from renewable resources, to balance the power supply and demand. The curtailment typically occurs during the day between the second and third ramps between 7a and 3p, to ensure that the grid reliability is not compromised. Figure 4 below shows the curtailment totals (in MWh) by month over the course of the most recent 1 year between March 2019 to February 2020. From Figure 6, it follows that the total annual curtailment energy is about 1,161,029 MWh which represents about 12% of the total annual renewable energy production in California (DOE 2020). While curtailment is an acceptable operational tool with grid operations, the increased amounts of solar energy generation projected over the next 5 years and beyond, will result in oversupply conditions which may result in more curtailment of this solar energy produced. It is therefore imperative to seek solutions to avoid or reduce the amount of curtailment of solar power to maximize the use of clean energy sources.

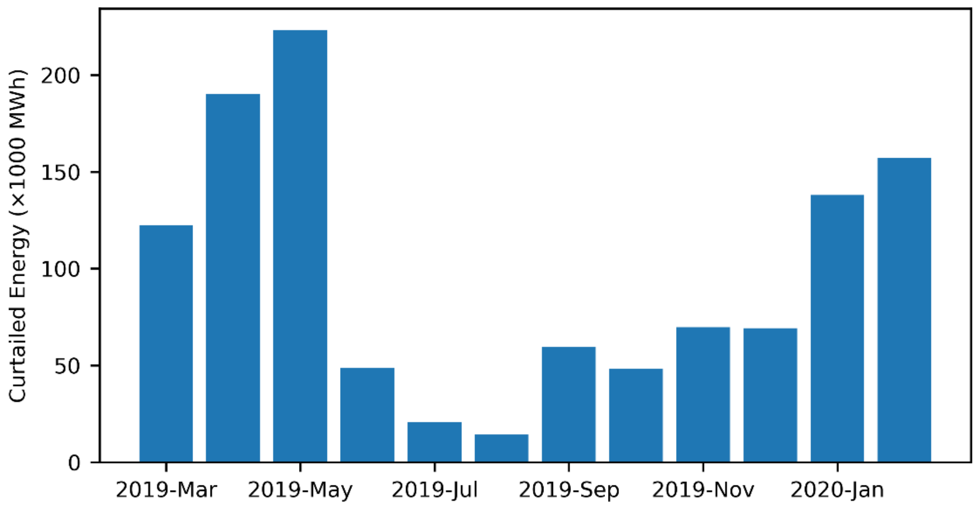

Figure 4. Monthly curtailed solar and wind energy totals over the last 12 months. Source CAISO

I-TES for Permanent Load Shifting

Permanent Load Shifting (PLS) measures assists with the shifting of energy usage from the peak hours of the day to the off-peak hours on a recurring basis. I-TES systems are considered to be one of the PLS technologies due to its ability to store thermal energy during the off-peak hours and use this energy during peak hours to support the building cooling loads on a daily basis. Of the PLS technologies at the customer level, I-TES systems are more suited for deployment as energy storage solution because of the following reasons:

- The potential sites for the I-TES technology deployment are numerous unlike conventional PSH's that require topography.
- Relatively lower costs than conventional battery storage energy systems. Based on an MIT review in 2018 [MIT 2018], using battery storage technologies as the primary energy storage option in accordance with the state's future renewable goals, will result in an exponential increase in energy storage costs.
- The deployment of I-TES will help develop multiple small – medium scale facilities at different sites, based on a distributed architecture network which allows for higher levels of flexibility to the grid (in terms of congestion patterns, and locational marginal prices).

