THERMAL ENERGY STORAGE:
THE SALT RIVER PROJECT EXPERIENCE

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Abstract

This paper presents the results of an in-depth impact evaluation of Salt River Project's (SRP) Thermal Energy Storage (TES) Program. The evaluation consisted of on-site inspections of twenty-four TES facilities with short term monitoring of twelve sites during 1993 and 1994. Monitoring sites were chosen to provide a representative cross-section of both building sector (office, school, etc.), and TES system type (storage media) and size.

Analysis results reveal that SRP is currently achieving approximately 70% of its incentivized demand. The discrepancy between the incentivized and actual on-peak demand shift was primarily attributed to overestimation of projected peak cooling loads, incorrect estimates for auxiliary system demand, and the use of unrealistic conventional (baseline) HVAC systems as the basis for comparison to the TES system.

As a result of this program evaluation, a number of key recommendations are made with respect to both SRP's TES program and to TES systems in general. The most salient of these include: increased and improved maintenance of existing TES installations, a commissioning/verification process where the incentive payment is partially based on the actual demand shift realized by the facility, and a targeting of "favorable" facilities for TES installations. Also, improved rate design or a reduction in the demand penalty associated with occasional on-peak usage during non-system peak periods is recommended.

This paper also discusses some of the potential impacts that retail competition may have on the viability of TES systems and provides a general discussion on how TES may continue to be an important tool in a less regulated market.

Salt River Project

Salt River Project (SRP), named for the river that supplies water to the region, is comprised of two organizations - the Salt River Valley Water User's Association and the Salt River Project Agricultural Improvement and Power District. The Association is a private non-profit Arizona Corporation (1903) which operates and maintains the irrigation system which supplies water to municipal, industrial, residential and agricultural users. The District is a political subdivision of Arizona (since 1937) which operates under contract with the United States government. The Power District's total energy source (as of April, 1993) is comprised of seven major power plants and numerous smaller generating stations, including coal (61.9%), natural gas (2.1%), nuclear (23%), and hydroelectric (8.1%)

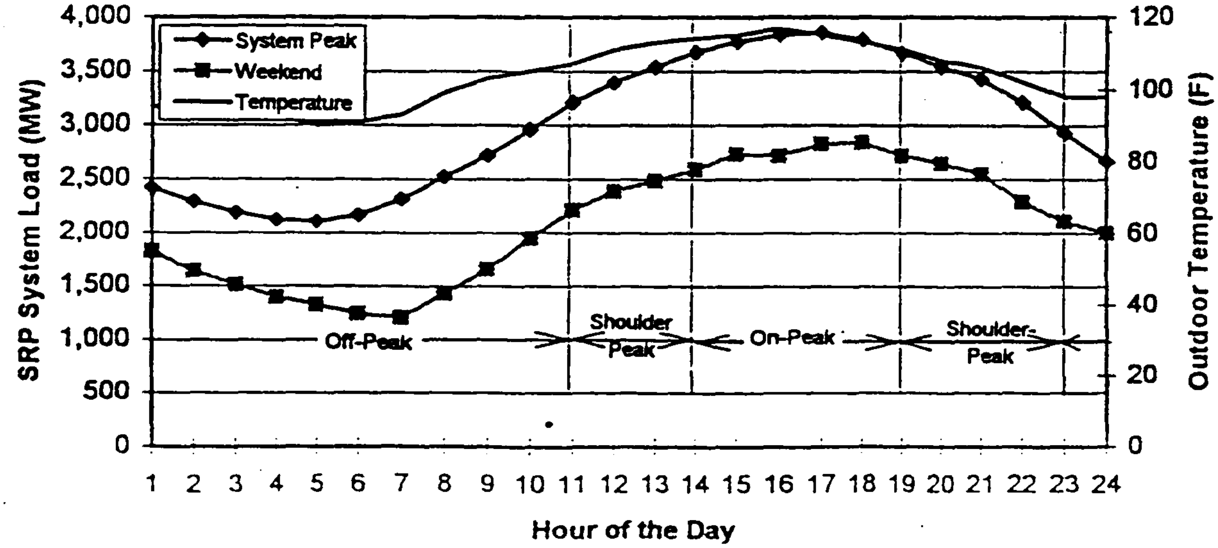

Figure 1 Salt River Project Peak Day

facilities. The remaining 4.9% comes from purchased power from other suppliers.

