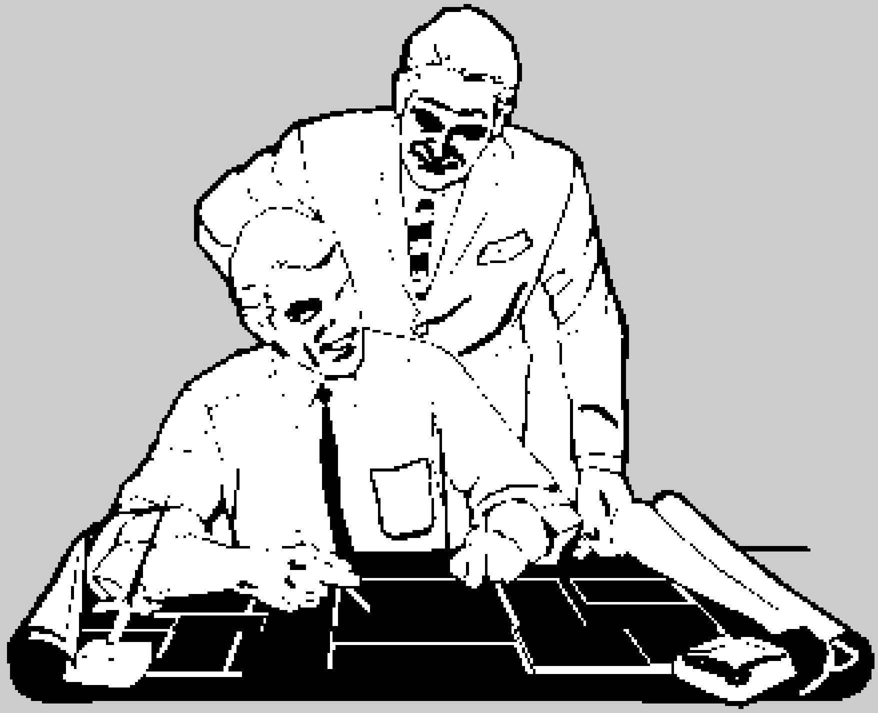

SOURCE ENERGY AND ENVIRONMENTAL IMPACTS OF THERMAL ENERGY STORAGE

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COMMISSION

Pete Wilson, *Governor*

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Prepared for:

CALIFORNIA ENERGY COMMISSION
Thermal Energy Storage
Systems Collaborative

Prepared by:

Tabors Caramanis & Associates
Davis, CA

Jamie Patterson, *Project Manager*
Pramod Kulkarni, *Program Manager*
Michael Smith, *Manager*

RESEARCH & DEVELOPMENT OFFICE

Nancy Deller, *Deputy Director*

ENERGY TECHNOLOGY
DEVELOPMENT DIVISION

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A full list of Collaborative members is included in the Appendix.

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FOREWORD

The California Energy Commission has a program called Opportunity Technology Commercialization (OTCOM). OTCOM's mission is to "effectively increase the market penetration of energy technologies offering compelling energy, environmental, diversity and economic development benefits". OTCOM selected Thermal Energy Storage (TES) as one such technology. TES allows cooling made at night to be stored for building air conditioning during the day.

To promote TES (as other technologies), OTCOM organized a Collaborative of utilities, consultants, proactive facility managers and TES product manufacturers. The Collaborative suggested the first key item of business was authoritatively analyzing the source energy[1] and other environmental benefits of TES in California. The Collaborative believed that one major obstacle to TES was a perception that TES increased energy use and increased environmental emissions. Therefore, the Collaborative decided an authoritative analysis on this issue in California was a necessary and desirable first step.

The Collaborative selected Tabors Caramanis & Associates to conduct this analysis for California with review by other respected organizations, such as those listed in the Acknowledgments. This report contains the results of this analysis. Based on the source energy and environmental results, the report also identifies possible policy actions by key energy and environmental policy makers.

[1] In California the "source energy" use of electrical equipment is defined as the BTU's of primary fuel required at the electric generating plant (or power plant) to run this electrical equipment.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The Thermal Energy Storage (TES) Systems Collaborative organized by the California Energy Commission requested an analysis of the source energy (power plant fuel) savings of electric Thermal Energy Storage (TES) systems in California. The Collaborative also requested an analysis of other TES impacts that are of concern to the California Energy Commission:

- Energy efficiency (source and site)
- Environmental (air emissions savings and CFC reductions)
- Economic development and competitiveness

Energy Analysis

Source Energy Analysis

In analyzing the source energy use of TES, the study focused on the two largest electric utilities in the state, the Pacific Gas and Electric Company (PG&E) and the Southern California Edison Company (SCE). These two utilities supply almost three-fourths of the electricity in the state. Two methodologies were used in this study. The first methodology—the “Incremental Energy method”—applied the standard planning methodologies used in California.[2] The second methodology—the “Marginal Plant method”—was a variation of the Standard California methodologies.[3] and is sometimes used outside of the state of California.

The results of the methods showed that the source energy savings for a particular TES system at a particular building depend on a number of factors, including:

- The building’s normal air conditioning usage pattern without TES (e.g., what percent of the cooling is summer vs. winter or day vs. night)

[2] As discussed in more detail in the section titled *Source Energy Analysis*, the “incremental energy” methodology applies the state's official methodology (as used by the California Public Utilities Commission, California Energy Commission, and utilities) for marginal cost calculations and resource planning (including Demand-Side Management programs such as TES) to the state's official guidelines for source energy analysis to develop time-differentiated source energy impacts. These impacts allowed the determination of source energy savings by shifting electricity usage from day to night with TES.

[3] The “marginal plant” method is similar to the state’s official methodology with one exception. It has a different way of computing marginal source fuel use in different time periods. This alternate methodology is also described in the section titled *Source Energy Analysis*.

- The design and operating strategy for the TES system (e.g., is the TES storage tank sized so that the air conditioning compressor runs only at night—full storage, or runs all day long—partial storage). [4]
- The characteristics of the utility supplying the electricity (e.g., amount of hydro power available).
- The methodology used—in particular, whether the savings from reduced "unit commitment" are included.[5]

	SCE	PG&E
Incremental Energy method	36%–43%	20%–30%
Marginal Plant method	12%–24%	8%–10%

Source Energy Savings of TES from Load Shifting (ignoring kWh savings).

In many California TES installations, 40 percent to 80 percent of the annual kWhs of electricity use for air conditioning will be shifted from day to night. In such installations the official Energy Commission methodology, the Incremental Energy method, showed large source energy savings. The savings per kWh shifted range from 36 percent to 43 percent for SCE and 20 percent to 30 percent for PG&E. The savings from the Marginal Plant method were lower but still substantial—12 percent to 24 percent for SCE and 8 percent to 10 percent for PG&E. This means that even if some TES systems used more kWhs than conventional air conditioning, such TES systems could still yield a net source energy savings.

If TES achieved a 20 percent market penetration by 2005[6], enough source energy would be saved from load shifting only (ignoring kWh impacts) to supply the energy needs of over a fifth of all new air conditioning growth projected by the California Energy Commission during the next decade. From another perspective, TES could save enough source energy to supply all the electric cars projected by the California Energy Commission to exist in the state in 2005. These are large potential fuel savings to the state of California.

Aggressive use of TES can save enough source energy to supply all 500,000 electric cars added in the next decade.

Site Energy Analysis

TES systems can notably improve energy efficiency over conventional air conditioning systems. Although early TES systems used more kWhs than conventional systems, monitoring of many recent TES systems shows these systems

[4] This study assumes that TES is operated under conventional Time-of-Use rates. Some studies have found that for thermal storage operating with intelligent control systems under hourly varying Real-Time Pricing, the utility's marginal energy cost savings (and presumably source energy savings) were up to double the savings for thermal storage operating under conventional Time-of-Use rates. (See, B. Daryanian, L.K. Norford, and R.D. Tabors, "RTP Based Energy Management Systems: Monitoring, Communication, and Control Requirements for Buildings under Real-Time Pricing." ASHRAE Transactions 1992, V.98, Pt. 1.) The California Public Utilities Commission recommends Real-Time Pricing as the dominant type of pricing in a competitive or re-structured electric power industry. Therefore, the source energy savings of TES under the increasingly more common Real-Time Pricing could be considerably higher than the source energy savings reported here.

[5] The main difference between the two methods is that the "Incremental Energy method" captures the fuel savings from reduced need for "unit commitment"—"committing" a power plant "unit" to run much of the day to be available to meet daily peak demand.

[6] Pacific Gas & Electric Company conducted an internal study, *Off-Peak Cooling Market Potential Study*, that conservatively estimates 20% as an achievable market penetration for TES.

use 12 percent fewer kWhs than conventional systems. These efficiencies are also attractive compared to the 20 percent to 50 percent energy penalties from using conventional utility storage technologies such as pumped hydro. Improving TES efficiencies reflect increased experience in applying some of the distinctive advantages of the TES technology.

Source and Site Energy Analysis Combined

When the site energy savings are combined with TES source energy savings noted above from shifting load, TES can achieve very considerable energy savings. In particular, again assuming a 20 percent market penetration by 2005, TES could save enough energy to supply over a third of the new air conditioning load projected by the California Energy Commission.

Environmental Analysis

Source Emissions Analysis

TES also provides a number of environmental benefits. TES can also help reduce combustion air emissions. In southern California, the South Coast Air Quality Management District (SCAQMD) explicitly identifies thermal storage as one way to reduce site emissions.[7] However, TES can also greatly reduce air emissions from power plants. In California where natural gas is usually the fuel of the marginal power plant, the reductions in power plant emissions are comparable to the energy savings from TES.[8] Assuming a 20 percent market penetration by 2005, TES could save 260,000 tons of CO_2 annually statewide. Just as importantly it could save about 1.6 tons of NOx per day in the SCAQMD. These NOx savings are equivalent to the savings from substituting almost 100,000 electric vehicles for gasoline vehicles.

TES can Reduce Air Emissions

At the Power Plant Source

TES can save 260,000 tons of CO_2 annually statewide. It also can save 1.6 tons of NOx per day for the SCAQMD—equivalent to almost 100,000 vehicles.

At the Building Site

TES can help reduce CFCs and combustion emissions.

Site Emissions Analysis

TES can help in the transition to air conditioning refrigerants without CFCs. For example, when existing chillers are converted to a non-CFC refrigerant, the chillers effective cooling capacity may be reduced. Some key facility managers see TES as making up the difference. In addition, partial storage TES systems can often only require half as much chiller capacity, which means half as much refrigerant is necessary.

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[7] These savings take place when a heat recovery storage system is used with cool storage system to use heat from the chillers in lieu of a separate boiler.

[8] As discussed in the section titled *Other Impacts of Thermal Energy Storage*, the difference in emissions costs for day vs. night are greater than the difference in source energy use. However, some of that difference is due to emissions being generated in different air basins. Therefore, to be conservative, the conclusion is that air emissions reductions are at least as great as the source energy and site energy savings combined—20 percent to 40 percent per kWh of annual cooling energy (using the “incremental energy” method), depending on the TES system application.

Economic Development / Competitiveness

TES enhances the competitiveness and economic development of both California energy suppliers and building owners. If a conservative 20 percent statewide market penetration of TES is assumed for California, considerable financial benefits can be illustrated:

For Energy Suppliers statewide, a few of the benefits that TES provides are:

- lower costs (30 percent to 50 percent lower to serve air conditioning load),
- reduced financing requirements ($1-2 billion), and
- improved customer retention.

For Building Owners statewide, a few of the benefits that TES provides are:

- lower costs (over half billion dollars annually),
- increased property values ($5 billion),
- increased financing capability ($3-4 billion), and
- increased revenues.

Note: These statewide numbers assume a 20 percent market penetration of TES for California.

Energy Supplier Competitiveness

Several factors work to enhance the energy supplier's competitiveness. For example, the marginal cost of serving a customer's air conditioning load can be decreased by 30 percent to 50 percent. In addition, electric utilities are about five times more capital intensive than other manufacturing businesses per dollar of revenue. Therefore, improving the customer's load factor by 30 percent to 50 percent with TES can mean a considerable reduction in the financing requirements and financial exposure from serving TES customers. Financing requirements could be reduced a billion dollars in Transmission and Distribution systems and perhaps comparable savings in generation capacity. Finally, the ability of TES to lower the average price to a customer provides another customer retention tool for energy suppliers.

TES' Value to Energy Suppliers Should Increase in a Deregulated Competitive Electricity Future

- **The Electric Power Industry is considerably more capital intensive than most other industries.**
- **Historically under "rate base" regulation, utilities had an incentive to *increase* capital investment.**
- **Under the emerging competitive markets and Performance Based Rate making, energy suppliers will *minimize* capital investment.**
- **TES improves load factor and capital efficiency better than most DSM programs; while accomplishing environmental benefits.**

Building Owner Competitiveness

The competitiveness of California building owners can also be enhanced. For example, the building owner can have lower energy and other costs (e.g., chilled water storage tanks can lower fire insurance premiums). Moreover, some commercial facilities managers believe that TES could be the best tool available for lowering power costs in a deregulated electricity industry. In addition, because TES increases the property value, the building owner can often obtain more external financing on a project and use less of the developer’s own cash. Finally, the building owner can increase revenues with TES—cold air distribution systems allow more floors of leasable space than conventional distribution systems, and, hence, greater revenues. These factors work to enhance the building owner’s competitive position in California.

TES is the best tool a commercial facility manager has for managing power costs under Real-Time Pricing, which the California Public Utilities Commission has proposed as the dominant type of pricing in a deregulated competitive electricity industry.

—Bill Kane, Energy Management Coordinator, San Francisco Moscone Marriott Hotel

—Ted Bischak, Senior VP, Tooley & Co., which manages several million square feet for The Irvine Company

Possible Policy Actions

Based on the energy savings and other benefits of TES, several possible policy actions emerge for consideration.

The first possible policy action is making TES a priority energy efficiency or Demand-Side Management program in state energy resource policy decisions. TES has demonstrated impressively large energy and air emission savings like other energy efficiency programs. But unlike most energy efficiency measures, TES also measurably improves load factor and provides cost savings that help both energy users and energy suppliers be more competitive.

1. Make TES a priority DSM technology in energy policy decisions.
2. Modify California’s Title 24 Building Standards to reflect TES’ source energy savings and peak demands reductions.
3. Use TES as an air emissions control measure statewide.
4. Identify TES as a priority option for new and replacement cooling systems in “competitive energy environmental partnerships” with key energy users, such as:
   a) local, state, and federal government buildings, and
   b) businesses striving to be environmental leaders, as in the EPA’s Energy Star Program.

Possible Policy Actions to Promote TES.

The second possible policy action is to modify the State of California Title 24 Building Standards method of comparing alternative cooling technologies’ energy efficiencies. The California Energy Commission could re-examine the role of source energy comparisons of alternative systems including the opportunities of TES systems. In addition, as in Switzerland[9], the building code could encourage designers to lower the building peak demands with TES.

The third policy action is recognizing TES as an effective air emissions control measure. The South Coast Air Quality Management District has recognized thermal storage as a way to reduce site emissions.[10] Other air districts could follow suit. In addition, many California air districts would benefit from encouraging TES as a control measure for power plant emissions.

The fourth policy action is promoting TES as a priority cooling system option in “environmental partnerships” with key energy user groups. One such group could be “sister” governmental agencies of the Energy Commission, including local, state and possibly federal government agencies. Another possible group includes businesses striving to be “environmental partners.” As an example, the US Environmental Protection Agency has had considerable success in obtaining business “environmental partners” in their Energy Star programs such as Green Lights. This program has obtained a number of business partners in California who have committed to installing high efficiency lighting in 90 percent of their floor space over a five year period when the internal rate of return (IRR) exceeds 20 percent. California could develop a “Competitive Electricity Environmental Partnership” program for TES that is modeled after the Energy Star program This partnership would position California businesses to benefit from a competitive electricity market and help clean the air as well. Alternatively, perhaps TES could be included as a priority cooling technology in the second phase of the Energy Star program—which moves from lighting to heating and air conditioning system improvements.