Market Analysis

Given that the application of I-TES in chilled water storage systems has been analyzed prior (Yin et.al. 2015), our paper here will focus primarily on I-TES systems for packaged air-conditioning (AC) or heat pump (HP) units in commercial and residential sectors. Within commercial sector, typically light commercial building types have packaged HVAC equipment. These buildings include strip malls, small offices, retail, restaurants, grocery stores, etc. Approximately 70% of the light commercial floor space are served by packaged HVAC systems in CA (WCEC 2013). The total cooling energy consumed by this light commercial building stock is approximately 22.6 billion kWh per year (WCEC 2013). In residential sector, central AC or

HP units, either packaged or split are becoming more and more common. 74% of the homes in western US have central AC (WCEC 2013). Per published standards (CECD 2018 and RASS 2009), the total cooling energy consumed in residential sector served by the (3) major electric CA-IOUs and using central ACs is estimated approximately at 8.7 billion kWh per year[3]. This paper uses the term "Packaged HVAC" for packaged AC with direct expansion cooling or Heat Pump (HP) and central AC or HP.

Figure 5 below shows the estimated cooling load profile of the light commercial and residential building stocks during an average summer[4] and spring day. These load profiles were developed based on review of the 8760-hour load profiles for the packaged AC units (DEER, 2011) in conjunction with the annual energy use mentioned above. From the figure, it can be observed that for residential sector, the peak cooling load hours are between 4 p.m. and 8 p.m. which aligns with the on-peak grid hours described in Figure 3 above. For the light commercial sector, the peak cooling load hours are primarily between 2 p.m. and 6 p.m. coinciding with the working hours in the commercial industry. Given that our intent is to reduce the cooling load between 4 p.m. to 9 p.m., the paper will only be focusing on light commercial building types (such as small retail, restaurants and grocery) that will have a substantial cooling load during these time periods.

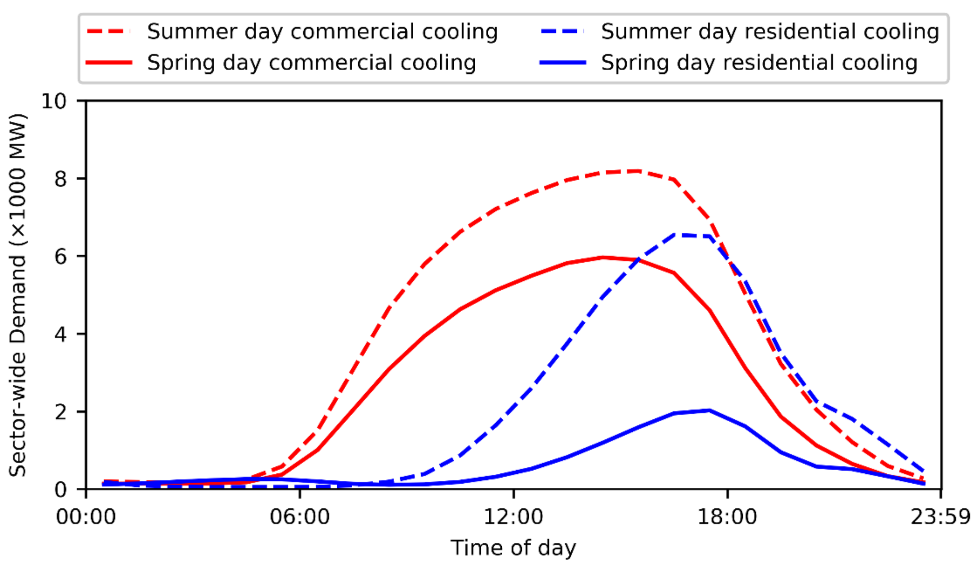

Figure 5. Average hourly electricity demand (MW) for cooling load on a typical spring and summer day for residential sector (res) and commercial sector (com) served by packaged HVAC systems.

I-TES systems can be sized to fully offset the cooling demand during on-peak hours. Currently in California, the on-peak hours are between 4 p.m. to 9 p.m. which is when the TOU rates are higher in most of the rate structures consistent with the steepest ramp of the CAISO's

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[3] California Energy Consumption Database, where the total residential kWh in 2018 was 63.9 billion across three major IOUs (SCE, PG&E and SDG&E) in CA and 2009 Residential Saturation Survey which indicates that on average 15% of the residential energy is used by central ACs.