SRP has a total customer base of approximately 600,000 customers, of which approximately 90% are residential customers. For the 1994 calendar year, SRP had electric sales of approximately 6,900 GWh. The breakdown between residential, and commercial and industrial (C&I) sales was 35% and 43%, respectively with the remainder supplied to other utilities and municipalities. Given SRP's customer base, a large portion of whose space conditioning (including commercial) is provided by package unitary equipment, the overall system load is greatly influenced by the outdoor ambient conditions. Phoenix typically has approximately 5,000 cooling degree days (base 65°F) per year. Summer peak temperatures between 110°F and 115°F are not uncommon. Figure 1 depicts the system electric profile and the coincident outdoor drybulb temperature for SRP's peak day in 1994. For comparative purposes, a typical weekend day is also provided.

Srp Electric Utility Rates

The economics of a TES system are significantly influenced by two parameters, the difference in demand and energy charges between the *on-peak* and *off-peak* periods, and the duration of the *on-peak* window. (Shoulder period charges can be significant depending on the rate structure.) While the applicable rate schedule for a facility is dependent on its demand (kW) requirements, SRP's current time-of-use (TOU) periods are common for all of its time-of-use rates. In fact, it is mandatory for all facilities with a demand greater than 1,000 kW to be on a TOU rate, irrespective of whether the facility has a TES system.

There are currently three commercial "Electric Savings Time" (EST) rates; E-32, E-37, and E-39, which are applicable depending on facility demand. Table 1 summarizes the summer demand and energy charges associated with each TOU period for each rate. The ratio between on-peak and off-peak energy (kWh) charges is approximately two and a half to one. On-peak demand charges vary from $5.00 to $7.46 per kW with no off-peak demand charges. Although SRP's electric rates are relatively inexpensive as compared to many regions of the country, it should be re-iterated that it is the differential and not the absolute charges, which impact the economics of the TES system.

SRP's summer time-of-use (TOU) periods are illustrated Figure 1. There is very good agreement between the TOU periods and the shape of the overall system load curve. Summer rates are applicable from May 15 through October 14. The corresponding winter *on-peak* period and *shoulder-peak*periods are from 5:00 am to 9:00 am and 5:00 p.m. to 9:00 p.m., respectively. All remaining hours are *off-peak*. Winter rates are applicable from October 15 through May 14. Note that the TOU periods described above apply on <u>both</u> weekdays and weekends for C&I customers.

Tes Program Description

The TES incentive program requires a demand shift from *on-peak* to *off-peak* hours. This shift is determined by a comparison of the design day peak electric demand (kW) of a <u>reasonably</u> designed conventional cooling system against the design day *on-peak* demand of a TES system. The difference in *on-peak* demand between conventional and TES systems is the basis for the incentive calculation. This comparison includes not only the demand shift due to the primary refrigeration equipment (chillers), but also related auxiliary equipment such as primary chilled water pumps, condenser pumps, and cooling tower fan motors.

SRP has two incentive payment plans for thermal storage installations. Plan 1 is a declining block incentive rate which pays $300 per kW for the first 300 kW, $115 per kW for the next 200 kW, and $60 per kW, thereafter. Plan 2 pays a constant incentive rate of $150 per kW for all demand (kW) shifted but the owner repays $1.75 per kW shifted per month back to SRP in years four through ten after installation. For large TES installations, (>1,000 kW) Plan 2 offers more upfront money to help offset the initial cost of the TES system. Of the twenty-four sites which were evaluated, only <u>one</u> facility opted for Plan 2.