• Allergan*	• Long’s Drugs
• ARCO	• McDonald’s*
• Bank of America*	• Rockwell*
• California State University System*	• SCAQMD
• State of California*	• The Shorenstein Company
• Chevron*	• TransAmerica
• Embarcadero Center*	• Wal-Mart*
• Hewlett Packard*	• Walt Disney Studios*

*Organizations with TES installed in at least one site.

Sample of Organizations in EPA Energy Star/Green Lights Program that have a Significant California Presence.

In summary, this study demonstrates that TES is an “energy technology offering compelling energy, environmental, diversity, and economic development benefits to California.” Moreover, TES is now poised for full commercialization. Institutional policies, such as those previously identified, can be pursued to “effectively increase the market penetration” of TES—as the California Energy Commission desires.

[9] For example, the Geneva Electric Utilities Article 117A requires in any building over 10 kW demand that “the installation must be designed to limit the maximum needed power by cutting excessive thermal charges.” Moreover, the designs reviewed by a commission must analyze the possibility of thermal storage and waste heat recovery.

[10] South Coast Air Quality Management District, 1994 Air Quality Management Plan. Appendix IV-A, Stationary Source Control Measures. “Area Source Credit Program for Commercial and Residential Combustion Equipment [NOx]”.

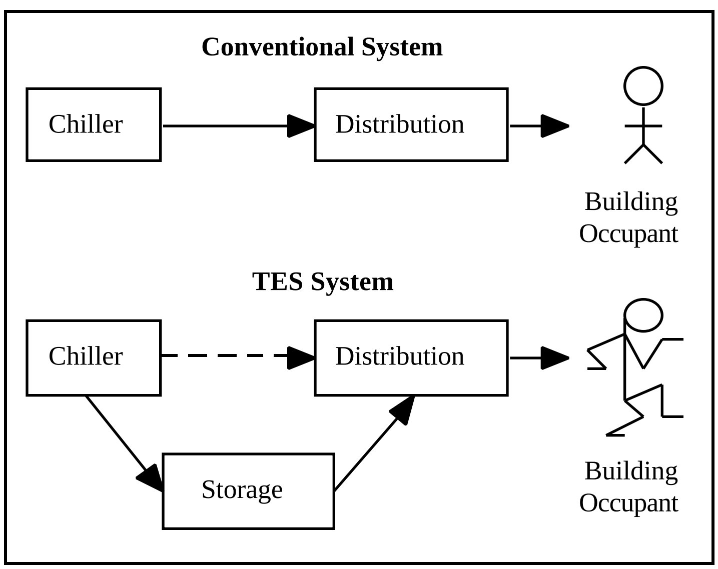
WHAT IS THERMAL ENERGY STORAGE?

WHAT IS THERMAL ENERGY STORAGE?

Thermal Energy Storage is a technology that stores "cooling" energy in a thermal storage mass.[11] As Figure 1 shows, the storage mass can be a third major component of an air conditioning or cooling system in a building. In most conventional cooling systems, there are two major components:

- Chiller—to make water or some other fluid cool
- Distribution system—to take the cool water (or fluid) from the chiller to a place where it cools air for the building occupants.

In conventional systems, the chiller must be run only when the building occupants want cool air. In a storage cooling system, the chiller can be run at times other than only when the occupants want cooling.

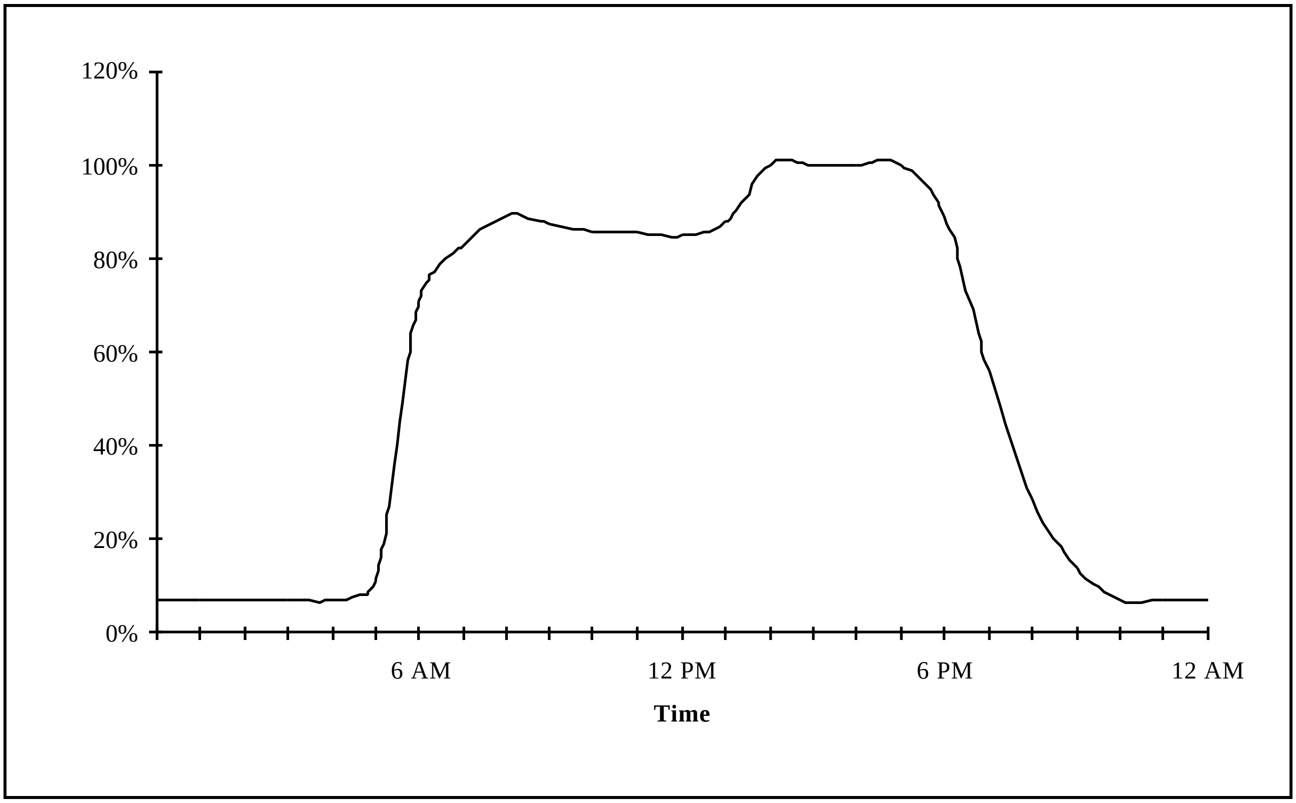


Major System Cooling Components.

Figure 1

[11] The term "Thermal Storage" usually includes systems that store heat as well as store cool. In California the primary use for storage is cool storage because of the dominant summer electricity peaks due to air conditioning. In this report, Thermal Energy Storage implies cool storage.

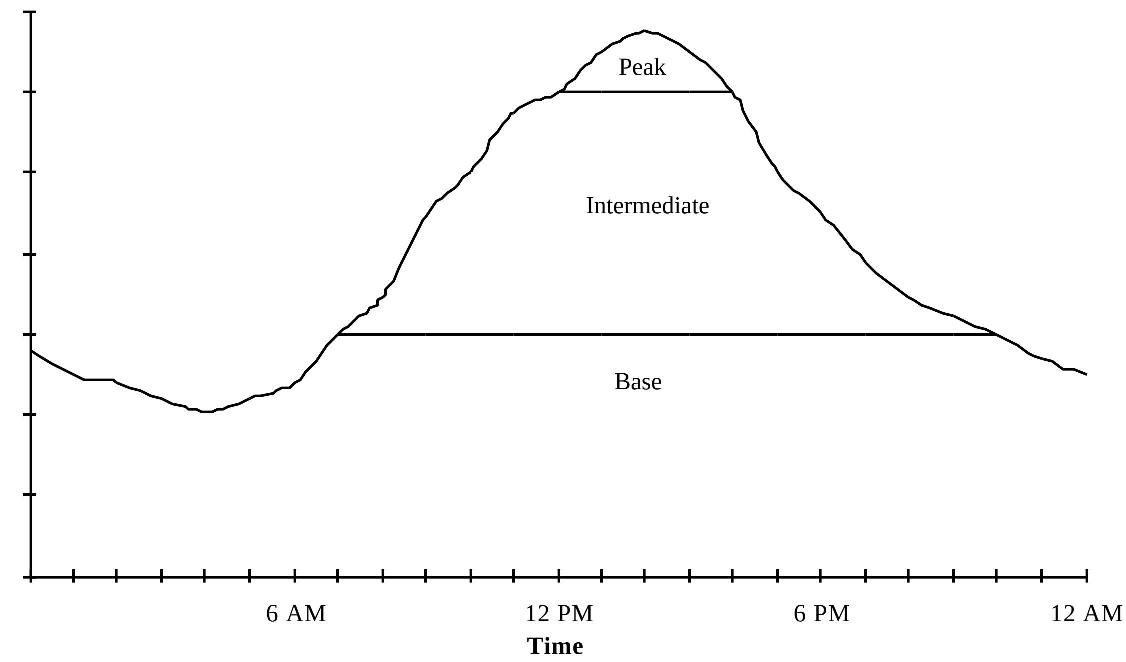
There are some advantages to being flexible as to when the chiller can run, since the chiller is typically the most energy intensive part of a cooling system. For example, Figure 2 shows the amount of cooling desired at various hours of the day in a typical commercial office building. Not surprisingly, the cooling demands are highest when the building is occupied and when the outside temperature is hottest during the afternoon. In a conventional cooling system the electricity use follows the demand for cooling—since the chiller must run to cool the building.



Cooling Requirements Vary Throughout the Day
A Commercial Building Example.

Figure 2

Air conditioning (and industrial process cooling) makes up almost a third of the aggregate electricity demand on California utility systems during the summer. Therefore, the aggregate utility demand tends to have the same pattern as a building's cooling demand. Compare Figure 3 to Figure 2. Moreover, to keep over-all electricity costs down, electric utilities run their most economic (and typically most efficient) "base load" power plants as much as possible. Other power plants are somewhat less efficient. These "intermediate" power plants see limited use during the day. Finally, plants with the highest operating costs (and typically lowest efficiency) are mainly used during the few "on-peak" hours. Hence, they are called "peak" load power plants or sometimes just "peakers."



Total Demand on Electric Utility is Served by Different Types of Power Plants.

Figure 3

The cost to produce a kWh of electricity is highest during these on-peak hours. Two factors contribute to these high costs. First, the California utilities must build enough capacity to meet the highest or peak demand. Therefore, much of the utility's capacity related costs are charged during these on-peak hours (often as peak "demand" charges). Second, because the least efficient power plants run during the on-peak hours, the costs of generating the electrical "energy" are higher during those hours. This leads to a situation in which electricity users can reduce their electricity costs under Time-of-Use[12] rates if they can reduce their peak electricity use. TES provides electricity users that opportunity.

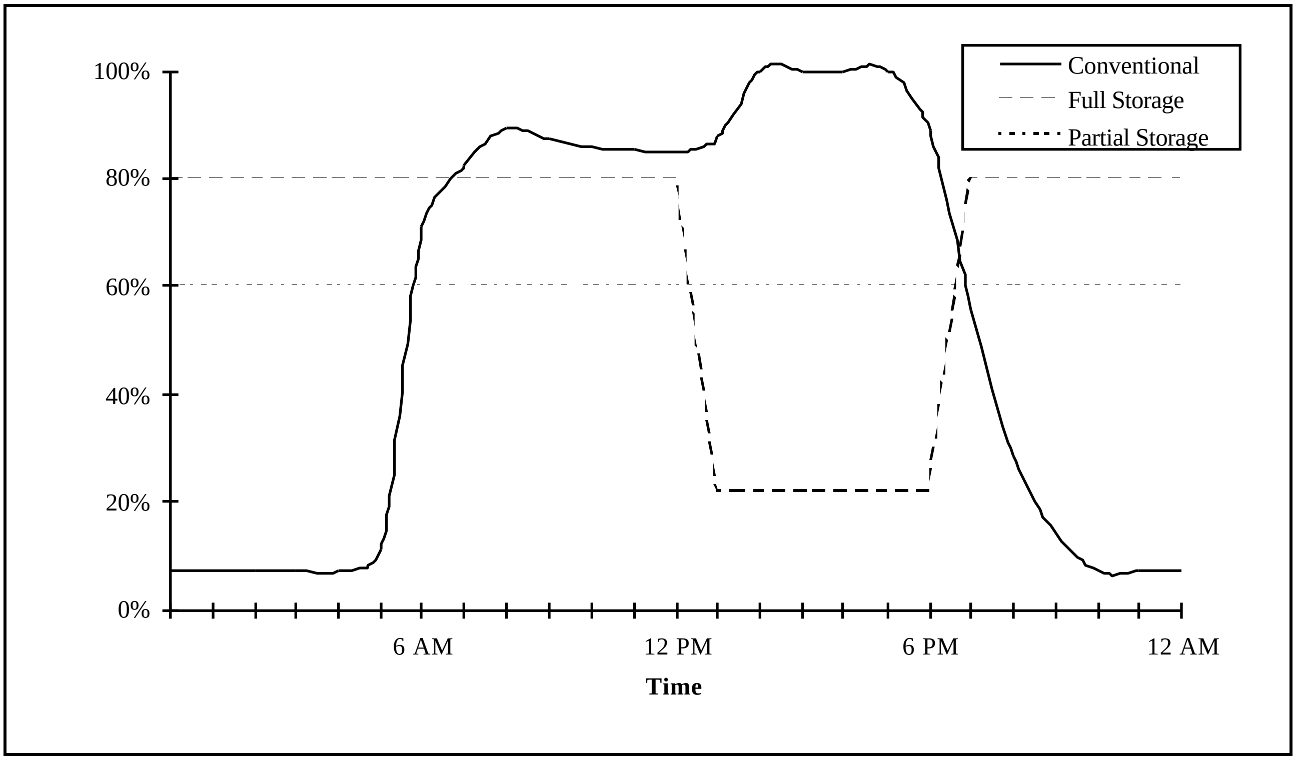
TES Offers Money Saving Opportunities!

- **An Electric Utility's costs and prices are much higher during on-peak hours.**
- **An energy user who uses less on-peak electricity will save money.**
- **Thermal Energy Storage reduces on-peak electricity use.**

There are typically two basic strategies for using TES to reduce on-peak electricity use, as Figure 4 shows. The first strategy, "full storage," sizes the chiller and storage tank so that the chiller does not run at all during the peak hours even on the hottest days. In contrast, the "partial storage" strategy sizes the chiller and storage tank so that a smaller

[12]Time-of-Use rates are utility service options in which the price varies by the "time-of-use." In California prices are highest during the summer weekday afternoons and lowest at nights and weekends.

chiller runs continuously on hot days. The main advantage of the “full storage” system is that it minimizes electricity costs. The main advantage of the “partial storage” system is that a smaller chiller and smaller storage tank reduce the capital costs of the TES system.



Electricity Use for Cooling with TES.

Figure 4

To achieve these strategies, five major types of TES systems usually are used, as Table 1 shows. The first type uses “chilled water” as the storage medium. It has the advantage of being compatible with existing chillers and probably being the most energy efficient storage system. It has the disadvantage of requiring much larger storage tanks than the other storage media.