[4] Summer period is considered as June 22 to September 21st and Spring period is considered as March 21st to June 21st.

net demand curve. Assuming 100% adoption of I-TES[5], Table 1 below presents the potential daily energy (in MWh) use that can be offset from 4 p.m. to 9 p.m. on a consistent basis in residential and light commercial sector on a typical spring and summer day.

Table 1. Daily energy offset potential for residential and commercial sector in spring and summer seasons using I-TES on packaged units

Sector	Spring MWh/day offset	Summer MWh/day offset
Residential	5,724	24,923
Light -Commercial	18,071	30,694

Selection of Building Types and Climate Zones for I-TES Evaluations

The top two commercial and top one residential building types by building weights assigned by California Public Utilities Commission (CPUC) (DEER 2020) using packaged HVAC units with their peak cooling loads coinciding with the CAISO's on-peak periods, were selected to perform the I-TES evaluations within this current analysis. For the commercial sector, these turned out to be small retail and restaurants (fast food and sit-down) whereas, for the residential sector, single family building type was chosen.

For the Climate Zone (CZ) selection, one climate zone within each IOU that has the highest product of cooling degree days (CDD) and building weights was chosen. This choice of using higher CDD and building weights to select representative CZ for evaluation is logical due to their direct correlation with the market size and higher energy savings potential associated with I-TES installations. Table 2 summarizes the selected building types and climate zones.

Table 2. Selected climate zones and building types for TES analysis

<table>
<tr><th>Electric IOU</th><th>Selected CZ for Residential and Commercial sector</th><th>Selected commercial building types</th><th>Selected residential building type</th></tr>
<tr><td>SCE</td><td>CZ10</td><td rowspan="3">Retail and Restaurant (Fast Food and Sit-Down)</td><td rowspan="3">Single family</td></tr>
<tr><td>PG&E</td><td>CZ12[6]</td></tr>
<tr><td>SDG&E</td><td>CZ07</td></tr>
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Customer payback analysis

Methodology

Lincus has developed a customizable, interactive, I-TES engineering analysis tool to allow rapid exploration of the interplay between ice-making/melting schedules, TOU rate tariffs, utility incentives, and customer economics for the measure. This excel-based tool leverages the

[5] Sized based on the average summer day cooling loads during 4pm to 9pm. Summer period is from June 1st to September 30th coinciding with IOUs most of the rate structures.

[6] For PG&E, the product of CZ13 building weights and CDD is slightly higher than CZ12 because of significantly higher CDDs in CZ13. Given that I-TES systems are applicable to both hot and warm climates, it seemed logical to give building stock a higher weightage over CDD based on which CZ12 was selected for our evaluations.

hourly cooling loads and end use energy consumption from CPUC's DEER 2020 prototypes and generates the results for this paper.

Simplified model. The I-TES Analysis Tool reads in building simulation hourly data for cooling loads, representing the baseline case of a building without I-TES, then sizes a storage system and develops results for the measure case of the same building with I-TES installed and operating. The tool groups the hourly data by billing season[7] and aggregates electric demand serving cooling loads from 365 days of 24-hour profiles into two representative 24-hour profiles, a summer average day and a non-summer average day. Based on the summer average day, thermal storage capacity is sized to meet the cumulative cooling loads (in ton-hours) within the user-input storage discharge (ice-melting) window. Then, the following hourly calculations were performed on each of the average day profiles:

- Within the ice-melting window, for each hour, the tool calculates cooling ton-hours available from ice storage and the reduced cooling demand met by the packaged HVAC system. The tool then totals the ton-hours of ice required for the day.
- The tool calculates tons of ice to be produced in each hour of the storage charge window, according to a user-input ice-making profile.
- Based on the SEER ratings for the packaged HVAC and I-TES system, the tool calculates impacts on hourly meter readings due to the ice-making and ice-melting operations of the I-TES. The tool adds these impacts to the baseline data to get the new hourly meter reads.
- Based on the meter readings, utility bills are calculated according to the user-input TOU rate tariff. The scope of the bills is limited to incremental charges related to energy and demand, excluding for instance, flat service fees. All values output from the tool refer to cooling loads only.