Research Design and Methodology

The overall work plan was divided into two major tasks: on-site inspections and short term monitoring. The purpose of the on-site inspections was to provide a qualitative

Table 1 SRP Electric Rate Comparison

Rate	On-peak kW/kWH	Shoulder-peak kW/kWh	Off-peak kW/kWh
E-32	$5.00/$0.1061	$0.50/$0.0741	none/$0.038
E-37	$5.10/$0.0871	$1.80/$0.0648	none/$0.0348
E-39	$7.46/$0.0697	$1.60/$0.0544	none/$0.0255

assessment of the TES system based on a one day site visit and interviews with key facility personnel. In all, on-site inspections were completed for twenty-four of the twenty-six TES installations SRP had incentivized. The purposes of the on-site inspections were to determine if the installed systems were consistent with the original designs, to identify any obvious problems associated with the TES design and operation, and to develop a detailed site monitoring plan. Upon completion of the on-site inspection and review of the electric billing history, each site was assigned a "qualitative" assessment of the peak demand shift.

The overall success of a TES system must be evaluated from the perspective of both the utility (SRP) and the TES system owner. That is a "good" TES system should provide SRP with the predicted demand shift it has incentivized, and also provide the TES owner with utility savings and reliable operation. The grading system used for the qualitative assessment is provided below.

As part of the second task, twelve sites were selected for short-term performance monitoring (three to ten days) to quantify the actual demand shift achieved by the system. The sites were selected to provide a representative cross-section of both facility type (office, school, etc.) and TES system type. Other criteria included the security of the site and the suitability of the site for monitoring with respect to system configuration. The primary constraint on the monitoring equipment was that it resulted in as little disruption to facility operations as possible. To this end, all temperature and flow measurements were done non-intrusively using strap-on temperature sensors and ultrasonic flow meters.

The principle objective of monitoring was to determine the actual *on-peak* demand shift being achieved by the TES system. Due to the relatively short duration of the monitoring, no attempt was made to monitor the storage inventory, tank efficiencies, or ambient storage losses. Monitoring was limited to those points necessary to calculate the building cooling load, performance of the primary cooling equipment and the total facility electric demand profile. The demand shift was calculated using building load and the efficiency of the primary cooling equipment and/or baseline system. Building load was assumed to be independent of the type of cooling system (TES or conventional). An overview of the analysis procedure is depicted in Figure 2. The analysis consisted of four major steps:

Step 1: Calculate the Conventional (non-TES) Cooling Electric Demand:

The conventional cooling electric demand is calculated by multiplying the monitored building load (tons) by the performance (kW/ton) of the baseline system. Note that in the case of primary/secondary chilled water systems, the building load is the secondary chilled water load and not the primary chilled water load. Building load was assumed to be independent of the central plant configuration. For buildings in which the TES system has been added as a retrofit to an existing system, the baseline system was assumed to be the existing system without TES. In almost all cases, this applied to central plant configurations. The performance of the baseline system was determined by monitoring the primary chilled water load and the cooling (chiller) electric demand. For facilities such as small schools and office buildings, the baseline system may have consisted of unitary package equipment. The performance of the unitary equipment was assumed to have a 8.5 EER at ARI conditions (95°F). Weather data coincident to the monitoring period was used to adjust the efficiency of the unitary equipment.

Step 2: Calculate the Base Electric Demand:

The base electric demand represents the electric demand which can not be shifted by the TES system. It can be calculated by subtracting the monitored cooling electric demand from the total facility (meter) electric demand. The cooling electric demand is comprised of all *shiftable* cooling electric, including chillers, condenser pumps, and primary chilled water pumps. Secondary chilled water pumps operate in response to building load and, therefore, are included in the base electric demand.