The second type of TES system uses a “eutectic salt” water solution as the storage medium. Eutectic salt systems store cooling by freezing a solution at a temperature typically near 47°F. This gives these systems two major advantages. One, by storing cooling through a phase change (freezing) smaller tanks are required than for chilled water. Two, by freezing at 47°F, standard chillers producing 41°F chilled water in commercial facilities can be used. The biggest disadvantage is that the tank typically cools the water for the distribution system to only 48–50°F, which accomplishes less dehumidification of the building and requires more pumping energy.

Chiller [13]	Storage	Distribution
Conventional	***Chilled Water***	Conventional
Conventional	***Eutectic Salt***	Conventional
Ice	***Ice***[14]	Conventional
Ice	***Ice***	Cold Air
Ice	***Ice***	Unitary (Rooftop)

Major TES Cooling System Options

Table 1

The next three storage systems have one thing in common—ice as the storage medium. They differ in how the “cool” from the ice is distributed to the building occupants. Before considering the differences in the distribution systems, consider the features of their common components—ice storage and chiller. The main advantage of ice systems is their compact storage size—ice tanks may be only 10 percent to 20 percent and 30 percent to 50 percent of the size of comparable chilled water and eutectic salt tanks, respectively. For many commercial developers where space is a premium this can be a real advantage. Another major benefit when used with cold air or rooftop distribution systems are the additional dehumidification benefits and fan energy savings. The major disadvantage of ice systems is that most conventional chillers that chill water cannot be used—special chillers capable of making ice must be used. Ice chillers use more energy than conventional water chillers because of the lower temperatures required to freeze water into ice.

Ice storage systems can be used with conventional chilled water distribution systems. Ice storage systems, however, are particularly beneficial when the distribution system has been designed to take advantage of the colder water to produce “cold air.”[15] The distribution system (fans and ducts) can be down-sized which leads to three major benefits. First, the initial cost of the distribution system is lower. Second, the energy use by the distribution system is lower—fan and pump energy use may be lower by 40% or more.

Third, smaller ducts can mean lower floor-to-floor heights in high rise buildings—which allows architects to design additional floors without increasing building height and lower the net cost per square foot of floor space.

The first four TES systems listed in Table 1 are used mostly with typical chilled water distribution systems in larger buildings. The last listed type of storage system is used with unitary systems. Unitary systems include those used with typical single-family residences with an outdoor condensing unit and indoor coil with a gas furnace or electric heat, or heat pumps and air handler. Unitary systems also include single-package systems that are roof mounted on low-rise commercial buildings and, in certain geographical locations, some residences. These unitary systems use a “direct expansion” process where the refrigerant, not chilled water, cools the air that is delivered directly to the occupied structure. These smaller unitary systems are typically air cooled and are generally not as efficient as most of the water-cooled chilled water systems used on larger buildings. Because of the usually lower efficiency of these air-cooled unitary systems, these systems maybe an attractive target for the next wave of TES installations.

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13 Electrical centrifugal or gas absorption chillers are typically the conventional water chillers. Electrical reciprocating, screw scroll or multi-stage centrifugal chillers and gas reciprocating chillers are normally used to make ice.

14 There are several types of ice storage systems including ice harvester, external melt ice, internal melt ice, and encapsulated ice. For simplicity they are combined here. For more detail on each, see ASHRAE's "Design Guide for Cool Thermal Storage."

15 Ice systems typically discharge water at 34–38°F from the storage tank and supply “cold air” at 42°F to the occupant space. In contrast, conventional systems send water into the distribution system at 40–44°F and supply air at 55°F into the occupant space. Please note that some chilled water storage tanks may be super cooled to also discharge water at 34–38°F.

Another factor about these unitary systems makes them an attractive target. Because they run fewer hours, they leave residential and small commercial customers with poor load factors—which are more costly for utilities to serve. Since a high proportion of utility capital expenditures are to provide T & D systems for these customers, improving their load factors can save large amounts of capital dollars.

This concludes a brief description of TES, its benefits to the energy user, the California electricity supply system, and the five main types of TES system technologies. The next section analyzes the source energy use of TES.

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SOURCE ENERGY ANALYSIS

SOURCE ENERGY ANALYSIS

A major focus of this study is determining the increase or decrease in energy use at the source due to Thermal Energy Storage (TES). The general belief is that TES reduces the fuel or energy required at the source by changing the time at which kWhs of electricity are used. This study tests that belief by quantifying the source energy impact of TES.

Two methodologies for determining source energy impacts are first defined. Then the methodologies are applied to California's two largest utilities, SCE and PG&E, which together supply almost three–fourths of the electricity in the state.

Methodology

Two methods were developed for calculating source energy savings.

- Incremental Energy method
- Marginal Plant method

The Incremental Energy method is the most consistent with existing planning methods in California. The Marginal Plant method is fairly consistent with the Incremental Energy method, but has one major difference—its energy savings are based on system lambda which does not recognize the energy use associated with unit commitment.[16]

In the following discussion, the Incremental Energy method development is fully described. Then the Marginal Plant method is described, with emphasis on its major difference with the Incremental Energy method. Finally, this major difference—the inclusion of unit commitment savings in the Incremental Energy method—is discussed.

Incremental Energy Method

In defining the methodology for this study, the first source of guidance was the standard planning methodologies used in the state of California. In particular, several accepted standard methodologies guided the development of this study's methodology. The first was the use of "marginal" costs (rather than average costs) for all resource planning and rate design decisions. That is, the decision about which resource to use is based on how the costs of providing power would change for a marginal or incremental change in electricity use beyond current usage levels. The State (both California Public Utilities Commission (CPUC), and California Energy Commission) also believes that the

[16] "Unit commitment" refers to the system operating practice of "committing" a power plant "unit" to warm up and run for many hours in a day so that it's available to meet the daily peak demand.

marginal costs should be reflected in the design of electric rates so that the energy users get a proper price signal that will lead to wise use of energy resources in the state.

From this perspective, a Standard Practice Methodology[17] has been developed for evaluating the cost-effectiveness of both new supply resources and demand side (or Demand-Side Management—DSM) resources. DSM resources reflect the perspective that energy efficiency programs (aimed primarily at reducing the kWh use) and load management programs (aimed primarily at reducing the kW of peak demand) can be considered as the equivalent of a special type of supply-side resources in resource planning decisions. The Standard Practice Methodology evaluates DSM programs by comparing the kWh and kW savings against the marginal cost (of supply) for providing those kWhs and kWs. This Methodology has gained national and international acceptance as a rational way to evaluate DSM programs—including TES.

One key feature of the Standard Methodology for evaluating TES programs is that it divides the year into time periods—and differentiates the marginal costs (both kW and kWh) by time periods. Figure 5 shows how SCE and PG&E currently divide the year into five time periods. Note that both SCE and PG&E define the summer on-peak period as being (working) weekdays from noon to 6 P.M. The two utilities' definitions of mid-peak and off-peak differ slightly. Note that there is no winter on-peak period because of the dominance of the summer peak in determining new (marginal) capacity decisions. Finally note that SCE defines a four-month summer whereas PG&E defines a six-month summer. The number of summer months will later influence the source energy results.

		SCE	**PG&E**
Summer	**Days:**	**Jun.–Sept.**	**May–Oct**
On-Peak	Weekdays:	12–6 P.M.	Noon–6 P.M.
Mid-Peak	Weekdays:	8 A.M.–Noon 6 P.M.–11 P.M.	8:30 A.M.–Noon 6 P.M.–9:30 P.M.
Off-Peak—all other hours, including holidays and weekends.			
Winter	**Days:**	**Oct.–May**	**Nov.–April**
Mid-Peak	Weekdays:	8 A.M.–9 P.M.	8:30 A.M.–9:30 P.M.
Off-Peak—all other hours, including holidays and weekends.			

Five Time Periods Used in the Standard Practice

Figure 5

The core formula for the Standard Practice methodology is shown in Figure 6. Note that the annual dollar savings of resource benefits of a DSM program is computed by determining the kWh and kW savings in each of the five time periods, multiplying those savings by the marginal cost for that time period, and then summing the dollar savings across all time periods.

$$\text{DSM Program Savings} = \sum_{i=1}^{5}\Big[\big(\text{kWh Savings}\big)_i \times \big(\text{Marginal Cost of kWh}\big)_i\Big] + \sum_{i=1}^{5}\Big[\big(\text{kW Savings}\big)_i \times \big(\text{Marginal Cost of kW}\big)_i\Big]$$

The Standard Practice Core Formula

Figure 6

[17] See, for example, California Public Utilities Commission and California Energy Commission, *Standard Practice Manual: Economic Analysis of Demand-Site Management Programs*. December, 1987.

Recently the CPUC (with Energy Commission concurrence) has modified the Standard Practice to provide some guidelines on source energy analysis. In particular, the CPUC was faced with the decision of how to evaluate the appropriateness of “fuel substitution” programs—that is, programs designed to have a customer substitute a technology using one “fuel” with a technology using a different “fuel”. An example of this is encouraging heat pumps to replace gas furnaces (or vice versa). As part of the fuel substitution guidelines, the CPUC developed a source energy test. The CPUC said that, among other things, for a fuel substitution program to be acceptable, it could not use any more BTU’s of source fuel than the fuel it was replacing. Moreover, the CPUC defined the “source BTUs” of electricity to be those fuel BTUs used at the power plant to generate electricity.[18]

The CPUC also said the way to equate source BTUs of natural gas with source BTUs of electricity was to use the Energy Commission’s official annual average electric power plant “heat rate” contained in the Title 24 Building Efficiency Standards (10,239 BTUs/kWh). For most DSM programs, using an annual average number is acceptable for determining source energy savings. However, for TES it is not. The CPUC has previously not needed to modify the source energy method for TES because TES was considered a “load management” program rather than a “fuel substitution” program—and source energy calculations are not required for load management programs.

Personal communication with CPUC staff reveals an acceptable way to modify the Standard Practice method and numbers to develop source energy savings estimates of TES programs.[19] In particular, the “marginal cost of a kWh” is often called the “marginal energy cost.” This cost (in $/kWh) for each of the five time periods equals the cost of fuel (in $/BTU or usually $/million BTUs) multiplied by the average heat rate or more precisely Incremental Energy Rate (in BTU/kWh). Since natural gas is almost always the fuel of the marginal plant,[20] dividing the marginal energy cost for each of the five time periods by the price of natural gas yields the average Incremental Energy Rate (in BTU/kWh) for each of the time periods, as shown in Figure 7. In fact, SCE explicitly makes such a calculation as part of its materials submitted to the CPUC in calculating marginal energy costs for rate design.[21]

For each of the five time periods:

$$\text{Incremental Energy Rate (BTU/ kWh)} = \frac{\text{Marginal Energy Cost (\$/ kWh)}}{\text{Price of Marginal Plant's Fuel (\$/ BTU)}}$$

Determining the Incremental Energy Rate

Figure 7

This Incremental Energy Rate perspective can be applied to the Standard Practice’s Core Formula in Figure 6 to develop a formula for calculating source energy savings. In particular, dividing all marginal energy (kWh) cost terms in the formula in Figure 6 by the marginal fuel price ($/BTU) yields the formula in Figure 8 for calculating source energy savings.[22]

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[18] The CPUC also defined the source BTUs of natural gas and other fuels essentially to be those used at the burner tip of the energy user's equipment, such as a furnace. See CPUC decision D94-10-059 for more details.

[19] Don Schultz, Personal communication, December 1993, and Scott Logan, Personal communication, June 1995.

[20] Natural gas is the fuel of the marginal power plant enough of the time that in calculating marginal costs for resource planning decisions it is assumed to be the marginal fuel all of the time. Personal communication, PG&E planner, January, 1995. Also see the working papers to SCE's Marginal Cost exhibit in the General Rate Case for test year 1995.

[21] See the working papers to SCE's Marginal Cost exhibit in the General Rate Case for test year 1995.

[22] The “kW” terms fall out of the equation in Figure 8 since there is no “energy” use associated with them.

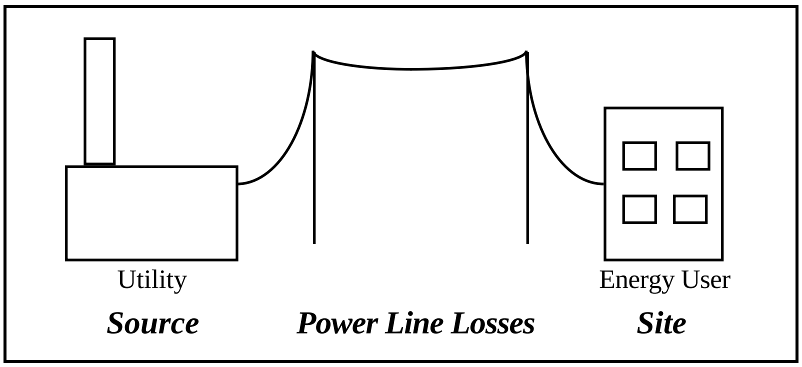
$$\text{DSM Program Source Energy Savings} = \sum_{i=1}^{5}\left[(\text{kWh Savings})_i \times (\text{Incremental Energy Rate})_i\right]$$

Source Energy Savings Formula

Figure 8

Before applying the formula of Figure 8 to calculate the source energy savings of TES, one clarification and one simplification should be made. Figure 9 shows three components in determining source energy use. The first component is the number of kWhs at the energy user's site. The second component, as discussed previously, is the fuel used at the power plant to generate the kWhs for use at the energy user's site. But a third component is sometimes overlooked.

The third component is the energy used to get the electricity across the power lines from the power plant to the user. In particular, energy is lost due to resistance in the power lines (line losses). For example, to get 1.00 kWh of electricity delivered to the energy user's site, 1.10 kWhs may need to be input into the power lines at the power plant. This amounts to a 10 percent line loss. Moreover, an important factor in this TES analysis is that these line losses vary across the five time periods. In particular, line losses are highest when the lines are more fully loaded and when the ambient temperature is hotter. Both of these factors lead to line losses being higher during the summer on-peak period. Therefore, TES saves energy by shifting electricity use to times of lower line losses.



Three Components of Source Energy Use

Figure 9

Marginal cost numbers may or may not reflect line losses. In some analyses, the utility is concerned about marginal costs at the power plant (or generation) level. In other analyses, the utility is concerned about marginal costs at the energy user site (or distribution) level. When calculating marginal costs at the distribution level, the generation level marginal costs are increased to reflect the line losses to the distribution level, as Figure 10 shows. When evaluating DSM programs which have their impacts at the energy user's site, the utilities, CPUC, and California Energy Commission use the distribution level marginal costs that reflect the line losses.

$$\text{Marginal Energy Cost (\$/ kWh at Site)}$$
$$= \text{(Marginal Fuel's Price)} \times \text{(Incremental Energy Rate)} \times \text{(Line Loss Factor)}$$
$$= \text{(\$/ BTU at Power Plant)} \times \text{(BTU/ kWh at Power Plant)} \times \frac{\text{(kWh input at Power Plant)}}{\text{(kWh output at Site)}}$$

Calculating Marginal Energy Costs at the Site Distribution Level

Figure 10

This point is highlighted to show that the source energy savings formula for DSM programs in Figure 8 needs to start with marginal energy costs at the distribution level. If not, then the Incremental Energy Rates at the generation level need to be multiplied by the line loss factors to reflect energy usage at the distribution or site level. Indeed, the data provided for this study was Incremental Energy Rates at the generation level—to which line loss adjustments were made to get source energy savings from a kWh change at the site level. To clearly accommodate the line-loss factors, the source energy savings formula in Figure 8 is modified to that shown in Figure 11. Note that the formula is the same as in Figure 8 except that the Incremental Energy Rate is broken into two components—the Incremental Energy Rate at the power plant source and the line loss factor to get the energy to the customer site.[23]

$$\text{TES Source Energy Savings} =$$
$$\sum_{i=1}^{5} \left[\left(\text{kWh Savings}\right)_i \times \left(\text{Incremental Energy Rate}\right)_i \times \left(\text{Line Loss Factor}\right)_i \right]$$

Final Source Energy Savings Formula

Figure 11

In addition to this clarification, one simplification made the source energy savings calculations easier. The simplification is that the source energy savings are normalized and are assumed to yield no net kWh savings at the site. This is illustrated in Figure 12. For example, a kWh "saved" in the summer on-peak period was assumed to be shifted to the mid-peak and off-peak period (where it shows up as increased kWh use).