Note that using a summer average day as the design day basis for sizing results in storage capacity less than what is sometimes referred to as *full storage*. A full storage system can reduce peak period cooling loads to zero during demand response events. However, on most days, only a fraction of the capacity of a full storage system will be used. The algorithm used by the analysis tool to size the storage capacity (from the seasonal average day) is not only convenient for the simplified analysis but also can be viewed as a practical sizing choice for PLS. Although this sizing does not zero out peak period cooling loads on above-average summer days, it offers a lower-cost build and storage capacity that will be fully utilized more consistently throughout the year. Partial storage offers a balance between the goal of installing the maximum feasible load shifting capacity per building and the competing goal to show "the biggest bang for the buck" for the customer on a TOU rate, whose utility bill savings per unit storage capacity depend on the average utilization.

Charge and discharge schedules. Figure 6 shows a load shifting profile for a sit-down restaurant in CZ10 when the equipment is configured to charge during hours of overgeneration (7a to 3p) and discharge during hours of high net grid demand (4p to 9p). With this charge/discharge schedule, the load shifted by the I-TES measure resembles an inverted duck curve. Depending on the existing energy and demand prices from their rate tariffs, customers may find it costs more to charge their storage systems according to this schedule. However, this

[7] SCE and PG&E apply summer schedules from June through September, whereas SDG&E applies summer schedules from June through October.

analysis assumes that the priority is creating the greatest benefit to the grid – smoothening out the net grid demand curve and minimizing renewable curtailment.

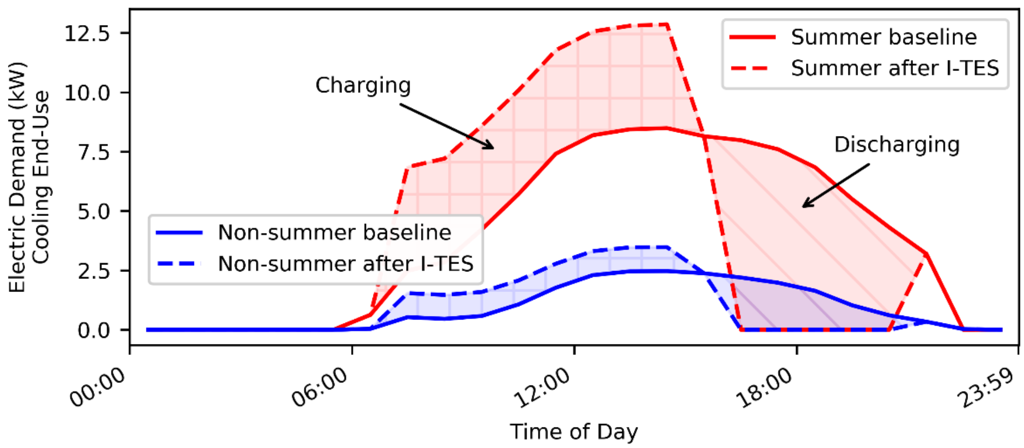

Figure 6. Charging during hours of low grid net demand (Restaurant Sit Down, CZ10).

Building models and existing rate plans. Table 3 shows standardized figures pulled from the DEER 2020 prototype building models, and the rate plans selected to model typical energy and demand charges. Note that each model contains multiple copies of nearly identical buildings with slight permutations. Each calculation is based on the set of buildings in the model rather than an individual building, which gives simulation results that are more representative of a population average. Table 4 lists other key inputs to the TES Analysis Tool used for this work.

