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Governor

BENEFITS ASSESSMENT OF SEVEN PIER-SPONSORED PROJECTS

PIER DRAFT PROJECT REPORT

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Assessment of the Benefits and Costs of Seven PIER-Supported Projects is the draft report for the PIER Benefits Assessment project (Contract Number 500-06-014, Work Authorization Number KEMA-06-013-P-R) conducted by KEMA, Inc. The information from this project contributes to PIER's Renewable Energy Technologies Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

This report presents the results of benefit-cost analyses of seven projects supported by the California Energy Commission's Public Interest Energy Research (PIER) program. The analyses summarized below quantify the physical and financial benefits and costs associated with the development and deployment of the technologies under review. The seven PIER projects assessed are:

- Technical support for the incorporation of energy-efficient external power supplies for consumer and office electronics into the California appliance standards.
- Demonstration of the ThermoSorber, a dual-acting heat pump that supplies both hot and chilled water to industrial process applications.
- Funding and technical guidance for the development of the Real Time Display Monitoring System used by the California Independent System Operator to monitor conditions on the transmission grid and to direct efforts to avoid reliability problems.
- Co-funding the development of INFORM, an integrated forecasting and decision support system used to help reservoir operators in the Sacramento River Valley better predict operating conditions and manage trade-offs among conflicting objectives.
- Support the development of a reference design for advanced thermostats. The reference design was intended to be used by manufacturers to adopt a feature set specified to promote flexible use of advanced thermostats and to reduce their unit prices through standardization.
- Financial and market support for NightBreeze night ventilation technology, to promote energy and demand savings in California's residential building sector.
- Support for the Hotel Bathroom LED Night Lighting. The primary goals of the project were to develop both a switch retrofit controller (Lighting Control System) and a vanity light fixture (Smart Light Fixture) that resulted in quantifiable savings.

The study also contains analysis of the role that PIER played vis-à-vis other organizations that supported the development and deployment of the technologies in enabling the achievement of the quantified benefits. This information is used to attribute to PIER activities a portion of the total benefits of advancing the subject technologies.

Keywords: research and development, benefit-cost analysis, cost effectiveness

Executive Summary

Introduction

This report presents the results of benefit-cost analyses of seven projects supported by the California Energy Commission's Public Interest Energy Research (PIER) program. The analyses summarized below quantify the physical and financial benefits and costs associated with the development and deployment of the technologies under review. They also assess the role that PIER played vis-à-vis other organizations that supported the development and deployment of the technologies in enabling the achievement of the quantified benefits. This information is used to attribute to PIER activities a portion of the total benefits of advancing the subject technologies. Thus, in terms familiar from cost-effectiveness assessments of energy efficiency programs funded by public goods charges, the analyses presented here can be understood as estimates of the net benefits associated with seven PIER projects.

The basic objectives of the PIER Benefit-Cost Assessment were to:

- Develop appropriate methods to assess the benefits produced by PIER research, development, and demonstration (RD&D) projects and programs.
- Test the methods on a variety of PIER projects.

Two basic types of project were subjected to benefit-cost analysis for this report. The specific examples chosen were as follows.

Development and deployment of efficient end-use devices.

- Technical support for the incorporation of energy-efficient external power supplies for consumer and office electronics into the California appliance standards.
    - Demonstration of the ThermoSorber, a dual-acting heat pump that supplies both hot and chilled water to industrial process applications.
    - Support the development of a reference design for advanced thermostats. The reference design was intended to be used by manufacturers to adopt a feature set specified to promote flexible use of advanced thermostats and to reduce their unit prices through standardization.
    - Financial and market support for NightBreeze night ventilation technology, to promote energy and demand savings in California's residential building sector.
    - Support for the Hotel Bathroom LED Night Lighting. The primary goals of the project were to develop both a switch retrofit controller (Lighting Control System) and a vanity light fixture (Smart Light Fixture) that resulted in quantifiable savings.
- Development and deployment of tools designed to provide more efficient and rereliable large resource delivery systems.

- Funding and technical guidance for the development of the Real-Time Display Monitoring System used by the California Independent System Operator to monitor conditions on the transmission grid and to direct efforts to avoid reliability problems.
- Co-funding the development of INFORM, an integrated forecasting and decision support system used to help reservoir operators in the Sacramento River Valley better predict operating conditions and manage trade-offs among conflicting goals.

Methods

Efficient End-Use Devices

KEMA used the following procedure to estimate the benefits and costs of the PIER projects that supported efficient end-use devices.

- Estimate unit energy savings and other consumer benefits, as well as how much it would cost consumers to use the technology.
- Estimate the monetary value of consumer benefits using avoided cost rates and other additional sources of information.
- Compile PIER Program records of financial awards and other types of assistance provided to the project.
- Compile data on actual annual levels of efficient product adoption to date. Develop forecasts of the annual levels of adoption through the appropriate evaluation period.
- Develop a baseline forecast of annual product adoptions in the absence of PIER support using the results of Step 3 and additional research on project attribution.
- Apply the Total Resource Cost test to estimates of net benefits developed using the results of Steps 1 – 5.

Efficient Resource Delivery Systems

KEMA used scenarios to estimate the benefits of projects aimed at increasing the efficiency and reliability of resource delivery systems. The basic steps in the analysis were as follows.

- Compile records of system performance over a number of recent years.
- Use these records to model the differences in system performance between scenarios with and without the PIER-supported technology in place.
- Use relevant market data and information from secondary sources to place a monetary value on the differences in system performance.
- Estimate the net present value of benefits generated by the project.

The authors elected to use the benefit-cost framework established by the California Public Utilities Commission to assess the cost-effectiveness of energy efficiency programs because of its familiarity and broad acceptance in the energy policy and regulatory arena. That framework has been used primarily to assess the cost-effectiveness of programs that promote and deploy market-ready technologies. The Total Resource Cost is more stringent than the kinds of cost-effectiveness tests typically applied to R&D and early-stage market development programs in the following ways:

- It counts only avoided system costs of energy savings, not savings to customers who, as taxpayers, fund PIER and other R&D programs.
- It uses a relatively high discount rate – 8.15 percent –that significantly reduces the net present value of benefits achieved in far in the future. Many PIER projects specifically target opportunities for technical development that may not return benefits for a long time.
- It counts as costs the expenses that technology users assume to purchase or install the technology. In some frameworks, those costs are not counted or are used as inputs into economic models that estimate income and employment benefits associated with the substitution of local goods and services for imported energy.
- It focuses on a narrow range of benefit types – namely avoided energy costs and largely excludes the value of other benefits, including: avoided environmental damages, increased local income and employment due to reduced energy imports, and knowledge benefits gained through diffusion of experience and research findings.

For this study the authors have made one adaptation of the Total Resource Cost approach to make it more compatible with PIER's mission and program approach. Namely, the authors have limited the amount of potential net costs or negative benefits to the value of PIER's expenditures on the projects in question. In applying the resource costs to typical energy efficiency programs, it is possible to arrive at large negative estimates, far in excess of the sponsor's program costs. This can occur if program evaluations find that the supported measures achieve much less than the planned level of energy savings per unit, or if evaluations find that a high portion of the projects supported by the program would have gone forward in its absence (high free ridership). Beyond very small demonstration are projects designed primarily to assess technical performance, PIER does not provide subsidies (money) to end users to adopt the technologies supported by the program. Thus, the concept of free ridership does not apply. In regard to the effects of poor performance in the field, the authors assume that end-use customers or institutions that manage large energy systems will not purchase products or services that do not work or whose costs far exceed expected benefits. Thus, in the worst case, a product or system developed PIER could generate zero benefits as they are identified by the Total Resource Cost. However, in those cases they would also generate zero customer costs. The authors' analyses of the NightBreeze, ventilation system, INFORM, and the advanced thermostat projects yielded this result as a potential lower limit for net project benefits.

Assessment of Attribution

Prior to undertaking the case studies reported here, KEMA thoroughly review of the literature on evaluation and benefit-cost assessment of RD&D programs. The authors used the findings from this review along with their familiarity with the projects to identify the most appropriate method to estimate the net benefits attributable to PIER activities for each study. The authors selected the following approaches for the projects analyzed here.

- **Expert Judging (Delphi Process).** For the benefit-cost assessment of PIER's involvement in the development of efficient external power supplies, KEMA used a Delphi process to develop quantitative estimates of the net benefits attributable to PIER's activities. Six subject matter experts representing a range of stakeholders participated in the process. KEMA conducted two repeated rounds of structured questioning designed to yield a refined set of opinions on the likely trajectory of market share for efficient power supplies with and without PIER involvement, as well as opinions on the trends of other key parameters in the benefit-cost analysis. KEMA selected the Delphi process for this project because there were enough informed individuals from which to build a usable panel of judges and because the information needed for the analysis could be reduced to a small number of relatively straightforward questions.
- **Historical Tracing.** For the remaining projects, KEMA used historical tracing, also known as the *case study method*, to develop assessments of PIER program influence and estimates of net project benefits. This method involves the carefully reconstructing events leading to the outcome of interest, for example, the launch of a product or the passage of legislation, to develop a "weight of evidence" conclusion regarding the specific influence or role of the program in question on the outcome. Historical tracing relies on logical devices typically found in historical studies, journalism, and legal argument. These include:
  - Compiling, comparing, and weighing the merits of narratives of the same set of events provided by individuals with different points of view and interests in the outcome.
  - Compiling detailed chronological narratives of the events in question to validate hypotheses.
  - Positing a number of alternative causal hypotheses and examining their consistency with the narratives.

KEMA opted to use historical tracing methods for these projects primarily because there were too few individuals with close knowledge of a broad range of factors affecting project success or the targeted market to create a functional expert panel.

Summary of Key Findings

Overview of Program Cost Effectiveness

Even though this study was able to assess only a small portion of the PIER portfolio, the results of the individual case studies strongly suggest that California taxpayers have reaped benefits from the program that significantly exceed its costs. If the authors lift the focus of the benefits assessment to the United States, the success of the PIER program as a public investment becomes even more apparent.

Table 34 summarizes the benefits and costs of the projects assessed for this report. The projects included were identified by PIER staff as having a high probability of generating energy and environmental benefits over a relatively short time frame. Thus, they are not a representative sample of projects in the PIER portfolio, and the results shown in Table 1 cannot be expanded to the portfolio in using statistical procedures or simple scaling.

Table 1. Summary of Project Costs and Benefits

		California		United States	
Project	**PIER Costs**	**Low Benefits**	**High Benefits**	**Low Benefits**	**High Benefits**
Efficient External Power Supplies	$577,082	$58,000,000	$105,000,000	$908,000,000	$1,135,000,000
ThermoSorber	$250,000	$2,600,000	$2,600,000	$2,600,000	$2,600,000
Real Time Display Monitoring System	$7,000,000	$2,000,000	$229,600,000	$17,500,000	$629,300,000
INFORM	$400,000	-$400,000	$81,500,000	-$400,000	$82,000,000
Advanced Thermostats	$1,000,000	-$1,000,000	$45,700,000	-$1,000,000	$45,700,000
NightBreeze	$995,000	-$995,000	-$995,000	-$995,000	-$995,000
Light Emitting Diode Bathroom Lighting	$387,000	-$387,000	$568,000	-$387,000	$568,000
Total	**$10,609,082**	**$59,818,000**	**$463,973,000**	**$925,318,000**	**$1,894,173,000**

Source: KEMA

However, the authors emphasize that the high estimates of benefits for the seven projects more than $463 million for California citizens alone and that the authors applied very conservative assumptions in developing even the high estimates. The most important of these restrictive assumptions are as follows:

- **Omission of key project benefits.** For several of the case studies, restriction in schedule and budget precluded the estimation of certain key benefits. For example, in the Real Time Display Monitoring System case, the authors did not measure the economic benefits associated with expanded capabilities to integrate large amounts of intermittent resources such as wind and solar into the transmission grid. Similarly, the authors did not account for the reliability value associated with widespread adoption of demand response devices that will be supported by advanced thermostats.
- **Application of steep discounting.** In keeping with the Total Resource Cost framework the authors applied a discount rate of 8.15 percent to forecasted annual savings. Evaluations of public sector programs such as PIER typically apply lower discount rates. The U.S. Office of Management and Budget recommends the use of a 7 percent discount rate for assessment of programs that supplement or displace private investment.

Academic economists generally recommend the use of lower discount rates, especially for programs that have intergenerational effects, such as those that mitigate address change.

- **Conservative specification of key inputs.** In all of the case studies involving a choice among several sources or methods for developing key input assumptions, the authors chose the most conservative alternatives.
- **Omission of broader program benefits.** Most of the general methodological guides to evaluating R&D programs identify a broad set of potential benefits, including diffusion of technical and market information to other organizations and entrepreneurs, stimulation of private investment that would not otherwise have occurred, and the development of organizational infrastructure to support further innovation. While the case study research provides strong evidence of such benefits, the did not seek to quantify them.
- **Benefits to households and businesses outside California.** Due to the international structure of the supply chain for external power supplies and the dominant size of the California market for consumer and office electronics, PIER's contribution to the adoption of efficient power supply standards clearly boosted market share of the efficient devices outside California. Even if the authors were to cut their low estimate of the national benefits of this initiative by 40 percent, the resulting net benefits would offset the full cost of the PIER program from inception through 2008. Similarly, the benefits of the Real-Time Display Monitoring System initiative will be experienced by customers on the entire Western Electricity Coordinating Council grid, not just those in California.

Of course, the seven projects assessed here represent only a very small portion of the total PIER portfolio. It is not unreasonable to assume that the portfolio contains a handful of additional "big winners" and that the total net benefits of the portfolio exceed cumulative program costs, even within the stringent requirements of the Total Resource Cost benefit-cost framework.

Summary of Individual Project Benefit-Cost Assessments

External Power Supplies

Product Description. Power supplies are special circuits designed to reduce voltage delivered to electronic products from 120 volts to between 3 and 15 volts, convert it from alternating current (AC) to direct current (DC), and regulate the output to power a wide range of consumer electronics devices. Power supplies are used in a vast range of home and office electronics. There are two basic design types for external power supplies: "linear" and "switching." Compared to linear designs, switching designs are smaller and more energy efficient. Growth in saturation of power supplies has been very rapid. Recent studies estimate that more than 6 percent of national electricity consumption or 217 terawatt hours (TWh) per year passes through power supplies. Proponents of more efficient power supplies argued that use of switching technology could lead to annual electricity savings of 524 gigawatt hours (GWh) in

California alone as conventional technology was displaced in the market. Attention initially focused on external power supplies.

PIER's Role and Project Costs. The PIER External Power Supply project was intended to support accelerated market acceptance of switched technology in external power supplies. A number of organizations had been active in promoting the technology to manufacturers before PIER's involvement in 2003. A number of activities, most notably the development of test procedures, were undertaken to promote this shift in market share. Ultimately, work carried out by the PIER project supported the incorporation of efficient external power supplies into California's Title 20 Appliance Efficiency Regulations by the Energy Commission, which in turn supported the incorporation of somewhat more stringent specifications into federal product standards that took effect in 2008.

The total cost of PIER support for the incorporation of efficient external power supply specifications into the California Appliance Standards was $577,082.

Estimate of benefits. KEMA estimated the benefits associated with PIER's support of the California code revisions at both the state and U.S. levels through the following analytical steps.

- **Forecast the volume of devices covered by California and federal external power supply standards.** KEMA used market studies and proprietary data from 2003, 2005, and 2008 to develop trends in the sales volumes of key product categories covered by the external power supply standards through 2015.
- **Develop baseline estimates of the market share of energy-efficient power supplies.** KEMA used the results of a Delphi process with a panel of six industry experts to develop baseline forecasts of the market share of efficient power supplies over the analysis period, that is: a forecast of what the market share would have been if California and federal power supply standards had not been promulgated in 2007 and 2008. Baseline forecasts were developed for six scenarios that differed by rate of growth of efficient power supply market share.
- **Estimate the annual number of efficient power supplies sold that were attributable to PIER activities.** This was calculated as the difference between the actual number sold and the baseline.
- **Estimate the stream of annual costs and benefits required for application of the Total Resource Cost test.** KEMA developed appropriate values for average savings per unit, average customer cost per unit, and average effective useful life from a wide variety of sources, including in-depth interviews with industry observers, technical studies, and market studies. These parameters were applied to the estimates of net units sold due to PIER intervention.

The key results of this analysis were as follows.

- Participants in the Delphi process stated that PIER's involvement accelerated the adoption of product standards for efficient power supplies by 1 to 10 years, with most noting change in the 2 to 3 year range.

- Using the annual baseline market share values, the authors estimated that PIER's efforts were associated with incremental sales of 917 million to 1.24 billion efficient units beyond what would have occurred in the absence of PIER efforts, over the 10-year analysis period. This is roughly 15 percent of the total number of covered devices forecasted to be sold over the analysis period.
- The authors estimated the net present value of these incremental unit sales at $58 million to $105 million ni California; $983 million to $1.135 billion for the United States as a whole, depending on the input scenarios used.

ThermoSorber

Product Description. The ThermoSorber is a thermally activated heat pump/chiller based on an ammonia-absorption cycle. It can simultaneously produce hot water at 130 to 170 degrees Farenheit and chilled water at 20 to 45 degrees. The heating efficiency of the device is 160 percent, and cooling efficiency is about 60 percent. To date, two ThermoSorbers have been installed at poultry processors, installation is underway at a meat processor, and an industrial laundry is applying for incentives to install one.

PIER's Role and Project Costs. The U.S. Department of Energy had funded the research and development work needed for the inventor, Energy Concepts Company (based in Maryland), to create a working prototype of ThermoSorber. There were no commercial installations at the time that PIER became involved with the project. The PIER project had three goals: develop and install two industrial scale units; integrate them into industrial processes; and do it all cost-effectively. To help meet these objectives, the PIER Program provided financial support, assisted in site selection, arranged third-party monitoring, and promoted ThermoSorber technology. PIER also worked with the California investor-owned utilities to include ThermoSorber in the Emerging Technologies program, which led to one of the current installations. The California utilities also paid for a rigorous assessment of savings actually achieved through this installation, which confirmed engineering-based calculations of benefits.

The contract cost of PIER's involvement in the project was $250,000, used primarily as incentives to plant owners to develop the demonstration sites. Other costs not currently reflected in the analysis include relatively small amounts of PIER project staff time used for project administration and recruitment of demonstration sites.

Estimate of Benefits. KEMA's independent assessment of the market for the ThermoSorber found that it is very much a niche product with maximum annual sales of 150 to 200 units. Despite its small potential market, unit savings are so high that programmatic support for the device can still be cost-effective. For example, the ratio of the present value of energy savings to measure costs (Total Resource Cost ratio) ranges from 9.3 to 9.5 for food service applications, using operating results from the first few installations.

KEMA developed a number of 10-year market penetration trajectories using diffusion models. The authors used the mid-range set of assumptions to develop estimates of annual installations.

Based on that assumed pattern of sales, the authors developed estimates of savings and applied the TRC test. The key results of this analysis are as follows:

- Annual energy savings from ThermoSorbers installed in 2018 were estimated at 24.4 GWh and 4.6 MW for electricity, and 4.9 MTherms for gas.
- The present value of savings over the period 2007 – 2018 was calculated to be $12.0 million, versus customer and program costs of $3.5 million.
- Based on interviews with representatives of process heating and refrigeration equipment, as well as others familiar with the project, KEMA determined that it was appropriate to credit net benefits associated with projected installations of the ThermoSorber equally to the three organizations that had provided support for research, development, and demonstration: the U.S. Department of Energy, the PIER Program, and Pacific Gas and Electric, through the Emerging Technology Program. Thus, the net benefits attributable to PIER support of the ThermoSorber were estimated at $2.6 million, with a Total Resource Cost benefit-cost ratio of 2.87.
- Given the dispersed nature of public support for the development of the ThermoSorber, the authors believed it was appropriate to estimate net benefits at the national level only.

Real-Time Display Monitoring System

Product Description. The Real-Time Display Monitoring System is a set of computational and visualization tools that enable the operators of California's transmission grid to use phasor measurements to identify potential reliability problems and to identify strategies to avoid them or reduce their impact. Phasors are measurement devices that monitor local transmission system conditions at very short intervals – up to 20 times per second. The currently deployed network of phasors covers much of the California transmission grid.

PIER's Role and Project Costs. The Energy Commission has supported the development and testing of the elements of the RTDMS since 1999, with the first PIER contract issued in 2000. Some earlier prototyping of various elements of the system was supported by the U.S. Department of Energy's Transmission Reliability program. Over the past nine years, PIER has provided roughly $7 million to the project to support research and development of the various software and visualization tools required for real-time processing and display of phasor measurements.

Estimate of Benefits. KEMA estimated the value of the Real Time Display Monitoring System by assessing its impact on the probability of outages and applying monetary values to the reduced experience of outages. This is not an academic exercise. On January 26, 2008 grid operators at the California Independent System Operator (California ISO) used the Real Time Display Monitoring System to detect undamped low-frequency oscillations in a portion of the grid that could have spread and caused significant instability in the system, including outages. The operators were able to take corrective action quickly to restore normal conditions and limit the spread of the oscillations.

The steps KEMA took to estimate the value of outages avoided, along with key intermediate results, are as follows.

- **Set the potential outage boundaries**. The Western Electric Coordinating Council reliability control area, which encompasses California, more than 150,000 MW of peak load. California accounts for roughly one-third of that. Given the physical configuration of the system, instability at any point could lead to outages on the whole system.
- **Estimate outage probabilities**. KEMA used published analyses of North American Electric Reliability Corporation outage data and data specific to WECC to estimate the expected value of an outage in terms of MWh of lost load. Using the probability distribution derived from the North American Electric Reliability Corporation analysis, the expected outage size for California is 3,839 MWh and 10,645 MWh for Western Electric Coordinating Council.
- **Estimate and apply outage costs per MWh**. KEMA used a variety of secondary sources on the value of lost load and the economic impacts of outages to estimate their social cost. The literature in this field presents a very wide range of estimates – from $2,000 to $40,000 per MWh of lost load. For purposes of this study, KEMA selected a value of $13,338 per MWh, based on an analysis of the impacts of the 2003 Northeast blackout.
- **Apply a factor for reduction of probability of lost load**. The Real-Time Display Monitoring System cannot be expected to eliminate outages entirely but reduces their probability of occurrence in a given period. KEMA estimated benefits from implementation of Real-Time Display Monitoring System assuming potential decreases in the probability of lost load of 10, 20, 30, 40, and 50 percent.
- **Estimate the total value of reduced probability of lost load.** For the California region, estimated benefits over a 10-year period ranged from $13 million to $338 million for California, and from $35 million to $909 million for the entire Western Electric Coordinating Council region.
- **Estimate the portion of total benefits attributable to PIER activities.** Based on the results of in-depth interviews with industry experts and representatives of the California ISO, KEMA determined that PIER support of the development of the Real-Time Display Monitoring System accelerated its development and deployment by at least 7 years. Applying these results we estimated benefits net of PIER costs over the 10-year analysis period attributable to PIER activities ranging from $2 million to $230 million in California and $18 million to $629 million for Western Electric Coordinating Council.

These estimates do not include values for a number of hard-to-quantify benefits, such as reduction of security threats associated with outages and relief of transmission system congestion. Nor do they include the benefits associated with increased ability to manage growing injections of intermittent power from renewable sources into the Western Electric Coordinating Council grid without compromising system stability.

INFORM

Product Description. INFORM is an integrated set of weather forecasting, hydrological modeling, and decision support tools designed to help reservoir operators identify water release schedules that strike a balance among competing objectives under uncertain conditions. The objectives include: fulfillment of contracted water deliveries; flood control; maintenance of carry-forward reserves; power generation; and maintenance of healthy ecological conditions for plants and wildlife. The basic data-gathering and software components of the system have been developed and tested against historical weather, hydrological, and reservoir management data. The system has been shown to provide improved accuracy of forecasts of key conditions when compared to more established methods, although initial testing indicated the need for additional refinements. Moreover, further development, piloting, and training will be required for integration of the system into day-to-day reservoir operations.

PIER's Role and Project Costs. INFORM has been jointly funded by the National Oceanographic and Atmospheric Administration, CALFED – a consortium of federal and state agencies that manage water resources in the Sacramento River Valley, and PIER. Funding for the project from these sources has totaled roughly $1.7 million to date, of which PIER has contributed $400,000. Funding applications to continue the project are under consideration.

Estimate of benefits. Benefits and costs associated with INFORM were estimated using the following approach:

- Document key reservoir management outcomes – water deliveries, carry-over storage levels, and electric generation–for 2006 – 2008.
- Use the INFORM forecast and decision support tools in conjunction with actual weather and hydrological data to generate trade-off curves between water deliveries, system carry-over storage, and electric generation for the beginning of each year in the analysis.
- Estimate the range of achievable levels of carry-forward storage and energy generation taking water delivery as given.
- Compare the modeled levels of carry-forward storage and energy generation to those actually achieved through conventional practice. The value of the differences in those quantities was used as the value of benefits that could have been achieved over the 2006 – 2008 operating years if INFORM had been implemented during that period**.**

Results show that the average level of electricity that could be generated using release schedules indicated by INFORM exceeded actual production by 700 GWh over the three years in the analysis period. This incremental production has a market value of $42 million. If reservoir operators had used INFORM forecasts as a guide instead of standard operating procedures in 2006, they would have ended up with higher levels of carry-forward storage in two of the three years modeled. The value of potential incremental carry-over storage created through the application of the INFORM forecasts and decision rules ranged from -$7 million to $9 million for the average values.

Based on the results of in-depth interviews with nine individuals familiar with the INFORM project and the operating environment in which it is to be implemented, the authors determined that it would be appropriate to credit PIER with developing these prospective benefits in proportion to the funding it contributed to the project, namely 31 percent. Applying this factor to the estimates of gross benefits discussed above, the authors calculated that benefits attributable to PIER ranged from $14 million to $82 million. However, given circumstances surrounding reservoir construction and management as of the completion of this study, it is possible that the INFORM system will not be implemented at all. Therefore, the authors assign a lower limit on net benefits equal to INFORM's project costs: $400,000.

Given that the INFORM system is not yet complete and has not been piloted in day-to-day operations, estimates of projected benefits must be regarded as somewhat speculative.

AdvancedThermostats

Product Description. Advanced thermostats are advanced thermostats which have the ability to receive demand response signals and, in response, reduce space conditioning use by adjusting temperature set-points. Several types of advanced thermostats are on the market today, with a variety of capabilities and communication methods available. At its most basic, an advanced thermostat consists of a customer interface, a heating, ventilation, and air conditioning (HVAC) interface, and demand response communications capability. The customer interface allows users to define temperature set-points throughout the day and, in some versions, define temperature offsets for when space conditioning is reduced. The HVAC system interface is the equipment controller which interacts with the HVAC unit based on unit settings and responds to demand response signals. Finally, the demand response communications component provides the means for receiving price or curtailment signals from utilities, aggregators or grid operators, indicating when to reduce space conditioning.

PIER's Role and Project Costs. The purpose of the PIER Advanced Thermostats effort was to facilitate the development of new reference designs for sensors, meters and thermostats that would make demand response infrastructure cost-effective for residential consumers in California, and adaptive to changes in communications capabilities and protocols over time. The PIER program sponsored the development of a reference design for advanced thermostats and tasked a team of researchers at the University of California, Berkeley with addressing technical questions associated with implementing residential advanced thermostats in California. Work on the reference design was begun in 2005 and completed in 2007. The advanced thermostats reference design was developed over twenty months in which manufacturers, utilities, and consultants participated in public workshops and conference calls. Based on conversations with Energy Commission staff and others, KEMA estimated the total likely cost of the PIER advanced thermostats efforts at $ 1 million.

Ultimately, project efforts achieved the Energy Commission’s vision of a minimum functionality advanced thermostat capable of receiving statewide broadcasts and adaptable for additional communications, available for retail at under $100. This work laid the groundwork for the development of the reference design. Continued input from stakeholders in the Title 24 Standards helped to form the reference design drafted for the building standards.

Estimate of Benefits. KEMA developed three scenarios to structure the benefit-cost assessment of PIER’s activities in support of advanced thermostats: Baseline Scenario, PIER Project Scenario, and PIER Project plus Title 24 Scenario. Depending on scenario, PIER support for advanced thermostats will generate net electricity savings of between 7,135 and 10,955 MWh per year over a fifteen-year period, and demand savings of between 526 and 796 MW. These figures assume that advanced thermostats achieve only modest unit demand reductions and energy savings.

The net present value associated with each scenario relies heavily on the assumed per unit savings. Under the base case assumptions concerning energy savings and demand reductions per unit, the increased adoption of PCTs associated with the PIER project lead to a gain of $28.4 million in net present value over the baseline scenario. Additional adoptions in new construction due to the effect of incorporation of PCTs into Title 24 building codes yield a gain of $45.7 million in net present value. Under pessimistic assumptions regarding energy savings and demand reductions per unit, PCTs are not cost-effective within the TRC framework and their deployment leads to substantial costs in excess benefits. As discussed in regard to the INFORM project benefit-cost analysis, we treat this situation by assigning a low net present value equal to the cost of the PIER project: in this case -$995,000.

NightBreeze

Product Description. The NightBreeze system combines heating, ventilation cooling, and air conditioning functions in an energy-efficient, user-friendly control system. In essence, NightBreeze supplements standard HVAC systems with ventilation cooling functionality, and places all aspects of residential climate control under a single set of controls. A central system controller uses climate and usage data to predict future daytime cooling demand. Based on these predictions, the controller ventilates the house with cool, filtered outside air overnight to lower indoor air temperature. In the morning, NightBreeze closes off the house from outside to preserve the cool indoor air mass. As the day grows hotter, temperatures inside the pre-cooled home will rise slowly compared to homes without night ventilation, and less air conditioning will be needed to achieve an identical level of comfort. NightBreeze is most effective in hot, dry climates and transition zones.