The same approach was used for the winter—in which all kWh savings during the mid-peak period were assumed to be shifted to off-peak. However, the size of the number of kWhs "saved" during the winter mid-peak was varied to reflect the fact that for different buildings in different locations the winter mid-peak kWhs and summer on-peak kWhs will be a different percentage of the annual kWhs. For example, assume a building site without TES would normally use 30 percent of its annual cooling kWh during the summer on-peak period and 40 percent of its annual cooling kWh during the winter

[23] The formula of Figure 11 assumes that the TES system is operated under conventional Time-of-Use rates whose time periods match the five time periods of this analysis. TES systems can also be operated with intelligent control systems under hourly varying Real-Time Pricing (RTP). Such operation can exploit cost variations within the five time periods. Indeed, in some situations the thermal storage savings of marginal energy costs (and presumably source energy) under intelligent Real-Time Pricing control was almost double the savings under conventional Time-of-Use control. (See, B. Daryanian, L.K. Norford, and R.D. Tabors, "RTP Based Energy Management Systems: Monitoring, Communication, and Control Requirements for Buildings under Real-Time Pricing." ASHRAE Transactions 1992, V.98, Pt. 1.) The California Public Utilities Commission recommends Real-Time Pricing as the dominant type of pricing in a competitive or re-structured electric power industry. Therefore, the source energy savings of TES under the increasingly more common Real-Time Pricing could be considerably higher than the source energy savings reported here.

mid-peak period. Also assume the site then installed a full storage TES system and shifted all summer on-peak kWhs and all winter mid-peak kWhs. In this situation, the X in Figure 12 would become 1.33, (40% ÷ 30%). If the building used a partial storage system, then maybe only $^{2}/_{3}$'s of the summer on-peak kWhs could be shifted. Then the X in Figure 12 would become 2, (40% ÷ ($^{2}/_{3}$ × 30%)). In the analysis later in this section, the value of X is varied to reflect a range of building types (e.g., large office, small office and hospital), TES storage systems (full vs. partial), and utility service areas.

Summer[24]		
	On-peak	–1.00 kWh
	Mid-peak	.25 kWh
	Off-Peak	.75 kWh
Winter		
	Mid-peak	–X kWh
	Off-Peak	X kWh

Typical TES kWh Shifting Across Time Periods

Figure 12

One of the advantages of making the assumption of no net kWh savings in Figure 12 is that it allowed this study to separate the source energy savings analysis from the site (or kWh) savings analysis. A number of other studies have been conducted examining site energy savings, as discussed in the next section. The Collaborative wanted this source energy analysis to be separated from any analysis of site savings.

This concludes the discussion of the Incremental Energy methodology for calculating source energy savings. This is the methodology most consistent with existing DSM planning and evaluation practices in California. As a point of comparison, however, one other methodology, the Marginal Plant method, was used. This alternate method is further described.

Marginal Plant Method

The Marginal Plant method is the same as the Incremental Energy method with one major difference—a "Marginal Plant" heat rate is calculated to replace the Incremental Energy Rate in the formula in Figure 11. In this method, the heat rates implicit in the "system lambda" (or modified system lambda) used by system operators to regulate power plant operation is used. System lambda is the marginal cost per kWh at any given time to serve an increased or decreased load. System lambda is used to adjust most power plants operating levels up or down so as to minimize production costs while matching generation to the level of electrical demand. If system lambda is divided by the cost of fuel for the marginal power plant, then marginal heat rate numbers can be also derived from it. Alternatively, the heat rate of the marginal plant can directly be determined. The heat rates of the marginal plant were averaged across all hours of a time period to determine the "marginal plant" heat rate for that time period. These heat rates can be compared for the different time periods to determine the source energy savings from shifting a kWh.

Unit Commitment Energy Use—the major difference between the two methods. The CPUC and California Energy Commission do not use system lambda (as the Marginal Plant method does) to determine marginal energy costs in their marginal costs analyses for rate design and resource planning. The major reason is that system lambda does not reflect the fuel use required for "unit

[24] These numbers are based on Pacific Gas & Electric Company's experience with TES systems. Ken Gillespie, PG&E, Personal Communication, January 1995. Also note that these numbers are changes in kWh use—or the negative of changes in savings.

commitment". That is, most conventional steam power plants cannot be turned on only during the hour that they are needed. Therefore, a utility often must "commit" some power plants to warm up and operate in the middle of the night even though they are only needed to meet daily peak demand. Leaving the plants running during the night at lower capacity levels uses fuel less efficiently. Lowering the daily peak demand reduces the number of power plant units that must be committed. Then all other units can operate more fully loaded and, thus, more efficiently.

The fuel efficiency impact of plant loading is illustrated with California utility data submitted to the Energy Commission, as Figure 13 shows. The steam plant is quite efficient at full loading with a heat rate of 7,900 BTU/kWh. The heat rate, however, increases (and efficiency decreases) when the plant is run only partially loaded. For example, at a 30 percent loading (130.5 MW) level, the heat rate increases to 11,744 BTU/kWh—almost a 50 percent decrease in efficiency.

Steam Plant		
% of Full Loading	**MW**	**Heat Rate BTU/kWh**
100%	435.0	7,900
70%	304.5	7,950
50%	217.5	8,934
30%	130.5	11,744

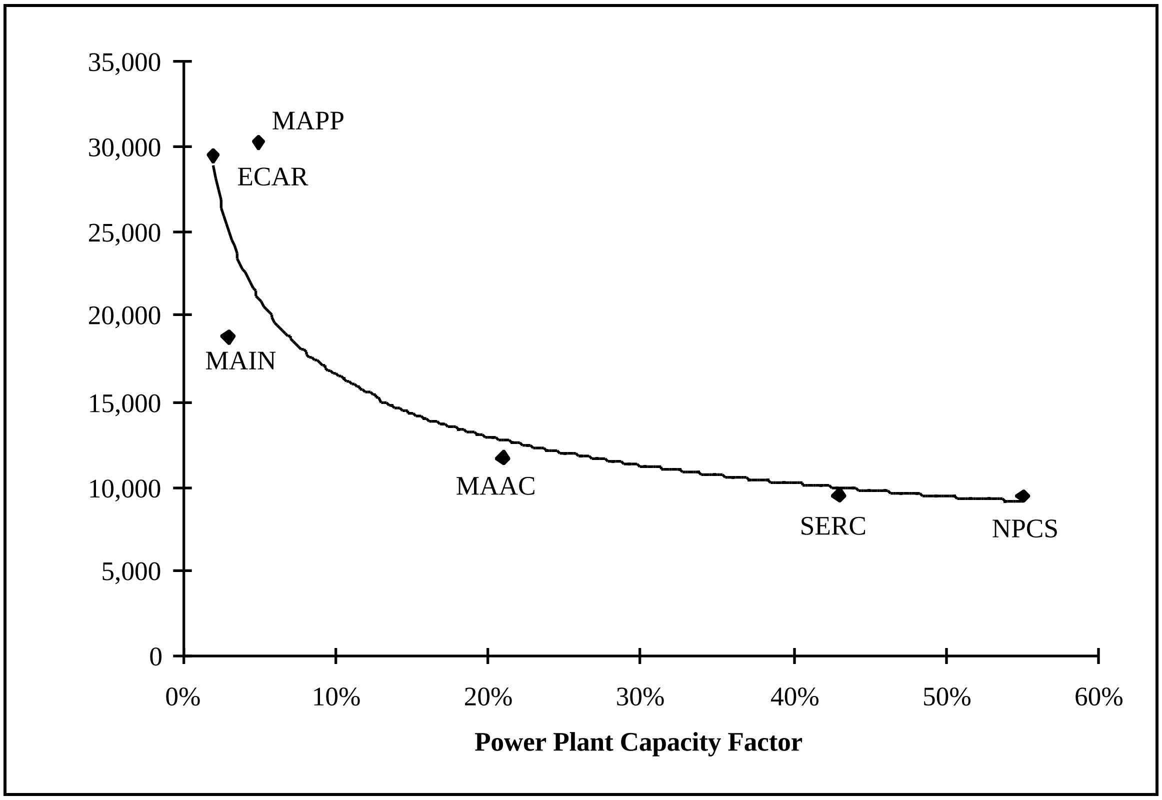
Typical California Power Plant Heat Rates are Higher at Lower Plant Loads

Figure 13

This point is further illustrated in Figure 14 with regional data on oil steam plant use.[25] Oil steam units are used in different ways in different parts of the country. In the West Central states MAPP Reliability region, (such as North Dakota)[26] the steam plants are used mainly to provide spinning reserve. In such situations, the plants may be on and burning fuel to back up other plants or meet daily peaks. Such plants have a low net output or capacity factor and very high net heat rate. In contrast, in the Southeast or SERC region such plants may be used more as intermediate or base load plants. The plants operate more fully loaded most of the time—and have a higher capacity factor and lower heat rate. Figure 14 shows considerable variation in 1991, in oil steam plant heat rate—strongly related to power plant capacity factor loading.

[25] Each utility across the country must report to the Federal Energy Regulatory Commission on Form 1 what the heat rate was during the previous year for each power plant. Each utility also must report the net kWh output of each power plant. The net kWh output divided by the annual maximum possible output yields the "capacity factor" or annual average plant loading.

[26] Often, nationwide data is reported by different regions of the North American Reliability Council (NERC). The data points in Figure 14 are data summarized by NERC regions.



Nationwide Data Shows 1991 Oil Steam Plant Heat Rates as a Function of Plant Loading [27]

Figure 14

TES helps to improve capacity factor and efficiency in two ways:

- by *reducing* peak demand, fewer power plants must be turned on or "committed" to run and burn fuel.
- by *increasing* the off peak usage, other power plants can operate at higher, more efficient levels.[28]

This concludes description of the methodology. Now the methodology is applied to determine the source energy savings.

Analysis

With the methodology defined, the source energy savings from TES can now be calculated by applying the formula in Figure 11 for the SCE and PG&E areas. The source energy savings are calculated first using the Incremental Energy method and then using the Marginal Plant method.

[27] Source: 1991 FERC Form 1 Data Aggregated by Reliability Regions as reported in *Primary Source Energy Position Paper* by Lennox Industries, August 24, 1994.

[28] Sometimes utilities face the situation where nighttime load is so low that efficient base-load units must be turned off and less efficient intermediate plants must be used more. Reducing the occurrence of such situations increases the source fuel savings.

SCE savings—Incremental Energy method

To apply the formula of Figure 11, the inputs for the three terms must be determined. As discussed above, to simplify the analysis the inputs for the kWh savings term will be the numbers of Figure 12. But the value of X (the ratio of winter mid-peak kWhs shifted to the summer on-peak kWhs shifted) is varied from 0.5 to 4.0 to capture the range of possible load shift ratios, as noted in Figure 15.

Ratio of Winter kWhs shifted to Summer kWhs shifted
for selected buildings on partial storage in SCE's territory

Figure 15

Figure 15 shows how the ratio of winter to summer kWhs shifted (X) varies for partial storage systems in three representative building types[29]

- hospital, typically with a 24 hour per day operation,
- large office building, typically with a high internal load and 10-16 hour operation using a central chiller, and
- small office building typically using package air conditioning.

For full storage systems, the ratios are about $^2/_3$'s this size—since full storage systems can shift all the summer on-peak kWhs.

The second term of concern in the formula in Figure 11 is the Incremental Energy Rates by time period. Figure 16 shows SCE's projected Incremental Energy Rates at the power plant for 1995. The summer on-peak and winter mid-peak Incremental Energy Rates include fuel use for "unit commitment." Note that the Incremental Energy Rate for the summer mid-peak and off-peak are 38 percent and 46 percent less, respectively, than the Incremental Energy Rate for the summer on-peak

[29] The allocation of annual air conditioning use across the five time period is based on savings numbers for new high efficiency air conditioning systems found in Southern California Edison Company's "Demand-Side Management Unit Energy Savings" report of October, 1992.

period. By comparison, the Incremental Energy Rate of the winter off-peak period is 31 percent less than the winter mid-peak period. These numbers mean TES can save source energy by shifting kWhs in *both* summer *and* winter.

"Incremental Energy Rates" by Time Period

	Summer	Winter
On-Peak	14251	—
Mid-Peak	8818	10714
Off-Peak	7647	7419

% Difference by Time Period

	Summer	Winter
On-Peak	—	—
Mid-Peak	–38%	—
Off-Peak	–46%	–31%

Relative SCE "Incremental Energy Rates" by Time Period [30]

Figure 16

The third term of concern in the formula in Figure 11 is the line loss factors. Figure 17 shows the relative loss factors used.[31] It shows that the off-peak line losses at the secondary voltage average about 5 percent lower than the line losses during the summer on-peak.

	Summer	Winter
On-Peak	1.000	—
Mid-Peak	0.967	0.983
Off-Peak	0.953	0.956

Power Line Loss Factors at Secondary Voltage [32]

Figure 17

The effect of the differences in Incremental Energy Rate and line loss factors can be combined. Figure 18 shows that the combined effect yields a source energy savings of 49 percent for each summer on-peak kWh that is shifted to the off-peak.[33]

[30] Southern California Edison "Marginal Cost" Exhibit documentation for the CPUC in the General Rate Case for test year 1995. Revised March 1995.

[31] These line loss factors are Pacific Gas & Electric Company's 1995 marginal cost data submitted to the CPUC as part of its General Rate Case filing for test year 1996. Southern California Edison's data is not expected to vary substantially from this.

[32] Used for both PG&E and SCE. Source: Pacific Gas & Electric Company's 1995 Marginal Cost data submitted to the CPUC for the 1996 General Rate Case.

[33] The percent savings of Figure 16 and Figure 17 are not additive because of the multiplicative relationship of energy used at the power plant and source energy.

	Summer	Winter
On-Peak	—	—
Mid-Peak	–40%	—
Off-Peak	–49%	–33%

SCE Source Energy Use % Differences
Incremental Energy Method [34]

Figure 18

The source energy savings now can be calculated per kWh shifted using the formula in Figure 11. Applying this formula yields source energy savings per kWh shifted that varies depending on how many of the kWhs are from the winter vs. the summer. This occurs because the source energy savings from shifting one kWh is lower in the winter than in the summer (see Figure 18. Total source energy savings will be lower when the ratio of winter to summer kWh shifted is higher. Figure 19 shows this by illustrating how percent source energy savings per kWh shifted varies as a function of the X ratio—winter kWh shifted divided by summer kWh shifted. For buildings like hospitals where the air conditioning typically runs 24 hours-a -day, often 365 days a year, this ratio will be higher—and the percent source energy savings will be lower (e.g., 36 percent). In contrast, for smaller office buildings with package air conditioning or for full storage TES systems, the ratio will be lower—and the percent source energy savings will be higher (e.g. 43 percent).