Table 3. Standardized values used in energy models

DEER prototype short name		RFF	RSD	RtS	SFm
Description		**Restaurant Fast Food**	**Restaurant Sit Down**	**Retail, Small**	**Single Family dwelling**
Copies of building in one model (permutations)		2 (east-west, north-south)	2 (east-west, north-south)	4 (east-west, north-south)	4 (east-west, north-south, 1-story, 2-story)
Aggregate conditioned area (ft^2)		2,500	5,600	8,000	8,000
"Full storage" ton-hours	CZ07	16.8	29.3	22.8	15.0
	CZ10	30.9	54.5	46.1	31.5
	CZ12	34.6	59.6	49.8	34.8
Presumed rate tariff	CZ07	SDG&E TOU-M			SDG&E TOU-DR1
	CZ10	SCE TOU GS-2 Option D			SCE E-TOU-D
	CZ12	PG&E B-19			E-TOU Option B

Table 4. Key inputs to TES Analysis Tool

Packaged HVAC SEER	13
I-TES SEER	12
Ice-melting hours	4p to 9p
Ice-making hours	7a to 3p
I-TES cost (material plus labor)	$700 per ton-hour[8]
Incentive rate	$0.35 per W-h shifted

Beneficial rate structure. In cases where customer economics is not favorable to the proposed charging window, the analysis finds the additional costs savings per year that would be needed to show a 7-year payback. For discussion purposes, this work also examines a simple rate adjustment scheme that could yield this cost savings for the customer: a price discount for hours when there is an oversupply and energy is being curtailed (9a to 3p). With this rate adjustment scheme, the utility would trigger the price discount when the customer installs a PLS measure. The price discount strengthens the price differential between on-peak and mid-day energy purchases, which encourages the customer to continue operating the PLS equipment to take advantage of cheap energy. The mid-day energy price adjustment is then calculated to yield a 7-year payback period for the customer. This adjustment represents the degree of change to the rate structure needed to create economics favorable to implementation and persistence of the I-TES PLS measure[9]. In some cases where energy price differential alone does not yield a 7-year payback, the energy price discount is accompanied by an additional adjustment such that maximum demand calculations for billing purposes exclude the hours 9a to 3p.

Results and Discussion

Table 5 shows the model results for the sample building types and rate plans. Sizing and install costs are higher in CZ10/CZ12 than in CZ07, which is a more moderate climate with lower cooling loads. Also, the selected rate plans have significantly higher energy prices ($/kWh) and a greater price differential between peak and mid-day hours in CZ07 than in CZ10/CZ12, which results in a better payback for CZ7 buildings. To get a 7-year payback period in CZ10 and CZ12 for restaurant and retail buildings requires adjustments to both demand charges and energy charges for the mid-day charging period. In fact, PG&E's B-19 rate offers opt-in Option S (storage) that makes such adjustments.

[8] Inferred from $14,000 per unit with 20 ton-hour capacity (Anderson 2017).
[9] This analysis assumes discounted rates being applied only to the measure case. Utility regulations need to be set in place (or alternate pricing structures developed) to ensure that customers do not take undue advantage of these discounted pricing without using the I-TES equipment.

Table 5. Model results for permanent load shifting with I-TES in CZ07, CZ10, and CZ12.