SRP	Building Owner
Good: System provides consistent on-peak demand shift near the incentivized demand.	**Good:** System is operating reliably and providing utility savings.
Fair: System provides a demand shift albeit at less than the incentivized demand.	**Fair:** System has high maintenance and/or reliability problems, however, is operating most of the time.
Poor: System is providing little or no benefit to SRP.	**Poor:** The owner is dissatisfied with the TES system and, in retrospect, would have installed a conventional HVAC system.

Step 3: Calculate the Total non-TES Facility Electric Demand:

The total non-TES facility electric demand is calculated by summing the conventional cooling electric demand (Step 1) and the base electric demand (Step 2). Typically, this will result in a total non-TES facility electric demand profile which is greater than the corresponding TES profile for *on-peak* hours when the TES system is in discharge mode and less than the TES profile during *off-peak* hours when the TES system is in charging mode.

Step 4: Calculate the *On-peak* Demand Shift

The *on-peak* demand shift is found by subtracting the maximum conventional non-TES total facility demand from the maximum TES facility demand (as-monitored) experienced from 2 pm to 7 pm. Note that the maximum demand for the TES and non-TES scenarios may not necessarily be coincident. Finally, if monitoring occurred at less than peak conditions, the *on-peak* demand shift was increased to reflect peak conditions.

Program Evaluation Results

Table 2 summarizes the results of all twenty-four sites included in the impact evaluation. Included in the analysis were seven chilled water systems, six ice harvesters, ten ice banks, and an ice slurry TES system. Building sectors included shopping centers, offices, churches, schools, and manufacturing facilities. The table provides an assessment of each site and the estimated on-peak demand shift. For the sites selected for short-term monitoring (denoted by shading), this demand shift is based on the actual short-term monitoring data. For all remaining sites, the demand shift was estimated based on the on-site inspection and the facility's billing history. In all, SRP provided a total of $1.5 million in incentives for a projected demand shift of 7.9 MW.

Results

The following provides a general overview of the results of the on-site inspections. These summaries give a qualitative view of the system, independent of demand shift, as seen by the customer and the utility.

- The TES systems at three sites (sites ten, eighteen, and twenty-four) are no longer operational. These systems were removed or bypassed because of ongoing operational and equipment problems at the sites. These systems represented a relatively small portion (2%) of the total incentivized demand.