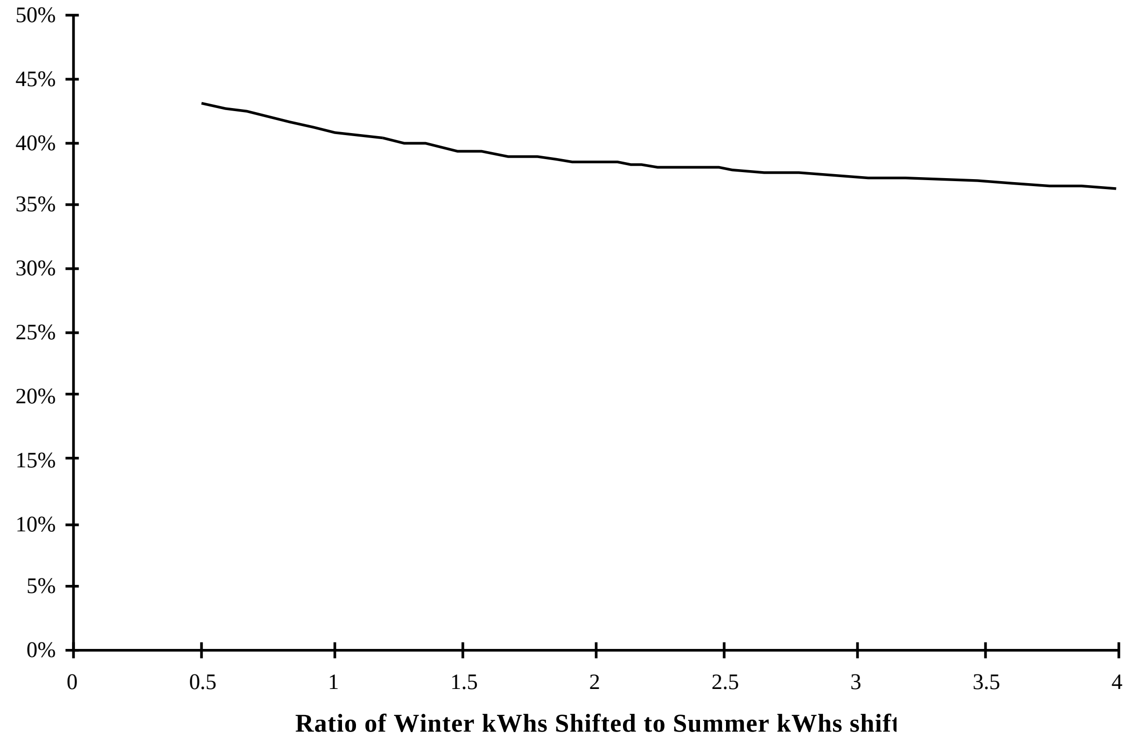
Air conditioning engineers also will find it useful to characterize this information in an alternate way. The source energy savings can be characterized as a percentage of the source energy required to meet the total annual cooling load. This percentage can be calculated by the equation where:

$$\text{\% source energy savings per kWh of annual cooling load} =$$

$$\left[\text{\% source energy savings per kWh shifted}\right] \times \left[\text{\% of annual kWh shifted by TES}\right]$$

The first multiplicand—(percent source energy savings per kWh shifted)—comes from Figure 19. The second multiplicand—(percentage of annual kWh shifted by TES)—will again vary by TES system. Typically, the second multiplicand will range from about 40 percent for hospitals with partial storage systems to about 65 percent for office buildings with full storage systems.

[34] Incremental energy rate and line losses combined.



SCE Source Energy Savings per kWh Shifted
Using the Incremental Energy Method

Figure 19

Multiplying these range of percentages together yields the following range of percent source energy savings per kWh of annual cooling:

- 14 percent, typically for organizations with 24 hour a day cooling and partial storage,
- 28 percent, typically for small office buildings with package air conditioners replaced with full storage.

In summary, the Incremental Energy method for Southern California Edison reveals very large source energy savings from shifting kWhs of electricity with TES.

SCE savings—Marginal Plant method

The savings calculations for the Marginal Plant method are essentially the same, except the heat rates used will be different than the Incremental Energy Rates.

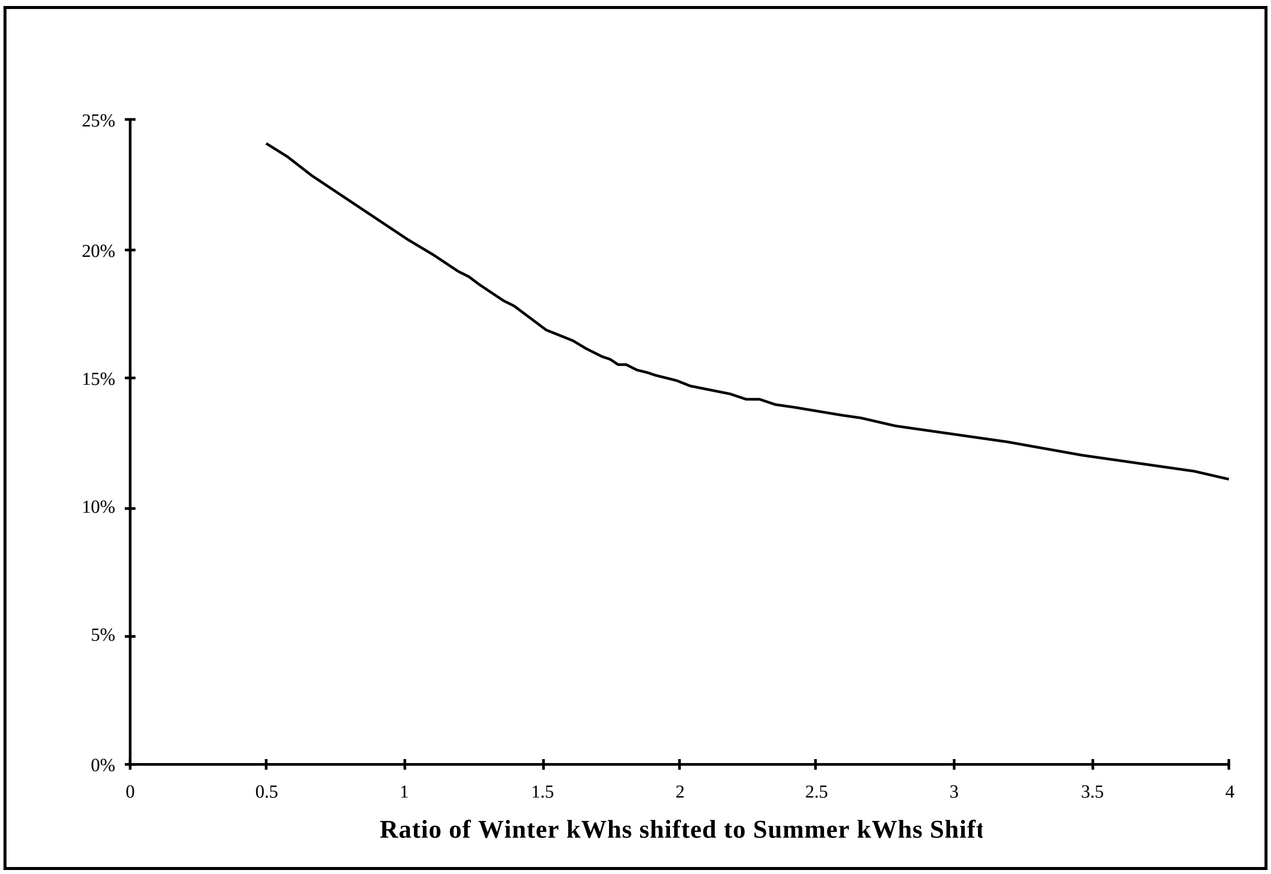
Figure 20 shows the relative heat rates for the five time periods using the Marginal Plant method. Note that the differences among time periods are lower than under the Incremental Energy method. This is particularly true in the winter time.

	Summer	Winter
On-Peak	1.000	—
Mid-Peak	0.708	1.000
Off-Peak	0.693	0.973
% Difference by Time Period		
	Summer	Winter
On-Peak	—	—
Mid-Peak	–29%	—
Off-Peak	–31%	–3%

SCE Relative Marginal Plant "Heat Rates" [35]

Figure 20

Applying these heat rate numbers in the formula of Figure 11 yields percent source energy savings like those shown in Figure 21. These numbers (ranging from 12 percent to 24 percent) are considerably lower than those in Figure 19 using the Incremental Energy method. Thus, excluding the impact of fuel used for unit commitment greatly influences the energy savings calculations.



SCE Source Energy Savings per kWh Shifted
Using the Marginal Plant Method

Figure 21

[35] Southern California Edison System Planning for 1992 and 1993 and FERC Form 1 data.

This concludes the source energy analysis for Southern California Edison.

PG&E savings—Incremental Energy Method

PG&E's source energy savings can be analyzed in a similar manner using the formula in Figure 15. The line loss factors are assumed to be the same (see Figure 17). But the savings allocation by time period and the incremental energy rates will be different. Figure 15 showed the ratio of winter peak hours shifted to summer peak hours shifted for SCE. The ratios for PG&E are essentially half of that. The reason for this can be easily seen in noting that the ratio of winter months to summer months for PG&E ($1 = {}^6/_6$) is half the ratio of winter to summer months for SCE ($2 = {}^8/_4$). PG&E does not explicitly calculate Incremental Energy Rates as SCE does. However, PG&E develops comparable marginal energy costs. As Figure 7 showed, Incremental Energy Rates (or the relative size of the IER's) can be derived from these generation level marginal energy costs. Figure 22 shows PG&E's marginal energy costs and their relative difference by time period. As for SCE, the summer on-peak and winter mid-peak numbers include the effect of "unit commitment."

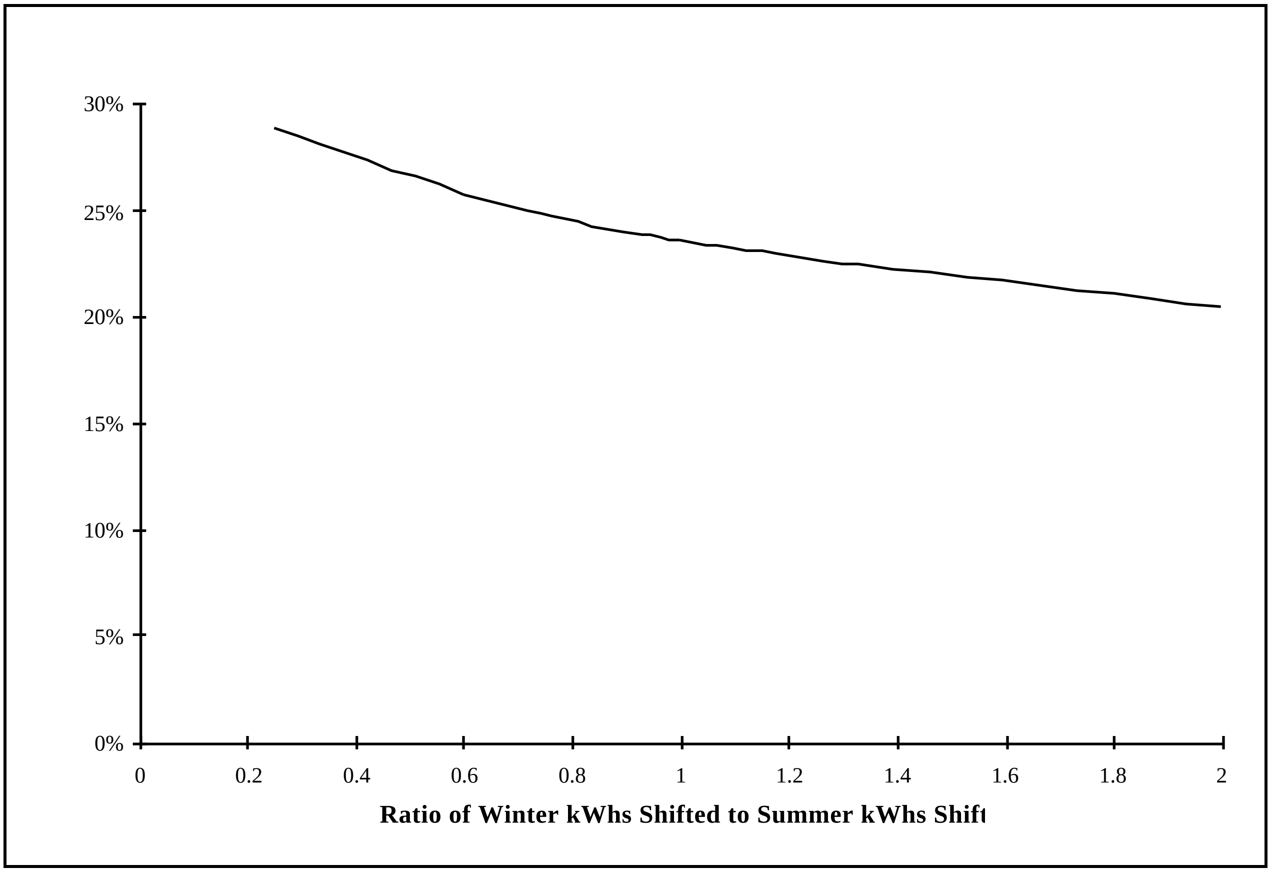
	Summer	Winter
On-Peak	**2.81**	**—**
Mid-Peak	**2.18**	**2.50**
Off-Peak	**1.93**	**2.22**
% Difference by Time Period		
	Summer	**Winter**
On-Peak	**—**	**—**
Mid-Peak	**–22%**	**—**
Off-Peak	**–31%**	**–11%**

PG&E Marginal Energy (Production) Costs
by Time Period (cents/kWh)

Figure 22

Applying the above numbers to the formula of Figure 11 yields the percent source energy savings per kWh shifted shown in Figure 23. Some facilities, with a high proportion of the shifted kWhs in the summer (such as small commercial), have source energy savings approaching 30 percent. In other facilities with more constant cooling loads (such as hospitals), the savings approaches 20 percent.

As noted under the SCE discussion, not all cooling kWhs are shifted by TES and sometimes air conditioning engineers find it useful to express source energy savings as a percentage of total air conditioning load. For PG&E, typically 40 percent to 80 percent of the annual cooling energy may be shifted by TES. Multiplying these % by the savings per kWh shifted yields the savings per kWh of annual cooling energy. These savings would range from 8 percent to 24 percent of annual cooling energy requirements.



PG&E Source Energy Savings per kWh Shifted
Using the Incremental Energy Method

Figure 23

PG&E savings—Marginal Plant Method

As for SCE, the Marginal Plant method is an alternate way to calculate source energy savings. This method again applies the formula in Figure 11, but uses different inputs for heat rate, as Figure 24 shows.