	Climate zone CZ07				Climate zone CZ10				Climate zone CZ12			
Building	RFF	RSD	RtS	SFm	RFF	RSD	RtS	SFm	RFF	RSD	RtS	SFm
Utility tariff	SDG&E TOU-M			TOU-DR1	SCE TOU GS-2 Option D			E-TOU-D	PGE B-19			E-TOU-B
I-TES Capacity (ton-hours) [a]	8.9	16.6	13.9	5.4	19.6	34.9	32.4	16.7	20.4	36.6	33.7	15.9
I-TES Storage % [b]	53%	57%	61%	35%	64%	64%	70%	53%	59%	61%	68%	45%
Maximum on-peak demand reduction (kW) [a]	2.1	3.9	4.3	1.5	4.4	8.0	9.2	4.4	4.5	8.2	9.3	4.0
Summer load shifted (kWh/day) [a]	8.2	15.4	12.8	5.0	18.1	32.2	29.9	15.4	18.8	33.8	31.1	14.6
DEER peak demand reduction (kW) [a]	1.6	3.1	2.6	1.0	3.6	6.4	6.0	3.1	3.8	6.8	6.2	2.9
Install cost (material & labor)	$6,233	$11,641	$9,737	$3,774	$13,724	$24,440	$22,653	$11,675	$14,255	$25,601	$23,609	$11,099
Charging option: make ice from 7 a.m. to 3 p.m.												
Baseline annual cooling-related charges	$1,283	$2,400	$2,509	$881	$1,757	$3,133	$3,565	$1,659	$2,114	$3,779	$4,253	$1,344
Customer annual bill savings	$192	$359	$299	$144	$527	$960	$1,130	$362	$310	$556	$682	$140
Payback w/o incentive (yrs)	32.5	32.5	32.6	26.2	26.0	25.5	20.0	32.3	45.9	46.0	34.6	79.3
Incentive at current rates	$2,872	$5,373	$4,494	$1,742	$6,334	$11,280	$10,455	$5,389	$6,334	$11,280	$10,455	$5,389
Payback w/ incentive (yrs)	17.5	17.5	17.5	14.1	14.0	13.7	10.8	17.4	24.7	24.8	18.6	42.7
To hit simple payback target: 7 years												
Annual customer savings adjustment needed	$291	$545	$459	$146	$529	$920	$612	$536	$786	$1,413	$1,134	$714
Energy price discount (9 a.m - 3 p.m.)	39%	38%	29%	28%	70% [c]	65% [c]	31% [c]	59%	78% [c]	76% [c]	50%[c]	90%
Demand discount (9 to 3)	None	None	None	None	Yes	Yes	Yes	None	Yes	Yes	Yes	None

[a] Capacity sized for summer average day, meeting loads from 4 to 9 p.m. Demand reduction and load shift results apply to summer average day.
[b] For storage percent, the denominator (full storage) here refers to the 98th percentile over 365 days of cooling demand integrated from 4 pm to 9 pm (ton-hours).
[c] For these buildings, annual bonus savings is met by energy price discount plus exclusion of 9 a.m. to 3 p.m. from facilities- and time-related maximum demand charges.

Utility Grid Operations Impact

Market analysis section presents the total energy potential of permanent load shifting (PLS) with I-TES. In this section, we present the market potential of I-TES PLS and the resultant impact on the grid by considering reasonable market adoption rates. To evaluate the market adoption rates for the I-TES technology in this analysis, the standard curve for market penetration of products from the law of innovation of diffusion (LaMorte 2019) has been used. According to this curve, the first 2.5% of the target population are innovators, the next 13.5% are early adopters while the following 34% are early majority. Assuming that the current IOU programs by utilities have already captured the innovators, the adoption of discounted pricing TOU rate models described above is estimated to target the 13.5% of early adopters and nearly half of early majority (50% x 34%) customers, resulting in a total market adoption rate of ~30.5%. Applying this percentage to the total potential, we estimate the market potential of cooling load energy (MWh) shift that can be permanently offset through the recommended I-TES installations.

The following figures (Figures 7 through 10) shows the results of the I-TES installations implemented at the market potential adoption rates and its resultant impacts on the net cooling load demands during an average summer and spring day in a year for residential and light commercial sectors in California. The plots show the cooling load before and after the I-TES installations indicating how I-TES is a potential solution to alleviate the duck curve. As can be seen, in the existing conditions, the ramp-up of cooling loads was occurring at time periods coincident to the steepest rise of the CAISO net demand curve which was resulting in a heightened arch (or neck) of the duck. With I-TES installations, these cooling load ramp-ups can be shifted to hours when the CAISO net demand curve bellies resulting in a more smoothened out net demand curve devoid of steep rise and falls. With I-TES installations at 30.5% market penetration rate, it is estimated that the CAISO net demand during the peak time period (4p to 9p) can be shifted by about 9% and 13% on an average spring and summer day respectively. From the plots below, it can be noted that the implementation of I-TES technology will result in permanent load shifting of energy use to the belly portion of the duck curve thus helping smoothen out the loads. For residential and commercial sector, the benefits of I-TES are more evident on a spring day when there is more curtailment of renewable energy as seen in Figure 4.