PIER’s Role and Project Costs. PIER has delivered support for the NightBreeze system through two separate projects. The primary goal of the first project, known formally as “Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling” (1998-2004), was to develop, test, and demonstrate an integrated HVAC night ventilation system. To accomplish this goal, PIER contracted with Davis Energy Group to build and evaluate the system, which was named NightBreeze. The original NightBreeze was a single-zone “hydronic” system, or one in which heat is derived from a water heater or boiler.

To gain market share and have meaningful impacts in terms of energy savings and demand reduction, proponents of ventilation cooling needed to develop a furnace version of the NightBreeze. This was the principal objective of the second PIER project in support of ventilation cooling. Like Alternatives to Compressor Cooling Phase V, this follow-up project, known as "NightBreeze Products Development Project" (2002-2007), also relied primarily on Davis Energy Group to carry out essential tasks. Davis Energy Group successfully designed and built a furnace version of the NightBreeze ("NB2") to complement the original hydronic version ("NB1").

The project budget for Alternatives to Compressor Cooling Phase V was approximately $715,000, and the budget for the market development project was approximately $280,000.

Estimate of Benefits. KEMA developed benefit-cost ratios, discounted net benefits, and net present value figures associated with PIER support for NightBreeze night ventilation technology through the following steps:

- Establish avoided costs for California.
- Develop estimates of quantity of NightBreeze systems sold annually.
- Estimate energy savings for NightBreeze systems.
- Estimate cost savings associated with NightBreeze.
- Determine incremental cost of NightBreeze.
- Assessment of the effect of PIER activities on NightBreeze development.

KEMA calculated NightBreeze benefits over the period 2006 – 2025. In terms of physical quantities, the authors estimated energy savings of between 1,300 MWh and 3,000 MWh per year. However, Total Resource Cost net benefits were negative under all combinations of assumptions concerning number of units installed, unit costs, annual energy savings per unit, and the avoided cost of electricity.

The problem lies with the relatively high cost of the measure (incremental cost is $1,500-$2,000) compared to its potential energy savings. The NightBreeze is a complicated measure, consisting of many diverse components, jumper ducts between the room in which the main return duct is located and other rooms, and HVAC controls that are much more sophisticated and difficult to set up than those with which the typical residential HVAC technician is familiar. Given this product configuration, it is difficult to imagine circumstances under which installation costs could be reduced significantly or large numbers of HVAC contractors would invest in the training needed to install these devices in significant volumes.

PIER's investment in the NightBreeze technology does not yield positive net present values or benefit-cost ratios greater than 1.00 under any of the sets of assumptions concerning unit savings and cost described above. The maximum TRC benefit-cost ratio achieved is 0.615. Given these results, the authors set the net present value of the project at PIER's project cost, namely $995,000.

Hotel Bathroom LED Night Lighting

Product Descriptions. The PIER Hotel Bathroom LED Night Lighting project developed two technologies: a Lighting Control System and a Smart Light Fixture. Both the Lighting Control System and the Smart Light Fixture include a Light Emitting Diode night light and an occupancy sensor in their design. Both technologies save power by simultaneously turning on an Light Emitting Diode night light and turning off the vanity fixture lighting when the occupancy sensor fails to detect an occupant for a pre-determined period. Turning on the Light Emitting Diode nightlight protects motionless occupants (long bath takers) from being plunged into complete darkness while saving electricity when the lights are left on either accidentally or to serve as a night light. The time out for the occupancy sensor is typically set to an hour or more to minimize the chance of turning off the lights with an occupant in the room (a "false-off"). This hour time-period is much longer than normal occupancy sensors' time-out of 15 to 30 minutes. This time setting is a compromise between energy savings and hotel operator's fear of inconveniencing guests.

PIER's Role and Project Costs. PIER delivered support for the Hotel Bathroom LED Night Lighting through funding under an umbrella program: the Lighting Research Program. The primary goals of the project were to develop both a switch retrofit controller (Lighting Control System) and a vanity light fixture (Smart Light Fixture) that resulted in quantifiable savings. The technology was expected to reduce bathroom-lighting electricity use by at least 50 percent. The Lighting Control System was developed in Phase I of the projects and Smart Light Fixture was developed in Phase II of the project.

Watt Stopper successfully developed a Lighting Control System device in Phase 1 of the project: the WN-100. Project reports and interviews with Sacramento Municipal Utility District (SMUD) employees involved with the project indicate the device was favorably received by both hotel guests and staff. Watt Stopper and SpecLight developed a Smart Light Fixture in Phase 2 of the project. SMUD project staff reports that the results were similar to those obtained for the Lighting Control System.

Funding totaled $440,000. The California Energy Commission provided $220,000, and matching funds of $220,000 were provided by third parties. Watt Stopper provided the majority of money but Double Tree and SMUD also provided financial support.

Estimate of Benefits. The BCR lies somewhere between .63 (all fluorescent) and 1.88 (all incandescent). PIER support for hotel bathroom Light Emitting Diode night lighting will produce electricity savings of between 469 and 1,355 MWh per year over the period 2003 – 2010. Over 20 years, this PIER effort will produce net benefits of between -$357,000 and $568,000. PIER's investment in the Hotel Bathroom Light Emitting Diode Night Lighting technology yields positive net present values only under the assumption that the load controlled is primarily incandescent lighting. If the technology were targeted to budget-oriented chains that had not recently updated their bathroom lighting, it could possibly become cost-effective for utilities to promote the technology through their commercial lighting programs in cost effectively.

Current utility programs addressing a wide range of hotel energy efficiency measures are unlikely to meet goals with regard to Light Emitting Diode night lighting. To date, they have not convinced sufficient numbers of hotel operators to install these devices. Unless programs attempt to reach more hotels or drastically improve their ability to convince operators to adopt this technology, the current program enrollment goals are not sufficient to make the Hotel LED Night Lighting project cost-effective.

Conclusions and Recommendations

Strategic Lessons the Case Studies

PIER program staff identified the seven projects assessed in this study as efforts that were likely to produce significant net energy and environmental benefits. The authors found, however, that not all of these projects are likely to do so. KEMA identified patterns in these results that may prove useful in project management and selection.

Product-Oriented Projects

The Advantages and Limits of Code-Related Strategies. PIER enjoys an unusual advantage over other R&D programs in that its parent organization sets appliance and building energy efficiency standards for the seventh-largest economy in the world, the State of California. Because California accounts for such a large share of international electronics and mechanical equipment markets, standards promulgated there can exercise a significant effect on manufacturers and other standard setting bodies. Similarly, the California construction and renovation markets are so enormous (although subject to cyclical fluctuations) that changes in the building code can greatly accelerate the adoption of efficient products and design approaches.

Many of the projects assessed for this study, as well as some that were reviewed and put aside, contained code-related strategies for diffusion of the technology in question. The authors review of these cases suggests the following observations in regard to the potential benefits and limits of strategies that rely on code enhancements to support the diffusion of supported technologies.

- **Support of mandatory standards for manufactured products offer the greatest opportunity to leverage technology-oriented R&D.** The large and relatively certain benefits associated with PIER's support of external power supplies illustrate this point. This is a strategy that PIER is clearly well-situated to pursue, with its access to academic institutions, technology companies, utility programs, and standard-setting bodies in California and elsewhere. Flexibility in the use of budget resources also enables PIER to fill gaps in national and international efforts. The external power supply case illustrates effective use of all of these organizational assets.
- **Inclusion of a technology in Title 24 as a compliance option does not necessarily lead to increased adoption.** A number of PIER-supported products and measures that have been incorporated into the Title 24 as compliance options have experienced only minimal levels of adoption. The reasons for these outcomes include the following:
    - o Less expensive and more familiar products and methods for compliance are already in the market.

- o The products are not cost-effective from the customer's point of view. For manufactured products such as the night lighting system, customer incentives may be an effective method to overcome this barrier and, with sufficient increases in volume, reduce unit costs of manufacture. Given the complexity of the NightBreeze system and its installation, it is less likely that costs would decrease significantly with increased volume.
- o Elements of the product's performance are incompatible with target customers' business practices and strategies. This is the case for the hotel night lighting system for more upscale chains that see automated lighting control as a possible inconvenience for guests.

These examples point out the need to address the issues typically associated with business planning–market sizing, segmentation, characterization of competition and competing products – early in the project or even in the project selection and contract development process. The prospects of a difficult sell or vigorous competition should not in themselves discourage PIER investment. Rather, investments in technology developments are most likely to yield benefits if all aspects of the project are informed by a realistic assessment of the challenges to be faced in the commercialization phase.

The value of institutional relationships. Several of the projects reviewed for this study contributed to the development of on going organizations or strategic alliances that will likely support technology diffusion after the project ends. Examples include the following:

- Manufacturers who developed advanced thermostats based on the reference design have joined with other industry players to form an organization dedicated to ensuring interoperability of home area network-enabled appliances and smart meters. This effort should greatly facilitate customer use participation in demand response and pricing programs that involve advanced metering infrastructure or other forms of data communication.
- PIER facilitated cooperation between the developers of the NightBreeze system and a large manufacturer/installer of residential furnace and HVAC systems to incorporate elements of the NightBreeze control system into an existing ventilation cooling system.
- PIER contractors worked closely with manufacturers associations in developing testing methods for external power supplies. These relationships will be important if and when standard-setting bodies develop initiatives for product categories not addressed by current standards.

In the projects assessed, PIER did a good job in identifying and cultivating the organizational relationships needed to advance the development and early deployment of the products supported. Our point here is that these relationships can be viewed as enduring assets that can, for example, be used to support future applications for code enhancements to incorporate advanced thermostats.

System-Oriented Projects

The contrasts between the Real Time Display Monitoring System and INFORM projects offer insights into the nature of successful strategies to advance the development of improvements in large infrastructure systems. PIER provided continuous support for the development of synchrophasor-based grid monitoring and control systems for 9 years (at the point the case study was completed). Over that span, PIER supported the full range of activities required to deploy infrastructure control systems: conceptual system development, development and refinement of prototypes for key elements of the system, research and analysis to develop control algorithms, development and deployment of production-level hardware and software, operator training and supervision, and ongoing testing and reworking of key hardware, software, and management components. At this point, Real-Time Display Monitoring System is a fully functional system which has been used successfully to detect faults on the system and to guide operator actions to mitigate potential reliability problems. A number of individuals involved in or close to the project identified the importance of the consistency of PIER support, particularly for system installation and training, as the key factor in advancing Real-Time Display Monitoring System capabilities well beyond those of similar systems under development elsewhere. The authors also note that Energy Commission's PIER staff were deeply and consistently involved in the Project Review Committee, which shaped the research agenda in response to system needs and the successes and setbacks experienced at successive stages of project development.

By contrast, PIER supported only one round of funding for the INFORM system, which resulted in the development of a prototype and proof-of-concept testing using historical data. Moreover, PIER staff was not actively engaged in the oversight of the project, leaving that function primarily to federal and state water management agencies and National Oceanographic and Atmospheric Administration. When funding of successive rounds of the project encountered problems related to conflicting policy objectives, PIER staff was not in position to advance the project by offering either technical or financial support. It waited for other parties in the project to resolve internal and external obstacles to further support for INFORM. At this point, work on the development of INFORM has been suspended for more than three years. The longer this inaction continues, the less likely it is that the work PIER funded will lead to any concrete environmental and economic benefits at all.

The strategic lessons to be derived from the project experience summarized above are fairly obvious.

- Major infrastructure systems take a long time and a great deal of effort to develop and deploy. If PIER hopes to generate tangible benefits from investments in these systems, it must be prepared to make substantial sums available over a protracted period.

- Achievement of benefits requires the active cooperation of system managers. To ensure that system operators maintain commitment to the project, PIER staff needs to be actively involved in its oversight and governance. This high level of involvement is required both to ensure that PIER targets its funding to critical project components at various stages of development and to hold system managers accountable for following through on their commitments.

Recommendations: Integrating Benefits Assessment Into Operations

The following paragraphs present recommendations for methods to integrate benefits assessment into project selection and management processes, as well as continued evaluation efforts to support those efforts.

Operational Recommendations

- Ensure that project applications and plans contain explicit models of the means and schedule by which economic and environmental benefits will be realized. The authors found that PIER project managers and awardees shared general concepts about the ways and timeframe in which their projects would generate benefits. However, these ideas were seldom sufficiently detailed to support the development of commercialization strategies or to provide a framework for project or office managers to assess the success of the project. To address this situation, the authors recommend that applicants for PIER funding be required to include an explicit model of benefits realization that addresses the following:
    - Nature of the benefits to be achieved: energy use reductions, reliability improvements, etc.
    - Specific processes by which the benefits are to be produced: substitution of more efficient equipment, installation of more sophisticated infrastructure control systems, increased flood control, etc.
    - Specification of the market actors who will be carrying out the above practices, including their motivations and barriers to adoption of the supported technologies.
    - Specification of the population of households and businesses that will experience or reap the benefits.
    - Timing of the realization of benefits, including identification of major contingencies and their effect on the timing and magnitude of benefits.
    - Measures that the project principals and the Energy Commission's PIER Program could take to lower the risks posed by the identified contingencies.
    - Practical methods for measuring or estimating project benefits.

- Develop measurements to link with the benefits realization/logic model, and update these metrics as part of annual project reviews and reporting. The authors view this process as being similar and complementary to the "stage/gate" process currently used for ongoing program assessment. In this case, however, the assessment would be broadened to address not only the accomplishment of specific milestones but also changes in the market, regulatory environment, or competition that may affect the timing or magnitude of benefits achieved.

- Pilot the development of the benefits assessment components of project application and management systems. To maximize the likelihood that PIER project managers will adopt and use the benefits assessment methods described above, the authors recommend that they be piloted with a select group of project managers. This will enable PIER to work through the mechanics of the process and use feedback received to make the process as useful and easy to use as possible.
- Roll out the benefits assessment methods to all project managers. Once a workable system is developed, it can be rolled out to project managers for use on all projects. Annual compilations of the project assessments can be used as the basis for a portfolio-level evaluation system.

Recommendations for Further Evaluation Efforts

- Conduct a small number of additional project benefit-cost assessments, focusing on project types not addressed by the current study. For various reasons, this study did not assess a number of project types that appear frequently in PIER's portfolio. These include basic and applied research in support of major policy initiatives such as AB 32 (Global Climate Change Act), basic environmental science research, and development of new infrastructure systems such as carbon sequestration. The authors expect that it will be more difficult to quantify the benefits of such projects and to attribute to PIER activities than it was for the first seven projects covered here. However, given the prominence of these projects in the PIER portfolio, the authors believe it will be important to undertake those assessments.
- Assess the benefits of PIER's information dissemination activities. Although the authors formally assessed of PIER's information dissemination activities, they believe energy efficiency professionals that those activities generate contribute significant value. Specifically, in the course of preparing the project benefit-cost assessments and in working on projects for clients in California and other jurisdictions, the authors have used many documents available on the PIER website and have found them to be extremely useful for a variety of applications. The authors recommend that PIER formally assess of the use of its web site and other information dissemination activities to characterize the range of users and activities supported by these information resources.

1.0 Introduction

1.1. Overview

The California state legislature established the Public Interest Energy Research (PIER) program within the California Energy Commission (Energy Commission) in 1996. Since that time, PIER has provided over $580 million in funding to some 1,700 projects. PIER's legislative mandate and the program's interpretation of that mandate are broad. The program supports not only the development and demonstration of energy-efficient products and services for end user markets, but many other kinds of projects as well. These include devices and operating methods that improve the efficiency and reliability of large energy and water systems such as the California transmission grid. PIER also commissions or conducts research to inform administrative and legislative initiatives related to energy efficiency. This last category of projects encompasses the provision of technical support for code changes as well as basic science and engineering research in support of much broader initiatives such as AB 32, California's comprehensive climate change legislation.

This report presents the results of benefit-cost analyses of seven projects supported by the PIER program. The analyses summarized below quantify the physical and financial benefits and costs associated with the development and deployment of the technologies under review. They also assess the role that PIER played vis-à-vis other organizations that supported the development and deployment of the technologies in enabling the achievement of the quantified benefits. This information is used to attribute to PIER activities a portion of the total benefits of advancing the subject technologies. Thus, in terms familiar from cost-effectiveness assessments of energy efficiency programs funded by public goods charges, the analyses presented here can be understood as estimates of the net benefits associated with seven PIER projects.

The basic objectives of the PIER Benefit-Cost Assessment are to:

1. Develop appropriate methods to assess the benefits produced by PIER research, development, and demonstration (RD&D) projects and programs.
2. Test the methods on a variety of PIER projects.

To address the first objective, KEMA surveyed the literature on quantification of benefits and general evaluation of government-funded Research, Development, and Demonstration (RD&D) programs and identified approaches that would be appropriate to the range of activities supported by PIER. We presented this work in the 2008 report *Methods to Assess the Benefits and Costs of Government-Sponsored Energy Research and Development: Applications to the PIER Program*.[1] This report also identified the first four (of a total seven) projects supported by PIER to be

1 KEMA, Inc., *Methods to Assess the Benefits and Costs of Government-Sponsored Energy Research and Development: Applications to the PIER Program*, prepared for the California Energy Commission, July 1, 2008.

subjected to detailed benefit-cost analysis. The present report brings together the benefit-cost assessments subsequently carried out on seven PIER projects.

Two basic types of project were subjected to benefit-cost analysis for the present report:

- Development and deployment of efficient end-use devices.
    - Technical support for the incorporation of energy-efficient external power supplies for consumer and office electronics into the California appliance standards.
    - Demonstration of the ThermoSorber, a dual-acting heat pump that supplies both hot and chilled water to industrial process applications.
    - Financial and market support for NightBreeze night ventilation technology, to promote energy and demand savings in California's residential building sector.
- Development and deployment of tools designed to enhance the efficiency and reliability of large resource delivery systems.
    - Funding and technical guidance for the development of the Real Time Display Monitoring System used by the California Independent System Operator to monitor conditions on the transmission grid and to direct efforts to avoid reliability problems.
    - Co-funding the development of INFORM, an integrated forecasting and decision support system used to help reservoir operators in the Sacramento River Valley better predict operating conditions and manage trade-offs among conflicting objectives.

1.2. Organization of the Report

Chapter 2 of the report details the methods used to conduct the benefit-costs analyses of the seven projects. KEMA used the Total Resource Cost (TRC) test structure familiar from cost-effectiveness assessments of energy efficiency programs funded through public benefits charges to analyze the costs and benefits of PIER's involvement in the development and deployment of external power supplies, the ThermoSorber, and NightBreeze. RTDMS and INFORM are not products oriented to reducing end-use of electricity or water. Rather they are management tools designed to help resource delivery systems work more effectively and reliably. To estimate the benefits of these projects, KEMA developed scenarios to assess the effect of implementing the subject systems on the probability of various conditions occurring, such as outages in the case of RTDMS and insufficient water storage during dry seasons for INFORM. We then used available market data and the results of secondary studies to estimate the benefits of avoiding unfavorable system conditions.

Chapter 3 presents the benefit-cost analysis for the external power supply project. The technology is described, project activities are summarized, and benefits are assessed for both California and the US as a whole.

Chapter 4 considers the benefits associated with PIER's ThermoSorber project. Project background is provided, calculations are traced, and results are discussed. The assessment involves use of Bass diffusion curves to estimate net present value.

Chapter 5 details the benefit-cost analysis for the RTDMS project. Project background is summarized, benefits are estimated, and an additional sensitivity analysis is conducted.

Chapter 6 presents the benefit-cost analysis for INFORM. The INFORM system is described, project history is detailed, and preliminary benefit estimates are provided for selected outcomes.

Chapter 7 assesses PIER support for PCTs. PCT technology and PIER project activities are described, followed by detailed benefit-cost calculations and results for California.

Chapter 8 presents the benefit-cost analysis for NightBreeze. NightBreeze technology is described, PIER support is discussed, and benefit-cost figures are calculated.

Chapter 9 presents the benefit-cost analysis conducted on PIER support for Hotel Bathroom LED Night Lighting technology development. It describes the technology and associated PIER support, details benefit-cost calculations and results, and ends with concluding remarks.

Chapter 10 presents lessons learned and recommendations for further benefit-cost assessment work and integration of benefits assessment into PIER's day-to-day operations.

2.0 Methods

KEMA employed two basic methods to calculate costs and benefits for selected PIER projects. For external power supplies, ThermoSorber, and NightBreeze, the TRC test adopted by the California Public Utilities Commission (CPUC) served as the methodological platform for conducting benefit-cost analysis. For RTDMS and INFORM, a scenario analysis method was utilized. This chapter describes the TRC and scenario analysis methods.

2.1. Total Resource Cost Test

For assessment of the external power supply, ThermoSorber, PCT, NightBreeze, and Hotel LED Nightlighting cases, KEMA calculated net benefits and benefit-cost ratios using the template for the TRC test established by CPUC in its *California Standard Practice Manual* (SPM).[2] The TRC test is designed to measure the net costs of energy-efficiency programs from a comprehensive perspective incorporating costs to participants and costs to utilities. We used the following formulas to estimate the benefit-cost ratio:

$BCR_{TRC} = B_{TRC}/C_{TRC}$, where

BCR_{TRC} = Benefit-cost ratio of total resource costs

B_{TRC} = Benefits of the program

C_{TRC} = Costs of the program

The B_{TRC} and C_{TRC} terms are further defined as follows:

$$B_{TRC} = \sum_{t=1}^{N} \frac{(AC \times U \times RS)(1+r)^{t-1}}{(1+d)^{t-1}}$$, where

AC = Avoided costs

U = Units sold

RS = Replacement savings

r = Rate of inflation

d = Discount rate

$$C_{TRC} = \sum_{t=1}^{N} \frac{PRC + (U \times IC^{t})}{(1+d)^{t-1}}$$, where

PRC = Program administrative costs

IC^t = Incremental cost in year t

2 *California Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects*, October 2001.

We used the 2 percent inflation rate (r) incorporated in the CPUC Avoided Cost Database. We set the discount rate (d) at 8.15 percent, per CPUC's *Energy Efficiency Policy Manual*.[3] Other inputs and calculations specific to each of the three relevant cases are described in Chapters 3, 4, and 7 below.

We elected to use the benefit-cost framework established by the California Public Utilities Commission to assess the cost-effectiveness of energy efficiency programs because of its familiarity and broad acceptance in the energy policy and regulatory arena. That framework has been used primarily to assess the cost-effectiveness of programs that promote and deploy market-ready technologies. The TRC is more stringent than the kinds of cost-effectiveness tests typically applied to R&D and early-stage market development programs in the following ways:

- It counts only avoided system costs of energy savings, not savings to customers who, as taxpayers, provide the funding for PIER and other R&D programs.
- It uses a relatively high discount rate – 8.15 percent – which significantly reduces the net present value of benefits achieved in relatively far in the future. May PIER projects are specifically target opportunities for technical development which may not return benefits for a significant period of time.
- It counts as costs the expenses that technology users assume to purchase or install the technology. In some frameworks, those costs are not counted or are used as inputs into economic models that estimate income and employment benefits associated with the substitution of local goods and services for imported energy.
- It focuses on a narrow range of benefit types – namely avoided energy costs and largely excludes the value of other benefits, including: avoided environmental damages, increased local income and employment due to reduced energy imports, and knowledge benefits gained through diffusion of experience and research findings.

For this study we have made one adaptation of the TRC approach to make it more compatible with PIER's mission and program approach. Namely, we have limited the amount of potential net costs or negative benefits to the value of PIER's expenditures on the projects in question. In applying the TRC to typical energy efficiency programs, it is possible to arrive at large negative Net Present Value estimates, far in excess of the sponsor's program costs. This can occur if program evaluations find that the supported measures achieve much less than the planned level of energy savings per unit, or if evaluations find that a high portion of the projects supported by the program would have gone forward in its absence (high free ridership). Beyond very small demonstration projects designed primarily to assess technical performance, PIER does not provide subsidies to end users to adopt the technologies supported by the program. Thus, the concept of free ridership does not apply. In regard to the effects of poor performance in the field, we assume that end use customers or institutions that manage large energy systems will

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3 California Public Utilities Commission, *Energy Efficiency Policy Manual, Version 2*, prepared by the Energy Division, August 2003, 19.

not purchase products or services that do not work or whose costs far exceed expected benefits. Thus, in the worst case, a product or system developed PIER could generate zero benefits as they are identified by the TRC. However, in those cases they would also generate zero customer costs. Our analysis of the NightBreeze ventilation system yielded this result.

2.2. Scenario Analysis

The remaining two technologies, RTDMS and INFORM, differ from the other products in that they are not designed to increase resource efficiency at the end-use stage. Rather, RTDMS and INFORM are resource delivery system technologies, designed to enhance the reliability and effectiveness of resource provision. The TRC test is focused on the benefits and costs of end-use devices, as opposed to upstream systems, and therefore is unsuited to analysis of resource delivery technologies such as RTDMS and INFORM. In order to assess the benefits and costs of resource delivery system technologies, KEMA developed a scenario analysis method capable of measuring system performance under alternative technological scenarios.

Specifically, the scenario analysis method compares system operations over a given period of time under two different scenarios: with the PIER project technology incorporated into the resource delivery system, and without the PIER technology incorporated into the system. Variations in system performance under these two scenarios are assessed and quantified. In particular, the probability that suboptimal conditions (such as system instability or incapacity) will obtain under these alternative scenarios is determined. Finally, a monetary value is assigned to these variations, drawing on available market data and information from secondary sources. This value represents the benefits generated by the technology in question.

RTDMS and INFORM differ in the type of resource delivery system each is designed to improve. Thus, the scenario analysis proceeds in substantially different ways for each of these case studies. Inputs and calculations specific to each case are described in Chapters 5 and 6 below.

2.3. Assessment of Attribution

KEMA used the findings from the methodological review along with our familiarity with the projects to identify the most appropriate method to develop estimates of the net benefits attributable to PIER activities for each study. We selected the following approaches for the projects analyzed here.

- **Expert Judging (**Delphi Process). For the benefit-cost assessment of PIER's involvement in the development of efficient external power supplies, KEMA used a structured expert judging approach to develop quantitative estimates of the net benefits attributable to PIER's activities. Structured expert judgment studies assemble panels of individuals with close working knowledge of the technology, infrastructure systems, markets, and political environments addressed by a project measure to estimate baseline market share and, in some cases, forecast the development of the market with and without the program in place. Structured expert judgment processes employ a variety of specific techniques to ensure that the participating experts specify and take into account key assumptions about the project, the technologies supported, and the development of other influence factors over time.

For this project, KEMA developed and deployed a Delphi process, which is the most widely known expert judging approach. Six subject matter experts representing a range of stakeholders participated in the process. KEMA conducted two iterative rounds of structured questioning designed to yield a refined set of opinions on the likely trajectory of market share for efficient power supplies with and without PIER involvement, as well as opinions on the trends of other key parameters in the benefit-cost analysis. KEMA selected the Delphi process for this project because there were a sufficient number of informed individuals from which to build a usable panel of judges and because the information needed for the analysis could be reduced to a small number of relatively straightforward questions.

- **Historical Tracing.** For the remaining projects, KEMA used historical tracing, also known as the case study method, to develop assessments of PIER program influence and estimates of net project benefits. This method involves the careful reconstruction of events leading to the outcome of interest, for example, the launch of a product or the passage of legislation, to develop a 'weight of evidence' conclusion regarding the specific influence or role of the program in question on the outcome. Historical tracing relies on logical devices typically found in historical studies, journalism, and legal argument. These include:
    - Compiling, comparing, and weighing the merits of narratives of the same set of events provided by individuals with different points of view and interests in the outcome.
    - Compiling detailed chronological narratives of the events in question to validate hypotheses regarding patterns of influence.
    - Positing a number of alternative causal hypotheses and examining their consistency with the narrative fact pattern.

KEMA opted to use historical tracing methods for these projects primarily because there were too few individuals with close knowledge of a broad range of factors affecting project success or the targeted market to create a functional expert panel.

3.0 Case Study - External Power Supplies

This chapter presents the benefit-cost analysis conducted on the PIER program's External Power Supply project. It begins with a brief description of external power supply technology and PIER project activities. This is followed by detailed benefit-cost calculations and results, for both California and the US as a whole.

3.1. Product Description

Power supplies are special circuits designed to reduce wall voltage from 120 volts to between 3 and 15 volts, convert it from AC to DC, and regulate the output to power a wide range of consumer electronics devices. Power supplies are used in a vast range of home and office electronics, including televisions, cordless phones, answering machines, video games, computers, stereo equipment, cordless tools, and microwave ovens. Power supplies contained within end-use products are referred to as internal power supplies, and power supplies that exist as a separate unit are referred to as external power supplies. External power supplies are also known as "AC adapters."

There are two basic design types for external power supplies: "linear" and "switching." Historically, linear designs were the industry standard. Linear power supplies rely on conventional transformer technology and operate at low frequencies. They are relatively bulky, inexpensive, and energy-inefficient. Linear designs are typically 20 to 40 percent efficient. By contrast, switching external power supplies use solid-state components and operate at frequencies higher than 60 hertz. Compared to linear designs, switching designs are smaller, slightly more expensive, and much more energy-efficient. Switching external power supplies are typically 65 to 85 percent efficient and produce energy savings of approximately 4 kWh per year.

It is also important to distinguish between different power supply energy consumption modes. "Active" mode refers to the condition in which the load draws a fraction of the power supply's energy output greater than zero. "Standby," or "no-load," mode refers to the condition in which a power supply's output is not connected to a load. The energy savings produced by switching power supplies are attributable to efficiency gains in active mode.

Growth in sales and saturation of power supplies in home and office settings has been very rapid. Recent studies estimate that more than six percent of national electricity consumption or 217 TWh per year passes through power supplies. Given their omnipresence, energy savings potential, and "least common denominator" role, power supplies were identified as a productive target by energy efficiency advocates beginning in the early 2000s. Proponents of more efficient power supplies argued that use of switching technology could lead to annual electricity savings of 645 GWh in California alone as conventional technology was displaced in the market. Attention initially focused on external power supplies. Observers believed it would be much easier to regulate power supplies physically detached and manufactured separately from consumer products, than to devise and enforce standards for power supplies that were wholly incorporated within larger end-use equipment.