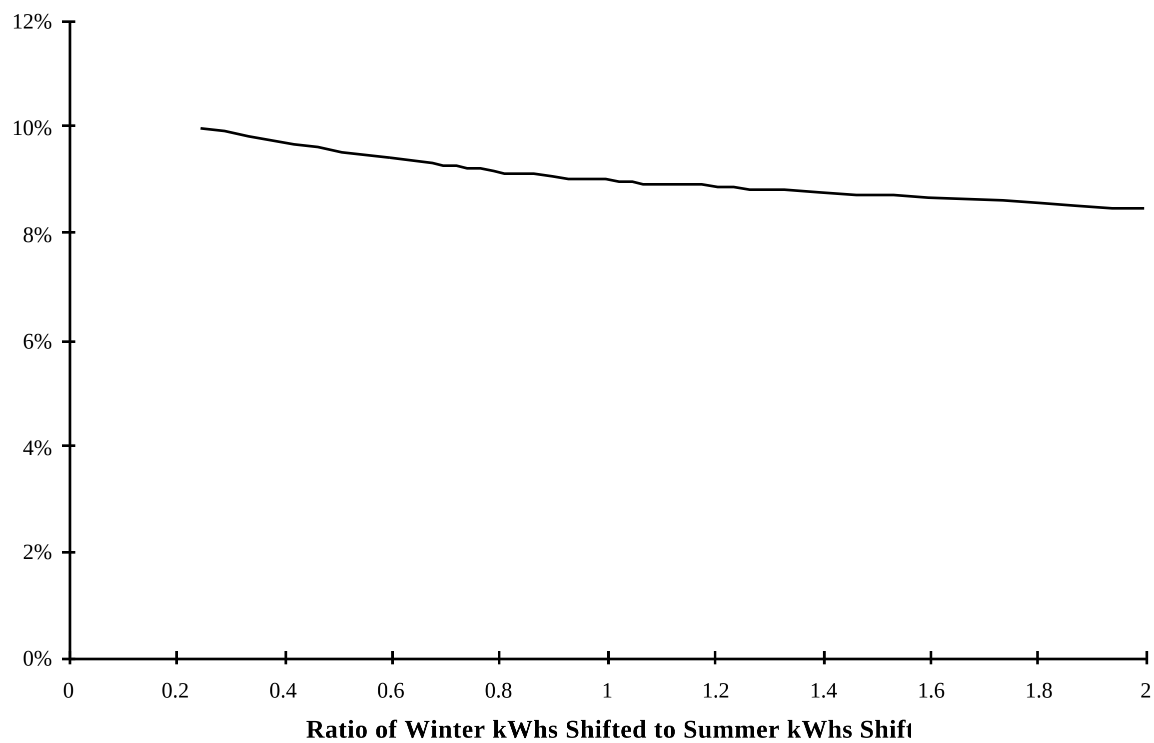
	Summer	Winter
On-Peak	1.000	—
Mid-Peak	0.969	1.000
Off-Peak	0.923	0.933
% Difference by Time Period		
	Summer	Winter
On-Peak	—	—
Mid-Peak	–3%	—
Off-Peak	–8%	–7%

PG&E Relative Marginal Plant
"Heat Rates" for 1993 and 1994 [36]

Figure 24

When applying these alternate heat rates to the formula, an alternate set of estimates are obtained for source energy savings, as Figure 25 shows. These savings show little variation in source energy savings as a function of ratio of winter to summer shifting. The savings estimates vary between 8 percent and 10 percent per kWh shifted.

[36] Source: Pacific Gas & Electric Company system operations staff. October 1994.



PG&E Source Energy Savings per kWh Shifted
Using the Marginal Plant Method

Figure 25

Conclusions of analysis

This concludes the analysis of source energy savings from TES. The savings calculations from the Incremental Energy method are the recommended savings estimates because of the consistency with other California planning and evaluation methods. Such savings were:

- 36-43 percent savings per kWh shifted for buildings in SCE's area and
- 20-30 percent savings per kWh shifted for buildings in PG&E's area.

Statewide Potential of Source Energy Savings

To provide some perspective on this value of such savings in California consider the following. Today the electricity use for air conditioning in California is about 30,000 GWhs. By 2005 it will be close to 36,000 GWhs—which equals the electricity use today for all customers served by the Los Angeles Department of Water & Power and Sacramento Municipal Utility District combined. This is also about 14 percent of the total electricity use in California.

If TES achieved an 20 percent market penetration by 2005[37], then about 1300[38] GWh equivalents of source energy could be saved. Based on the California Energy Commission's forecasts, this is enough

[37] PG&E conducted an internal study—*Off-Peak Cooling Market Potential Study*—that conservatively estimates 20% as an achievable market penetration for TES.

source energy savings to supply about a fifth of all new air conditioning growth in the next decade—even if TES doesn't save any kWhs of electricity. From another perspective, this is saving enough source energy to supply all electric cars added to California in the next decade.[39]

In summary, TES can provide major source energy savings to California in the next decade if TES systems are properly designed and operated and if TES is aggressively promoted.

[38] 1300 GWh = (36,000 GWh of air conditioning) x (20% market penetration) x (18% savings) where 18% savings assumes 60% of the state will reflect 20% source energy savings per kWh of cooling like SCE's and 40% of the state will reflect 16% source energy savings like PG&E's.

[39] The California Energy Commission projects electric cars to use 1618 GWhs in 2005. Personal communication, Lynn Marshall, California Energy Commission Demand Analysis Office. August 1995.

OTHER IMPACTS OF THERMAL ENERGY STORAGE

OTHER IMPACTS OF THERMAL ENERGY STORAGE

In addition to the Source Energy savings analyzed in the previous section, several other TES impacts are of concern. These impacts are related to the benefits that the Energy Commission seeks in any technology assisted by the Energy Commission's commercialization efforts:

- Site energy efficiency
- Air emissions reductions
- Economic development/competitiveness

These three impacts are individually analyzed.

Site Energy Analysis

Many energy professionals perceive that TES cooling systems require more kWhs to deliver a ton-hour of cooling than conventional cooling systems. There is some basis for this perception. For example, the Electric Power Research Institute monitored some early TES systems in the early-1980s and concluded that those particular TES systems used more electricity than conventional systems.[40]

Certainly, there are some components inherent in TES systems that lead to some inefficiency compared to conventional systems, as listed below:

- Stand-by losses and heat (cool) transfer
- Ice Chiller
- Increased cooling tower and chiller pump/fan operation (if not designed and operated properly)

For stand by losses, for example, the system can lose cool energy to (absorb heat from) the outside environment. Also, in transferring the cool energy from the chiller to the storage tank (and then on to distribution system) additional energy can be used. In ice storage systems the ice chillers use more energy than water chillers due to the lower refrigerant temperatures required to produce ice. Finally, if the TES systems are not designed or operated properly (as was all too often the case in the 1980s

[40] Electric Power Research Institute, Operation and Performance of Commercial Cool Storage Systems, Vol. 1: 1987 Cooling Season and Vol. 2: 1988 Cooling Season. CU 6561, 1989.

as designers and facility operators learned about the TES technology) then the chiller auxiliary equipment (pumps and fans) could run longer.[41]

Over time, the TES designers and operators became more skilled and began to take advantage of some of the features of TES that lead to improved site efficiency as listed in Figure 26. One of the main ways that TES systems can provide enhanced efficiency is by having the chillers (and their supporting pumps and fans) run fully loaded most of the time at their peak efficiency. As noted in the previous section, the chillers and support equipment of conventional cooling systems must run whenever the building occupants want cooling. The chiller system capacity is sized for the peak (or design) cooling day. Most of the year, however, the chiller system does not operate near peak cooling conditions in California, as Figure 27 shows. In fact, about half of the year the typical chiller system operates at less than 30 percent of capacity. At such low capacity loading, the energy efficiency of a conventional chiller system decreases—or its energy intensity (kWh/ton-hour of cooling) substantially increases, as Figure 28 shows.[42] Thus, much of the year a conventional chiller system can operate an energy intensity that is 2–4 times higher than its design intensity. Analyses showing that conventional cooling systems are more efficient than TES systems generally have not captured the increased energy use of partially loaded conventional systems.[43]

Chiller

- Fully loaded
- Cooler nighttime temperatures
- Enhanced heat recovery
- Free (economizer) cooling in winter
- More efficient than rooftop (unitary) units

Distribution System

- Lower volume of cooler water/air is moved by pumps/fans
- Lower humidity can allow higher indoor temperatures

TES Site Efficiency

Figure 26

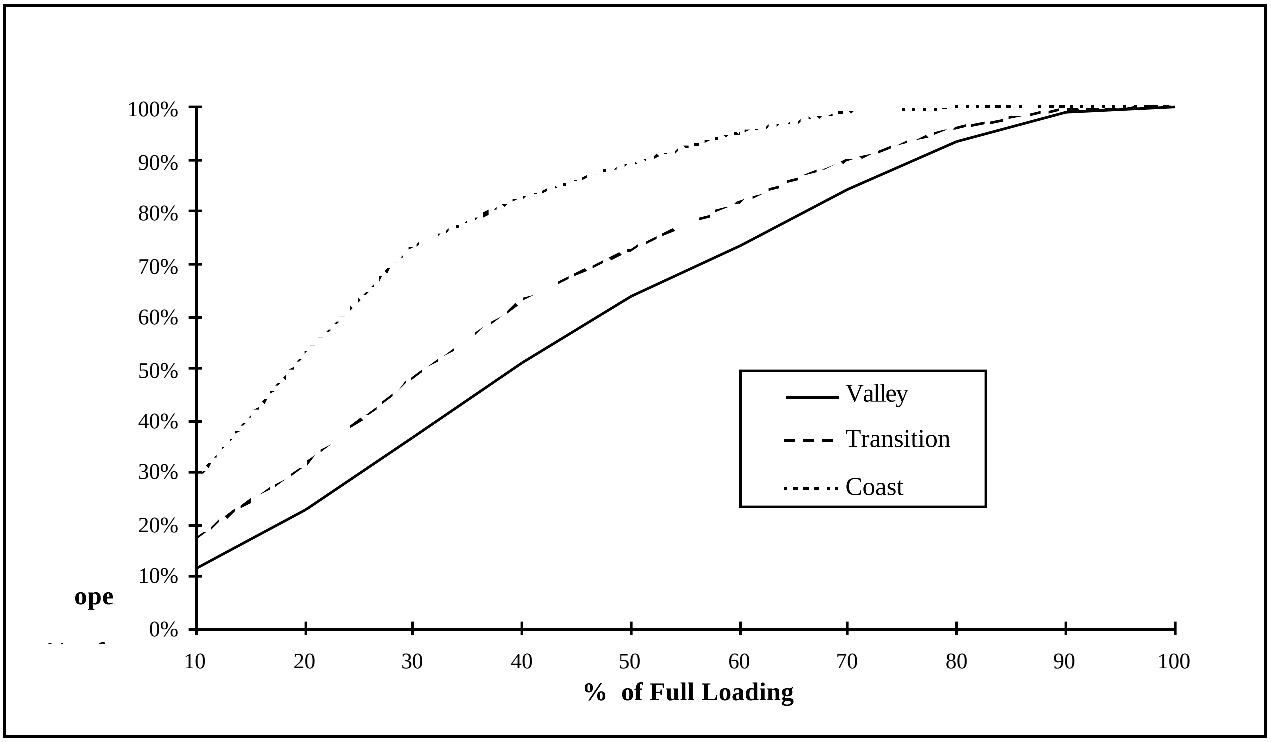
In well-designed TES systems, the chiller system almost always operates fully loaded. By having a set of chiller (primary) pumps that operate separately from the distribution system (secondary) pumps, the chiller and its pumps can run at efficient fully loaded levels. Thus, the more frequently that the

[41] The experience and motivation of the building engineer is a problem for conventional cooling systems as well as TES. See Richard Sterrett's *Operator Influence on the Performance of Chillers and Thermal Energy Storage Systems. Energy Engineering*: 89,4. 1992. p. 66.

[42] Field measurement of many chiller systems by the Energy Engineering Institute of San Diego State University lead to a curve like that in Figure 30. See K. Liu et al. *A Comparison of the Field Performance of Thermal Energy Storage (TES) and Conventional Chiller Systems, Energy*: 19,8, 1994. p. 889. A major reason that the energy intensity increases is that the chiller pumps and (to some extent) cooling tower typically operate at full load energy use levels even though they are providing much less cooling.

[43] Liu et al. See footnote 42 for a full citation.

cooling load is less than design capacity, the better that TES looks compared to conventional cooling systems.[44]

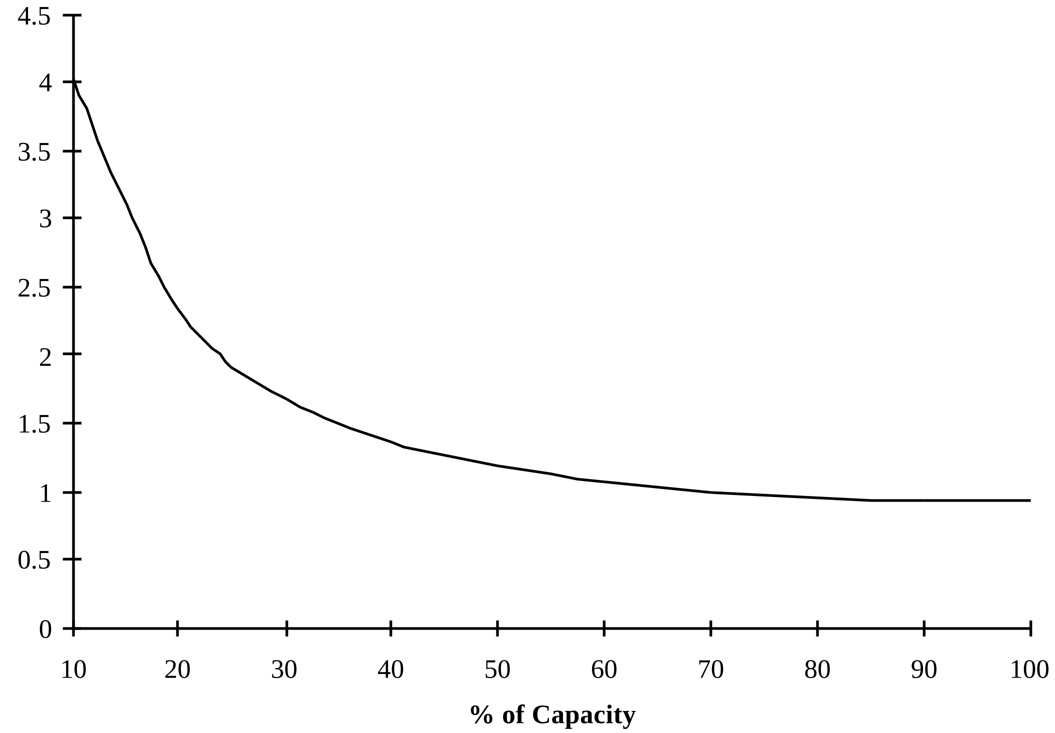


California Cooling Systems
Often are Not Fully Loaded[45]

Figure 27

[44] Of course, some things can be done to conventional systems to solve the inefficiency caused by partial loading. The first is to have multiple smaller chillers that can be operated in a staged sequence. For example, if a building has two chillers each sized at 50 percent of the building cooling requirements, then when faced with a cooling load of only 50 percent of capacity, only one chiller needs operate at a full efficiency level. A second solution to the partial loading problem is to have variable speed drives on the chiller and its pumps. Then the electricity usage of the chillers and pumps tends to track the cooling demand. Offsetting this, some observers note that for the cost of installing multiple chillers or putting variable speed drives on the chillers and pumps some buildings can pay for much of a TES system. In addition, many building owners today with dual chillers often size each so that they could carry the full cooling load—a high value is placed on cooling system reliability. In actual practice, PG&E, for example, has found a number of chiller systems operating at much higher than their design energy intensities.

[45] Source: Pacific Gas & Electric Company, DOE-2 Analysis, 1995.



Conventional Centrifugal Chiller Systems
Energy Intensity Increases When Partially Loaded [46]

Figure 28

In addition to operating more fully loaded, TES offer several other opportunities for improving efficiency. For example, TES chillers running at night are more efficient. Related to this, some places in California require daytime cooling in the winter but may have nighttime temperatures in the low 40s. Running the cooling tower without the chiller may allow a chilled water or eutectic salt storage system to be charged with almost "free" cooling, using 85 percent to 90 percent less energy [47] than a conventional cooling plant.