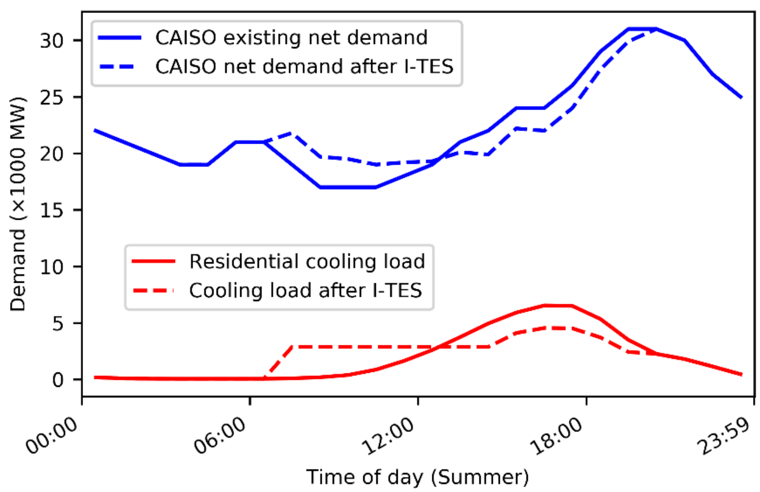

Figure 7. Summer day residential sector – Average hourly cooling load (MW) and CAISO net demand (GW) without and with I-TES market adoption

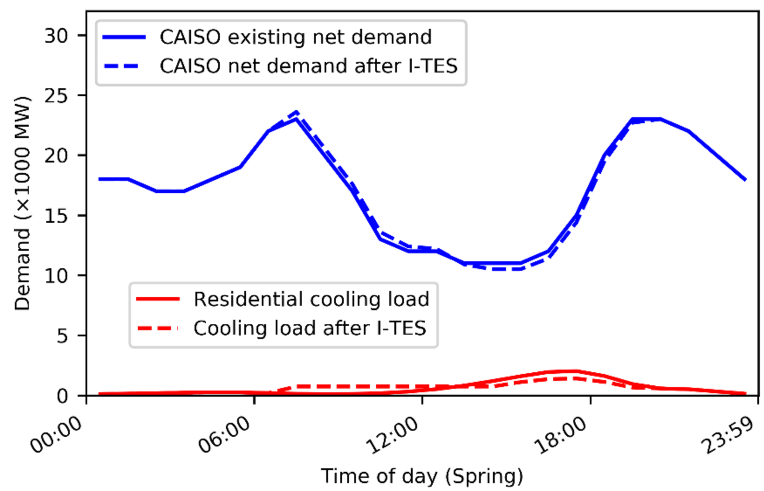

Figure 8. Spring day residential sector – Average hourly cooling load (MW) and CAISO net demand (GW) without and with I-TES market adoption