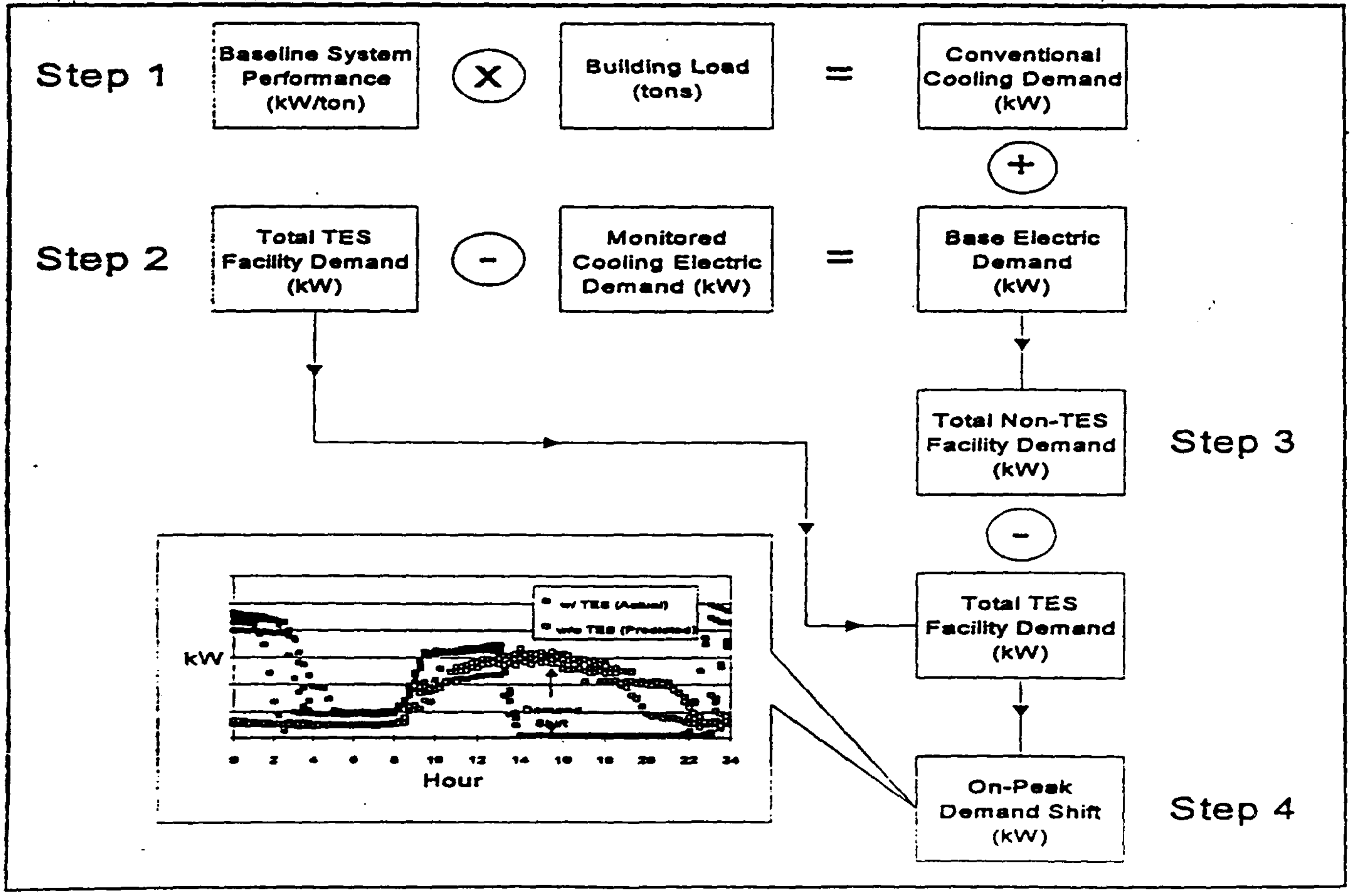

Figure 3 Analysis Methodology

- Three of the TES sites visited (sites three, fourteen, and twenty-one) were not being operated according to the correct time-of-use schedule. Although the building owners were informed of a change in the SRP rate periods, this information was not directly relayed to the TES operators. Operational changes were made subsequent to the on-site inspections.
- All five of the ice harvester system owners expressed significant concern over the maintenance costs and reliability of these systems. One of the units (site ten) was removed and replaced with a conventional system. Ice harvester installations represent 14% of SRP's incentivized demand.
- Most of the TES systems inspected had at one point or another experienced some on-peak electric usage as a result of a programming error, equipment failure, etc. As a result, the TES facilities have incurred penalties in the form of increased demand charges. This demand penalty is incurred even if the additional usage occurs for only a single fifteen minute time period during the on-peak window each month. As previously stated, for SRP C&I customers, this also includes weekends and holidays.
- Some of the facilities (areas served by the TES system) were not being used on a regular basis. These include two churches (sites eight and fourteen), and a school auditorium (site twenty-four). As a result, predicted demand shift at these sites was much less than the 369 kW expected by SRP and is unlikely to coincide with the on-peak period.
- The large chilled water systems (sites one and two) have proven to be very reliable TES applications from both SRP's and the Owner's perspective.