When Not Operating at Design Capacity—

- **Conventional cooling efficiency usually decreases.**
- **TES can be more efficient.**

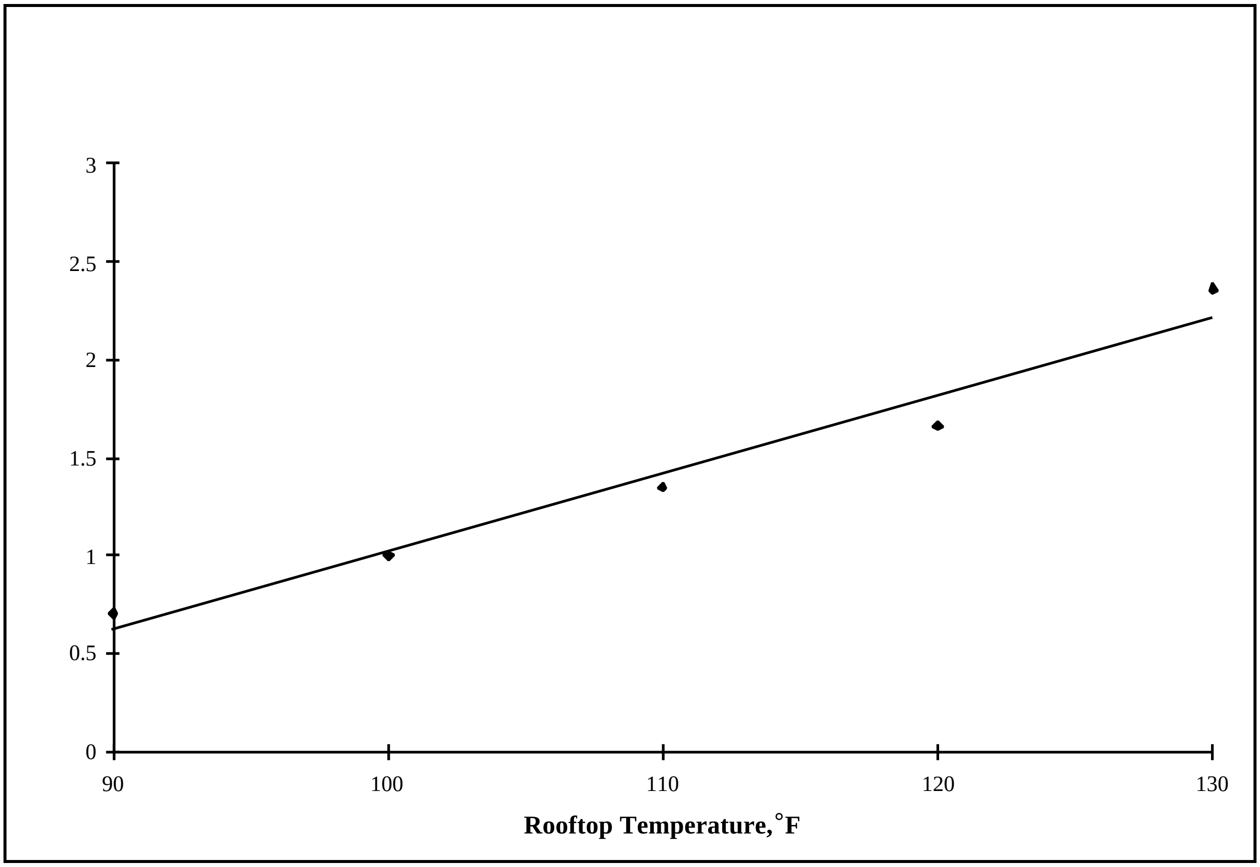
Another efficiency gain that thermal storage facilitates is waste heat recovery. That is, the "waste heat" from the chillers is captured and used to supply hot water to the building. Separate storage for hot water again allows the supply of hot water to be generated at times other than when demanded. This has enhanced the feasibility of chiller waste heat recovery—in residential buildings as well as commercial buildings.

Another efficiency gain is more applicable for small commercial buildings and single-family residences. Such structures typically use unitary air-cooled, direct expansion split systems or single-package rooftop units to provide cooling rather than chilled water systems. The unitary systems are typically 10 percent to 50 percent more energy intensive under normal conditions. Even worse, the

[46] Source: TGK Consulting, EPA/NRDC Chiller System EER Study, 1995.
[47] Scot Duncan, Personal communication. June, 1995.

energy intensity of the rooftop units increases as the rooftop temperature increases as Figure 29 shows. Indeed, PG&E has found that on hot summer days rooftop temperatures of 130°F are not uncommon and energy intensity can increase by 70 percent. Of greater concern to the building owner is that the cooling capacity of the air conditioner is then decreased by 40 percent.

In addition to enhancing chiller, TES also can enhance distribution system efficiency. Such enhanced efficiency is achieved through cold air distribution. As described in the section titled *What is Thermal Energy Storage?*, colder supply air into the distribution system means that a smaller volume of water and air must be moved to achieve the desired cooling. A smaller volume of water and air requires (up to 40 percent[48]) less energy to move—either through smaller pumps and fans or through adjustable speed drives on pumps and fans.



Rooftop Air Conditioner's Energy Intensity Increases Considerably with Temperature [49]

Figure 29

In addition to enhancing chiller performance, TES also can enhance distribution system efficiency. Such enhanced efficiency is achieved through cold air distribution. As described in the section titled *What is Thermal Energy Storage?*, colder supply air into the distribution system means that a smaller volume of water and air must be moved to achieve the desired cooling. A smaller volume of water and air requires (up to 40 percent[50]) less energy to move—either through smaller pumps and fans or through adjustable speed drives on pumps and fans.

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[48] Some have seen savings as high as 80 percent. Scot Duncan, Personal communication. June, 1995.
[49] Source: Air-conditioning & Refrigeration Institute (ARI) test data supplied by Pacific Gas & Electric Company.
[50] Some have seen savings as high as 80 percent. Scot Duncan, Personal communication. June, 1995.

Another factor can lead to greater energy efficiency in the distribution system. Colder air holds less moisture (i.e., is less humid). When it is added to the occupant area, it leads to less humid conditions than from conventional supply systems. The lower humidity can mean the temperature can be raised and the occupants will be just as comfortable.[51] The higher cooling temperature means even less cold air is needed.

This concludes a quick overview of how TES systems have inherent opportunities for system efficiencies as well as system inefficiencies. Now some case studies of where TES systems have achieved net kWh efficiencies are summarized in Figure 30.

Building	Location	TES Size (ton-hours)	Partial/ Full	New/ Retrofit	Summer kW Savings	% Cooling kWh Savings	Method[52]	Source	Comments
Commercial-Industrial									
Chilled Water Storage									
Electro-Optics	Dallas, TX	24500	F	R					
Plant					2900	12%	M, B	Energy Engineering, Vol. 89, 4	heat recovery
University	Fullerton, CA	40000	F	R	3360	13%	S	Brown & Caldwell	heat recovery
University	Tempe, AZ			R	7000	13%	B	ITSAC, Tech Bulletin, 1-92	
College	Houston, TX	4000		R		8-9%	B	CBI, ASHRAE, 6-93	
Prison	Lancaster, CA	12600		N		15-25%	S	ITSAC, Vol. 5,4	LTD water & water side economizer
Supermarket	Miami, FL					17%		EPRI, CU-3031	
Data Processing	Bloomington, IL	44800		N	5400	3%	S	CBI, ASHRAE, 6-93	
Chilled Water replacing rooftops									
Assembly	Winsboro, SC	7500		N		44%	S	ITSAC, Vol. 5,3	
Ice Storage with Cold Air Distribution									
School	Morristown, PA	720	P	N		30%	B	ITSAC, Vol. 9,6	includes Energy Mgmnt System
Office	Chicago, IL					5-15%	B	ITSAC, Vol. 9,5	
Office		2000	P	N	400	6-14%	S	BAC Bulletin: Case Study 3-6	
Ice Storage replacing Rooftop/Unitary Systems									
Office	Vincennes, IN	25	P		7	16%	M	EPRI, TR-101038	
Assembly	Granston, RI	3000	F	R	700	50%	B	ITSAC, Vol. 9,6	
School	Cherry Hill, NJ		P	R		12%	M	EPRI	
Residential									
	Richmond, VA		F	N	3	12%	M	Virginia Power	heat recovery for hot water

TES Site Efficiency Case Studies

Figure 30

[51] ASHRAE has well documented that the comfort in a room is determined by the enthalpy (or total heat content) in the room. The enthalpy is determined by two factors—the temperature and the humidity. (Clearly people in California understand this concept—they are more comfortable in their desert dry heat of 100˚F than they are when they visit on a 90 ˚F day in humid New Orleans.)

[52] Note: B = Bill Comparison, S = Simulation, M = Metered Data.

Site Efficiency Case Studies

In chilled water storage systems, site cooling efficiencies of 10 percent to 15 percent have often been achieved. One system achieving remarkably high savings (a prison in Lancaster, California) used a large temperature differential (ΔT) between supply water (40°F) and return water (70°F) and a water-side economizer. Another system (a university in Tempe, AZ) with impressive savings added secondary pumps at the same time as the storage tank to achieve a large savings in the operation of the primary chiller pumps.

The above case studies all included a TES tank in a chilled water cooling system. In one case study a chilled water TES system was used in lieu of rooftop units—with projected savings near 44 percent.

Some ice storage systems with cold air distribution have achieved site efficiencies approaching those of chilled water central systems. Ice systems replacing rooftop systems in areas with lower rooftop temperatures than California typically have achieved site efficiencies comparable to those of central chilled water TES systems and better than conventional systems.

Finally, some residential TES systems have been used that include heat storage and heat recovery for hot water as well as cool storage. In some instances they have achieved kWh savings.

Statewide Potential Site Energy Savings

Aggregate potential site efficiency savings can be estimated from this information. In particular, 36,000 GWhs of air conditioning load will exist in 2005 (from the section titled *Source Energy Analysis*). Suppose the 12 percent potential site efficiency could be achieved at 20 percent of the installations. Then 15 percent of the electricity required to supply new air conditioning load in the next decade could come from these site efficiency improvements. If site efficiency and source energy savings are combined, then 20 percent penetration of TES can supply over a third of the energy needs of new air conditioning in the next decade.

In summary, the TES community is evolving. In an increasing number of instances, site efficiency improvements have been achieved along with load shifting. If California supports the design and building operator communities in the use of TES, California could expect to see continued site efficiency improvements from TES systems. With this analysis of site efficiency complete, air emission impacts are analyzed.

Air Emission Analysis

TES can potentially reduce air emissions at the power plant source and the building site. The following analysis first considers source impacts and then site impacts.

Air Emissions Impacts at the Power Plant Source

As for the Source Energy analysis, information from the utilities' marginal cost submittals in the General Rate Case filings with the PUC can he helpful in determining the air emissions impacts of TES. Figure 31 shows how PG&E's power plant air emission's costs vary by time period. As in the Source Energy analysis, by recognizing that a natural gas fired power plant is usually the marginal plant, the percent difference in costs between time periods reflect the percent difference in air emissions.

Figure 31 shows that the air emissions savings from shifting a kWh are slightly higher than the source energy savings. For example, Figure 31 shows a 47 percent savings in emissions by shifting a kWh of cooling load from on-peak to off-peak. By contrast, the source energy savings were only 35 percent. Three factors could explain these higher savings. The first factor is that emission free hydro power may have been on the margin off-peak for part of the year. The second factor is that utilities usually have less stringent emission control measures on power plants that operate fewer hours—such as those used mainly for summer on-peak hours. The third factor is that the marginal off-peak power may have been purchased from another utility. In this limited scope project, the relative importance of these three factors could not be determined. Therefore, the air emissions savings are assumed to be the same as the source energy savings—shown in Figure 22 and Figure 23.

Emission Costs (mils/kWh) by Time Period		
	Summer	**Winter**
On-Peak	**1.142**	**—**
Mid-Peak	**0.788**	**0.620**
Off-Peak	**0.610**	**0.519**
% Difference by Time Period		
	Summer	**Winter**
On-Peak	**—**	**—**
Mid-Peak	**–31%**	**—**
Off-Peak	**–47%**	**–16%**

PG&E Power Plant Air Emissions Costs by Time Period [53]

Figure 31

The emission information from SCE’s General Rate Case filing further reflects the importance of these three factors. Figure 32 shows SCE’s environmental cost information. SCE took a different approach to calculating the cost emissions than PG&E. SCE had the fortunate situation in which the RECLAIM market for trading air emissions by the South Coast Air Quality Management District (SCAQMD) allowed SCE to put a true market value on the emissions rather than an imputed cost. Therefore, SCE chose to use the market approach. The main drawback for this TES analysis is that the SCE power plants and purchased power from other utilities that supplied the marginal kWhs off-peak often was outside of the SCAQMD area. Therefore, the third factor played a larger role. This leads to amazing results in which shifting a kWh from on-peak to off-peak in the summer can lead to a 97% reduction in air emissions in the SCAQMD area.

In that the SCAQMD is one of the most critical air basins in the world, any action that can help that air basin is of positive benefit. On the other hand, it is beyond the scope of this study to trade off the value of decreasing air emissions in one air basin with the value of increasing air emissions in another air basin. Therefore, the conservative path is chosen of assuming that the percentage air emission savings from shifting a kWh follows the percentage source energy (or fuel) savings from shifting a kWh. For SCE these percentages are reported in Figure 17 to Figure 19.

[53] Pacific Gas & Electric Company Working Paper for Marginal Cost exhibit before the California Public Utilities Commission in the General Rate Case for Test Year 1996.

Emission Costs per RECLAIM credits (mils/kWh) by Time Period		
	Summer	**Winter**
On-Peak	**0.035**	**—**
Mid-Peak	**0.006**	**0.013**
Off-Peak	**0.001**	**0.001**
% Difference by Time Period		
	Summer	**Winter**
On-Peak	**—**	**—**
Mid-Peak	**–83%**	**—**
Off-Peak	**–97%**	**–92%**

SCE Power Plant Air Emissions Costs by Time Period [54]

Figure 32

Other studies have documented the air emissions savings of TES. For example, a study in the United Kingdom found that TES systems could reduce CO_2 by 14 percent to 46 percent by shifting load off-peak.[55] An EPRI co-sponsored analysis of TES in TU Electric's system found that TES could reduce CO_2 by 7 percent over conventional electric cooling technologies.[56]

Statewide Potential of Power Plant Emission

The potential aggregate emission savings at the power plant from TES is great. Data from the California Energy Commission indicates that PG&E's existing gas plants will produce about 0.13 lb. of NOx and 33 lb. of CO_2 per million BTU of fuel burned and that SCE's existing gas plants will produce about 0.05 lb. of NOx and 33 lb. of CO_2 per million BTU of fuel.[57] Assuming that TES installations save an average of 6 percent of the total cooling BTUs[58] implies that TES could save about 560 tons of NOx and 260,000 tons of CO_2 annually statewide.

As a point of perspective, TES in the South Coast Air Quality Management District Air Basin would reduce about 1.6 tons of NOx per day (although some of this is shifted to other basins.) Based on California Energy Commission staff estimates, these savings could be worth $32 million per year in NOx credits in the SCAQMD.[59] This 1.6 tons is about a tenth of the total NOx emissions from all

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[54] Southern California Edison Working Paper for Marginal Cost exhibit before the California Public Utilities Commission in the General Rate Case for Test Year 1995

[55] CB Beggs, *Ice Thermal Storage: Impact on United Kingdom Carbon Dioxide Emissions*. Building Services Engineering Research and Technology 15(1), 1994.

[56] DT Reindl, Thermal Storage Applications Research Center, *Characterizing the Marginal Basis Source Energy Emissions Associated with Comfort Cooling Systems*, Report No. TSARC 94-1, December 1994. The methodology used in this analysis defined "source" differently. In particular, it took source to include the place where the fuel for the power plant was extracted. Thus, it considered the emissions not only at the power plant, but also in extracting and transporting the fuel to the power plant. This definition of source was used to also provide a "source" emissions comparison to natural gas cooling systems.

[57] Angela Tanghetti, California Energy Commission, Personal Communication, June 1995. Edison's new gas plants emit about 0.09 lb. of NOx per million BTU.

[58] A 30 percent reduction from both load shifting (18 percent) and kWh reductions (12 percent) per site with an assumed 20 percent market penetration by 2005 yields of 6 percent total source BTU's used for cooling.