3.2. Project Overview

PIER initiated its activities in regard to efficient external power supplies in May 2003. At that point, the U.S. Environmental Protection Agency, the Natural Resources Defense Council (NRDC) and their technical consultants Ecos Consulting had been working for two-and-a-half years to engage manufacturers in increasing the share of switched external power supplies accompanying their products. This work had led to the identification of individuals at certain manufacturers and within the industry association who were willing to support the effort as well as preliminary elaboration of standards and test methods.

The PIER External Power Supply project lasted from May 2003 to May 2005. When it first launched, Don Aumann of the Energy Commission served as project manager. The project budget was $288,541 each year for two years. The project included three members. As the prime contractor, the Electricity Innovation Institute (E2I) was responsible for overall project and contract management. Given its expertise and experience in the field, Ecos Consulting oversaw policy and market issues. And the Power Electronics Applications Center (PEAC) was charged with conducting technical research. Both E2I and PEAC were subsidiary units of the Electric Power Research Institute (EPRI). Formal project collaboration between E2I, Ecos Consulting, and PEAC was paralleled by informal collaboration, primarily focused on policy, between Ecos Consulting, the Energy Commission, EPA, and NRDC.

The objectives of the External Power Supply project were threefold.

- Stimulate the development of efficient power supplies, both external and internal.
- Devise a standard test method for measuring standby and active power supply efficiency, and compile a dataset of test results.
- Develop specific policy recommendations in regard to the adoption of relevant standards for the state of California.

In order to meet these objectives, the project engaged in the following activities:

- Website development/information sharing.
- Test method development.
- Test results database.
- Market research and energy savings estimates.
- Technology development and industry outreach.
- Design competition.
- Policy action plans.

As the project unfolded, test method development emerged as the core pursuit. In recent attempts to incorporate new or substantially more energy-efficient technologies into product standards, development of test methods has been a major objective.[4] Ultimately, standard setting and enforcement requires consistency in measurement, and many of the technical controversies in standard setting have focused on identification of test methods that are feasible and acceptable to all parties. The starting point for elaborating a standard method was IEEE 1515-2000. While serving as a useful launch pad, stakeholders viewed IEEE 1515-2000 as insufficiently specific with respect to loading conditions and reporting requirements. Thus, the project refined this test procedure at a series of stakeholder workshops.

Ecos Consulting and PEAC presented a draft testing method on behalf of PIER at the Technical Workshop on the Energy Efficiency of External Power Supplies & Battery Chargers, held in San Francisco in November 2003. The method was designed only for external, AC-DC power supplies. It was based on testing at no load and at four active mode points, 25 percent, 50 percent, 75 percent, and 100 percent of rated output current. Tests were to be conducted within the nominal input voltage range, as opposed to the minimum or maximum, and the use of line voltage and resistive loads was permitted. Environmental and technical parameters were specified. A detailed testing protocol was laid out, covering device preparation, load conditions, the sequence of measurements, and efficiency calculations. Finally, a standardized test report format was provided to ensure uniformity across different jurisdictions and organizations. In developing the procedure, tests were conducted on more than 200 external power supplies to ensure it was practical.

The project contract and budget were atypical for PIER in that they explicitly authorized substantial direct materials purchases, which were critical to the creation of a test method and accompanying dataset. The scope of the work that PIER supported reflects the program's acknowledgement of the importance of testing procedures in gaining manufacturer and OEM acceptance for the new technology.

Ecos and PEAC made slight revisions to the procedure in the following months, and presented the revised test method at a February 2004 meeting. At this meeting, EPA, which was considering inclusion of external power supplies in its ENERGY STAR program, formally adopted the PIER test method as standard procedure. EPA subsequently added protocols for external AC-AC power supplies to the method, and a final version was published in August 2004.[5] This version, drafted under the auspices of the External Power Supply project, became the accepted standard both in California and at the national level.

With significant technical support work from PIER and Pacific Gas & Electric Company (PG&E), the Energy Commission incorporated external power supply standards into Title 20 in

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4 See, for example, Feldman, Shel, Jane Peters and Mitchell Rosenberg. *The Residential Clothes Washer Initiative: A Case Study of a Collaborative Effort to Transform a Market.* Consortium for Energy Efficiency. 2001,

5 Calwell, Chris, et al., *Test Method for Calculating the Energy Efficiency of Single-Voltage External Ac-Dc and Ac-Ac Power Supplies*, report prepared for the Public Interest Energy Research (PIER) program, California Energy Commission, August 11, 2004.

2004. The standards were designed to be phased in over a number of years, with weaker Tier 1 standards instituted first followed by stricter Tier 2 standards. At the same time that the Energy Commission adopted mandatory standards for California, the EPA, through its ENERGY STAR program, crafted voluntary external power supply efficiency specifications. These took effect in January 2005. After delays were granted to help manufacturers meet Title 20 standards, Tier 1 regulations entered into force in California in January 2007. Through the Energy Independence and Security Act of 2007 (EISA), the federal government incorporated specifications nearly identical to Title 20 Tier 2 regulations into national standards. Both federal and California Tier 2 standards came into force in July 2008, although Title 20 now effectively duplicates the superseding EISA provisions. The PIER test method was an important element of Title 20 standards, EPA ENERGY STAR specifications, and ultimately federal standards under EISA.

In the years since the project's closeout in 2005, many observers have credited the project with playing a critical role in the creation of Title 20 energy efficiency standards for external power supplies, EPA ENERGY STAR specifications, and national standards under EISA. In addition, the PIER project and in particular its test method are cited by many as an important factor in the adoption of power supply standards by the European Union (EU), China, Australia, and other countries.

3.3. Benefit-Cost Calculations: Methods

KEMA conducted a cost-effectiveness assessment of PIER's involvement in the advancement of efficient external power supplies using the California Total Resource Cost Test framework discussed in Chapter 2. The assessment proceeded in the following steps.

- Identify key variables. KEMA used information from documents developed in support of the 2004 Title 20 change and in-depth interviews with project participants and market actors to develop a set of initial scenarios for cost-effectiveness testing within the TRC framework. This work identified key areas of uncertainty in regard to variables that exercised a large influence on net benefits and benefit-cost ratios.
    - **The effective date of California and U.S. product standards**. As discussed above, many domestic and international developments were underway to accelerate the adoption of efficient power supplies and facilitate the promulgation of stricter product standards. Based on the in-depth interviews we concluded that both California and the United States would have adopted the standards at some point in the relatively near future in the absence of PIER activity. The key question in terms of cost-effectiveness was when these changes would have occurred. This was one of the key issues addressed in the Delphi process.
    - **The effective useful life of the power supplies**. The initial Ecos Consulting analysis on which the Codes and Standards Enhancement (CASE) Report was based contained estimates of the effective useful life (EUL) for most of the 42 product categories with external power supplies. However, EUL values for a few key categories, such as cell and cordless phones, were missing. In 2003, these two

product categories accounted for 18 percent of all external power supplies covered by the standards. Given the structure of the benefit-cost calculations, it was important to develop appropriate values for these parameters. We included questions on this issue in the Delphi process.

- **Growth rate in the annual sales of devices that use power supplies covered by the California and U.S. standards**. In 2003, U.S. consumers purchased over 380 million devices with external power supplies covered by the prospective standards. The Ecos Consulting analyses contained historic annual sales data for some product categories, but the coverage was inconsistent and trends differed by product. We felt that these data could not adequately support unit sales forecasts through the end of the analysis period (2015). KEMA purchased proprietary sales data for 2008. We used the sales data for 2003 and 2008 to develop baseline growth trends and sensitivity scenarios for use in the cost-effectiveness analysis.
- **Incremental cost of the power supplies**. Estimates of the incremental costs of efficient power supplies contained in supporting materials for the U.S. and California standards procedures varied from $0.90 to $1.40 per unit. This variation was sufficiently large to swing net TRC benefits from positive to negative under a number of plausible scenarios. We included items on incremental cost in the Delphi process both to update the cost information and – we hoped – to narrow the range of potential values.

Estimate value ranges for key variables. KEMA estimated the plausible ranges of values for the variables identified above from the following key sources:

- **In-depth interviews.** KEMA conducted in-depth interviews with 13 individuals who have extensive professional involvement with and knowledge of the market and technology for external power supplies. These individuals represent governmental agencies (3), manufacturers and industry associations (4), technical and market research organizations (3), utility energy efficiency programs (1), and consultants to the project (2).
- These interviews covered all of the topics identified above, as well as more general observations on the development of external power supply technologies and markets, the underlying drivers of that development, and the influence of PIER activities on the adoption of efficient power supply standards.
- **Delphi Process.** KEMA recruited a panel of six experts from among the respondents to the in-depth interviews to take part in a Delphi process designed to generate estimates of the following:
  - Effective date of the adoption of efficient power supply product standards in California and the U.S. in the absence of PIER activities.
  - Annual market share of efficient power supplies in California and the U.S. in the absence of PIER activities.
  - Trends in the incremental cost of efficient power supplies.

- Effective useful life of power supplies for key product categories.

  We detail the results of the Delphi process in regard to these specific questions below. See the Annex to this section for details on the Delphi process itself.

- o **Proprietary Sales Data.** KEMA purchased data on worldwide sales of external AC-DC power supplies for 2008 from the Darnel Group.[6] This report contains estimates of current unit sales and prices, as well as forecasts of those quantities through 2013. The results are disaggregated by large geographic markets (e.g., North America, Europe, etc.), type of application (communication, computers, consumer appliances, medical), and regulation type (switching v. linear). KEMA worked directly with the Darnel Group to obtain estimates for the United States.
- o **Data from the CASE Study.** Ecos Consulting furnished analysis files it prepared as part of its work for PIER in support of the Title 20 changes. From these, KEMA extracted data on unit energy savings and expected useful life for power supplies serving different types of devices. We also used sales data contained in these files to build forecasts.

Formulate scenarios and estimate TRC net benefits and benefit-cost ratios. Using the results of Step 2 above, KEMA developed specifications for scenarios that we believe reflected the minimum, most likely, and maximum effects of PIER involvement in the development of the technology and market for efficient external power supplies. We then used those scenarios to calculate a range of TRC net benefits and benefit-cost ratios.

3.4. Benefit-Cost Calculations: Inputs and Results

3.4.1. National Calculations

National Benefits Estimate. KEMA developed the estimate of energy and energy cost savings from the introduction of the power supply standards through the following steps:

- **Estimate avoided electric costs at the national level.** Data on national avoided costs (AC) were derived from the Energy Information Agency's (EIA) *Annual Energy Outlook 2008*. Specifically, $62.31 per MWh was used as the AC rate.[7] This rate applies to the year 2008, but was adopted as the standard AC rate for all calculations.
- **Develop estimates of number of appliances sold annually with external power supplies covered by the California standard.** KEMA developed an estimate of the number of units covered by the California appliance standard for 2003 using information from the US Power Supply Census prepared by Ecos Consulting as part of the CASE filing. This dataset provides raw sales data from 1990 to 2003 for 151 unique

6 Darnel Group Inc. *External AC-DC Power Supplies: Worldwide Forecast, 3rd Edition.* Corona, CA: 2008. Data from earlier versions of this report were used in the supporting materials for the federal product standard.

7 Energy Information Agency, *Annual Energy Outlook 2008*, released June 2008, Figure 63.

end-use products that use power supplies. Products are coded according to whether they use internal or external power supplies. Sales data are not available for each product each year. For appliances with actual sales data, we used the 2003 annual unit sales figure. For those products lacking 2003 sales data, the research team estimated figures based on sales data from previous years and sales data from comparable products. With these raw and estimated sales data, we estimated U.S. unit sales for 2003 at 381.9 million.

The Darnel Group estimated 2008 sales for the U.S. at 567.2 million units, distributed among the major product categories as follows:

- o Consumer appliances and battery chargers: 15 percent;
- o Computer and office equipment: 18 percent;
- o Telecommunications: 67 percent.

Compared to sales in 2003, the 2008 estimate implies a Compound Annual Growth Rate (CAGR) of 8.2 percent. KEMA used this historical rate as the baseline rate of growth in sales. (The Darnel Group also uses the 8.2 percent figure for its sales forecasts.) To test the sensitivity of cost-effectiveness calculations to assumptions concerning growth rates we established the following three growth scenarios:

- ▪ Low growth: 6.4 percent CAGR
- ▪ Most likely: 8.2 percent CAGR
- ▪ High growth: 10.0 percent CAGR

- Qualitative assessment of the effect of PIER activities on adoption of standards and market share of efficient power supplies. As a first step in the analysis of net sales of efficient power supplies attributable to PIER activities, KEMA reviewed the results of the in-depth interviews to identify issues to be explored in the Delphi process. The key findings from the interviews in regard to PIER's influence on the adoption of product standards were as follows.

  Changes in market conditions and barriers. Respondents to the in-depth interviews identified incremental cost as the primary barrier to adoption of efficient power supplies prior to the inception of program activities by EPA and others. Ten of the thirteen interviewees identified cost as the primary barrier, including all four industry respondents. Put simply, the higher cost of switching designs relative to linear designs was viewed as an impediment to deeper market penetration by efficient power supplies. Several respondents noted that OEMs were especially sensitive to the price premium, wary of its potential to damage relationships with retailers.

  Two other barriers received numerous mentions. Many interviewees pointed to the market disruptions a shift to more efficient devices might entail. This was a particular problem for manufacturers who would be forced to upgrade production lines as well as for OEMs who would need to integrate new components into existing products. In addition, multiple respondents asserted that the lack of an energy efficiency test procedure inhibited the spread of energy-efficient external power supplies in the market.

Respondents agreed that barriers had been overcome as of 2008. The main barrier, incremental cost, was surmounted due to a variety of factors. The rising price of copper, used in the manufacture of linear power supplies, reduced the cost gap between linear and switching designs. Incremental cost was further reduced as industry developed improved products and more efficient production techniques. The reason provided most often by interviewees was the promulgation of efficiency standards, both state and federal. In particular, Title 20 standards were cited by eight respondents (including all from industry), who argued that mandatory standards in a market the size of California gave firms little choice but to comply, regardless of cost.

The market and production disruptions threatened by a move toward switching designs were avoided, according to respondents, by leading firms that embraced switching technology and generated positive "ripple effects" throughout industry, as well as by the "green" marketing opportunities afforded by energy-efficient power supplies. Title 20 was also mentioned as a factor that forced change and reduced uncertainty. The lack of a test method was rectified through the technical work performed by PIER.

PIER Project Effects. Respondents identified two sets of effects resulting from PIER project activities. Direct effects of the External Power Supply project were those deriving from the research conducted by the project team. The most significant direct effect was the creation of an energy-efficiency test method. Two researchers, and all respondents associated with utilities and the project itself, cited the test procedure as a critical contribution. Multiple interviewees noted the importance of basic technical and market research carried out by PIER in creating a strong and reliable knowledge base. Both project interviewees said that the efficiency design competition sponsored by PIER galvanized interest within the power supply industry.

Several respondents, including both members of the project team and an industry representative, argued that PIER's work on external power supplies was key to increasing awareness of the energy savings potential of switching designs among manufacturers, retailers, regulators, and other stakeholders. More concretely, many respondents credited the PIER project with being a major force behind the development of Title 20 efficiency standards. Two state government respondents affiliated with the Energy Commission stated that PIER, and in particular the test method, were instrumental in enabling the articulation and implementation of Title 20 standards. One emphasized the influence PIER exercised on work performed by PG&E and Ecos Consulting, which in turn formed the basis of power supply standards. The other interviewee associated with the Energy Commission described PIER as "crucial" to the adoption of Title 20 standards, assigning particular significance to the PIER test procedure. All utility and project respondents also cited the PIER project and test method as critical to the development of Title 20 standards.

Market Impacts. All but one respondent believed that the shift toward efficient, switching external power supplies would have occurred at a slower pace in the absence of Title 20 standards. Twelve of the thirteen respondents believed that Title 20 had acted as a market "accelerant," increasing the rate of switching design market penetration beyond what would have taken place under "natural" conditions. But there was a wide range of opinion on the force of this accelerant effect. Many interviewees asserted that without Title 20 standards, market changes would have been delayed by approximately three to five years. Other respondents envisioned a delay of up to a decade. One interviewee stated that higher market shares of efficient external power supplies were 90 percent attributable to Title 20 standards, and only 10 percent attributable to unrelated market forces such as copper price increases.

A number of the respondents believed that PIER's effect on the development of the market for efficient power supplies was less apparent. However, those who recognized market effects driven by PIER considered the project to be very important, particularly as a necessary condition of efficiency standards. Nine respondents identified the PIER test method as key to the adoption of Title 20 standards. One interviewee associated with the Energy Commission characterized the test method as "integral." Similarly, an industry respondent stated that manufacturers viewed PIER as "critical" in generating broader market transformation. None of the respondents regarded PIER as unimportant to Title 20 standards or the growth in market share of efficient external power supplies.

Taken together, these interviews establish a plausible narrative of the effect of the PIER project on the market for external power supplies. The project, and especially the efficiency test procedure developed under its auspices, are widely agreed to have been a virtual prerequisite of Title 20 standards as they evolved. Title 20 standards, in turn, were a motive force behind growing market penetration by switching devices. In particular, standards were a primary means by which the dominant incremental cost barrier was overcome. And reducing incremental cost was essential to increasing the market share of efficient external power supplies.

- Develop inputs for the quantitative assessment of the effect of PIER activities on adoption of standards and market share of efficient power supplies. The results of the in-depth interviews served as a point of departure for development of a Delphi process to estimate key parameters required for quantifying the effect of PIER activities on the market share of efficient power supplies, which in turn drives estimates of energy savings and net benefits. The Delphi process explored four issues in regard to attribution of market changes to PIER activities. These were the likely effective date of product standards at both the Federal and California state levels in the absence of the program, and the likely annual market share of efficient power supplies at the Federal and state levels. The following paragraphs summarize the Delphi panel's responses to these items.

Question 3. Energy Independence and Security Act energy-efficiency standards for external power supplies came into effect on July 1, 2008. If Title 20 standards had come into effect in the year you selected in response to Question 1, in what year do you think EISA federal external power supply efficiency standards (or their equivalent) would have come into effect?

In response to this question, one panelist selected 2008, one selected 2009, one selected 2010, two selected 2011, and one selected 2015. (One panelist added that EISA standards would have come into effect in 2014 in the event battery chargers had not been incorporated into California's Title 20 standards.) Between Rounds 1 and 2, responses converged around 2010-2011. One response changed from 2009 to 2010, and one changed from 2012 to 2011. For Round 2, the median response to this question was 2010-2011.

Panelists who selected 2008 and 2009 agreed that "the delay of the Title 20 standards coming into effect would not have affected the delay between the Title 20 and EISA standards." One panelist elaborated, arguing that California standards would have triggered identical levels of manufacturer support for federal standards regardless of when they came into force. Support for EISA standards was essentially "a preemptive end run by manufacturers to get past Energy Commission standards – especially the battery charger standards that were included in the Energy Commission standard."

The respondents who selected 2010 and 2011 also assumed there would be "a similar lapse in time between the effectiveness date of the actual Energy Commission standard and the effectiveness date of the federal standard." However, these panelists attributed this identical interval between effectivity dates to other factors. One panelist cited consistent manufacturer support for EISA standards based on the need for regulatory harmonization. Another panelist asserted that delayed Title 20 standards still would have been copied by other states and would have created "the political conditions that made a negotiated, legislative federal solution possible … with a short lead time for its effectiveness date."

The panelist who selected 2015 believed that Title 20 external power supply standards would not have evolved in the absence of PIER. Other domestic efforts would not have resulted in mandatory federal regulations. Ultimately, the respondent maintained, "I don't think that EISA standards would have come about lacking California's work until International Standards work spilled over into the U.S."

Question 4. For each year between 2005 and the year you selected in response to Question 3 (that is, the year you believe EISA standards would have come into effect if Title 20 had been delayed), what do you think the market share of energy-efficient external power supplies in the US national market would have been?

Error! Reference source not found. summarizes the panelists' responses to Question 4. Market share estimates provided by Panelists 15 and 17 were outliers in both Delphi rounds. Panelists 12 and 18 made minor adjustments between rounds, but their estimates, along with those from Panelist 13, consistently formed a central cluster aligned with the average market share curve. Panelist 11 also made slight adjustments, but the resulting curve retained a distinctive path also exhibited in Round 1.

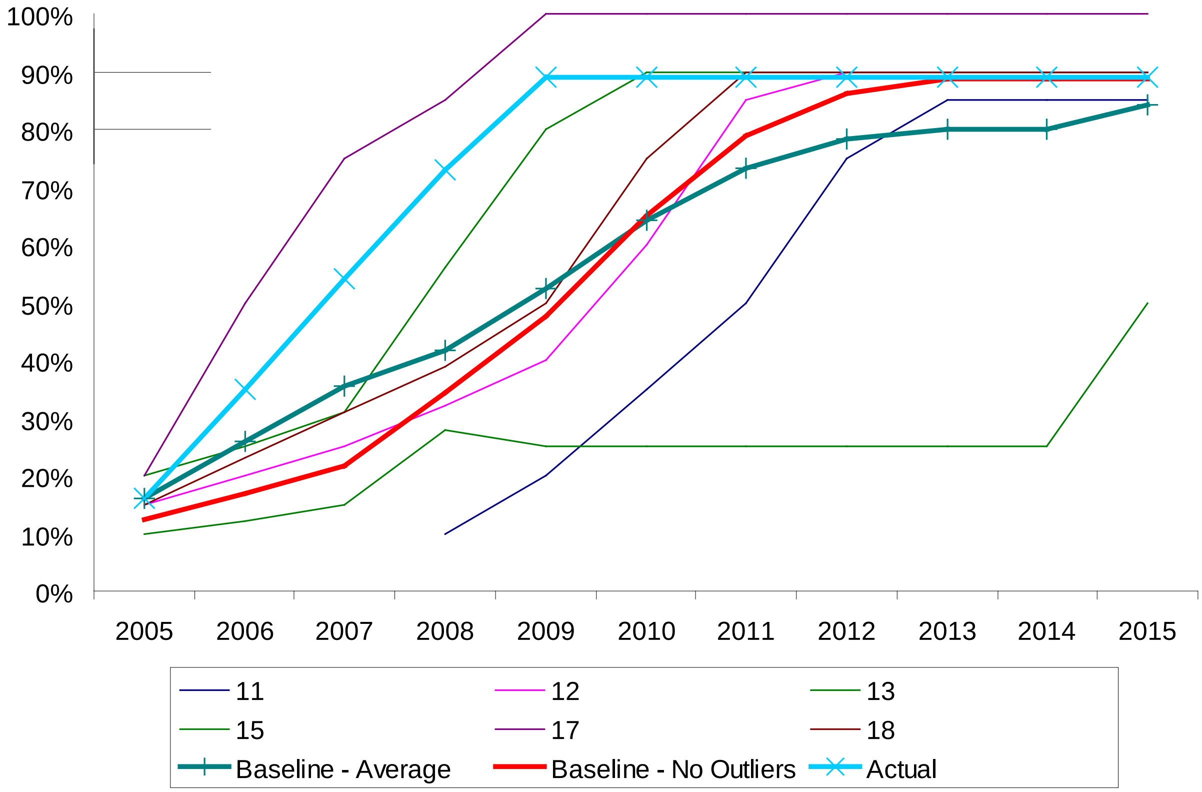

Figure 1. Delphi Panel Estimates and Forecasts of EPS Market Share, U.S.

Panelist 17 again offered the most optimistic estimates of national market share under hypothetical regulatory delays. Developments in California would have driven national increases in market share of efficient devices, regardless of federal regulations. According to this panelist, "power supply companies … don't do separate designs for different regions, and since California is likely a good share of their market, they would tend to let the California standards drive their product designs."

Panelists 12, 13, and 18 provided similar rationales for their market share estimates, including:

- o A delay in Title 20 standards would have had no impact on the interval between Title 20 and federal ENERGY STAR effectivity. ENERGY STAR criteria would have produced identical but delayed market share figures at the national level prior to EISA.

- o Manufacturers do not operate California distribution channels separate from the rest of the country. Given the size of the California market, industry would have increased the efficiency of external power supplies nationwide in response to Title 20 before EISA took effect. As one respondent stated, "Because of the CA standard 'signpost,' … many manufacturers of EPS-powered products are likely to start shipping efficient EPSs nationwide, rather than separating distribution streams to CA and the rest of the U.S."
- o Delayed California standards would have been mimicked by other jurisdictions, which in turn would have generated national market pressures. In this process, "a delayed Title 20 standard would have been followed by similarly delayed standards in other states, steadily pushing the market toward a tipping point where manufacturers would simply ship compliant power supplies to nearly all states, whether or not federal standards were adopted."

  The national market share estimates provided by Panelist 11 represented, for this respondent, the maximum rate at which industry would have adapted to delayed Title 20 power supply standards. Production and market constraints would have impeded greater market penetration. This panelist declared, "I don't believe that manufacturers could possibly rush to compliance much faster than I have indicated."

  Panelist 15 was least optimistic about the prospects for switching design market share gains had California and federal standards been delayed. For this respondent, the sole impetus for market share gains would have been heightened demand for product features that incidentally enhanced efficiency. "Both the California and national markets would have been equally affected by products valuing self-improvement," although these effects would have been minimal.

- **Estimate baseline trends in market share.** As discussed above, two panelists' projections of the trend in EPS market share in the absence of the program differed substantially from their peers: one believed that the program had a considerably stronger effect on market share; the other that the baseline trend would have approximated the actual trend due to influences other than the program. To take account of this pattern, we developed two estimates of annual baseline market share. One simply averaged the annual estimates. The other took the average of estimates without the upper and lower outliers. As shown in **Error! Reference source not found.**, the two baseline trends differ somewhat. Through 2009, the trend built from the simple average of responses is somewhat higher than the trend that does not include the outliers. In subsequent years, the positions reverse and the baseline market share without outliers equals our estimate of the actual market share attained.
- **Estimate the actual market share.** Although the enabling legislation for California and for federal product standards provide for enforcement mechanisms and penalties for non-compliance, most panelists believed that actual market share would not reach 100 percent. This assessment was based largely on the huge number of manufacturers and

OEMs involved in the market and their scattered locations all over the globe. Only one panelist believed that actual market share would attain 100 percent. Three panelists put the maximum market share at 90 percent and one at 85 percent. The remaining panelist did not think that the maximum market share would be attained during the analysis period.[8] We used the average panel estimate of the maximum market share not including outliers to represent the actual maximum. We took a similar approach to estimating the actual 2005 market share. We used a simple straight line forecast for the years between 2005 and the effective date of the respective codes, at which point we assumed the maximum market share values would be attained.

- **Estimate change in the market share of efficient external power supplies attributable to PIER activities.** We used the difference between our estimate of actual and baseline market shares to represent the net effect of PIER activities.

  Figure 2 displays the results of this calculation using the two baseline estimates discussed above. Over the forecast period, the cumulative estimate of net market share for efficient power supplies is somewhat higher using the simple average baseline v. the baseline without outliers.

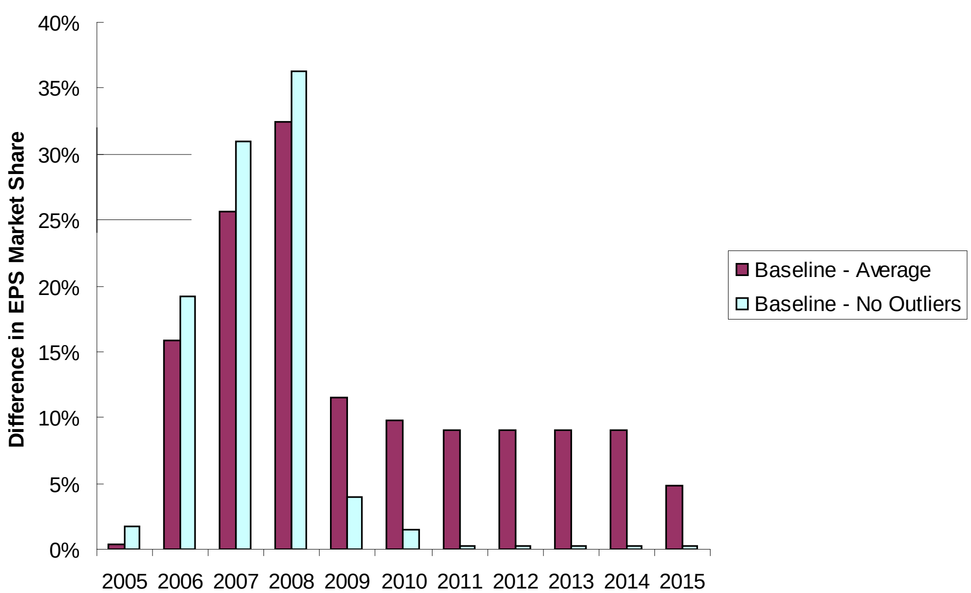

Figure 2. Effect of PIER Activities on Annual Market Shares of Efficient External Power Supplies, U.S.

- **Estimate the net unit sales of efficient power supplies attributable to PIER activities.** We estimated the net number of unit sales of efficient power supplies attributable to PIER activities by multiplying the annual difference in market share shown in Figure 2

[8] The Darnel Report estimates the current market share for switching power supplies at 99 percent. However, the authors do no provide sources for that estimate.

by the estimated annual sales for covered devices. Recall that we had developed three forecasts of unit sales after 2008. We applied both estimates of net market share (with and without outliers) to each of the sales forecasts to generate six forecasts of net unit sales. As shown in Table 2, the analysis yields estimates of net unit sales of efficient external power supplies attributable to PIER activities of 917,000 to 1.24 million over the period from 2005 to 2015. To put this estimate in perspective, these "net" sales figures amount to 15 percent of total unit sales over the analysis period, under the historic growth scenario.

Table 2. Effect of PIER Activities on Annual Sales of Efficient External Power Supplies, U.S.