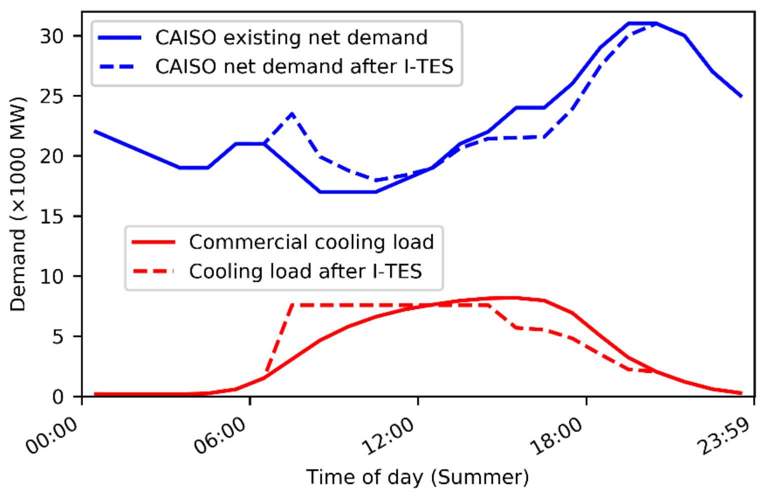

Figure 9. Summer day commercial sector – Average hourly cooling load (MW) and CAISO net demand (GW) without and with I-TES market adoption

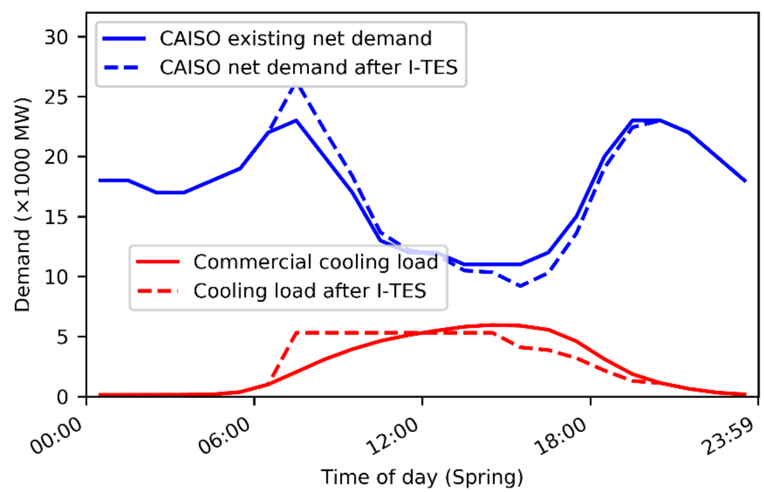

Figure 10. Spring day residential sector – Average hourly cooling load (MW) and CAISO net demand (GW) without and with I-TES market adoption

Conclusions

Distributed energy storage solutions (especially at customer sites) offers great flexibility to utility companies because of their ability to be deployed at numerous sites congregating into a substantial distributed architectural network that can address local and state level grid issues. The proliferation of these energy storage solutions enables the integration of the growing solar market whilst managing the 'duck curve' impacts at the CA grid. I-TES technologies offers a potential solution to CA utilities for improving their current energy storage capacities at the customer sited grid domain. In this paper, we evaluated the payback economics of customers installing I-TES solutions with the existing IOU TOU rates and demonstrated the importance of the energy price differential between on-peak and off-peak time periods to promote reasonable financial returns.

The results from our model show that the customer payback periods with the existing TOU rate structures are long which may be a huge barrier towards implementing this I-TES solutions. Through a simplified, customized engineering calculation tool, we evaluated the price discounts that need to be provided to customers to create favorable economics to implementation and persistence of the I-TES PLS measure. Provision of such energy price discounts during periods of overgeneration allows utility companies to leverage the over-generated clean energy to lessen the negative impacts of the 'duck curve' experienced in their electric grid. Some of the CA IOUs have already started looking into rate tariffs or opt-in options that are marketed toward customer sited storage.

Based on the framework presented in this paper, future effort will focus on expanding our analysis tool to capture daily variations of cooling demands for the evaluation of I-TES utilization based on discrete capacity levels available in the commercial market, and revenue neutral TOU rates for the IOUs to promote these installations. In addition, we also intend to study the economics of I-TES installations associated with tiered rate tariffs of energy/demand and the impact of modulating control schemes that can tailor the load shifting profile to match the local grid patterns of overgeneration.

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