[59] California Energy Commission staff testimony, "RECLAIM Trading Credit, SO_2 Allowance, and Offset Costs" April 14, 1994. California Energy Commission Docket 93-ER-94.

Edison gas fired plants.[60] It also represents the NOx emissions savings from using 100,000 electric vehicles in the SCAQMD area.[61] Thus, TES can make substantial contributions in reducing air emissions.

Air Emission Impacts at the Building Site

Thermal Storage can affect air emissions at the building site in two ways. First, it can affect the amount of ozone-depleting CFCs or HCFCs in chiller refrigerants. Second, it can affect the amount of combustion emissions used in fuel-fired heating and costing equipment. Each of these impacts is considered.

TES helps reduce CFCs in two ways. First, cooling systems with TES require less chiller capacity than conventional systems. Using fewer or smaller chillers means less refrigerant is necessary. Second, when existing chillers are converted to more benign refrigerants, there can be a loss in cooling capacity. Using TES can off-set this lost cooling capacity—making building operators more willing to switch refrigerants.[62]

Thermal Storage has been used to reduce air emissions at the building site. For example, at California State University at Fullerton, a waste heat recovery storage system as an adjunct to a larger TES system allowed the replacement of an old boiler system. This conversion was co-funded by the South Coast Air Quality Management District in Southern California. Moreover, the District recognizes thermal storage as an air emissions control measure.[63]

Economic Development/Competitive Impacts

The last major impact of concern to the Energy Commission is enhancing the economic development potential of California. That is, the Energy Commission wants technologies that will help California businesses and energy utilities be more competitive. The following considers TES ability to provide such economic benefits.

TES provides several economic benefits to electricity suppliers. The first major benefit is lower operating or production costs. Recall that the Incremental Energy method used in the Source Energy calculations is also used to calculate the marginal energy costs. Thus, the utility is not only reducing its source energy requirements by 20 percent to 43 percent per kWh shifted with TES, it is also reducing its marginal energy costs of producing a kWh by 20 percent to 43 percent.

A second major benefit is improving the capital asset utilization of electric suppliers. The electricity supply industry is one of the most capital intensive industries in the US. It requires almost five times as many dollars of capital to generate a dollar of revenue as the average US manufacturing industry. Therefore, financial analysts know that the load factor of an electricity supplier (generation, transmission or distribution) is a key indicator of the supplier effectively using its capital assets.

TES Economic Benefits for Electricity suppliers

- **Lower production/operating costs.**
- **Improved asset utilization/reduced T&D capital expenditures.**
- **More competitive prices.**

TES provides the capability to improve the load factor of many commercial facilities by 30 percent to 50 percent. That means an electricity

[60] Angela Tanghetti, California Energy Commission, Personal Communication, June 1995.

[61] The Air Resource Board has adopted standards for new gasoline automobiles of 0.4 grams of NOx per mile. California Energy Commission Staff assume electric vehicles will displace vehicles traveling about 15,000 miles per year. At a cost of $15,000 per electric vehicle, it would require $1.5 billion (assuming TES costs about $600/kW) worth of electric vehicles to save the same amount of NOx as TES systems costing half that amount.

[62] DP Fiorino, *Thermal Energy Storage Program for the 1990s* **Energy Engineering** 89, 4, 1992. p. 23

[63] There has been a lot of discussion among regulatory bodies and gas and electric utilities about the trade-off between site emissions of gas equipment and the source emissions of power plants. It is beyond the scope of this paper to fully engage in that discussion. This study recognizes that at least the South Coast Air Quality Management District has decided that thermal storage with heat recovery is a net plus in its District.

supplier can reduce its capital intensity (expenditures) in serving such customers by 30 percent to 50 percent, huge capital savings. Indeed, to capture these capital savings in Switzerland, some conditions of service for large commercial buildings strongly encourage thermal storage.[64] Such capital savings could become increasingly important in California as electricity suppliers move from an era in which they are rewarded for investing *more* capital (under traditional rate base regulation) to an era in which they will be rewarded for investing *less* capital (under performance based ratemaking regulation).

Statewide Potential Economic Savings

The potential aggregate peak demand savings of TES is quite large. The potential new growth in air conditioning load in the next decade is about 2500 MW. Air conditioning is currently about 14,000 MW or about a third of the total peak demand in California. TES in 20 percent of buildings by 2005 could reduce air conditioning load by 2500 MW—off setting all new growth in air conditioning load over the next decade. If most of these TES installations are targeted for new construction or T&D constrained areas, then TES could save over a billion dollars of investment in the T&D system and perhaps equal savings in generation capacity investment.[65] This translates into savings for utility stockholders and California energy users alike.

Combining the operating cost savings with the capital cost savings means TES can help electricity suppliers greatly reduce their over-all costs. Since marginal fuel and capacity related costs are about 30 percent to 40 percent of an electric utility's total costs, reducing those by 30 percent for TES customers means the electric utility can shave 9 percent to 12 percent off its total costs in serving such customers. Some California utility CEOs have set objectives of shaving total cost by 5 percent in nominal dollars (or about 25 percent in real dollars) over the next five years. Certainly TES can be one tool in achieving such cost reductions.

Of course, the main reason California utility CEOs are interested in shaving costs is so that they can provide more competitive prices. Today, a large commercial customer typically pays about $.16/kWh[66] for air conditioning in the summer. If the customer properly uses TES, then the costs could be reduced to $.08 - $.12 per kWh, depending on the storage system and customer. This amounts to a 25 percent to 50 percent reduction in the cost of air conditioning. Since air conditioning is often 30 percent to 40 percent of the load in a large commercial facility, TES could allow a utility to sell power for 8 percent to 20 percent less. Thus, TES can help provide lower, more competitive prices—with considerable cost savings to make the lower price more profitable.

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[64] For example, the Geneva Electric Utilities Article 117A requires in any building over 10 kW demand that "the installation must be designed to limit the maximum needed power by cutting excessive thermal charges." Moreover, the designs reviewed by a commission must analyze the possibility of thermal storage and waste heat recovery. One TES manufacturer reports that this rule "helped our sales dramatically in that localized area." Mark MacCracken, CALMAC, Personal communication. July, 1995.

[65] The capital savings on the Transmission and particularly Distribution system usually are best captured when TES is installed in New Construction rather than Retrofit situations. Thus, the T&D benefits from TES installations can vary from zero in some areas to nearly $2000 per kW in other areas. In a conventional utility environment, there could be equal or greater savings in the generation side of the business. However, with the advent of de-regulation in the generation, many feel that few power plants will be built for capacity reasons in the next decade.

[66] PG&E analysis.

Not only do utilities or energy suppliers receive economic benefits from TES, so do building owners (or occupants). The first major benefit is lower energy costs. As noted previously, the power bill for air conditioning could be reduced 25 percent to 50 percent with TES. With a targeted 20 percent market penetration by 2005, TES could save over a half billion dollars annually in power costs. Moreover, some commercial facility managers believe that TES could be the best tool available for lowering power costs under Real-Time Pricing in a re-structured electricity industry.

TES is the best tool a commercial facility manager has for managing power costs under Real-Time Pricing, which the California Public Utilities Commission has proposed as the dominant type of pricing in a deregulated competitive electricity industry.

—Bill Kane, Energy Management Coordinator, San Francisco Moscone Marriott Hotel

—Ted Bischak, Senior VP, Tooley & Co., which manages several million square feet for The Irvine Company

One TES benefit that a number of building owners have appreciated is the ability of TES to increase the property value of a building. The property value increase could amount to $10-20 billion (in today's dollars) by 2005. This has allowed building owners to obtain more external financing when purchasing, building or improving a facility. That is, they often needed *less* of their own *cash up-front* rather than more when installing TES. This has been an attractive feature of TES.[67]

TES Economic Benefits for Building Owners

- **Lower energy costs (half billion dollars annually)**
- **Higher property values ($5 billion)**
- **Increased external financing ($3-4 billion)**
- **Increased leasable floor space (cold air distribution)**
- **Improved tenant comfort (less humidity)**
- **Lower fire insurance costs (chilled water)**

TES has also helped building owners increase the revenues from their facilities. In particular, as noted in the section titled *What is Thermal Energy Storage?*, cold air distribution systems require smaller ducts for air distribution. The smaller ducts can mean lower floor-to-floor heights—which allow architects to design additional floors without increasing building height. The additional floors mean more leasable floor space and greater revenues.

TES can also make the space more attractive and leasable by increasing tenant comfort. That is, cold air distribution means less humidity is supplied to the space, as noted in the section titled *What is Thermal Energy Storage?*. Most people find the drier air to be more comfortable.

Finally, chilled water TES systems have allowed some building owners to have lower fire insurance costs. The large storage tank of water is viewed by the insurance companies as additional fire protection. In return, such companies have lowered the fire insurance premiums at some facilities.

[67] Eric Hafter, ELH Development Services, Inc. Presentation to California Energy Commission TES Collaborative. August, 1994. The installed cost of the storage system is assumed to be $600 per kW of storage for a total investment of $1.5 billion. Because of the increase in property values, however, a TES investment could net building owner $3-4 billion in additional cash from financial institutions rather than requiring internal financing.

This information shows that TES provides several economic benefits to increase the competitiveness of both California utilities and California building owners. This increased competitiveness could enhance the economic development opportunities for California with an appropriate strong TES program.

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CONCLUSIONS

CONCLUSIONS

TES provides major compelling benefits of concern to the California Energy Commission:

- Energy efficiency (source and site)
- Environmental (air emissions savings and CFC reductions)
- Economic development and competitiveness (increased competitiveness of California energy suppliers and energy users)

For these reasons, the California Energy Commission and other energy/environmental institutions should consider policy actions that will encourage the market penetration of TES. Possible policy actions are further suggested.

Possible Policy Actions

Based on the energy savings and other benefits of TES, several possible policy actions emerge for consideration.

1. Make TES a priority DSM technology in energy policy decisions.
2. Modify California's Title 24 Building Standards to reflect TES' source energy savings and peak demands reductions.
3. Use TES as an air emissions control measure statewide.
4. Identify TES as a priority option for new and replacement cooling systems in "competitive energy environmental partnerships" with key energy users, such as:
   a) local, state, and federal government buildings, and
   b) businesses striving to be environmental leaders, as in the EPA's Energy Star Program

Possible Policy Actions to Promote TES.

The first possible policy action is making TES a priority energy efficiency measure or Demand-Side management program in state energy resource policy decisions. TES has demonstrated energy and air emission savings like other energy efficiency programs. But unlike most energy efficiency measures, TES greatly improves load factor and provides cost savings that help both energy users and energy suppliers be more competitive.

The second possible policy action is to modify the State of California Title 24 Building Standards method of comparing alternative cooling technologies' energy efficiencies. Currently the standards provide no energy savings credit (or penalty) to TES. The California Energy Commission could re-examine the role of source energy comparisons of alternative systems including the opportunities of TES systems. In addition, as in Switzerland, the building code could encourage designers to lower the building peak demands.

The third policy action is recognizing TES as an effective air emissions control measure. The South Coast Air Quality Management District has recognized thermal storage as a way to reduce site emissions. Other air districts could follow suit. In addition, many California air districts would benefit from encouraging TES as a control measure for power plants emissions.

The fourth policy action is promoting TES as a priority cooling system option in "environmental partnerships" with key energy user groups. One such group could be "sister" governmental agencies of the California Energy Commission, including local, state, and possibly federal government agencies. Another possible group includes businesses striving to be "environmental partners." As an example, the US Environmental Protection Agency has had considerable success in obtaining business "environmental partners" in its Energy Star programs such as Green Lights. This program has obtained a number of business partners in California who have committed to installing high efficiency lighting in 90 percent of their floor space over a five year period when the internal rate of return (IRR) exceeds 20 percent. California could develop a "Competitive Electricity Environmental Partnership" program for TES that is modeled after the Energy Star program This partnership would position California businesses to benefit from a competitive electricity market and help clean the air as well. Alternatively, perhaps TES could be included as a priority cooling technology in the second phase of the Energy Star program—which moves from lighting to heating and air conditioning system improvements.

- Allergan*
- ARCO
- Bank of America*
- California State University System*
- State of California*
- Chevron*
- Embarcadero Center*
- Hewlett Packard*
- Long's Drugs
- McDonald's*
- Rockwell*
- SCAQMD
- The Shorenstein Company
- TransAmerica
- Wal-Mart*
- Walt Disney Studios*

*Organizations with TES installed in at least one site.

Sample of Organizations in EPA Energy Star/Green Lights Program that have a Significant California Presence.

In summary, the California Energy Commission initially believed, and this study confirms, that TES is an "energy technology offering compelling energy, environmental, diversity, and economic development benefits to California." Moreover, TES is now poised for full commercialization. Institutional policies such as those that have been previously identified, can be pursued to "effectively increase the market penetration" of TES—as the California Energy Commission desires.

APPENDIX

Participants in the Thermal Energy Storage Systems Collaborative of the California Energy Commission

Active Members:

Air Conditioning & Refrigeration Institute
John Andrepont of Chicago Bridge and Iron
Victor Ott of CRYOGEL

Ambient Technologies, Incorporated
Bruce Holmes

Baltimore Air-Coil
Bruce Rose

Brown & Caldwell
Jim Schettler

California Energy Commission
James Patterson

California State University of Fullerton
Jim Corbett

California State University of Sacramento
Linda Hafar

Calmac Manufacturing Corporation
Mark M. MacCracken
Chuck Thompson

Chicago Bridge and Iron
John Andrepont
Paul LoBello
Joe Lutz

Cinche Group Incorporated
Leslie H. Fesskin

CRYOGEL
Victor Ott

Electric Power Research Institute
Mukesh Khattar

FAFCO
Roldan Penagos

Flack and Kurtz
Ben Sun

Gabel Dodd and Associates
Martyn Dodd

GPEC (Morris & Associates)
Jay Witt

International Thermal Storage Advisory Council (ITSAC)
Loren McCannon

KS Engineers
Klaus Schiess

Lennox Industries, Incorporated
Ted Gilles

Oak Ridge National Laboratory
John Tomlinson

Pacific Gas and Electric Company
Ken Gillespie
Stan Tory

Pasadena Water & Power Department
Moudood A. Aslam

Pitt-Des Moines Incorporated
Clark Eustis

Retrofit Originality Incorporated
Scot Duncan

Rogers & Associates
Dave Rogers

Southern California Edison Company
Don Geistert

Southland Industries
David Peters

Tabors Caramanis and Associates
John Flory

Thermal Storage Applications Research Center
Douglas T. Reindl

Tooley and Company
Ted Bischak

UHR Corporation
Bill Uhr

Verle Williams and Associates
Verle Williams

Corresponding and other Contributing Members:

Baltimore Air-Coil
Russ Lindemann
Randy Young

Brady Consulting Services
Thomas Brady

California Energy Commission
Daryl Mills
Bill Pennington

California Office of Energy Assessments
Bobby Khaghani

Cohn-Daniel Company
Joseph Kinsella

Depaul Associates
Dennis Bottum

Edison Electric Institute
Mike McGrath

Engineered Mechanical Inc.
Garry Rose

FAFCO
Mike Anderson

Flack and Kurtz
Clark Bisel

McCaughey Energy Systems
Owen McCaughey

Meckler Group
Milt Meckler

Pacific Gas and Electric Co.
John Goodin
Kathryn Stein

Plumas Sierra Rural Electric
Paul Bony

Riverside Public Utilities
Tom Lacey

Sacramento Municipal Utility District
Bruce Vincent

Sindoni Associates
Frank Sindoni

Texas Instruments
Donald Fiorino

Union Carbide Corp.
Ted Johnson

US Department of Energy
Jim Broderick

US Environmental Protection Agency
Roger Mosier
Sam Rashkin