	Net annual Sales of Efficient Power Supplies (millions)							
Year	**2005**	**2006**	**2007**	**2008**	**2009**	**------**	**2015**	**Total**
Average – Historic Growth		44	97	177	224	----	48	**1,107**
Average – High Growth		46	104	193	247		58	**1,244**
Average – Low Growth		41	91	163	202		39	**984**
No Outliers – Historic Growth	16	87	169	219	254		2	**1,006**
No Outliers – High Growth	16	91	180	238	281		3	**1,102**
No Outliers – Low Growth	15	83	158	202	230		2	**917**

- Estimate annual energy savings associated with replacement of power supplies on all devices covered by federal product standards with efficient models. KEMA estimated average annual unit energy savings for the three main categories of devices powered by external power supplies: appliances with battery chargers, computers and office equipment, and telecommunications. The first step in this process was to compute the weighted average annual savings for devices included in each of these categories, using energy savings and sales figures for each of the 42 products included in the Ecos Consulting 2005 Power Supply Census. We then re-weighted those results to reflect updated sales figures from the 2008 Darnel Group report. The results of these calculations were as follows:
  - Appliances and battery chargers: 2.18 kWh/year
  - Computers and office equipment: 14.50 kWh/year
  - Telecommunications: 5.59 kWh/year
  - Weighted average of all devices: 6.68 kWh/year
- **Estimate effective useful life of devices covered by the federal standards.** As discussed above, the Ecos Consulting 2005 Power Supply Census contained estimates of effective useful life (EUL) for most of the covered devices. However, such estimates were missing for cell phones and cordless phones, which together accounted for two-thirds of annual unit sales of covered devices. We asked the participants in the Delphi panel to provide EUL estimates for cell phones and cordless phones. The average response for cell phones was 2.75 years; 5.50 years for cordless phones. Using this

information as well as EUL estimates for other products in the Ecos Consulting database, we developed the following estimates of average effective useful life:

- o Appliances and battery chargers: 4.5 years
- o Computers and office equipment: 4.1 years
- o Telecommunications: 4.8 years
- o Weighted average of all devices: 4.5 years

- **Estimate lifetime energy savings for each annual "cohort" of net efficient unit sales.** For each growth/PIER impact scenario, we multiplied the estimate of net efficient unit sales for each year by average annual savings and average EUL to obtain the total lifetime energy savings achieved by that cohort.
- **Estimate discounted avoided costs for each cohort.** KEMA developed a discounting factor that reflects the following assumptions:
  - o Annual inflation in avoided costs: 3 percent
  - o Discount rate: 8.15 percent per CPUC specifications
  - o Weighted average EUL: 4.5 years

  We applied the resulting factor along with the current avoided cost per MWh to the estimate of lifetime energy savings for each cohort to arrive at total discounted avoided costs for each annual cohort of net efficient external power supplies attributable to PIER activities.

- **Estimate TRC costs for each scenario.** As part of the Delphi process, KEMA asked panelists to estimate the incremental cost of switching versus linear external power supplies for each year over the analysis period.

  Figure 4 summarizes the panelists' responses and displays the average and median estimates for each year.[9] It is interesting to note that all panelists believe that incremental cost decreased much more quickly than the supporting materials for the federal and California product standard changes assumed they would. The average of the panelist estimates is generally higher than the median. To be conservative we used the average of the five forecasts to compute customer costs, which make up by far the largest component of the costs included in the TRC test. We estimated annual cost by multiplying the net number of efficient units sold as a result of PIER activities by the average incremental cost shown for the corresponding year in Table 3. We also added the costs of PIER program administration - $577,082 – to the first year costs in all scenarios.

9 Panelist 11 provided separate estimates for power supplies above and below 10 W capacity. The estimates shown in Figure 4 are a weighted average of those two estimates.

Table 3. Delphi Panelist Estimates of Incremental Costs for Efficient External Power Supplies

	Year								
Respondent	2005	2006	2007	2008	2009	2010	2011	2012	2013
11	$ 0.48	$ 0.28	$ 0.15	$ 0.09	$0.39	$ 0.37	$ 0.37	$ 0.38	$ -
12	$ 0.63	$ 0.38	$ 0.12	$ -	$ -	$ -	$ -	$ -	$ -
15	$ 1.00	$ 0.75	$ 0.50	$ 0.35	$0.20	$ 0.15	$ 0.10	$ -	$ -
17	$ 0.25	$ 0.20	$ 0.10	$ 0.05	$0.02	$ -	$ -	$ -	$ -
18	$ 0.63	$ 0.38	$ 0.12	$ -	$ -	$ -	$ -	$ -	$ -
Average	$ 0.60	$ 0.40	$ 0.20	$ 0.10	$0.12	$ 0.10	$ 0.09	$ 0.08	$ -
Median	$ 0.61	$ 0.38	$ 0.14	$0.07	$0.07	$ 0.05	$ 0.05	$ -	$ -

- Complete cost-effectiveness calculations. Table 4 shows key results of TRC cost-effectiveness calculations for the six baseline/growth scenarios. Using the assumptions and methods discussed above, the results of the benefit-cost calculations show that PIER's investment in activities to support adoption of efficient external power supply specifications into California and U.S. product standards yielded very high returns. Discounted net benefits for the various baseline/growth scenarios range from $908 million to $1.14 billion; the TRC benefit-cost ratio ranges from 8.3 to 12.7.[10] Even if we radically altered assumptions concerning incremental costs and energy savings or credited PIER with far more modest effects on market development than the Delphi panelists, the net benefits of the program would still range in the hundreds of millions of dollars, versus an initial investment of $577,082.
- Estimate lifetime energy savings. Lifetime energy savings at the national level resulting from PIER activities are estimated to be between 27,543 GWh and 37,340 GWh.

10 The sharp break in discounted net benefits and benefit-cost ratios between the Baseline: Average and Baseline: No Outliers scenarios is due largely to differences in the timing of net sales realization. They come earlier in the No Outliers scenario and end sooner. This has a more pronounced effect on discounted costs than on discounted benefits, since the incremental cost of net sales are all realized in the year they occur, versus a 4.5-year stream of savings.

Table 4. Summary of TRC Cost-Effectiveness Calculations, U.S.

Scenario	Lifecycle Energy Savings (GWh)	In 2005 $ millions NPV of Benefits	NPV of Costs	Discounted Net Benefits	B/C Ratio
Baseline: Average - Historic Growth	33,229	$1,098	$82	$1,016	12.4
Baseline: Average - High Growth	37,340	$1,225	$90	$1,135	12.7
Baseline: Average - Low Growth	29,560	$983	$75	$908	12.1
Baseline: No Outliers - Historic Growth	30,208	$1,112	$117	$995	8.5
Baseline: No Outliers - High Growth	33,104	$1,215	$127	$1,088	8.6
Baseline: No Outliers - Low Growth	27,543	$1,017	$109	$908	8.3

3.4.2. California Calculations

KEMA used the basic approach described for the national calculations to conduct a cost-effectiveness assessment of PIER's activities in support of efficient external power supplies at the California state level. The paragraphs below present highlights and key results of that analysis. We do not discuss inputs and methods that were used without alteration in both the California and national calculations.

- Establish avoided costs for California. Data on California avoided costs were derived from the CPUC Avoided Cost Database used for assessing cost-effectiveness of proposed 2009 – 2011 energy-efficiency programs. We used the weighted average of time-differentiated avoided costs - $67.71 per MWh – to value electric savings in California.
- Estimate annual sales of relevant devices in California. Data on U were only available at the national level in the 2005 US Power Supply Census. It was therefore necessary to estimate California sales based on national sales. We obtained data on total occupied housing units for both California and the entire US from the US Census Bureau's American Community Survey. According to the survey, in 2007, the US had 112.4 million occupied housing units, and California had 12.2 million occupied housing units. We applied the ratio of US to California occupied housing units to the sales figures developed for the national analysis to estimate unit sales of consumer devices with external power supplies in California.
- Develop inputs for the quantitative assessment of the effect of PIER activities on adoption of standards and market share of efficient power supplies. The following paragraphs summarize the Delphi panel's responses to items exploring the effect of

PIER activities on the timing of changes in Title 20 product standards and the state-level market share of efficient external power supplies.

Question 1: Effective date of California Title 20 standards. California's Title 20 energy-efficiency standards for external power supplies came into effect on January 1, 2007. If PIER had not helped create an external power supply energy-efficiency test method, in what year do you think Title 20 external power supply efficiency standards would have come into effect?

In response to this question, one panelist selected 2007, one selected 2008, and three selected 2009. The sixth panelist stated that Title 20 external power supply standards would not have come into effect over the period ending 2015 in the absence of the PIER test method. Between Rounds 1 and 2, responses coalesced around 2009, with one answer changing from 2008 to 2009 and another changing from 2010 to 2009. For Round 2, the median response was 2009.

The two respondents who selected 2007 and 2008 both argued that the PIER program was unnecessary to test method development. One stated that "the test method could have come from any consulting source within the time frame." The other panelist reasoned that, "Once the opportunity to save energy via enhancing the efficiency of external power supplies was identified, it was obvious that a test procedure would be needed. While PIER did a fine job, I expect that the job would have been done, one way or another, but perhaps not as efficiently and rigorously."

The three respondents who selected 2009 provided common justifications for their choice. Panelists believed that the timing of PIER's work helped ensure that the Energy Commission considered external power supplies in its 2004 Title 20 rulemaking proceeding. Without PIER's efforts, one respondent noted, "EPS might have been addressed in the current (2007-2010) Energy Commission standards rulemaking." Panelists also cited work performed by other domestic and international agencies. One panelist observed that "There were … other parties, including EPA, the Australian government, and China's labeling program, who were similarly committed to developing a test method, testing a large array of EPSs, and creating an energy efficiency specification." In the absence of PIER, these parties would have taken steps to develop a test method.

The panelist who believed Title 20 standards would not have taken effect contended that the PIER program was essential to test method development. The respondent argued that, "If the PIER/PG&E effort had not happened, the question determining the effective date of a potential standard depends on who else might have done it. My professional opinion is that nobody would have." Consequently, Title 20 standards would never have been adopted.

Question 2. **Trends in California market share.** For each year between 2005 and the year you selected in response to Question 1 (that is, the year you believe Title 20 standards would have come into effect in the absence of a PIER test method), what do you think the market share of energy-efficient external power supplies **in California** would have been?

The narrow lines in Figure 3 represent the individual panel members' estimates of the annual market share of efficient power supplies from 2005 through 2015. The estimates provided by Panelist 15 were an outlier in both Delphi rounds. Between Rounds 1 and 2, three respondents made minor adjustments to their estimates which shifted their responses closer to the average market share curve. These adjustments changed the estimates given by Panelist 17 into an outlier as well. These latter estimates were the most optimistic with regard to efficiency improvements in the absence of PIER activity. Panelist 17 offered the following rationale: "I started with 25%, since the Energy Star criteria put the spec at the 75 percentile level, then proposed that the market share would rise more slowly at first due to the power supply makers being slow to catch on to the standards, as evidenced in the early workshops. I then estimated that the curve would slope upward as my 2008 estimate drew near."

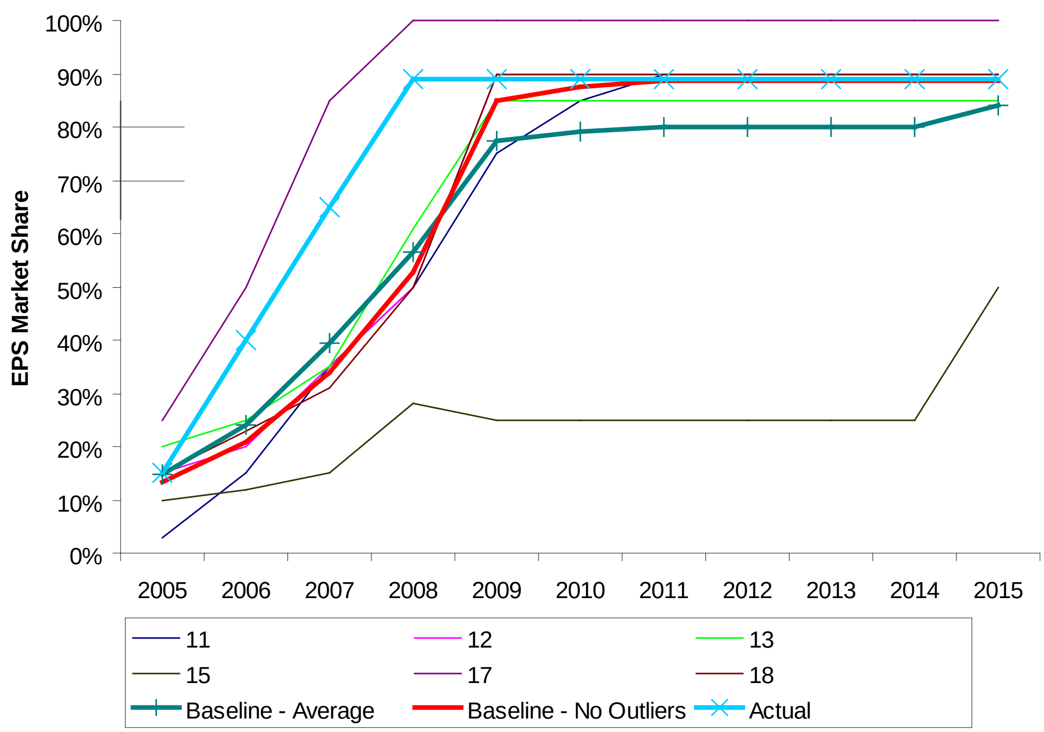

Figure 3. Delphi Panel Estimates and Forecasts of EPS Market Share, California

Panelists 11, 12, 13, and 18 provided multiple, overlapping reasons for their estimates. Primary reasons included:

- o Production of energy-efficient external power supplies was limited until the middle of the decade—"there was very little high efficiency EPS before 2005."
- o Stocks of inefficient external power supplies would have been cleared over a transition period—"the shelves needed to be cleared of old product."

- o Increases in the price of copper would have reduced the incremental cost of efficient external power supplies compared to inefficient power supplies. This development "could have caused some manufacturers to switch to the more efficient designs ahead of a standard."
- o Even in the absence of Title 20 standards, the market share of energy-efficient external power supplies in California would have risen due to the effects of "some other policies like ENERGY STAR."
- o Consumer interest in features other than energy efficiency would have led to moderate increases in market share for energy-efficient external power supplies even in the absence of Title 20 standards. For example, "Power supplies for portable products, such as cell phones and PDAs, were moving toward efficient designs in the absence of a standard in order to reduce weight and size, thereby increasing portability."
- o International regulatory efforts, including policies pursued by "other governments outside the US," would have resulted in increased market share for efficient external power supplies in California.

Panelist 15 offered the most conservative estimates of likely California market share in the absence of a PIER test method. This respondent also cited the importance of product features unrelated to energy efficiency ("self-improvement") as well as international initiatives in promoting increased market share for switching designs, but felt that the effects would be limited. The respondent maintained that "products characterized by the need for 'self-improvement' characterize 10 to 25% of the market and that international effects would begin to have a significant effect in the California market in 2015 or later."

KEMA developed estimates of the net effect of PIER activities on annual market share using the same approach employed for the national-level analysis.

- Complete cost-effectiveness calculations. Table 5 shows key results of TRC cost-effectiveness calculations for the six baseline/growth scenarios at the California state level. Discounted net benefits for the various baseline/growth scenarios range from $67 million to $114 million; the TRC benefit-cost ratio ranges from 7.7 to 11.8.
- Estimate lifetime energy savings. Lifetime energy savings at the California state level resulting from PIER activities are estimated to be between 1,533 GWh and 3,141GWh.

Table 5. Summary of TRC Cost-Effectiveness Calculations, U.S.

		In 2005 $ millions			
	Lifecycle Energy Savings (GWh)	NPV of Benefits	NPV of Costs	Discounted Net Benefits	B/C Ratio
Scenario					
Baseline: Average - Historic Growth	2,803	$103	$9	$94	11.4
Baseline: Average - High Growth	3,141	$114	$10	$105	11.8
Baseline: Average - Low Growth	2,503	$93	$8	$84	11.0
Baseline: No Outliers - Historic Growth	1,652	$72	$9	$62	7.8
Baseline: No Outliers - High Growth	1,779	$77	$10	$67	7.9
Baseline: No Outliers - Low Growth	1,533	$67	$9	$58	7.7

3.5. Conclusions

This benefit-cost assessment illustrates the enormous leverage offered by strategies that target and support changes in product standards. In the case of electronic power supplies, that leverage is particularly pronounced because Americans purchase more than half-a-billion units each year. Moreover, PIER is in an excellent position to link the technical expertise to which the program has access to the administration of code changes, which is handled by another division of the Energy Commission.

Even if we were to make highly conservative assumptions concerning the effect of the PIER activities to support changes to product standards – for example, that PIER efforts affected only events in California or that those efforts accelerated market development by no more than one year – their net benefits would still be substantial. All but one of the 13 experts interviewed for this study believed that PIER activities had a fairly significant impact on the pace of market development both in California and in the country as a whole. Thus, KEMA believes that the estimates of net benefits developed through analysis of the Delphi responses are reasonable.

Appendix to Chapter 2: Delphi Process Methods

KEMA recruited 6 panelists to take part in two Delphi rounds. As a condition of their involvement, panel members were guaranteed anonymity. Panelists were assigned random numbers. All but one panelist had participated in the initial attribution interviews.

In assembling the expert panel, KEMA sought to ensure a balanced distribution of interest, opinion, and gender (one woman served on the panel). The panel consisted of two representatives of the power supply and consumer electronics industries, two consultants who had worked on a variety of efforts to promote efficient external power supplies, one representative of federal government agencies involved in the change in product standards, and one utility program officer familiar with the upgrading of Title 20.

There are relatively few individuals with the appropriate combination of knowledge and experience necessary to serve on a panel of experts on external power supply energy efficiency standards. This methodological constraint placed firm limits on the size and diversity of the panelist candidate pool. KEMA attempted to minimize this inherent potential for bias by making Delphi questionnaires as neutral in tone as possible, and by stressing the importance of objectivity to panel members.

Once panelists had agreed to participate, the Delphi process proceeded in two rounds:

- In Round 1, panelists were given an initial questionnaire, an evidence packet with relevant documentary evidence, a panel agreement form, and instructions. The main part of the questionnaire asked respondents to speculate about counterfactual scenarios under which PIER had not created a test procedure and Title 20 standards were delayed. The questionnaire also collected additional information on EUL and incremental cost. Participants were given two weeks to complete the initial questionnaire.
- In Round 2, panelists were given a follow-up questionnaire, a summary of Round 1 results, and instructions. This second questionnaire duplicated the counterfactual questions posed in the first version, and provided participants an opportunity to revise their original answers in light of the collective results from the first round. Market share data were also requested. As before, participants were allowed two weeks to complete the follow-up questionnaire.

4.0 Case Study – ThermoSorber

This chapter presents the benefit-cost assessment of the PIER ThermoSorber project. The chapter begins by describing the ThermoSorber and project efforts to promote its adoption. We apply techniques familiar from energy efficiency program potential studies, including scenario and diffusion curve analyses to estimate benefits and costs. We apply the TRC framework to those results to assess cost-effectiveness.

4.1. Product Description

The ThermoSorber is a thermally-activated heat pump/chiller based on an ammonia-absorption cycle. It can simultaneously produce hot water at 130 to 170 degrees Farenheit and chilled water at 20 to 45 degrees. The heating efficiency of the device is 160 percent, and cooling efficiency is about 60 percent. The overall efficiency exceeds 200 percent. The device requires an initial heat input which may be provided by waste heat, natural gas, propane, or solar energy.

The device is appropriate for buildings with large balanced hot water and chilling needs, such as dairies, breweries, poultry processors, meat processors, fruit and vegetable dryers, hospitals, hotels, laundries, swimming pools, and ice rinks. Capacities range from 25 tons up to 150 tons, although the technology is applicable and cost-effective for loads as low as 10 tons.

The device was invented by Donald Erickson of Energy Concepts Company (ECC). The company designs and develops energy-efficient, heat-activated absorption systems and associated fluid contact equipment. Energy Concepts is located in Annapolis, Maryland, and has 3200 square feet of office space and 6000 square feet of shop and laboratory space. It has been in business for more than 30 years and holds more than 70 patents. It has 12 employees.

The ThermoSorber was developed as part of the Department of Energy's (DOE) Thermally Activated Heat Pump Program, part of the Building Energy Program. It was part of an effort to develop what DOE referred to as a "Hi-Cool" heat pump, designed to achieve high cooling efficiencies for heating and cooling applications in warmer cooling-dominated climates. Oak Ridge National Laboratory conducted a competitive procurement in the mid-1990s and selected multiple subcontractors, including Energy Concepts, to develop the heat pumps. Energy Concepts and another firm were selected to move ahead with the fabrication of components and, ultimately, the construction of a prototype device. ECC's prototype was constructed in 2001, and a paper describing the design and performance was presented at an American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Symposium in 2002, and published in ASHRAE Transactions later that year. The prototype device exists at ECC's facility. ECC received about $600,000 in funding from DOE over the various phases of the project.

To date, two ThermoSorbers have been installed at poultry processors (10 tons and 100 tons), installation is underway at a meat processor (300 tons), and an industrial laundry is applying for incentives to install one.

The ThermoSorber has qualified for energy efficiency incentives from Pacific Gas & Electric (PG&E) and Clean Tech Partners (for Wisconsin's Focus on Energy). While the other investor-owned utilities in California have not provided incentives for a ThermoSorber project, the technology could qualify for incentives under their existing custom commercial and industrial programs.

4.2. Project Overview

In 2002, PIER Industrial, Agriculture, and Water staff met the inventor at a DOE-sponsored industrial energy efficiency event. The technology appeared promising, and PIER staff began looking at potential industrial applications in California. After visiting Energy Concept's laboratory in Maryland and assessing the company's organizational capability, the inventor was encouraged to apply for a grant.

At that time, PIER was operating under "fast-track deployment" as a result of the 2001 energy crisis. The project was submitted and approved as a sole-source contract, providing $210,000 to pay for two demonstration sites. PIER had no role in shaping the application, beyond suggesting that the inventor apply.

The project had three goals:

- Develop and install an industrial-scale unit.
- Integrate it seamlessly into the industrial process.
- Do it all cost-effectively.

The first step was to recruit sites for the demonstration projects, which proved to be difficult. PIER assisted in identifying potential sites, but most fell through due to issues such as worries about process interruptions, uncertainty about technology performance or savings, budgeting issues, or changes in the facilities staff at prospective sites. Ultimately, PIER found a poultry processor and a microbrewery. In the end, the microbrewery backed out. The poultry processor, Squab Producers of California, completed the installation in 2003.

The Squab application is on the small end of the ThermoSorber's size range, at less than 10 tons of chilling capacity.

Energy Concepts studied Squab's existing hot water supply and chilling system, and developed design modifications to suit the site. Technical issues of interfacing with the existing systems were identified and interfacing schematics were prepared.

The ThermoSorber consists of eight major components, two of which were designed and fabricated by Energy Concepts. The remaining components were competitively bid and purchased from commercial vendors. The company fabricated the ThermoSorber for delivery to Squab at its Maryland facility, as well as a test unit. The Squab unit was tested at the ECC test facility using simulated hot water and chilling loads.

Once the unit’s performance was verified at the test facility, it was shipped and installed at the Squab facility. The unit was started, test-operated, and controls were adjusted. ECC trained Squab staff on the operation of the device, safety procedures, and the monitoring process. A manual was also provided.

Once the equipment was up and running, a number of problems developed related to the ThermoSorber, the existing refrigeration system, or the interface between the two. Some of these issues were commissioning issues like those that might come up with any large equipment installation, while others related specifically to the design and installation of the ThermoSorber. Energy Concepts incorporated lessons learned from the demonstration project into future designs.

PIER arranged for third-party monitoring to be conducted by the California Institute of Food & Agriculture Research at the University of California at Davis (UC-Davis). Over six months of monitoring, the project saved 68.3 percent of electricity and 27.7 percent in thermal energy, compared to the conventional technology.

In 2006, PIER nominated Squab for a “Flex Your Power” award, which was awarded in May 2007. Flex Your Power is California's statewide energy efficiency marketing and outreach campaign, and is widely recognized by California consumers. It is a partnership of California's utilities, residents, businesses, institutions, government agencies, and nonprofit organizations working to save energy.

PIER has a contract with UC-Davis to help with technology transfer at industry forums. Under that contract, UC-Davis held a forum for California food processors that showcased the ThermoSorber. One of the attendees, Foster Farms, Inc., another poultry processor, became interested in the technology. It took another 15 months, however, before they agreed to install the technology. The Foster Farms project will be discussed in greater detail below.

PIER also promoted the project to California’s investor-owned utilities at the Emerging Technologies Summit in October of 2006. PIER staff persuaded PG&E to undertake an independent assessment of the technology, which took the form of a monitoring project on the Foster Farms installation, and to begin giving rebates on a trial basis in order to assess whether the technology should be made part of its energy-efficiency rebate programs.

Fifteen months elapsed between the time Foster Farms first expressed interest in the technology and the time they finally agreed to the project. In order to move the project ahead, PIER provided $40,000 toward equipment costs under a separate contract with Energy Concepts.

The Foster Farms installation was completed in 2006. At 100 tons of chilling, this unit is 10 times larger than the Squab unit, which demonstrates the applicability of the technology at a range of capacities. The size is a closer match to Energy Concept’s target market of 25 to 250 tons.

PG&E provided performance measurement and validation through a third-party evaluator, Heschong Mahone Group (HMG). The evaluation report found a COP of 1.48 for water heating and 1.97 for combined water heating and chilling. Electricity energy savings were about 495 MWh per year, or almost 95 percent savings compared to the base technology. Peak demand savings were about 92.8 kW. Gas savings were about 33 percent compared to conventional technology (HMG, 2008). The economics for this project were better than for the Squab project due to the larger scale.

Benefits Calculations and Results

KEMA drew on the TRC test established by CPUC to develop estimates of the technical and economic potential of the ThermoSorber in the US market. Application of this method yields a maximum estimate of energy savings and customer spending on the device. We then use the results of interviews with manufacturers and other industry observers to develop a range for the level of market penetration the ThermoSorber is likely to reach.

Estimation of the potential benefits of the ThermoSorber proceeded in the following steps: (1) Define the relevant market; (2) Develop estimates of unit savings and costs; (3) Estimate technical and economic potential; (4) Forecast annual unit sales and market share; and (5) Estimate annual energy savings.

The subsections below discuss the methods used and findings for each of these steps.

4.2.1. Definition of the Relevant Market

The first step in estimating technical and economic potential for the ThermoSorber was to identify the commercial and industrial facilities that are most likely to benefit from the technology. We focused on a short list of industrial sectors and commercial building types identified as appropriate targets for the ThermoSorber in technical documents and project reports: hospitals, hotels, meat and poultry processors, dairy processors, breweries/beverages, fruit and vegetable canning, frozen fruit, juice and vegetable manufacturing, industrial laundries, swimming pools, ice rinks, and the paper industry. The paper industry is evaluated solely on the ThermoSorber's heating benefits, with the cooling output used to cool the waste stream. Of those industries, we have yet to obtain sufficiently detailed information on the population and energy use patterns of dairy processors, industrial laundries, swimming pools, and ice rinks to estimate the potential benefits for those market segments. Therefore, we have not included estimates of benefits for those segments in this report.

Size of the Potential Market

There are a number of possible metrics to use as a base measure of the market potential, such as number of buildings, floorspace, or base energy use. KEMA does many market potential studies, and typically uses floorspace for commercial analyses and base energy use for industrial analyses. The choice is driven by data availability, with EIA's Commercial Buildings Energy Consumption Survey (CBECS) providing detailed information about commercial floorspace, equipment types, and energy use, and EIA's Manufacturing Energy Consumption Survey (MECS) providing energy use by industrial sector, but only limited information by end-use. Because most of the segments we analyze are industrial sectors, we chose base energy use as the measure of the market size. Base energy use was calculated by combining refrigeration energy and heat energy estimates for each submarket, drawn from the above sources.

Since natural gas may be used for any number of purposes for which the ThermoSorber is inappropriate (e.g., high-temperature heating, steam), we needed to determine what share of total gas use might be addressed by the ThermoSorber. An energy database was found that breaks out industrial gas use by sector as low-, medium-, or high-temperature heat, among other end-uses (EECA 2008). The share of gas energy used for low-temperature heat was used to approximate the applicable gas use.

Because the ThermoSorber produces hot water and chilling at the same time and in a specific ratio (producing a given amount of hot water will produce a fixed amount of cold water, at specific temperatures), the ThermoSorber must be sized to meet either the heating or the cooling load, but not both (unless the loads are in perfect balance). We used information from the HMG (2003) report to estimate the ratio of heating to cooling for the 100-ton Foster Farms ThermoSorber. The base electricity energy use at that site was 522 MWh per year, while gas energy use was 0.21 million Therms per year, for a ratio of 2,486 MWh/Mtherm.

This ratio was used to estimate, for each market segment, whether the heating or cooling load was the binding constraint. For most segments, the heating load was the binding constraint (that is, if the ThermoSorber was sized to the full heating load, the amount of cooling would be less than the total cooling demand). In this case, we calculated the total market on the gas side as the full low temperature or water heating gas use, and on the electricity side, we calculated how much cooling (refrigeration) energy could be offset by that amount of heating. If cooling was the binding constraint, these calculations were reversed. We refer to the resulting values as the total market that can be addressed by the ThermoSorber.

Table 6 shows our estimate of the total size of the relevant market sectors in terms of number of establishments, electricity consumption, and gas consumption. According to counts compiled from the Manufacturing Energy Consumption Survey, the Economic Census, and the EECA database, there are 26,527 establishments in the various sectors for which the ThermoSorber may be appropriate: half in the industrial and half in the commercial sector. There are a number of significant barriers to the adoption of ammonia-based refrigeration technologies in the commercial sector. In the near and medium term, then, the total target market for the ThermoSorber constitutes roughly 13,000 industrial facilities. Given that the ThermoSorber technology is most cost-effective in larger-scale operations, the portion of the market for which the technology is advantageous is likely to be significantly smaller than the total population of firms. For example, only 3,700 firms in the targeted market segments employ more than 20 workers. It is unlikely that smaller firms will purchase an expensive piece of equipment like the ThermoSorber.