Although only twelve of the twenty-four sites were selected for short-term monitoring, these sites represented $1.2 million (80%) of the total incentive amount and 6.4 MW (80%) of the projected demand shift. The effective incentive payment for this demand shift was $186/kW. Based on monitoring results and extrapolating when necessary to peak load conditions, the actual projected *on-peak* demand shift is approximately 4.4 MW, or 70% of the incentivized demand. The corresponding effective incentive cost is $258 per kW. The discrepancy between the incentivized and monitored *on-peak* demand can be primarily attributed to the following:

- *Comparison to an unrealistic conventional base system.* For example, the conventional system selected for one school (site seven) was unitary package equipment with an efficiency of 1.7 kW/ton at 105°F ambient conditions. Actual monitored performance of the installed central plant was approximately 1.25 kW/ton (25% less).
- *Overestimation of the projected peak building cooling load.* As a result, the cooling electric demand due to primary cooling equipment and its associated auxiliaries was also overestimated.
- *Basing electric demand for pumps and motors on nominal horsepower (HP) and not brake horsepower (BHP), as per SRP guidelines.* This resulted in the demand savings due to auxiliary pumps that are off during the on-peak period being over estimated for almost all of the sites. For example, at one shopping mall (site one), assuming full load rated amperage for auxiliary motors resulted in the auxiliary electric demand being overestimated by approximately 100 kW as compared to actual operation.
- *Including demand savings from technologies other than TES in the incentive payment.* For example, one manufacturing site (site eleven) included the demand savings due to an air handler fan not being operated during the on-peak period. Also, a TES incentive payment for another manufacturing site (site six) reflected the demand savings associated with new more efficient chillers and high efficiency motors that were installed concurrently with the TES system.

By grouping TES sites into building categories, and evaluating both the on-site inspections and the monitored data, additional observations can be made about TES as it relates to the specific building sectors.

Churches: Churches are typically occupied on an intermittent basis. The TES systems at these sites were being used to meet relatively large and intermittent cooling loads of short duration which occur during morning mass. Since SRP's electric peak typically does not occur at this time, the incentive has effectively paid for cooling capacity rather than on-peak demand shift. That is, the thermal storage system serves to offset additional installed capacity.

Schools: The economics of installing TES systems at schools is very questionable from the building owners perspective. Since many schools are largely unoccupied during the summer months, utility savings are realized only during two summer months (May and September). The peak facility electric demand for schools typically occurs between 2 PM and 3 PM after which classes are dismissed and cooling requirements greatly decrease.

Large Retail: Although, only one shopping mall was monitored (site one), the building cooling load profiles were found to be very similar for both weekdays and weekends. Under the current SRP rate schedules (weekends are on-peak), mall owners will achieve utility savings seven days per week. From SRP's perspective, large retail malls will have a peak facility electric demand which is coincident with SRP's system electric demand. Large retail malls appear to be good candidates for TES systems.

Office: The peak electric and cooling profiles for office buildings tend to peak in the late afternoon. As such, office building represent a good TES application.

Industrial/Manufacturing: With the exception of one site (site eleven), all of the manufacturing facilities appeared to be good candidates for TES systems. (Two of the sites incorporated existing fire-water storage tanks.) The applicability of TES systems to this building sector should be decided on a case by case basis.