Table 6. Indicators of ThermoSorber Market Size by Segment

Building Type	# of Estab.	GWh/ Year	Mil. Therms/ Year
Hospital	3,206	1,941	26
Hotel	6,386	4,764	32
Meat & Poultry Processor	3,973	13,428	74
Dairy	1,681	*N/A*	*N/A*
Breweries/ Beverages	2,908	2,052	4
Fruit & Vegetable Canning	1,090	615	7
Frozen fruit, juice, and vegetable manufacturing	237	1,465	4
Industrial Laundries	2,636	*N/A*	*N/A*
Swimming Pools	3,405	*N/A*	*N/A*
Ice Rinks	443	*N/A*	*N/A*
Paper	561	1,720	157
Subtotal Commercial	13,441	6,705	58
Subtotal Industrial	13,086	19,280	246
Total	26,527	25,985	303

Estimate Annual Unit Sales

Based on the findings above we conclude that annual unit sales (U) of all types of large refrigeration and process heat equipment in the targeted segments are fairly modest—no more than 700 units per year. Our estimate is based on the following considerations:

- The number of firms in the target market segments—industrial and commercial—that need large-scale process heat and refrigeration equipment is no larger than 12,000.
- According to the Database for Energy Efficient Resources (DEER), EUL for equipment of this type is 20 years. Thus, the replacement market is likely to amount to no more than 600 units per year.
- Assuming some growth in the end-user base, maximum annual sales are not likely to exceed 700 units for all types of technologies, conventional and otherwise.

Estimates of Unit Savings and Costs

KEMA used energy savings information from the HMG monitoring report on the Foster Farms installation to estimate energy savings per installation for different market segments. The evaluation report found a COP of 1.48 for water heating and 1.97 for combined water heating and chilling. Electricity energy savings were about 495 MWh per year, or almost 95 percent savings compared to the base technology. Peak demand savings were about 92.8 kW. Gas savings were about 33 percent compared to conventional technology (HMG, 2008). We made adjustments for differences in operating hours among industries and commercial building types to the extent that data from various surveys supported these assumptions.

The following cost values and other inputs were also used in the analysis:

- Avoided cost levels. Typically, utility avoided costs (AC) are used to calculate the total resource cost of an energy efficiency measure. We know of no source for average avoided costs for the US, however, so we used energy price forecasts from EIA (2008). Because most of the segments analyzed are industrial sectors, we used industrial gas and electricity prices (industrial prices are lower than commercial, so if a technology is cost-effective at industrial prices, it will also be cost-effective at commercial prices). There are no national-level estimates for avoided demand costs, so we turned to KEMA's extensive library of potential studies for US utilities to establish the range of such costs. Based on our review, we estimated that $80 per kW represented a reasonable lower bound for US avoided demand cost. We assumed that prices would increase with inflation at a rate (r) based upon EIA forecasts.
- Commercialization date and equipment life. Factored into the present value calculations were the estimated commercialization date of the technology in each sector, and estimated equipment lifetime. Commercialization dates were based on expert judgment informed by knowledge of current and planned projects, and of conditions in segments in which no projects have yet been completed. We used the DEER estimate of EUL for commercial and industrial heat pump technologies to represent ThermoSorber equipment life. This is shorter than the EUL for some of the replaced technologies, such as process heat boilers (EUL = 20 years).
- Incremental measure cost. PG&E conducted a technical study of the ThermoSorber in the context of its Emerging Technologies program. In that study, average incremental costs (IC) for a 100-ton unit were estimated at $167,000 (PG&E 2007).

Estimate Technical and Economic Potential

Based on technical information on cost, savings, and EUL, KEMA estimated the TRC benefit-cost ratio for installations in each of the targeted market segments. For each segment in which the benefit-cost ratio exceeded 1.0, we estimated total economic potential savings. For this last set of calculations we used estimates of market size and unit energy cost savings developed in the previous steps.

We estimated technical potential separately for gas and electric by applying savings percentages derived from the ThermoSorber field tests to total energy in the relevant market segments and end-uses, as estimated above. We next developed a benefit-cost ratio for each segment to determine whether the technical potential savings were economic for the establishments included.

Table 7 shows the results for each market segment. They range from a low of 2.3 for hospitals and hotels to a high of 9.5 in dairies and meat and poultry processing. Differences are driven by differences in run times (the Foster Farms installation runs approximately 100 hours per week, which was taken to be typical of meat and poultry processors), as well as differences in when the technology will be begin to penetrate each segment.

Table 7. ThermoSorber Benefit-Cost Ratios by Market Segment

Segment	BCR_{TRC}
Hospital	2.3
Hotel	2.3
Meat & Poultry Processor	9.5
Dairy	9.5
Breweries/ Beverages	9.3
Fruit & Vegetable Canning	9.3
Frozen fruit, juice, and vegetable manufacturing	9.3
Industrial Laundries	4.7
Swimming Pools	4.6
Ice Rinks	4.6
Paper	8.1

The ThermoSorber was considered to be economic in a particular market segment if the TRC benefit-cost ratio was greater than 1. Since all of the segments have ratios greater than 1, the economic potential is equal to the technical potential.

Table 8 shows the economic potential savings by segment and overall. Note that program costs are not included in this analysis.

Table 8. Economic Potential for ThermoSorber

Building Type	Electricity		Gas
	GWh	MW	MTherms
Hospital	182.73	34.30	25.9
Hotel	224.50	42.14	31.8
Meat & Poultry Processor	524.59	98.47	74.3
Breweries/ Beverages	28.49	5.35	4.0
Fruit & Vegetable Canning	46.61	8.75	6.6
Frozen fruit, juice, and veg mfg	27.19	5.10	3.9
Paper	0.00	0.00	157
Total	1,034	194	303

Forecast Annual Unit Sales and Market Share

KEMA developed estimates of annual unit sales based on the results of the market sizing exercise conducted as part of the potential analysis, modified to reflect the results of interviews with manufacturers and other experts in the industrial refrigeration market concerning the commercial prospects for ThermoSorber.

KEMA developed a forecast of likely ThermoSorber unit sales over a period of ten years. This forecast was then used to drive estimates of energy savings achieved over that period. The steps in this process were as follows:

- Interview representatives of manufacturers and research organizations active in industrial refrigeration and process heat to obtain their views regarding the advantages the ThermoSorber offers to customers versus conventional process heat and cooling technologies, the barriers to customer acceptance of the ThermoSorber, and the potential threat of competing double-effect absorption technologies.
- Use the information from the interviews to develop a forecast of total market share to be achieved over the ten-year period ending 2018. Plot annual market share and sales for the technology using a Bass-type diffusion model.
- Use the annual market share estimates developed through this process to estimate annual benefits.

We identified factors that will influence the adoption of the ThermoSorber through a series of interviews with individuals familiar with the ThermoSorber and its potential markets. Interviewees included the inventor of the ThermoSorber, potential competitors and/or licensees, utility program managers, and experts in the fields of thermally-activated technologies and the food processing industry. Interviewees identified the following factors that they believed would inhibit or accelerate demand for the ThermoSorber:

- Health and safety issues associated with the use of ammonia.
- Lack of service infrastructure.
- Risk aversion among buyers.
- Variation among market segments in chilled/hot water load coincidence.
- Conditions in overseas versus domestic markets.

Don Erickson, the inventor of the ThermoSorber and president of ECC, stated in an interview for this project that ECC has no interest in and no capability for mass producing the device. Thus, licensing the product to another manufacturer is the only practical route to significant sales and product benefits. If a manufacturer can be found to produce the device in volume, it would drive down costs and increase the number of applications for which the ThermoSorber would be cost-effective. Having the name of a known manufacturer would improve the perception of reliability (warranty, service) and acceptability. Finally, a large manufacturer would have the resources and existing channels to support effective marketing and sales. The following factors minimize the likelihood that ECC can conclude a licensing agreement restricted to the US market:

- Highly concentrated markets.
- Little interest from US manufacturers.

- Competing products.
- Small domestic market size.

Given the combination of small domestic market size, current manufacturer investments in alternative technologies, and the presence of competing products, we believe it is unlikely that manufacturers serving the US market alone will license the ThermoSorber or devote resources to producing and promoting it. On the other hand, market observers mentioned that manufacturers serving primarily overseas markets may be more likely to license the technology and to export it into the US to address niche demands. Thus, in the estimate of achievable potential below, we assume that the ThermoSorber can capture 10 to 20 percent of unit sales in the relevant industrial refrigeration markets by the end of the forecast period.

Estimate Annual Energy Savings

We combined the results of the first four steps to estimate annual energy savings and energy cost savings. These figures were used in a net present value analysis of the benefits and compared to PIER's investment in the technology.

Achievable potential was calculated using Bass diffusion curves. Bass diffusion curves are technology adoption curves described by three parameters. The first parameter, m, is the maximum market penetration. The parameter p is called the coefficient of innovation, external influence, or advertising effect. The parameter q is called the coefficient of imitation, internal influence, or word-of-mouth effect. Studies of applications of the Bass model have found that the average value of p is 0.03 (and is often less than 0.01), while q typically falls in the range of 0.3 to 0.5 (Mahajan, et al., 1995).

In the context of the factors discussed above, utility promotion, the inventor's marketing efforts, and competing technologies would be captured in parameter p, while q would capture word-of-mouth and dissemination of information within the targeted market segments, as well as the possibility of unlicensed imitators.

Figure 4 illustrates a range of Bass diffusion curves, representing maximum penetrations of 5 and 10 percent. The chart shows curves with p values of 0.005 to 0.03, and q values of 0.3 and 0.4, representing the low to average end of typical adoption patterns.

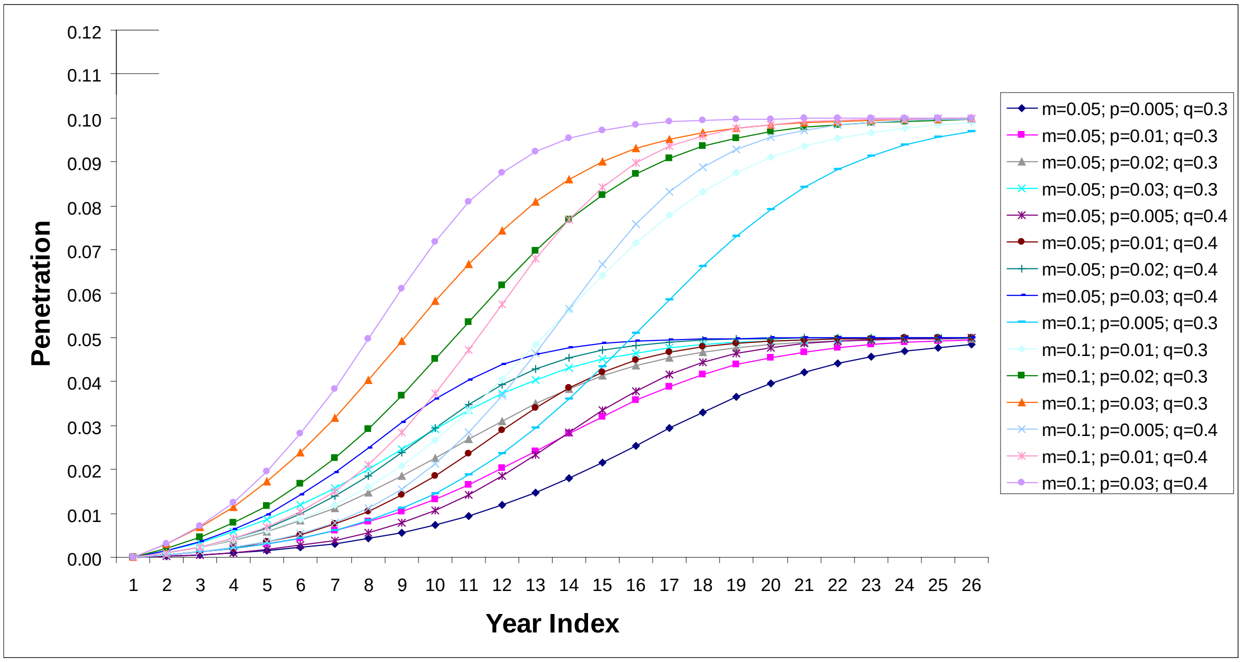

Figure 4. Examples of Bass Diffusion Curves

Penetration rates were developed for each measure-market segment combination using the Bass curves. Bass parameters were set to m = 0.1, p = 0.02, q = 0.4 for industrial sectors and to m = 0.05, p = 0.01, q = 0.3 for hospitals and hotels, in keeping with our assessment that commercialization will be limited and adoption will be slow, with both resistance to ammonia and competition from other technologies limiting the adoption in the commercial sector.

Penetration rates were set to zero for years prior to the estimated commercialization date, and were determined by the Bass curves thereafter. Penetration rates were applied to total economic potential to get achievable potential by year. Table 9 shows achievable potential savings in 2018 by market segment. Savings calculations for dairies, industrial laundries, swimming pools and ice rinks are not yet complete and not included in the table.

Table 9. Achievable Potential in 2018

Market Segment	Electricity		Gas
	GWh	MW	MTherms
Hospital	0.37	0.07	0.05
Hotel	0.45	0.08	0.06
Meat & Poultry Processor	20.57	3.86	2.91
Breweries/ Beverages	0.84	0.16	0.12
Fruit & Vegetable Canning	1.37	0.26	0.19
Frozen fruit, juice, and veg manuf.	0.80	0.15	0.11
Paper	0.00	0.00	1.46
Total	24.39	4.58	4.91

Table 10 compares PIER's investment in the Squab and Foster Farms demonstration projects to the present value of savings estimated for the ThermoSorber through 2018, including an estimate of savings accrued to date. The calculations do not include PIER staff labor, which included project management, site recruitment, and estimating the size of the industrial laundry potential in California. PIER project costs are approximately 2 percent of the savings expected for the technology over the next 10 years.

Table 10. Costs and Benefits of PIER Investment in the ThermoSorber Demonstration Project, 2003 – 2018

Cumulative installations 2008-2018	73
Annual electricity savings in 2018 (kWh)	30,405,600
Annual gas savings in 2018 (Mtherm)	4.31
Cumulative customer energy bill savings 2008-2018 (2006 $)[a]	$22,057,661
Present value of customer energy bill savings (2006 $)	$11,979,292

[a] Discounted at 8 percent (d). Includes savings for the Foster Farms installation for 2007, but not the Squab installation (installed in 2003) due to lack of data.

4.3. Attribution Analysis and Net Benefits

KEMA developed data for the assessment of attribution through a set of structured in-depth interviews with a subset of six experts identified in the course of conducting the research to develop the benefits estimates. The respondents included representatives of manufacturers active in the process heat and refrigeration equipment market, managers of other R&D and utility programs that have provided support to the product, and academic market and technology researchers. Based on the market analysis reported above, KEMA concluded that ThermSorber would likely remain a niche product with low sales volumes over the analysis period. The experts interviewed had offered the same opinion in the initial round of interviews. We therefore did not explore the issue of total sales forecasts in the "attribution round". Rather, we focused on assessing the relative importance of the three key sources of outside funding and promotion received by the ThermoSorber: DOE's original research and development (R&D) funding for technology development and construction of the prototype; PIER's funding of the demonstration project; and utility support and incentives (both PG&E's monitoring and any future support through custom commercial and industrial incentive programs).

4.3.1. Results of the In-Depth Attribution Interviews

The survey consisted of four multiple choice and two open-ended questions addressing the importance of the various sources of funding and support received by the ThermoSorber.

First, we asked respondents to assess the likelihood that *any* ThermoSorbers would now be installed, in the absence of PIER efforts to recruit pilot sites and its financial support for the two pilot installations. As can be seen in Figure 5, there was wide disagreement on this question, with each of the five responses, from "not at all likely" to "highly likely" receiving at least one vote. "Somewhat likely" received the tie-breaking vote, garnering two responses.

Respondents were asked to explain their responses. Reasons given for the "highly likely" and "likely" responses were the breadth of possible applications for simultaneous hot and chilled water and the strong interest from parties other than PIER, such as Wisconsin's CleanTech Energy Partners and distributors. The "likely" respondent noted that PIER involvement did accelerate the process. The "not likely at all" and "not very likely" respondents cited customers' risk aversion and PIER involvement adding validity to a project. One respondent also noted that the technology is competing in a very mature marketplace against products with a reliable and consistent performance history. The two "somewhat likely" responses acknowledged the technology risk and lack of familiarity with ammonia-absorption, but nonetheless thought that the technology could be viable (according to one respondent "under certain pricing conditions").

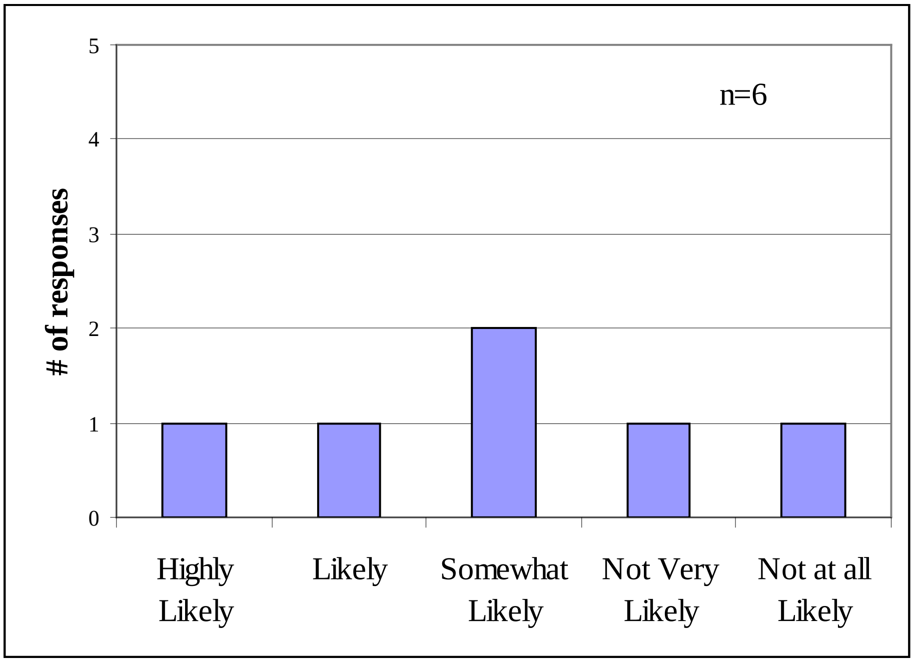

Figure 5. How Likely Is It That Any ThermoSorber Would Be Installed Now Without PIER Assistance?

We next asked respondents to rate the importance of the three key sources of funding and support for the ThermoSorber: the U.S. Department of Energy, PIER, and utilities. All respondents rated each of the three funding sources as “very important” or “important”, and there was little if any difference in the overall rating of the three funding sources.

4.3.2. Attribution Analysis

The experts consulted through the in-depth interviews reported a wide range of opinion on whether any ThermoSorbers would now be installed in the absence of the PIER project. However, only two of the six believed that it is “very likely” or “likely” that there would be any installations. In interpreting these results, observe that:

- The inventor is highly committed to the technology and would likely have continued to seek funds for a demonstration project if PIER had not agreed to support it.
- Even with PIER support, the market response to ThermoSorber has been slow to arrive. Only one installation other than those supported by PIER has gone forward, and it was completed five years after the initial PIER pilot.

Of course, it is difficult to gauge whether the Wisconsin project would have occurred at all, and if so whether it would have been on the same timeline without the existence of a successful demonstration project. Without the PIER project, the first ThermoSorber installation, if it occurred at all, likely would have been completed at least five years later, and possibly significantly later. We therefore conclude that PIER should receive more or less exclusive credit for supporting the “demonstration” phase of ThermoSorber’s commercialization process.

In comparing the importance of the three funding sources, there was only a slight difference in the responses, with DOE funding rated slightly less important than the other two sources. The three funding sources were all important in the market success of the ThermoSorber. This result is consistent with the many barriers that the ThermoSorber has faced over the various stages of product development and marketing. Developing a new technology and building a prototype is expensive, and without DOE funding, the development would have been delayed or would not have occurred at all. The market perceived the technology as unproven and very risky, and without outside funding, it is unlikely that any industrial site would have been willing to adopt the technology, given its high cost and the availability of proven alternative technologies.

The existence of the demonstration project allowed Energy Concepts to tout the success of the technology and cite demonstrated savings. However, the technology remains more expensive than competing technologies, and while the demonstration site mitigates the perceived risk, it does not eliminate it altogether. Without ongoing support and promotion from utilities through the emerging technology and early adoption phase, few firms would make the costly leap of installing the technology. Utility support will allow the technology to gain a foothold and become accepted practice in targeted industries.

Based on this reasoning, we believe it is appropriate to allocate credit for the current and prospective benefits estimated in the previous section equally among the three organizations that have provided support to ThermoSorber so far. Table 11 shows the TRC calculations for PIER’s ThermoSorber project incorporating the results of the attribution analysis. Net benefits of the project over the ten-year analysis period are estimated at $2.6 million, which yields a TRC benefit-cost ratio of 2.87.

Table 11. Total Resource Cost Test Calculations for the PIER ThermoSorber Project

Gross Project Costs and Benefits	
Present value of customer energy bill savings (2006 $)	$11,979,292
Present value of incremental customer costs 2008-2018 (2006 $)	$3,311,188
Net Project Costs and Benefits	
Present value of benefits of net installations attributable to PIER	$3,993,097
Present value of costs of net installations attributable to PIER	$1,103,729
Present value of project costs, including PIER administration	$1,393,729
Net Project Benefits and Benefit-Cost Ratio	
TRC net benefits of installations	$2,599,368
TRC Benefit-Cost Ratio, including program costs	2.87

4.4. Conclusion

The ThermoSorber analysis highlights how a particular product attribute – namely extremely high energy efficiency – can help overcome the risks inherent in supporting the development of a product with a small niche market. We conclude on the basis of our interviews with market actors and other market analysis that the maximum number of units sold over the next 10 years is likely to be fewer than 100 and certainly fewer than 150. This is because the US market for the device is limited by facility attributes (need for balanced heating and cooling loads) and barriers to acceptance of ammonia-based technologies in key sectors. On the supply side of the market, many major manufacturers have already developed and deployed similar, if not quite so cost-effective technologies. However, even with forecast sales volumes lower than 10 units per year, PIER's investment in support of the ThermoSorber is highly cost-effective within the TRC framework, largely because the device itself has proven to be so cost-effective in its early applications.

5.0 Case Study - RTDMS

The following chapter presents the benefit-cost case study of the RTDMS project. After summarizing features of the system and its associated PIER project, benefits are calculated and results discussed. Results of a sensitivity analysis of avoided outage costs are then provided.

5.1. Product Description

The Real Time Display Monitoring System is a set of computation and visualization tools that enable the operators of California's transmission grid to use phasor measurements to identify potential reliability problems and to identify strategies to avoid them or mitigate their impact. Phasors are measurement devices that monitor local transmission system conditions at very short intervals – up to 20 times per second. The currently deployed network of phasors covers much of the California transmission grid.

RTDMS applications in various stages of the RD&D cycle have already provided a reliable set of phasor measurement tools. In the summer of 2007, after several years in the R&D test platform, the RTDMS prototype was transitioned to a production-grade computer platform at the California Independent System Operator (California ISO). Since that time, it has been under active evaluation and has been used as the leading West Coast prototype phasor measurement visualization tool. It is also currently under active evaluation by the Bonneville Power Administration. The Western Electricity Coordinating Council (WECC) may also adopt it, in some form, at its new reliability coordinator locations.[11]

In an AC system, such as the power system, the instantaneous voltage at each point in the system can be represented by a unique "phasor" which comprises both an angle and magnitude. Thus, a display of voltage phasors across the power system is analogous to a weather map that displays real-time wind magnitude and direction. Just as a map of wind arrows indicates storm fronts and other weather anomalies, voltage phasors provide a key indicator of stressed operating conditions on the regional grid. Having this additional information at their fingertips is invaluable to operators and improves their odds of anticipating and averting a disturbance.

The California-Mexico Reliability Coordinator (CMRC) is currently one of three reliability coordinators for the WECC region, each staffed by real-time operating personnel. Various RTDMS displays are available to the operator depending on their specific needs in real time. Detailed graphics of real-time events can also be saved off-line for follow-up review and evaluation.

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11 Reliability coordinators are responsible for the real-time operating reliability of their designated areas and have authority from NERC to act as necessary to prevent or mitigate emergency operating situations in real time.

5.2. Project Overview

The Real Time Grid Reliability Management (RTGRM) component of the Energy Commission-PIER Transmission Research Program supports development of practical applications of phasor measurements of transmission system conditions to enhance grid reliability.[12] The RTDMS currently implemented by the California transmission grid operators is one of the major applications to be developed through this effort. The primary application of this system is to support real-time analysis and operator notification of grid stresses that may lead to system instability. This is accomplished by compiling very short interval measurements made by phasor devices in widely distributed locations on the grid, analyzing those measurements in near real-time, and displaying the results of those analyses to grid operators at their control desks.

The Real Time Grid Reliability Management research area originated from a proposal submitted by the Consortium for Electric Reliability Technology Solutions (CERTS) and the Electric Power Research Institute (EPRI) to the Energy Commission in 1999. The initial funding round of $3.65 million and supplemental work orders totaling $1.05 million supported a broad range of reliability research and development. The phasor-based tasks supported by the initial contract supported the improvement of prototypes developed by CERTS for the US DOE Transmission Reliability program. The incremental improvements to the prototypes produced near-term deliverables that were of immediate use to California ISO system operators, while at the same time laying the groundwork for future enhancements.

In 2004, PIER and the California Institute for Energy and the Environment (CIEE) took over joint management of the project. Working together with a small Project Review Committee representing the principal stakeholders in the project, PIER and CIEE established and funded a research agenda designed to provide the tools needed to monitor transmission system conditions in real time and to take steps to mitigate potential instability. Achieving this operational goal required the design, development, and testing of many individual hardware and software components over a number of years, as shown in Table 12 below.

Over the period from 2000 to 2008, PIER allocated roughly $11.5 million to the Real Time Grid Reliability Management research area, of which $8 million was used for various tasks in support of the development, testing, and operation of the Real Time Display Monitoring System.

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12 The Transmission Research Program also funds two other phasor-related components: State Estimation and Wide Area Protection. The benefits of research in State Estimation appear to be minimal compared to those of RTDMS research and have not yet been demonstrated as statistically significant. In addition, research in Wide Area Protection is in the investigation phase. As such, KEMA believes it is too early to develop a defensible estimate of benefits for those efforts.

Table 12. Sequence of Awards in Support of Development of the Real Time Display Monitoring System

Award Title, Number, Date/ Objectives and Accomplishments	Primary Investigator	Amount ('000s)
Real Time System Monitoring & Control, 150-99-003, June 2000 Develop & test post-disturbance assessment and monitoring workstation Develop & test improved stability nomograms and remedial action schemes Develop improved phasor measurement system operational and support procedures Simulate, demonstrate & test advanced real-time control system. Assess feasibility of implementing Wide Area Measurement System (WAMS) and Common Information Model (CIM) Develop and test reliability adequacy tools: synchronized phasor measurement dispatcher's workstation Develop and test California ISO security coordinator wide-area real-time reliability management system Validate and improve stability nomograms and remedial action schemes using wide-area synchronized phasor measurements	CERTS, EPRI	~$1,000
Real Time Grid Reliability Management Phase 1A & 1B, 500-99-013, 2004 RTDMS Version 2 (Client/Server replay capability & configurability) Complete functional specifications for small signal stability monitoring Assess feasibility and develop functional specification and integration of California ISO phasor data concentrator (PDC) with arbiters for frequency data collection for analysis Technical feasibility assessment and simulation studies vs. heuristic measurement-based approaches for wide-area real-time control applications using phasors	CERTS	$400
Real-Time Applications of Phasors for Monitoring, Alarming and Control, 500-02-004 - MR-036, 2005 – 6 RTDMS Version 3: detection of transients, alarming, archiving, improved visuals to incorporate data from a growing number of phasor measurement units.	CERTS	$1,600
Real Time Dynamic Information Systems, 500-02-004 - MR-041, 2006 – 7	CERTS	$2,500

Award Title, Number, Date/ Objectives and Accomplishments	Primary Investigator	Amount ('000s)
RTDMS versions 4, 5, and 5.5 improve capabilities to production level Develop small signal stability prototype tool (version 1) Develop commercial-grade production frequency data collection database integrated with RTDMS to support rapid event analysis Develop RTDMS Event Analyzer application tool		
Advanced Phasor Applications for Real Time System Operations Initiative Phase 3	CERTS	$2,500

5.3. Application of RTDMS in Maintaining System Reliability

Before going into a system-level assessment of the benefits of RTDMS, it is useful to discuss an actual application of the system to detect and avert a reliability problem. Using RTDMS, the California ISO and CMRC have observed repeated occurrences of low frequency voltage and current oscillations on the WECC system. These oscillations occur roughly over a range from 0.25 to 5.0 swings per second, or in electrical terminology, 0.25–5.0 Hertz.[13] Such electrical oscillations are analogous to mechanical vibrations that can occur in a network of springs and weights. However, it is important to note that these oscillations are not the normal (synchronous) 60 Hertz waveforms that are the design and operating standard used by electric utility systems across the US. Such "sub-synchronous oscillations" are commonly referred to as "small signal stability modes," where each mode represents a different frequency of oscillation.

Such oscillation modes are undesirable and can have detrimental effects on the electric power system. They can destabilize the regional grid and lead to blackouts. They can also cause damage to power system equipment, including generators and customer-owned equipment. It is difficult to model or predict exactly what effect such oscillations will have on key equipment and the power system as a whole. However, it is clear that the risk of equipment damage, system instability, and customer blackouts increases proportionally the longer such oscillation modes exist and the greater their intensity.[14]

Small signal stability modes cannot be seen with the conventional EMS technology used throughout the electric utility industry, since EMS measurements of power system quantities only occur once each two to ten seconds. While this "sampling rate" may be adequate for monitoring routine power system conditions, it is too slow to detect abnormal small signal stability modes. A major advantage of RTDMS is that it captures phasor measurements at a sampling rate on the order of 20 times (or more) per second. This high sample rate allows RTDMS to display and diagnose small signal stability modes, and provide real-time

[13] One Hertz equals one cycle per second.