Table 2 Results Summary

Site #	TES Type	Building Type	System Size (ton-hrs)	SRP Incentive	Incentivized Demand Shift (kW)	Probable Shift (kW)	TES System Assessment					
							SRP			Owner		
							Good	Fair	Poor	Good	Fair	Poor
1	Chilled Wat.	Shopping Ctr.	10,300	$258,867	1,761	850		x		x		
2	Chilled Wat.	Office Tower	10,500	$144,920	1,282	1,200	x			x		
3	Chilled Wat.	Elem. School	1,700	$46,150	185	100		x		x		
4	Chilled Wat.	Church	300	$33,150	133	100		x		x		
5	Chilled Wat.	Manufacturing	2,000	$89,789	429	355	x			x		
6	Chilled Wat.	Manufacturing	1,500	$71,100	284	200	x			x		
7	Chilled Wat.	High School	1,150	$104,600	610	310		x			x	
8	Chilled Wat.*	Church	100	$49,950	200	50			x			x
9	Ice Harv.	Library	360	$13,450	54	50		x			x	
10	Ice Harv.	Rec. Center	600	$15,875	64	0			x			x
11	Ice Harv.	Manufacturing	325	$76,260	311	70		x		x		
12	Ice Harv.	Manufacturing	330	$79,082	336	350	x			x		
13	Ice Harv.	Office	850	$63,975	256	70		x				x
14	Ice Harv.	Church	470	$20,400	82	40		x			x	
15	Ice Bank	Office	2,280	$80,635	349	373	x			x		
16	Ice Bank	Dairy	1,000	$50,651	203	200	x			x		
17	Ice Bank	Training Ctr.	1,350	$38,250	153	80		x			x	
18	Ice Bank	Library	100	$3,350	14	0			x			x
19	Ice Bank	Office	430	$17,315	70	70	x				x	
20	Ice Bank	Office	540	$35,850	144	110		x		x		
21	Ice Bank	Middle School	1,330	$88,087	414	165		x			x	
22	Ice Bank	Elem. School	950	$36,500	146	146	x			x		
23	Ice Bank	High School	2,660	$84,591	384	369	x			x		
24	Ice Bank	Auditorium	570	$21,750	87	25			x		x	
TOTALS			41,695	$1,524,547	7,951	5,283	9	11	4	13	7	4

* Estimate during on-peak summer demand period

Recommendations

Evaluation of the installed TES projects in the Salt River Project territory has led to the following recommendations. These relate to both TES systems and the TES program in general.

- For smaller systems which utilize conventional chillers as part of the cooling equipment, the chillers should be sized to meet the entire building cooling load without thermal storage. This results in increased system reliability, allows for future expansion and increases the charging capacity of the system.
- SRP should maintain periodic contact with the TES operators at each site to ensure proper scheduling of the TES system. Several of the TES operators were unaware of the TOU periods and the economic penalty associated with operating equipment during the on-peak period. Copies of each month's utility bills showing demand and energy consumption by TOU period should be sent directly to the TES operator.
- Most of the TES sites experienced some on-peak electric usage due to equipment downtime. A single incident with fifteen minutes of downtime will result in the building owner losing all demand savings for the entire month. However, from SRP's standpoint, it is unlikely that more than one site would be down at any given time. Therefore, from an overall program perspective, SRP may be achieving a significant reduction in overall on-peak electric demand but from the TES systems at their owners' expense. As such, SRP may wish to review its billing policy for TES installations with respect to demand penalties experienced as a result of equipment downtime. A softening of the demand

penalty for equipment failure during non-system peak times may encourage additional TES installations.

- SRP will soon offer a new large commercial rate (E-51). This rate includes a Load Factor (LF) adjustment on the respective TOU demand charges (ie kW x LF). (LF is defined as the ratio of the average to peak demand during the TOU period.) This adjustment recognizes that although a facility may have periodic surges in its on-peak demand, from an overall system load perspective, it has little impact. Although, the rate was not specifically defined for TES, it will help alleviate the demand penalties discussed in the previous paragraph.
- The on-peak hours for SRP time-of-use (TOU) rate schedules E-32, E-37 and E-39, consist of those hours from 2:00 p.m. to 7:00 p.m., daily. That is, all hours between 2:00 p.m. and 7:00 p.m. are on-peak irrespective of weekends and holidays. A review of SRP's overall system demand profile should be conducted to see if making all weekend hours off-peak is warranted. (Note that SRP currently offers residential TOU rates in which all weekend hours are off-peak.) This would allow TES owners a full two days each week in which to perform maintenance on their TES systems as well as allow additional TES charging time.
- The SRP TES program is currently universally available to all qualifying facilities within its service territory regardless of facility size or type. A more cost effective approach would be to target specific "favorable" facilities. For example, consider a large chilled water TES system with an estimated demand shift of 1,000 kW versus ten ice storage systems which shift 100 kW each. Under SRP's current incentive payment Plan 1, the incentive payment would be $128,000 ($128/kW) for the chilled water system and $250,000 ($250/kW) for the ten ice systems. Additionally, the large chilled water plant is likely to have full time operating personnel, and as a result, increased system reliability. From a program administration and maintenance perspective, it will also be simpler to administer one facility rather than ten separate facilities.
- SRP should consider incentivizing all demand shifts at an equal rate as opposed to the declining block incentive rate currently available under Plan 1 (All kW shifted on-peak should be of equal value to the utility). This would inherently improve the economics of larger TES installations which typically have a lower effective installed cost ($/ton-hour).
- The calculated demand shift for motors is currently based on either nominal HP or from a table provided by SRP which gives full load amperes for various motor sizes. This assumption can grossly overestimate the demand due to motors. Motor demand should be based on the brake horsepower or actual amperage draw.
- TES should be considered coincidentally with other energy efficient measures. That is, energy efficient lighting, high efficiency chillers and motors should be examined before considering a TES system. It is generally more cost effective (from the owner's perspective) to reduce rather than to shift load.
- SRP's incentive payments are currently calculated on a demand shift that is determined from design calculations prior to the TES system being installed and operated. As a result, SRP has no assurance that the incentivized demand will approach the actual demand shift achieved by the TES installation. (For the twelve sites monitored, SRP achieved only 70% of the total incentivized shift.) SRP should consider a commissioning procedure whereby the actual demand shift of the TES is verified and incentivized accordingly. Several methods can be used to do this, all requiring minimal instrumentation which could be included as part of the program requirements.

TES in a less Regulated Market

The potential for retail competition has resulted in many utilities either eliminating or downscaling their DSM programs. In most cases, these programs are being replaced with programs more oriented towards customer satisfaction and customer retention. The strategies behind these programs fall into several categories, most of which can utilize TES as a component. The first strategy is to lower the customer's cost for electricity. If costs are reduced, customers will have less incentive to change suppliers. For TES technologies, if the utility's rate structure truly reflects its costs, the utility should continue to generate the same net revenue on a percentage basis because the net kWh sales are approximately the same before and after the TES installation. This is as opposed to other energy efficiency technologies which decrease kWh sales and net revenue. The load shape resulting from TES also frees up daytime capacity that can be sold elsewhere, hopefully at a premium.

The next strategy is to become involved in the actual installation of cost saving technologies like TES. Whether this involvement is through facilitation of the project, taking on full design and construction responsibilities, or (only) project financing, customer agreements can be put in place that "lock in" the customer for an extended period of time. Again, TES is ideal for this scenario because it is capital intensive (customers may have trouble financing the project internally) yet typically generates significant customer bill savings.

A third strategy involves the use of TES in a real-time pricing (RTP) scenario where smaller, partial shift TES systems can play a significant role in allowing customers to respond to real-time price signals. Very few other technologies currently allow the customer to respond to an increasing price signal without impacting the customer's operation in some negative way. In most commercial applications, facilities do not have large discretionary loads or the flexibility to take full advantage of RTP. A TES system effectively decouples building load (comfort) and the electric demand associated with cooling generation. As such.

TES can allow building owners to actively schedule central plant operation in response to RTP signals.

As a final thought, Electric utilities face competition not only from other electricity providers, but also from gas utilities. Gas utilities are aggressively promoting the use of direct-fired and engine-driven chillers. By using TES to reduce on-peak cooling demand, justification of gas absorption cooling on a life cycle cost basis becomes extremely difficult despite the increased first cost of TES relative to gas chillers.

Given the potential advantages that TES systems offer to owners along with the leverage they provide electric utilities in promoting customer satisfaction and customer retention, TES will continue to play an active role and may even increase its role in a less regulated market environment.