[14] Power system instability usually causes uncontrolled loss of some amount of load and generation.

information so operators can respond to such conditions and avert potential system disturbances.[15]

Most occurrences of small signal stability modes in the WECC system have been reasonably well "damped" and have not required corrective actions by operators.[16] However, a mode in the range of four to five Hertz occurred on the WECC system on January 26, 2008 that was very poorly damped. In fact, operators monitored the oscillation event for nearly one hour on RTDMS. These oscillations were most noticeable in the vicinity of the Pacific Direct Current Intertie (PDCI), a major regional power line which runs from Washington State to southern California. Less pronounced oscillations were simultaneously observed over a wide portion of the WECC system. Due to the poor damping, these oscillations might have continued indefinitely. Fortunately, grid operators at the CMRC took decisive action and issued a directive to temporarily shut down the PDCI line.[17] In taking this action the operators relied on RTDMS displays to confirm the nature and extent of the oscillation mode.

Prudent action by WECC operators relying on RTDMS displays averted potential adverse consequences to the bulk power system, including loss of generation, load interruptions, damage to high voltage equipment and detrimental effects to customer facilities. Several generating units did trip off-line during the January 2008 event, but it is unknown if these were due to the 4-5 Hertz oscillation mode. At least one other major power plant noticed unusual interaction between the generating plant and the power system during the January 2008 event, but could not identify the cause. In fact, such interactions are not uncommon during oscillation modes as discussed below, and can be damaging to generation equipment.

The longer oscillation modes persist in real-time operation, the greater the risk of outages to generation and load. In fact, turbine-generators can react to the presence of small signal stability modes in the system and experience potentially damaging torsional vibrations. Some turbine-generators are equipped with torsional vibration monitors that could result in tripping of such units to protect plant equipment from damage if torsional vibration occurs. Such generator tripping would cause a demand-supply imbalance in the system and could lead to load curtailments. Abnormal heating could also occur in power transformer banks, capacitors, and other critical high voltage equipment. Furthermore, sensitive automatic protective relaying systems that are designed to detect and clear short circuits throughout the power system might

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15 Other than phasor measurement devices, the only real-time monitoring devices capable of observing this frequency of oscillation are analog strip-chart recorders, which utilize older technology and have largely been retired from use in the US. However, analog recorders cannot capture the actual numeric data needed to perform computerized analysis of the type performed by RTDMS. They also do not provide for time-synchronized comparison between different locations, which is an important feature of PMUs.

16 "Damping" is a term used to describe the rate at which oscillations die out when they occur. Well-damped oscillations die out rapidly. Poorly damped oscillations in the WECC can continue for hours.

17 The WECC system frequently experiences oscillations at certain frequencies or "modes" in the range of 0.25 to 1.0 Hertz, but the 4 Hertz oscillation under discussion may be more related to an interaction between the WECC system and computerized controls on the PDCI.

malfunction and weaken the power system. The risk of outages to generation and load (customers) increases when (i) a small signal stability mode is poorly damped allowing it to continue for minutes or hours, (ii) the frequency swings become larger in magnitude, and/or (iii) the perturbation becomes more widespread. In addition to its value in detecting and correcting risky oscillatory modes, RTDMS-based technology can also detect other types of real-time system conditions that impact power system reliability. As discussed below, that leads to improved reliability which results in tangible benefits.

While it is impossible to know how much load and generation was at risk due to the event on January 26, 2008, or what sequence of events would have occurred if the oscillation mode had continued, it is clear that the longer any type of abnormal condition exists on the interconnected system, the greater the likelihood of some other type of equipment outage occurring on the system. Any outage of a transmission or generation facility weakens the overall WECC system, which will tend to aggravate any oscillation modes that are already present. In order to maintain the strongest interconnected system, normal utility industry practice is to keep all transmission facilities in operation, except for scheduled maintenance or construction outages. Ironically, if WECC operators had followed this industry practice during the January 2008 event and left the PDCI in-service, it could have had serious detrimental consequences for the interconnected system. Fortunately, they elected to shut down the PDCI, stopping the oscillation before any type of blackout could occur. Although there is no way to prove that the action by WECC operators averted a WECC blackout on January 26, 2008, past operating experience with the system suggests that blackouts or brownouts could have occurred as a result of the monitored instability.

The January 26 event demonstrates that WECC operators now have a sufficient level of confidence in RTDMS to rely upon it to support crucial operating decisions. Developing operator confidence in any new real-time software tool is typically a lengthy process. In fact, some tools never achieve this status. Based on the operator confidence in RTDMS demonstrated on January 26, 2008, and a face-to-face interview with senior CMRC and California ISO operating personnel on August 21, 2008, KEMA concludes that RTDMS-based technology will continue to be a valuable real-time operating asset in coming years.

5.4. Benefits Calculations and Results

For the RTDMS project, a method was required to estimate the costs associated with power outages. Research in the area of outage cost estimation has not yet established a single preferred method. As such, KEMA has developed a method grounded in current research. This approach relies on estimates of outage costs by size and on the probability of outages by size.

In particular, KEMA took the following steps: (1) Define Outage Boundaries: This determines the maximum feasible outage size possible within the designated region. Defined here in units of MWh, the outage size includes both MW capacity lost and outage duration. (2) Estimate Expected Size of Outage: Using a distribution of outage probability by size (in MWh), one can estimate the expected outage size for the region (in MWh). Specifically, expected outage size is the expected value of the distribution of outage probabilities across the outage boundaries defined above. (3) Estimate and Apply Estimated Outage Cost: To estimate the average cost of outages within a region, KEMA applied an outage cost (in dollars per MWh) to the expected outage size (in MWh). (4) Annualize Cost: To annualize the cost of outages, KEMA took into account expected outage frequency (events per year). In particular, the average regional outage cost per year is the average regional outage cost (dollars per event) multiplied by the outage frequency (events per year). (5) Attribute RTDMS Benefit: Because outages are caused by multiple factors, the use of RTDMS will not eliminate all blackouts. Rather, it is expected to reduce the frequency of blackouts. As such, KEMA applied a factor to the above estimate, to estimate RTDMS' contribution to outage reduction.

The following subsections detail the calculation using the outage cost estimation method. To assess the sensitivity of these methods to changes in inputs, KEMA conducted a sensitivity analysis. It should be noted that for the purpose of the benefits calculations in this analysis, KEMA used current customer/demand levels and did not model growth projections, which would clearly increase the level of net benefits over the calculated values.

5.4.1. Benefits Estimate

RTDMS benefit estimates were calculated as follows:

- Definition of outage boundaries. California is part of the WECC region, which covers all or part of 14 states plus two Canadian provinces and part of Baja California, Mexico. WECC has over 150,000 MW of peak load, of which California represents about 55,000 MW. It is feasible that all of the peak load in WECC could be affected by a widespread blackout. As a point of comparison, the 2003 Northeast Blackout affected over 60,000 MW of customer load in the Eastern Interconnection.
- Estimation of outage probabilities. Based on published research, KEMA developed a probabilistic estimate of the expected loss of load for disturbances in both California and the WECC region. In particular, the estimate is based on historical North American Electric Reliability Corporation (NERC) outage data and adapted to the size of the California and WECC systems.[18] It uses a probability characteristic known as a "power-law relationship" to relate outage size (in MWh) and outage probability. Figure 6 illustrates this characteristic on a logarithmic (i.e., non-linear) scale.

18 In 2000, Carreras et al. fit historical NERC outage data to derive a relationship between outage size and outage probability of $P = 0.0045 \times MWh^{-0.98}$. B.A. Carreras, D.E. Newman, I. Dobson, A.B. Poole, "Initial Evidence for Self-Organized Criticality in Electric Power System Blackouts," Proc. Hawaii International Conf. System Sciences. IEEE, 2000.

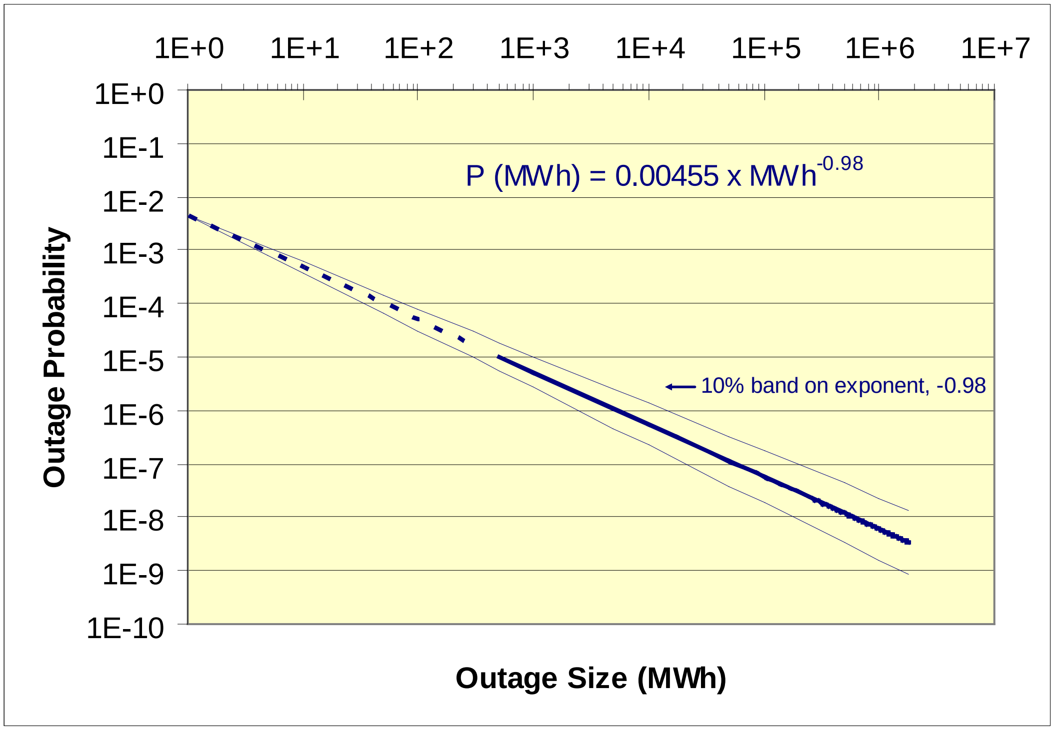

Figure 6. Outage Probability by Size in MWh

The expected outage size, EV (MWh), is calculated as:

EV (MWh) = $\int_{\min MWh}^{\max MWh} x \times \left(0.0045 \times x^{-0.98}\right)$, where the expected value is calculated over the range of feasible outage sizes for California and WECC. KEMA estimated the maximum feasible outage as a 12-hour outage over the regional maximum capacity of 54,889 MW in California and 149,147 MW in WECC.[19] KEMA set the minimum bulk power system outage size to an hour-long outage of 500 MW in both cases. Though the expected outage size is not very sensitive to the lower outage size boundary, KEMA limited it to 500 MW (represented by the cross-over to a dashed line on the left side of Figure 17), because according to Talukdar et al. the probability of smaller power losses of up to 500 MW generally follows an exponential form rather than a power law.[20] The expected outage estimate is quite sensitive to the exponent of the probability distribution. This sensitivity is discussed at greater length below. Using the probability distribution derived by Carreras et al. the expected outage size for California is 3,839 MWh and 10,645 MWh for WECC.

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19 According to a 2006 WECC information summary, WECC's summer peak demand in 2005 was 149,147 MW and the California-Mexico (Baja) summer peak demand in 2005 was 57,389 MW. KEMA adjusted 57,389 MW downward by 2,500 MW to estimate California-only peak demand. Western Electricity Coordinating Council. Information Summary, 2006. http://www.wecc.biz/documents/library/publications/infosum/2006_infosum.pdf

20 S. N. Talukdar, J. Apt, M. Ilic, L. B. Lave, and M. G. Morgan, "Cascading Failures: Survival versus Prevention," *The Electricity Journal*, Vol. 16, No. 9, November 2003, pp. 25-31.

- **Estimated value of avoided loss of load.** Estimates of the value of avoided loss of load are quite varied, but fall in the range of $2,000-$40,000 per MWh. The large range of estimates stems from the variety of methods used to compute them (such as willingness-to-pay surveys versus calculations based on gross domestic product and lost energy consumption) and the individual circumstances of the actual outages studied (such as the types of customers affected, outage duration, and time of day). For example, Energy & Environmental Economics and HMG estimate that on average, a summer afternoon outage costs $42.02 per kWh in California.[21] In addition, a 2004 publication by Sandia National Laboratories cites an estimated average cost of $20 per kWh while a 2000 survey of outage costs cites estimates of $2 to $12.87 per kWh.[22,23]

KEMA selected an average outage cost of $13,338 per MWh[24], based on the estimated costs of the 2003 outage in the northeast, which fits well within the range of values cited in outage studies. Using this estimate, the economic impact values of the average expected California and WECC blackout event can be calculated as follows:

Economic Value (EV) = Expected Outage Size (MWh) x Outage Cost ($/MWh).

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21 Energy & Environmental Economics and the Heschong Mahone Group, "Time Dependent Valuation of Energy for Developing Building Efficiency Standards 2008 Time Dependent Valuation (TDV): Data Sources and Inputs." 2008. http://www.energy.ca.gov/title24/2008standards/prerulemaking/documents/E3/draft-reports/TDVinputdata2008.doc

22 J.M. Eyer, J.J. Iannucci and G.P Corey, "Energy Storage Benefits and Market Analysis Handbook: A Study for the DOE Energy Storage Systems Program," 2004. Sandia National Laboratories. Paper SAND2004-6177.

23 P. Cramton and J. Lien, "Value of Lost Load." 2000. University of Maryland. http://www.iso-ne.com/committees/comm_wkgrps/inactive/rsvsrmoc_wkgrp/Literature_Survey_Value_of_Lost_Load.rtf

24 The estimated blackout cost of $13,338 per MWh was derived from three sources including: 1) a 2003 ICF paper for estimated blackout size in MWh; 2) a 2006 DOE-NRCan report for estimated cost in $million; and 3) data from the IESO Canada for the estimated portion of the blackout size in Canada. In particular, the DOE-NRC report estimated US outage costs of $4-10. The 2003 ICF paper estimated a total cumulative outage of 918,800 MWh (including parts of Canada) and IESO Canada noted an outage size of 394,000 MWh in Canada. KEMA derived the $13,338 per MWh estimate by subtracting the Canadian outage size from the US outage size, and dividing by the mid-point of the DOE estimate for US impact. See ICF Consulting, "The Economic Cost of the Blackout: An Issue Paper on the Northeastern Blackout, August 14, 2003," http://www.icfi.com/Markets/Energy/doc_files/blackout-economic-costs.pdf; Natural Resources Canada and US Department of Energy, "U.S.-Canada Power Systems Outage Task Force: Final Report on the Implementation of the Task Force Recommendations." 2006, http://www.ferc.gov/industries/electric/indus-act/blackout/09-06-final-report.pdf; and Independent Electricity System Operator, "Blackout 2003." 2008. Viewed 9/25/2008, http://www.ieso.ca/imoweb/EmergencyPrep/blackout2003/default.asp.

For California, the estimated economic impact value for the typical bulk power system outage is $51 million (= 3,839 MWh x $13,338/MWh), and the typical value for the entire WECC is $142 million (= 10,645 MWh x $13,338/MWh).

Although RTDMS is an effective deterrent, it will not eliminate all blackouts. However, it will reduce the number and severity of blackouts. Previous work authored by KEMA has concluded that with full deployment of PMU technology it can be expected that roughly 50 percent of power system load outages can be avoided.[25] In the present analysis, KEMA looks at the range of sensitivities from a 10 to 50 percent reduction in the number of major WECC outage events that could be eliminated by the utilization of RTDMS alone, ignoring the other applications of phasor technology.

5.4.2. Sensitivity Analysis on Avoided Outage Costs

Though the above calculation relies on best available information and expert judgment, there are many sources of uncertainty in the calculation inputs. In particular, the ability to predict outage rates and attribute the reduction in outage frequency due to RTDMS is limited. As such, KEMA explored the sensitivity of the RTDMS benefit estimates by inputting a range of feasible values for pre-RTDMS outage rates and percentage reductions due to RTDMS. Figures 7 and 8 illustrate the sensitivity of both the California and WECC economic impact estimates to the frequency of such outages and the projected economic benefits of RTDMS. As shown in the figures below, assuming a 30 percent improvement in outage rates will accrue due to RTDMS, the estimated RTDMS benefits fall in the range of $40 to $254 million per decade for California and $106 to $682 million per decade for the entire WECC region (including California).

[25] Novosel, Damir; Cole, Jim; Snyder, Bill; and Vu, Khoi. 2006. A Business Case Study on Applying Phasor Measurement Technology and Applications in the WECC/California Grid. California Energy Commission, PIER Renewable Energy Technologies Program Area, CEC-06-04

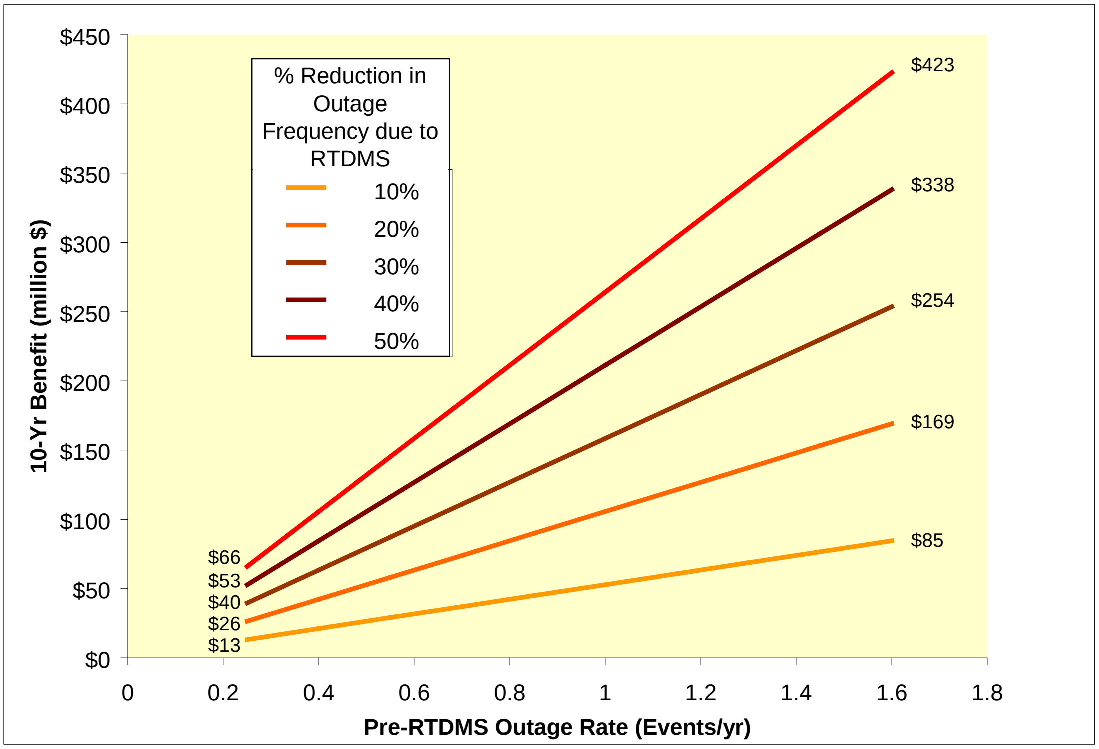

Figure 7. Estimate Sensitivity for California

Note: KEMA selected a maximum outage rate of 1.6 based on J. Chen et al., 2001. According to J. Chen et al., historical WECC data indicate outage rates of 1.56 events per year for outages over 900 MW. J. Chen, J. S. Thorp, M. Parashar, "Analysis of Electric Power System Disturbance Data," *Proc. Hawaii International Conf. System Sciences*. IEEE, 2001.

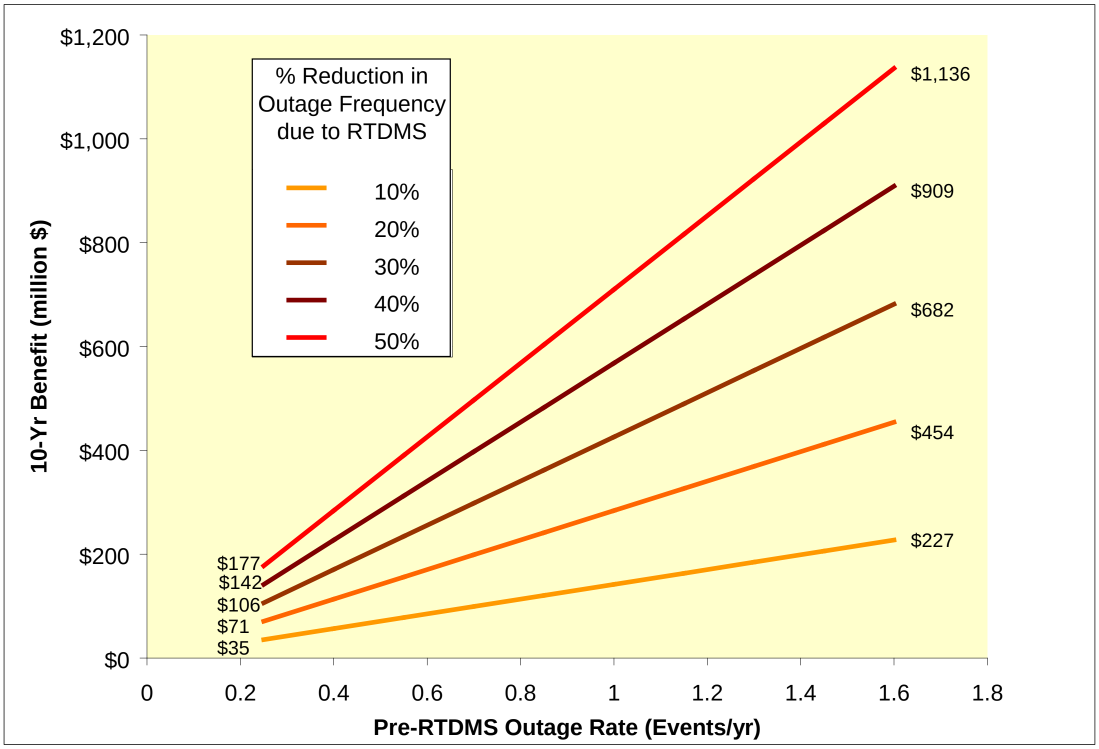

Figure 8. Estimate Sensitivity for WECC

As is apparent from Figures 7 and 8, RTDMS benefit estimates vary linearly with both pre-RTDMS outage rates and percentage reduction due to RTDMS. Additional sensitivity checks on assumptions regarding the maximum outage duration reveal that the estimates vary approximately linearly with this input. For the purpose of this analysis, it was assumed that the worst case outage duration during a widespread blackout in the WECC region would be 12 hours. In fact, following most major blackouts service to customers is typically restored in a random manner with some customers restored within hours and other customers not restored for a day or more. If the average duration is slightly shorter or longer than the 12 hours assumed in this analysis, the impact on the outage cost estimates would be roughly proportional. For example, if the calculation were to use 6 instead of 12 hours in the largest estimate of Figure 7, $423 million per decade (50 percent RTDMS benefit and a pre-RTDMS outage rate of 1.6 events per year), it would lower the estimated benefit to $208 million per decade. If the outage duration were 18 hours, it would increase the estimated benefit by a similar amount.

As noted above, the expected outage size is quite sensitive to the exponent of the outage probability distribution shown in Figure 17. KEMA was unable to determine the confidence interval of the distribution derived by Carreras et al. However, to examine sensitivities, KEMA calculated the sensitivity of the RTDMS benefit to this exponent using a plus and minus 10-percent bound on the value of the exponent. Assuming a 30 percent reduction in blackouts due to RTDMS and a pre-RTDMS outage frequency of 0.85 events per year, changing the exponent by plus and minus 10 percent produces a sensitivity distribution for the 10-year economic benefits to California ranging from $39 to $443 million (with a midpoint of $131 million). For WECC, the 10-year economic benefit sensitivity ranges from $98 million to $1.36 billion (with a midpoint of $362 million).

Research in the area of outage cost estimation has not yet established a single preferred method. As such, KEMA has developed a method grounded in current research. In addition, though the estimate is based on the best available information and expert judgment, some inputs to the calculations vary a great deal from one source to another (e.g., outage cost estimates) or are difficult to predict (e.g., reduction in outage rates or expected outage size due to RTDMS). However, KEMA concludes that the estimate and sensitivity analyses in this report bracket the plausible range of benefits. Assuming a 30 percent reduction in outages as a result of RTDMS, KEMA concludes that the likely range of benefits from RTDMS is between $40 and $254 million per decade for California and between $106 and $682 million per decade for WECC.

It is useful to compare these estimates to national estimates of outage costs. In particular, the variation in national outage cost estimates is a notable comparison. LaCommare et al. estimated that the national cost of sustained and momentary outages is $79 billion per year, with a range of $22 billion to $135 billion. Their estimated cost from sustained outages, with which this study is concerned, is $26 billion with an apparent range of just over $10 billion to just under $40 billion.[26] Their cost estimate for sustained and momentary outages in California is $8.1 billion per year and in the California, Pacific and Mountain regions combined is $17.6 billion per year. Although significant, the estimated RTDMS benefit is still just a small fraction of this regional outage cost.

5.5. Summary of Gross Impact Analysis

The current assessment has concluded that the greatest economic benefit attributable to RTDMS deployment is the value of avoided blackouts. Assuming that RTDMS will result in a roughly 30 percent reduction in blackout events, the expected societal cost benefit is in the range of $40 to $254 million per decade for California and $106 to $682 million per decade for WECC. As more operator tools and applications based on RTDMS mature and are deployed more extensively in California and WECC, more blackouts will be averted and the economic benefits to society will increase. Some of the future benefits will only be achievable through the development of automated small signal stability damping control methodologies using PMU measurements, which are still under development at this time.[27] The additional value of this capability is not captured in the estimate of economic benefits developed in the current study.

Reducing the number and size of blackouts represents a significant direct societal benefit, but ignores other potential consequential damages, such as the impact on stock prices that major outages can have on affected utilities[28] and unknown political ramifications of frequent or

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26 The range for the sustained outage estimate was obtained graphically as specific numbers were not provided in the text of the paper.

27 Ibid., pp 99-101.

28 CIEE "Phasor Measurement Application Study, 17 May 2007, p 14.

widespread blackouts. Such consequential damages are beyond the scope of this study. Many other categories of prospective economic benefits discussed in previous work (e.g., congestion mitigation)[29], have been excluded in the current report because actual real-life examples remain to be demonstrated in California or WECC. Even so, the future prospects for such benefits remain promising.

5.6. Attribution of Benefits to PIER Activities

5.6.1. Approach

To assess the role that PIER support for the development of the RTDMS played in the realization of the benefits estimated above, KEMA conducted structured in-depth interviews with three individuals who were closely associated with the project and who brought differing perspectives to this study. These individuals were:

- CERTS Program Manager and Staff Scientist at Lawrence Berkeley National Laboratory (LBNL). This individual was chosen as a survey respondent to share his perspective as a major advocate of RTGRM-related research. This individual has also tracked research on PMU applications for grid stability in regions outside of California.
- Director of Electric Transmission Research, and Senior Advisor on Transmission Research, both at CIEE. These individuals were chosen as survey respondents for their program management insights, stakeholder roles, and as shapers of RTGRM research. They were also aware of work on PMU applications outside of California.
- Lead Industry Relations Representative, Stakeholder & Industry Affairs at California ISO, was selected as a survey respondent for his unique perspective as representative of the user organization of RTGRM research products.

It is true that these individuals benefited professionally from association with the RTGRM projects and that their organizations also benefited from the projects in a number of ways. CERTS received funding directly from PIER for its oversight functions, and California ISO received direct assistance in-kind for setting up the RTDMS and other applications. This situation creates potential conflicts of interest for the respondents. However, this kind of intimate involvement with the project is required as the basis for defensible judgments concerning the effects of PIER support on the timing and success of the RTDMS-related initiatives. It is likely that any respondent drawn from the small pool of fully informed observers would have had an interest in the outcome of the RTDMS benefit-cost study. Yet it was essential to consult experts with extensive knowledge and experience concerning RTDMS and related issues.

In order to minimize the potential for bias, KEMA designed the survey to be as neutral and objective as possible. KEMA presented a set of counterfactual scenarios to the survey respondents in order to draw conclusions about the likely state of progress of an RTDMS-type

29 Ibid.

data interpretation system in the absence of PIER funding. Respondents were asked what they thought would have happened in the field of PMU research without PIER support. To the extent they believed that relevant PMU research and development would not have occurred, respondents signaled their belief that PIER was essential to developing a system resembling RTDMS.

The first three survey questions each framed a particular counterfactual scenario focused on different types of project support provided by PIER. The respondents were faced with one of two sets of follow-on questions depending on whether the respondent answered "Yes" or "No" to the above questions. The follow-on questions were designed to elicit the reasons behind these answers.

The last two questions of the survey required that the respondent synthesize previous answers into an opinion on the likely state of RTDMS in the absence of PIER's involvement. The answers provided to these questions were useful in that they offered a glimpse into the rationales behind the previous answers, and facilitated comparison across respondents.

Results of the Attribution Interviews

Question 1: If PIER had not funded the development and deployment of the Real Time Dynamics Monitoring System to the extent it actually did, do you think that other organizations would have supplied some or all of the required resources to the California ISO?

The survey respondents agreed that if PIER had not funded the development and deployment of RTDMS to the extent it actually did, other organizations would have supplied some resources to the California ISO, but not nearly to the same extent as PIER. The United States Department of Energy's Office of Electricity (OE) has a public policy interest in preventing major blackouts such as the 2006 Western Interconnection and 2003 Eastern Interconnection blackouts; reducing congestion costs ($500M to $1B/yr for California alone); integrating renewables; and moving the industry to a smart dynamic grid. As such, California ISO and CERTS would have received some funding from DOE OE for RTGRM research, but in smaller amounts and over a more protracted period. Furthermore, while DOE would have funded research in the West on phasor data visualization, this would have been subordinate to phasor data research in the East. According to the CIEE representatives:

> Following the Northeast Blackout, NERC stressed that a functioning synchrophasor measurement network would have reduced the extent of the blackout. Hence DOE OE did and probably still would have focused first on the Eastern Interconnection. Efforts in the West, inspired largely by BPA, likely would have created a national interest stakeholder perspective and constituency, but that would have again delayed the advent of the RTDMS for California ISO by many years.

Respondents highlighted two impacts of a counterfactual scenario in which PIER did not provide funding:

- Given the lack of funding sources specific to California apart from PIER, it is possible that California ISO might not have been a designated development partner. Assuming that DOE OE would have provided some funding in the absence of PIER, the agency likely would have partnered with an organization with a greater capacity for R&D than the ISO, such as BPA or TVA.

- Given CERTS involvement in both the Eastern Interconnection and PIER-funded research, many aspects of RTDMS would have been developed even in the absence of PIER funding. However, given DOE OE's focus on the Eastern Interconnection following the Northeast Blackout, it is possible that the oscillation damping application would not have been a priority, unless BPA or SCE stepped forward as development partners in the West. Even so, not much of the funding or resulting technology would have necessarily flowed to California ISO.

Question 2: If PIER had not funded the development of the RTDMS to the extent it did, do you think the California ISO would have funded the research on its own through levies on market participants?

The survey respondents agreed that if PIER had not funded the development of RTDMS to the extent it did, California ISO would not have funded the research on its own through levies on market participants. Respondents cited several reasons to explain why California ISO would not have funded the research on its own:

- California ISO has no mandate or budget to conduct intensive R&D activities. California ISO has used its limited R&D budget primarily for membership in EPRI and other organizations to gain access to research and expertise not supported by California ISO. The California ISO respondent also stressed that the ISO, when it has engaged in R&D-type activities, typically tests, but does not develop, technology.
- California ISO has been subject to strict budgetary constraints. All respondents observed that California ISO has been under pressure to reduce operating costs and "tighten their belts" in response to funding pressures like the Market Redesign and Technology Update (MRTU) and renewables integration, as well as the rising cost of electricity following restructuring.
- As part of the same restructuring that led to the creation of the ISO, a small charge was added to Investor-Owned Utility ratepayer bills to fund a public interest research organization: PIER. The representative of California ISO stated that, rather than "double-dip" and seek separate funds which would have imposed an additional cost burden on California consumers, the ISO depended on PIER to fulfill its designated mission of funding exactly the type of publicly beneficial research that led to RTDMS.

Question 3*: Did PIER provide technical assistance necessary to the success of the RTDMS research?*

Survey respondents agreed that while PIER did not provide much technical assistance necessary to the success of the RTDMS research, it did act in other important capacities beyond financial support:

- PIER's involvement supported customization, demonstration, and training tailored to California ISO, which advanced RTDMS.
- PIER funding leveraged DOE funding for RTDMS. The LBNL representative identified this role.
- According to the California ISO representative, PIER acted as a "facilitator" or "catalyzing agent." In this capacity, PIER organized the TRP Real-Time System Operations Technical Advisory Committee (TAC). This committee served several purposes:
    - To ensure that the research plan for each phase of funding provided to CERTS was a cooperative effort with California ISO and other interested parties.
    - To bring in technical experts from universities, Electric Power Group (EPG), BPA, and SCE to hold all-day annual research steering sessions.
    - To define the technical research questions and project approaches, and identify potential researchers.
- PIER funded other supporting research to advance the state of knowledge about phasor technology and promote its adoption. This included funding for the SDG&E state estimator project, the phasor business case study performed by KEMA, and facilitating industry knowledge exchange and transfer.

Question 4*: Considering the items we have discussed so far, what stage do you believe the development of the RTDMS would have attained as of January 2008 in the absence of PIER's involvement?*

and

Question 5*: What are the main reasons for your opinion?*

Based on their detailed answers to the prior questions, the survey respondents felt that, in the absence of PIER's involvement, the state of California ISO phasor visualization and analysis in January 2008 likely would have resembled the original BPA tool, "Streamreader," or some tool derived from the Eastern Interconnection Phasor Project (EIPP) research. They also believed that California ISO might not have been able to continue phasor-related initiatives due to more pressing day-to-day operational priorities such as managing generator interconnection queues, MRTU, renewables integration, and market power monitoring. One respondent questioned whether California ISO would have supported the real-time phasor data network in California that is the basis for RTDMS in the absence of PIER involvement. Without this network, any RTDMS-type platform as developed for the EIPP would have been useless for California.

The survey respondents made several other important points:

- The system, as an adaptation of EIPP research, would have been experimental and restricted to a backroom at California ISO.
- California ISO would have used the tool for post-event analysis but not for real-time diagnostic and event alert purposes, which has been the principal source of benefits.

- The California ISO IT department would not have managed the tool. This department played a significant role in controlling the flow of data into RTDMS and integrating the tool with the California ISO control center.
- California ISO and California in general would not have been recognized as the national leaders in phasor data visualization tool development. The industry is pleased and anxious for California ISO to continue playing a role in phasor data visualization and phasor network development.
- Because of its proven usefulness and rapid development, RTDMS will be promoted to other operators in the western interconnection. According to the California ISO representative, his organization expects to end the year with a data sharing agreement with SCE. SCE and the other IOUs, BPA, and WAPA will all eventually have their own displays. There is also interest from Arizona and British Columbia in sharing data and obtaining displays. By March of 2009, California ISO will be installing data controllers and an RTDMS display in the new reliability center in WECC.

Analysis of Attribution Interview Results

The key finding of the survey was that all respondents believed PIER support was essential to the development of RTDMS. Main points cited by survey respondents to support crediting PIER with the benefits derived from RTDMS include:

- Legislation directs PIER, and no other agency or private company, to invest public funds in research, development, and demonstration intended to serve public energy interests in California. Specifically, Senate Bill 1250 directs PIER to perform research not supported by competitive markets. While DOE and BPA did provide early stage funding for a nascent RTDMS, and would have continued to provide funding in the absence of PIER, it would have been at lower levels, less urgently disbursed, and subordinate to broader funding priorities. In other words, precisely because of the very region-specific benefits that would have accrued, funding would not have been allocated directly to California ISO with the intensity it was. The result of funding from non-PIER sources therefore would have been a much-delayed application of RTDMS.
- While California ISO receives research funds from DOE in addition to PIER, the ISO could not have provided the project management supplied by PIER's research team. Politically, California ISO could not have spent significant budget or human resources on a research project given that they are not a research organization. During the development of RTDMS, California ISO was able to supply budget and human resources as a "beta tester" complementary to PIER's project management and the research of several organizations. This was an appropriate role for the ISO, which, as the ultimate user of RTDMS, would be able to provide the most valuable feedback.
- The ISO could not have used the RTDMS predecessor, BPA's "Streamreader," in its operations room. While Streamreader used the same basic input as RTDMS – the western phasor network – it lacked sufficient intelligence. Therefore, given that there would not have been ample funding or management resources to develop an RTDMS-

like tool in the absence of PIER, grid reliability benefits would not have accrued. Streamreader would not have been allowed "on the floor" nor would it have been of much use to grid operators during a reliability event even if it had been available.

The results of the in-depth attribution interviews suggest that the development of the RTDMS or a similar system operating in California ISO would have been delayed by at least seven years in the absence of PIER support. Recall that we calculated gross benefit estimates on the basis of a 10-year analysis period. Given the "probabilistic" approach to estimation of gross benefits, we believe it is reasonable to factor the result by 70 percent (seven year delay/10 year analysis period) to represent net benefits.

Integrated Estimate of Net Benefits

As discussed in the "Benefits Calculations and Results" section above, two of the major uncertainties in estimating the gross value of outage reductions associated with the implementation of the RTDMS system concerned the percent reduction in outage probability and the average number of major outages experienced prior to implementation of the RTDMS. Both of those quantities are probabilistic in nature and cannot be estimated with known levels of precision from historical data. Thus, we must use sensitivity analysis to identify the upper and lower bounds of the likely range of benefits, both gross and net.

Table 13 shows the results of sensitivity analysis of the effects of using different assumptions concerning the effect of RTDMS on outage probability and the pre-implementation rate of major outages. We have used a conservative approach in setting the range of input variables. Specifically, the one available empirical study of the number of outages on the WECC system estimated their frequency at 1.56 per year on the basis of 10 years of operating data. We have used that average value as the maximum in the sensitivity analysis.

Table 13. Results of Sensitivity Analysis – Gross and Net Benefits of PIER Support for RTDMS

	California			WECC		
	Pre-Project Outages/Year			Pre-Project Outages/Year		
Assumed reduction in outage probability	**0.2**	**0.9**	**1.6**	**0.2**	**0.9**	**1.6**
Total Value of Outage Reduction (Gross Benefits)						
10%	$ 13.0	$ 49.0	$ 85.0	$ 35.0	$ 131.0	$ 227.0
20%	$ 26.0	$ 97.5	$ 169.0	$ 71.0	$ 262.5	$ 454.0
30%	$ 40.0	$ 147.0	$ 254.0	$ 106.0	$ 394.0	$ 682.0
40%	$ 53.0	$ 195.5	$ 338.0	$ 142.0	$ 525.5	$ 909.0
Value of Outage Reduction Attributable to PIER Support, Net of PIER Investments						
10%	$ 2.1	$ 28.3	$ 52.5	$ 17.5	$ 84.7	$ 151.9
20%	$ 11.2	$ 61.3	$ 111.3	$ 42.7	$ 176.8	$ 310.8
30%	$ 21.0	$ 105.9	$ 170.8	$ 67.2	$ 269.8	$ 470.4
40%	$ 30.1	$ 129.9	$ 229.6	$ 92.4	$ 360.9	$ 629.3

The sensitivity analysis results summarized in Table 13 suggest that PIER's investment in RTDMS yielded positive results through the plausible range of input values for the major variables in the benefit calculations. Even applying very conservative assumptions, for example, that the RDTMS reduces outage probabilities by only 10 percent and that pre-implementation outages occurred at the rate of 0.9 per year (one half the empirically estimated rate for WECC), the benefits of reduced outages net of PIER's investment total $28.3 million for the California ISO and $84.7 million for WECC as a whole.

5.6.2. Discussion

The analysis above illustrates how investments in major resource systems can produce significant benefits, even when highly conservative assumptions are applied in estimating those benefits. Our analysis is doubly conservative in that it does not take into account other, more prospective, benefits which the RTDMS will be used to achieve. Specifically, the grid management capabilities enabled by PMUs and the RTDMS system will play a key role in enabling WECC grid operators to integrate growing intermittent infusions of power from wind and other renewable sources as California moves forward in implementing Renewable Portfolio Standards.

This case study also highlights the value of maintaining a long term commitment to the development of resource systems-related technologies. PIER's ongoing support enabled California ISO not only to develop the necessary technical applications but to gain experience in integrating those applications into everyday operations. It was that experience that enabled grid operators to identify threats to grid stability and to take steps to mitigate those threats in real time.

6.0 Case Study: INFORM

6.1. Project Description

INFORM is an integrated set of weather forecasting, hydrological modeling, and decision support tools designed to help reservoir operators identify water release schedules that strike the optimal balance among competing objectives under uncertain conditions. The objectives include:

- Fulfillment of contracted water deliveries to local municipal and agricultural water systems.
- Flood control.
- Maintenance of carry-forward reserves to assure water supply during unusually dry periods.
- Power generation by dams in the reservoir system.
- Maintenance of healthy ecological conditions for plants and wildlife in the associated river and delta systems.

Currently, reservoir operators schedule releases for flood control based on analysis of records of conditions such as snow pack, precipitation, and weather forecasts from historical periods in which potential flood conditions arose. This practice has led to a number of spills that have proven to be unnecessary. Such spills decrease hydroelectric production, reduce carry-over reserves, and increase the total cost of water supply. More generally, the decision rules that support reservoir management reflect to only a limited extent the complexity of the interactions between long-term climate conditions, short-term local weather conditions, and regional hydrological systems that determine hourly reservoir levels now and in the future. From a decision support standpoint, these conditions are best understood and expressed as a set of probabilities that quantify the likelihood of attaining desired outcomes through alternative release schedules given current conditions and forecasts. INFORM will provide this kind of analysis in a sufficiently timely manner for reservoir operators to use in day-to-day management of a river system.

INFORM is being developed specifically to support the management of the five major reservoirs in the Sacramento River system.[30] This system provides two-thirds of the drinking water used in the California Bay-Delta region and irrigates 7 million acres of cropland. Dams on the system generate 15 percent of the State's electricity and regulate the flow, temperature and salinity of aquatic environments to safeguard the habitats of "130 species of fish, 225 species

30 The system consists of the five major Northern California reservoirs: Folsom, Trinity, New Bullards Bar, Shasta (controlled by the U.S. Bureau of Land Reclamation) and Oroville (controlled by the CA Department of Water Resources). Reservoirs managed by BLR account for roughly twice the storage capacity of the reservoirs managed by the DWR.

of birds, 52 types of mammals, and 400 plant species."[31] The system also plays a key role in supplying water to Southern California via the California Aqueduct.[32] Figure 9 displays a schematic version of the system and its principal facilities.

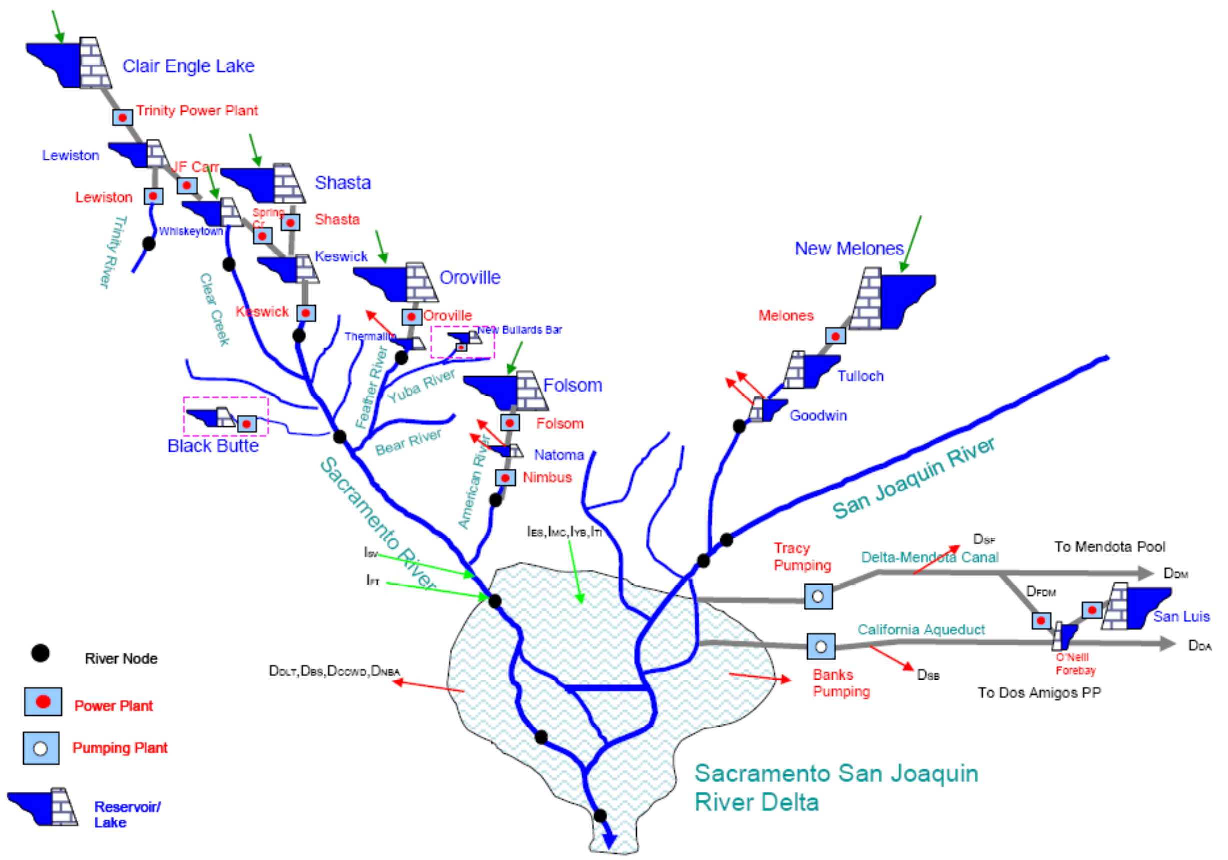

Figure 9. INFORM River and Reservoir System[33]

The system is administratively as well as ecologically complex. The U.S. Bureau of Reclamation's (BLR) Central Valley Project (CVP) and the California Department of Water Resource's (DWR) State Water Project (SWP) supply the Central Valley using reservoirs in the Sacramento Valley, pumping stations in the Sacramento-San Joaquin Estuary (the Delta), and

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31 Georgakakos, K., et al., "Integrated Forecast and Reservoir Management INFORM – A Demonstration for Northern California Phase I Progress Report," HRC Limited Distribution Report No. 17, 21 May 2004, page 1-5.

32 Peterson, Lloyd, and Paul Fujitani, "The Central Valley Operations Office Monthly Spreadsheet Model," Operating Reservoirs in Changing Conditions: Proceedings of the Operations Management 2006 Conference, 14-16 August 2006, Sacramento, CA. Page 2.

33 *HRC-GWRI. 2007. Integrated Forecast and Reservoir Management (INFORM) for Northern California: System Development and Initial Demonstration. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2006-109.* Page 24

shared facilities in the San Joaquin Valley that serve the Contra Costa Canal and the California Aqueduct. A number of other state and federal agencies are involved in management of the system. The Army Corps of Engineers establishes maximum reservoir storage levels designed to avoid flooding. The National Oceanographic and Atmospheric Administration contributes weather data and forecasts for use in developing release schedules. Similarly, the California-Nevada River Forecast Center (CNRFC) provides hydrological data and modeling to forecast flows into the reservoirs. Representatives of all of these agencies have participated in the development of INFORM. Their continued participation and cooperation will be required to implement the system once its development is complete.

The remaining sections of the INFORM benefits assessment address the following topics:

- Development of the system, PIER's role in its development, and current status of the project.
- Characterization of the potential benefits of implementing INFORM and the mechanisms by which those benefits will be achieved.
- Preliminary quantification of the benefits of implementing the INFORM system.

INFORM is similar to the PMU transmission system project in that its goal is to improve the management of a large, complex, and highly distributed resource system. Unlike the PMU project, however, the operators of the reservoir system have not yet integrated INFORM or any of its components into day-to-day operations. Indeed, most of INFORM's components require some additional technical work before they can be used effectively in ongoing operations. PIER and other stakeholders in the reservoir system are currently considering a proposal from INFORM's principal researchers to complete the remaining technical work, test the system in reservoir management on a pilot basis, and assess its results. To develop our preliminary estimate of benefits associated with implementation of INFORM, we have worked with its developers to model water release schedules that the system would have suggested over the past three years and compared the outcomes of those hypothetical release schedules to those achieved by operators using methods currently in place. These modeling methods and their results are detailed in the sections below.

6.2. Features and Development of the INFORM System

6.2.1. Key Features of the INFORM System

A team of scientists and water management experts associated with two academic research groups -- The Hydrologic Research Institute (HRC) and Georgia Water Resources Institute (GWRI) –developed the basic concepts and detailed analytic methods embodied in INFORM over the past decade.[34] These modeling concepts and capabilities – and the advances that they represent over typical reservoir management practices – are as follows.

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34 HRC is a publicly-funded non-profit based in San Diego, California. GWRI is based at Georgia Tech, and was authorized by the U.S. Congress through the Water Resources Act of 1964. The INFORM

- Integration of long-term climate forecasts into models of reservoir water levels. Long-term changes in climate introduce large and potentially disruptive uncertainties into reservoir management. Average levels of precipitation and temperature are subject to long-term variation, and recent evidence suggests that those swings are becoming more volatile and extreme. For example, California's reservoir operators are now trying to cope with the consequences of a prolonged dry period. Because the historical records used to develop reservoir management decision rules were developed during one of the wettest and most stable periods in California, the impacts of climate change – especially more concentrated periods of rainfall and reduced snow pack – are already beginning to compromise the effectiveness of water management systems.

  INFORM addresses this challenge by explicitly integrating long-term climatological forecasts based on global general circulation models into more local weather forecasts that in turn feed the hydrological models of reservoir inflow. INFORM receives data periodically from the general circulation model maintained by the National Centers for Environmental Prediction (NCEP) known as the Climate Forecast System (CFS). These data provide forecasts of temperature and precipitation on a monthly timescale out to nine months from the present for surface areas that are roughly 200 miles square. To be integrated into hydrological models, these forecasts must be allocated to significantly smaller areas and time resolutions as short as six hours. INFORM accomplishes this downscaling through a variety of statistical methods to produce 'climate model conditioned' inputs to the hydrologic models.

- Improved short-term weather forecasting. Over the past two decades, meteorologists have developed a technique known as ensemble forecasting to mitigate the effects of two common sources of uncertainty in weather forecasts. The first is error or incompleteness in observations of initial conditions, which become magnified in successive iterations of the model. The second is error or incompleteness in the ways in which the model represents physical processes. Ensemble forecasts are developed by conducting multiple runs of the same model, altering settings for initial conditions within plausible ranges based on historical observations. In some cases, parameters of the model itself may also be altered. This process yields a range of possible outcomes. These results can be expressed in probabilistic terms. For example if 30 out of 50 model runs result in precipitation greater than 1 cm in the forecast period, then that event can be assigned a probability of 60 percent.

  INFORM automatically downloads and downscales ensemble forecasts from NCEP's Global Forecast System (GFS) to model real-time, short-term weather forecasts. The

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researchers are, in alphabetical order: Theresa M. Carpenter (HRC, hydrologic modeling), Aris P. Georgakakos (GWRI, decision modeling and project Co-PI), K. P. Georgakakos (HRC, hydrometeorological modeling and project PI), Nicholas E. Graham (HRC, climate modeling and project Co-PI), Martin Kistenmacher (GWRI, river and reservoir modeling), Eylon Shamir (HRC, hydrologic modeling), Jason Sperfslage (HRC, systems programming), Stephen R. Taylor (HRC, hydrometeorological modeling), Jianzhong Wang (HRC, mesoscale atmospheric modeling), and Huaming Yao (GWRI, decision support and software development).

resultant downscaled GFS ensemble surface precipitation and air temperature fields produce the inputs for the hydrologic catchments in the region, at which point various hydrologic models (snow-soil-channel routing) are activated to create ensemble forecasts of hydrologic model outputs - such as reservoir inflow.

- Integration of hydrological models. The INFORM researchers adapted three existing operational forecast models used at the CNFRC to create an integrated stand-alone hydrologic model. The model supports prediction and validation of relationship between observed snow cover, snow depth, and snow melt on the one hand, to stream flows and reservoir inflows on the other. It also expands the geographic coverage of the hydrologic models to capture interactions between events and decisions at the five reservoirs. This capability supports potential increased coordination among operators of the five reservoirs to achieve improved outcomes.
- Integration of decision timescales. In setting schedules for water releases, reservoir managers need to balance trade-offs that unfold in the following three distinct timescales:
  - Turbine load control (hourly resolution over one day).
  - Short-/mid-range reservoir control (hourly resolution over one month).
  - Long-range reservoir control (monthly resolution over one year).

INFORM is designed to operate sequentially, so that long-range planning determines the boundaries within which decisions over shorter time periods are made. Moreover, the model is dynamic, so decisions are revised as new information comes in from the forecast component. Thus, INFORM provides the modeling capabilities, for example, to weigh the immediate benefits of releasing water in the current hour or day for electricity generation and delivery to local water systems versus the potential increased probability of having insufficient carry-over storage due to the short-term releases. See Figure 10 for a graphic depiction of the relationship between the model's time layers.

Generally speaking, INFORM feeds the probabilities of weather and hydrologic events into a risk-based operational framework and generates forecasted outcomes for the objectives which reservoir operators must take into consideration: flood control, hydropower production, recreation and navigation, river temperature requirements, Delta water quality and outflow, water deliveries, and carry-over storage requirements. The tolerances of violating each constraint are weighted (for example, it is more important to avoid a catastrophic flood than it is to increase carry-over storage a small amount), and because of this, the tool is able to offer optimized trade-offs based on the likelihood of future weather events. No model captures all of the day-to-day contingencies and constantly changing constraints of water management, but INFORM allows reservoir operators more accurate forecasts and transparent trade-off decisions.

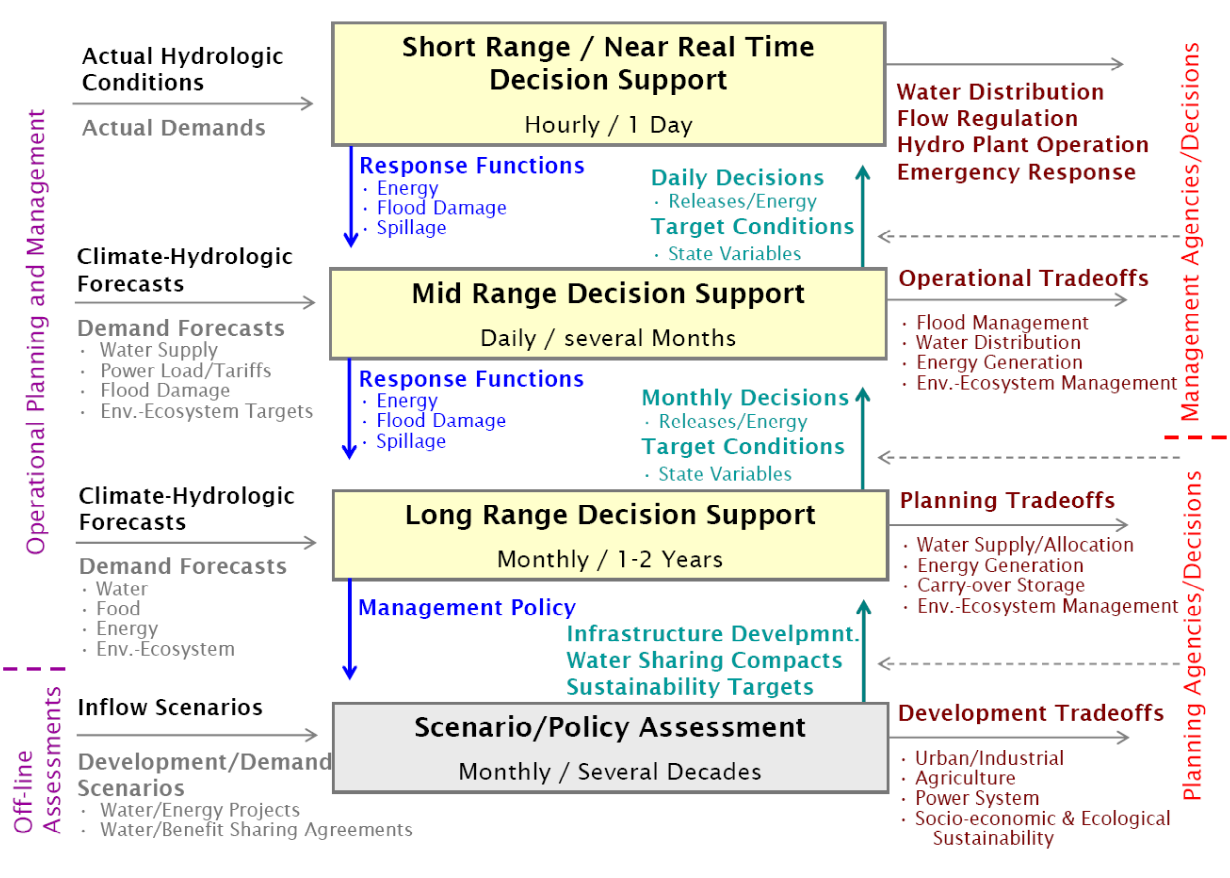

Figure 10. INFORM Decision Support System Time Layers & Components

6.2.2. Initial Development Prior to PIER Involvement

HRC and GWRI developed the underlying methodology of the integrated forecast and management of water resources through a number of paper studies.[35] The feasibility of the INFORM project was established via a retrospective study which applied a limited version of the model to the Folsom Reservoir.[36] The study, sponsored by NOAA's Office of Global Programs (OGP) in the late 1990s,[37] showed potential increases in hydroelectric production of up to 18%, and water supplies of up to 50%.[38]

35 See Georgakakos et al., 1998; Georgakakos, A., et al. 1998; Georgakakos, et al. 1995.

36 See Carpenter and Georgakakos, 2001; Yao and Georgakakos, 2001.

37 UCSD/ Scripps Institution of Oceanography NOAA Office of Global Programs (OGP) Grant: the California Applications Project (CAP)

38 "Improving Water Forecasting for Better Hydropower Production," PIER-EA, December 2007, page 2. Accessed on 18 September 2008. Available: [http://www.energy.ca.gov/research/environmental/project_fact_sheets/500-02-008.html]

NOAA convened a series of meetings in the second half of 2000 with the U.S. Bureau of Reclamation, the CA Department of Water Resources and other agencies active in the management of the Sacramento River system to assess their interest in hosting a project to further develop and implement the INFORM system. These meetings resulted in the formation of a committee that went on to draft the scope and guidelines of the present INFORM project in preparation for approaching potential funding agencies.

The proposal provided for five years of project activity guided by an Oversight and Implementation Committee (OIC) composed of representatives from funding agencies, operations managers, forecasters, and HRC and GWRI modelers.[39] The project's principal goals were to:

- Develop and implement an INFORM prototype for the primary Northern California reservoirs.
- Conduct a near-real-time test of the prototype against current management practices to demonstrate its effectiveness, using actual operating data.

Funding was awarded by NOAA OGP in September of 2002, the Energy Commission PIER in November of 2002, and CALFED in June of 2003, for a total of approximately $1.7 million. The INFORM project was managed by Konstantine Georgakakos at HRC, with Nick Graham (HRC) and Aris Georgakakos (GWRI) as co-PI's, and Joe O'Hagan as the Contract Manager at PIER. The Decision Support Structure (DSS) was developed primarily by GWRI and the climate and hydrological forecasting components were developed by HRC.

6.2.3. System Development and Testing: 2003 – 2006

During the period 2003 – 2006, the INFORM modelers, working closely with the OIC, developed the INFORM forecasting and decision models using the appropriate national, regional, and local data resources. The integrated model and its components were tested extensively and upgraded using input from all operational agencies. Testing consisted primarily of running the forecast models with historical data to assess how well they predicted more recent conditions, and making changes to the forecasting methods as needed to address observed biases in results. The utility of the integrated INFORM forecast-decision model was demonstrated for the mid-range management of the large reservoirs in Northern California (Folsom, Oroville, Shasta, and Trinity) using real-time data from the 2005–2006 wet season.

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39 The OIC consists of: Fris, Rebecca – California Bay Delta Authority Ecosystem Restoration Program; Fujitani, Paul – US Bureau of Reclamation Central Valley Operations; Hartman, Robert – NOAA NWS-California Nevada River Forecast Center; Bardini, Gary – California Department of Water Resources; Johnson, Borden – USACOE Sacramento District; Neill, Juniper – NOAA Office of Global Programs; Nierenberg, Claudia – NOAA Office of Global Programs; O'Hagen, Joe – California Energy Commission PIER; Georgakakos, Konstantine – HRC INFORM PI; Georgakakos, Aris – Georgia Tech INFORM Co-PI; Graham, Nick – HRC INFORM Co-PI.

At the end of the first contract period in June 2006, the OIC met to assess progress and to identify improvements in the model that would be required for use of the model in ongoing operations. These included the following:

- Continue compilation of forecasts versus actual climate and hydrological conditions to correct potential biases identified in the initial testing. The OIC believed that observations from two to three more wet seasons were needed to measure system performance and perform simple adjustments.
- Increase the computing infrastructure available to the system to take full advantage of all available ensemble forecasts.
- Harmonize the format of data imported from different sources in order to increase the range of data used in long-term forecasts and hence their accuracy.
- Revise the decision modeling component to account for effects of release schedules on temperature, fish release requirements, and exports to Southern California.
- Expand the capabilities of the decision modeling component to handle trade-offs during flood periods.

6.2.4. Current Status

Following the conclusion of the first contract period, the INFORM project team prepared a proposal to PIER, NOAA, and the reservoir management agencies to support a second phase of the project. The objectives of this phase are to complete the technical development of the various components of the system, implement the model in reservoir management on a pilot basis, and monitor and assess the results of the pilot. Decisions by reservoir managers in regard to this proposal have been delayed pending resolution of larger policy issues in regard to water supply and reservoir construction.

NOAA provided funding to maintain the operation of the INFORM system and to assess its performance during the 2007 to 2008 winter period. The OIC continues to meet at irregular intervals to review the results of the model. However, substantive work on the further development of the model and its implementation in the reservoir management agencies has been suspended pending the outcomes of further funding decisions.

6.3. Key Constraints and Trade-Offs

In this section we characterize the potential benefits of implementing INFORM by describing how the system can be used to improve trade-off decisions in regard to specific reservoir management objectives, compared to current reservoir management practices. These differences in management approach provide the basis for the modeling of comparative outcomes presented in Section 6.4.

6.3.1. Flood Control

Because floods can lead to loss of life as well as extensive property and economic damage, flood control takes priority over other reservoir management objectives during the flood season, which runs from November through the beginning of April, with peak conditions in January. During this period, the objective for the release schedule is to maintain sufficient capacity in the reservoirs to absorb potential surges in runoff from heavy rains while retaining as much water as possible in the reservoirs for use during the dry months.

Seasonal operations. Flood control diagrams developed by the Army Corps of Engineers using historical data determine the maximum reservoir level during the flood season. Generally, the curves require drawing reservoirs down starting in mid-September and maintaining low water levels through early April. The snowmelt season runs through May. In April and May, it is relatively easy to estimate the reservoir capacity needed to accommodate snow melt. However, precipitation patterns are extremely variable during this period. Therefore, reservoir operators have tended to pursue conservative practices, making releases that exceeded volumes usable to fulfill water delivery contracts or to generate electricity.

If INFORM's weather and hydrologic models prove to be sufficiently accurate, flood control diagrams could be revised to take into account weather forecasting. This means that operators could increase the volume of water retained to meet contracted deliveries and create carry-over storage during April and May (the end of the flood season and beginning of the snowmelt season), as reservoirs would only release enough water to handle the storms that were predicted going into the dry season. This capability may become more important if warmer average temperatures lead to reduced storage in snow cover during the spring.

Emergency Operations. Currently reservoir operators obtain 6-hour forecasts during a flood event, and monitor conditions to see if they are above or below that forecast until it is updated. INFORM provides the most likely flood scenarios along with probabilities so that operators can assess the risk of more severe levels of flooding, issue flood warnings, and take preventative measures earlier than the current approach allows. The value of this would increase with the severity of the flood event.

6.3.2. Fulfillment of Water Supply Contract Allocations

Annual water allocations to municipal and agricultural customers are issued on February 1st. However, these allocations contain error margins that reflect the uncertainty surrounding climate and hydrological conditions through the spring. The allocations are revised based on actual conditions, with a general goal of bringing the target to within + 10 percent of actual deliveries by May 1st. With more accurate long-term forecasts, reservoir managers will be able to more accurately assign water contracts at the start of the year, so that later revisions will be less dramatic. This will enable local water managers to plan more effectively to meet their obligations through pumping ground water and conservation. For example, farmers can shift crops ahead of time, or plant differently depending on the economics of pumping ground water to compensate for decreased State Water Project deliveries. The advantage of increased forecast accuracy is heightened in extreme wet or dry years, the frequency of which will increase as climate change continues to influence weather patterns.

6.3.3. Carry-Over Storage

Rule curves promulgated by the Corps of Engineers determine the minimum water level required to meet all the needs for which a reservoir is designed, including future water security in drought years. These levels vary based on the time of year. For example, the portion of water reserved for growing crops varies based on the crop and the growing season, and therefore influences the shape of the rule curve for the reservoir that supplies the water. To hedge against the risk of multi-year droughts, operators do not draw water levels down to minimum permitted levels every season. If dry conditions persist longer than usual, as they have in the past two years, the percentage of outflow allowed by the reservoir decreases in order to assure adequate carry-over storage for the next year. The outflows at the end of a drought phase could be increased if INFORM increases the accuracy of seasonal precipitation predictions. If reservoir operators feel comfortable with those forecasts, they may be willing to release more water for deliveries and energy generation.

6.4. Preliminary Estimate of INFORM Benefits for Selected Outcomes

6.4.1. Approach

As part of this study, KEMA asked the INFORM principal investigators to carry out an analytic exercise to quantify selected benefits of implementing the INFORM system. The analysis proceeded in the following steps.

- Document key reservoir management outcomes – water deliveries, carry-over storage levels, and electric generation -- for the years 2006 – 2008. The INFORM investigators collected information from the Bureau of Reclamation and the Department of Water Resources on total monthly water deliveries from the full system (in acre/feet or AF), AF of carry-over water stored at the end of the dry season (November) in the five main reservoirs, and annual energy generated by four of the five main dams in GWH. Figure 11 shows the decline in water deliveries from 2006 through 2008 due to prevailing dry conditions. The trends for storage capacity and energy generation are similar.
- Use the INFORM forecast and decision support tools in conjunction with actual weather and hydrological data to generate trade-off curves between water deliveries, system carry-over storage, and electric generation for the beginning of each year in the analysis. These curves represent the range of potential trade-offs among the three selected system objectives given actual conditions in each of the years and applicable operating constraints, such as flood control requirements. See Figure 12 for the trade-off curve between deliveries and storage for 2007, a relatively dry year.

  Prior to carrying out this analysis, the INFORM team used the climate and hydrology model components to generate estimates of inflows into the main reservoirs for months for which data were available: March – November of each of the three years. They then compared the average, maximum, and mean monthly forecasts to actual values to verify that the model yielded results that were sufficiently reliable to encourage operators to use the system. The results of this exercise showed that the model was sufficiently accurate for these purposes, with significant room for improvement in years such as

2007 that experience unusual weather patterns. It is expected that improvements to be made in the second phase of the project will address some of these issues.

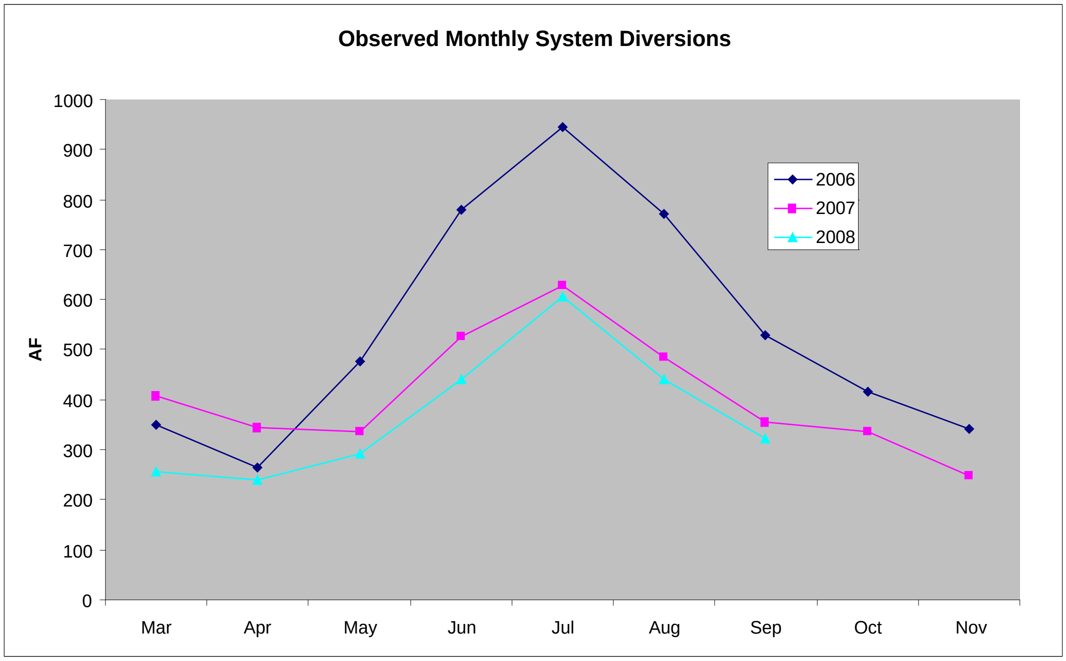

Figure 11. Total Water Monthly Diversions (Deliveries), 2006 – 2008

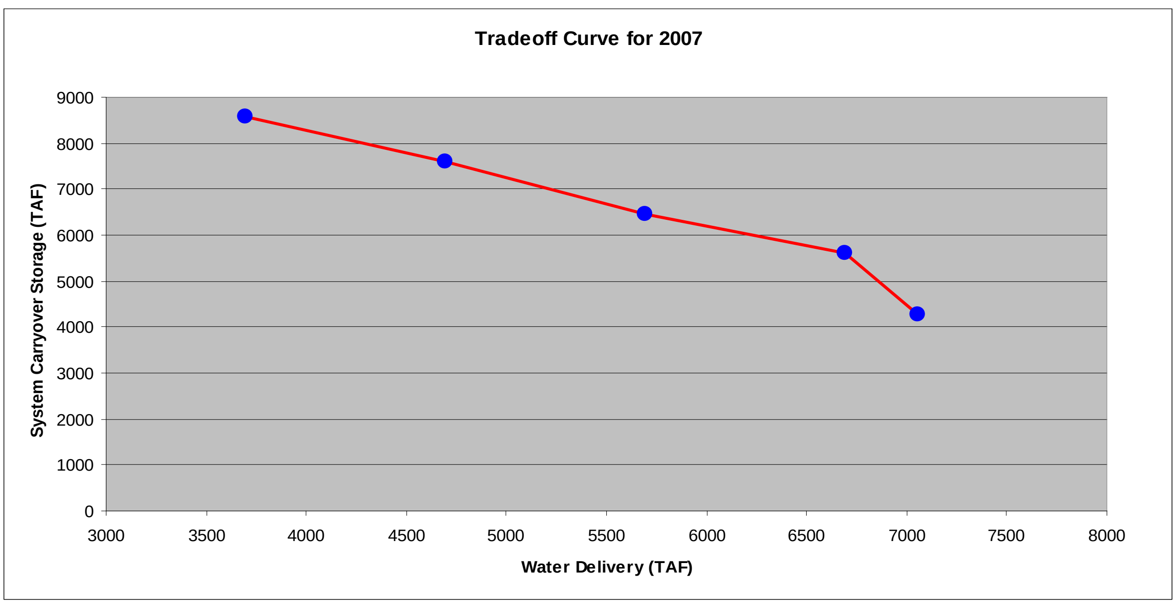

Figure 12. INFORM Trade-Off - Total Water Delivery vs. System Carry-Over Storage, 2007

- Estimate the range of achievable levels of carry-forward storage and energy generation taking water delivery as given. The probabilistic structure of INFORM yields a range of potential release schedules at each node of the trade-off curve. The INFORM team selected the node that corresponded most closely to the actual volume of water delivered to customers during the year in question. Essentially, this approach takes water demand as constant. The INFORM team then used the ensemble forecasts and decision support tool to estimate the average, minimum, and maximum carry-forward storage and energy generation levels that operators could have achieved using the INFORM forecasts, while meeting the actual historical pattern of water deliveries. Figure 13 shows the results of these calculations versus actual carry-forward storage for the three years in question. Figure 14 shows the same comparison for electric generation.

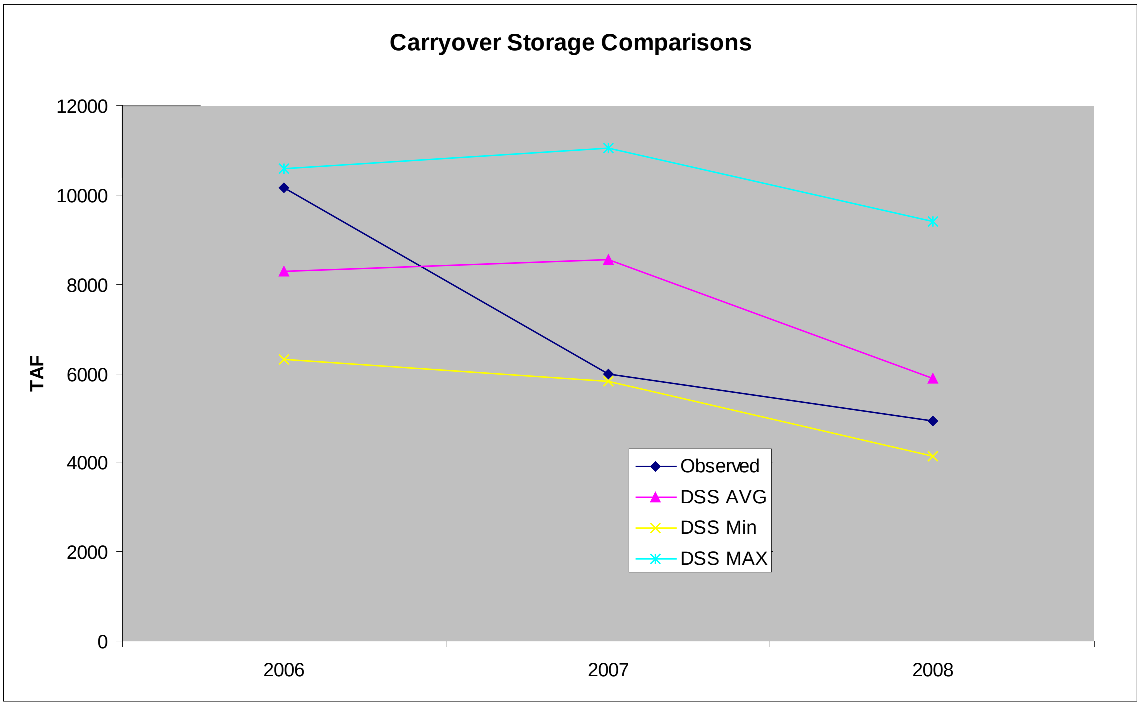

Figure 13. Modeled Carry-Over Storage versus Actual, 2006 - 2008

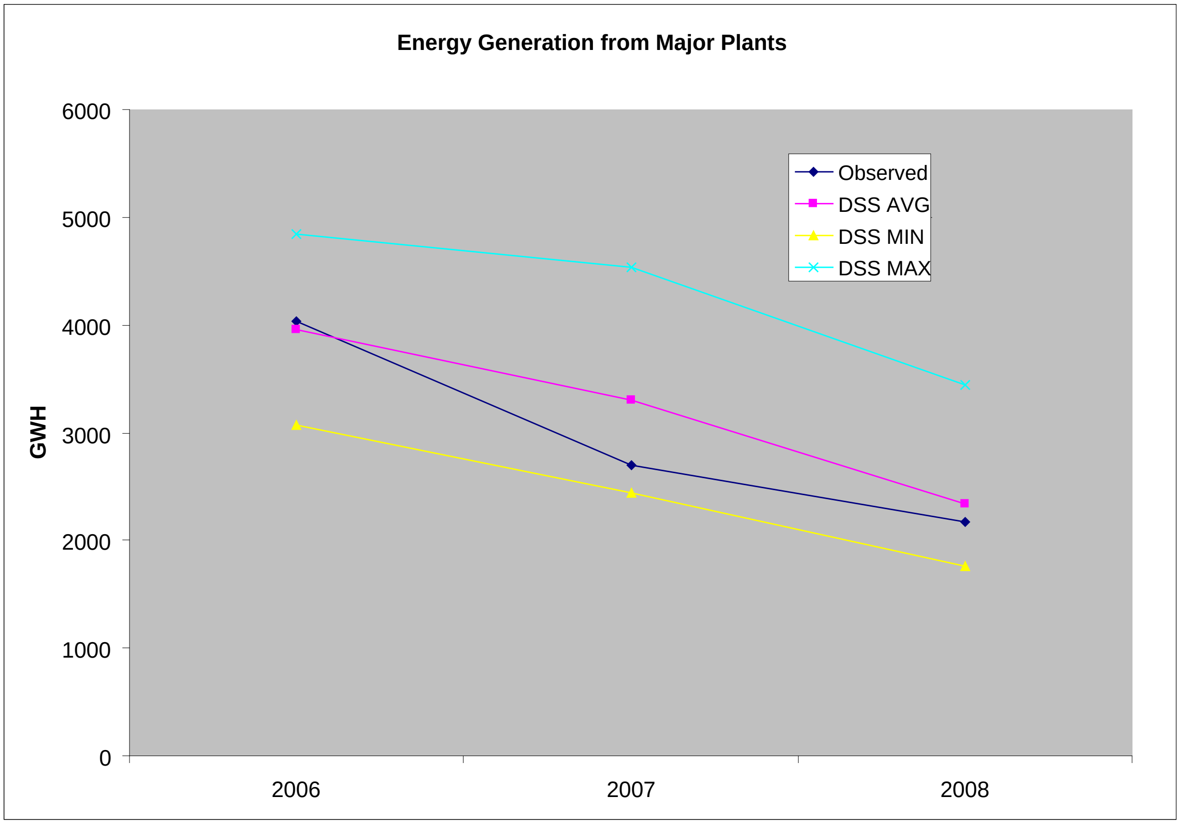

Figure 14. Modeled Energy Generation versus Actual, 2006 – 2008

- Obtain expert review of methods and results. KEMA sent the INFORM team's write-up of the analysis described above to Paul Fujitani, Chief of Water, Water Operations Division, Bureau of Land Reclamation, and to Art Hinojosa, Chief of the Hydrology Branch, Division of Flood Management, California Department of Water Resources, for review. Both reviewers have represented their agencies on the OIC, and both are very familiar with the operations and issues that INFORM is designed to address. Both men believe that INFORM shows a great deal of promise for improving reservoir operations and flood control. Mr. Hinojosa felt that the approach to estimating benefits was reasonable, given the project's early stage of development and the need for testing in real-time conditions. He also believed the results of the hydrologic "backcasts" used in developing the estimates of benefits were reasonable. His comments concerning the limits on interpretation of the results are shown below. Mr. Fujitani was less confident that the influence of INFORM on reservoir operator decisions could be predicted given its current state of development and the increasing importance of objectives that were not included in the analysis, such as support of fish populations.

Summary of Results

Tables 14 and 15 summarize the results of the analysis of potential outcomes of INFORM deployment and assign monetary value to the system performance improvements. The following paragraphs present these results and the assumptions used to estimate their monetary value.

Gains in electricity production. As shown in Table 14, the average level of electricity production that could be generated using release schedules indicated by INFORM exceeded actual production by 700 GWh over the three years in the analysis period. The maximum annual production values that can be achieved using release schedules indicated by INFORM exceed actual production by 3,800 GWh over the three-year period. It is unlikely that reservoir operators would be able to manage resources with the level of precision needed to reach the maximum, but including this value gives a sense of the range of outcomes encompassed by the probabilistic forecasts.

Table 14. Summary of Model Outcomes for Electricity Production, 2006 – 2008

	Year			
	2006	**2007**	**2008**	**Total**
Observed Production: GWh/Year	4,000	2,700	2,200	8,900
Average INFORM Production: GWh/Year	4,000	3,200	2,400	9,600
Maximum INFORM Production: GWh/Year	4,800	4,500	3,400	12,700
Average: GWh/Year	-	500	200	700
Maximum: GWh/Year	800	1,800	1,200	3,800
Value of Difference: $ million				
Average INFORM	$ -	$ 30	$ 12	$ 42
Maximum INFORM	$ 48	$ 108	$ 72	$ 228

We used the 2007 average wholesale electricity price of $60 per MWh to value the incremental electricity that could be generated by applying the INFORM approach to reservoir management.[40] Incremental production using the average production levels made possible by INFORM is valued at $42 million over the three-year period using this approach. The value of energy produced using the maximum values produced by the analysis is $228 million over 3 years. Again, it is highly unlikely that this level of production could be reached.

Carry-Forward Storage. Table 15 shows the results of the modeling of INFORM release scenarios for year-end carry-forward storage for the three years. The results vary substantially by year. If reservoir operators had used INFORM forecasts as a guide instead of standard operating procedures in 2006, they would have ended up with 1,900 thousand acre feet (taf) less storage on hand at the end of the wet season. In 2007 and 2008, they would have ended up with 2,400 and 1,000 taf more, respectively, to carry operations through the dry season.

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40 Department of Market Monitoring, California Independent System Operator. *2007 Annual Report: Market Issues and Performance.* Folsom, CA: April, 2008.

Carry-over storage is a form of insurance against water shortages in unusually dry periods. To place a value on that insurance we estimated the cost of alternative means of ensuring adequate water supply in future periods, namely, the cost of building and maintaining new reservoir capacity elsewhere in the river system. Specifically, we estimated the levelized cost of building and maintaining reservoir capacity per taf based on information about recent reservoir construction projects underway or in the planning stage in California and the Pacific Northwest.[41] The sources consulted presented average construction costs for eight projects, including pumping and other equipment, at $3,600 per taf and operating and maintenance costs of roughly $15 per taf.

Table 15. Summary of Model Outcomes for Carry-Over Storage, 2006 – 2008

	Year		
	2006	**2007**	**2008**
Observed End of Year: taf*	10,100	6,000	5,000
Average INFORM: taf	8,200	8,400	6,000
Maximum INFORM: taf	10,500	11,000	9,500
Average: taf	(1,900)	2,400	1,000
Maximum: taf	400	5,000	4,500
Value of Difference: $ million			
Average INFORM	$ (7)	$ 9	$ 4
Maximum INFORM	$ 1	$ 18	$ 16

* taf = thousand acre feet, a standard measure of storage volume

We used these figures to estimate levelized costs of providing one taf of reservoir capacity, applying the following assumptions:

- Asset Life: 30 years.
- Bond term: 29 years.
- Bond interest rate: 6 percent.
- Discount rate: 8.15 percent.

The levelized cost of reservoir storage computed using these methods was $3,065 per taf. The value of potential incremental carry-over storage created through the application of the INFORM forecasts and decision rules ranged from -$7 million to $9 million for the average values; $1 million to $18 million for the maximum values.

41 California Department of Water Resources, "Los Vaqueros Reservoir – Frequently Asked Questions", http://www.water.ca.gov/storage/docs/LV%20Project%20Docs/LV_FAQs.pdf. Accessed January 9, 2009. U.S. Bureau of Reclamation. *Boise-Payette Water Storage Assessment Report.* 2006. http://www.usbr.gov/pn/programs/srao_misc/bp_storagestudy/report/AppH.pdf, Accessed January 9 2009.

Limits on Interpretation of Results

Given that the INFORM system must undergo significant further development before it can be used by reservoir operators to support day-to-day resource management, and that, even in its current form, it has never been so deployed, the analysis of potential benefits presented above must be treated with a great deal of caution.

The major caveats to be taken into account are as follows.

- The effect of the availability of INFORM resources on reservoir management decisions is difficult to predict. The potential benefits of INFORM will be realized only if reservoir managers become sufficiently confident in its forecasting capabilities and convinced of the usefulness of the decision support programs to use INFORM in day-to-day operations. There is no historic record upon which to judge the likelihood that the Bureau of Reclamation and the DWR will adopt INFORM in that manner. Moreover, reviewers of the benefit analysis from both agencies remarked that short-term release decisions are often driven by factors that are not included in this version of the model. As the reviewer from DWR remarked:

  > Adaptive management of water resources in the Delta and the rivers are difficult to predict or simulate. Actions to address water temperature or other habitat needs in the river coupled with restrictions to exports in the Delta confound the logic employed by the models because their timing is often in response to observed fish behavior which has not been predictable and can be subjective (heightened levels of concern by regulatory biologists may be based in scientific observation but still dependent on considerable interpretation).[42]

  On the other hand, the Department of Water Resources draft 2009 update of the California Water Plan identifies improvements in reservoir management as a key component in addressing the state's water supply challenges.[43] Thus, reservoir operators may be highly motivated to take advantage of the capabilities that INFORM offers.

- Implementation of many types of changes to reservoir management practices requires approval and cooperation from other agencies. Under current operating protocols, reservoir operators must seek waivers from the Army Corps of Engineers to deviate significantly from guidelines provided by the flood control diagrams and rule curves. Thus, organizations other than the operating divisions of the USBR and DWR will need to be convinced of the efficacy and benefits of INFORM in order for the full range of its benefits to be realized.

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42 Personal correspondence with Art Hinojosa, December 5, 2008.

43 California Department of Water Resources. *Public Review Draft of the California Water Plan 2009 Update.* Section 4: California Water Today. http://www.waterplan.water.ca.gov/. Accessed January 10, 2009.

- The analysis quantifies only a small range of INFORM's potential benefits. Perhaps the largest potential benefit of INFORM, in terms of social value, is its promise to significantly improve flood control through incorporation of climate data into hydrologic forecasts. California's current drought conditions notwithstanding, the risk of flooding has increased dramatically in recent years due to changes in long-term weather patterns, erosion, and overbuilding in the system's watersheds. Even small incremental periods of advanced warning of flood conditions can provide time to make needed adjustments to release schedules. In an early study that applied INFORM forecasting and decision support concepts to historical climate and hydrological data from the Folsom reservoir, the authors estimated that flood damage avoided by using information from enhanced forecasts ranged from $219 million to $4.275 billion over the 25-year "backcast" period.
- **Data and other limitations of the model used for the analysis.** The analysts had data available for only the first nine months of each of the years modeled in the analysis. Under more realistic circumstances, operators would make adjustments in each of the 12 months based on analysis of current conditions. This would have had the effect of improving the performance of the model versus actual experience. Also, as discussed in Section 6.2, significant elements of the model need to be updated and revised.

6.5. Attribution Analysis and Net Benefits

In order to determine the extent to which benefits deriving from INFORM are attributable to the PIER program, KEMA conducted nine in-depth interviews with individuals drawn from within and outside the INFORM project. These nine respondents are listed by title and affiliation in Table 16. Each interview subject was asked a series of structured questions aimed at eliciting their views on the particular role played by PIER in developing INFORM, and on the overall importance of PIER to the INFORM project. The basic purpose of the survey was to quantify as precisely as possible the proportion of benefits generated by INFORM that can be credited solely to PIER.

Table 16. INFORM Attribution Survey Respondents

Title	Affiliation	Project Involvement
State Climatologist	**DWR**	**Reviewed INFORM project documentation and sat in on discussions of proposed activities at DWR Division of Flood Management and with NWS.**
Chief	**BLR, Central Valley Operations Office**	**OIC member, Phase I and II. Provided input on how BLR could potentially use INFORM, also coordinated and reviewed work.**
Director	**GWRI**	**INFORM co-PI**

Title	Affiliation	Project Involvement
Director	**HRC**	**INFORM PI**
Principal Supervisor	**NOAA CNRFC**	**Participated in inter-agency committee which formed INFORM's scope in 2000, also OIC Phase I & II member. Collaborator during development and testing of forecast component. Assisted PIs with gathering stakeholders and making connections. Provided input on how INFORM fit into CNRFC operations.**
Chief	**DWR, Hydrology Branch, Hydrology and Flood Operations Office, Division of Flood Management**	**OIC Phase I & II member. Provided operational information, reviewed tools, recommended changes, provided input on integrating INFORM with operations.**
Director (retired October 2007)	**USBR, Reservoir System Analysis Branch, Division of Planning, Mid-Pacific Regional Office**	**Folsom reservoir operator during Folsom Reservoir study. Participated in inter-agency committee which formed INFORM's scope in 2000, also OIC Phase I member.**
Chief Hydrologist (part-time; retired in 2000)	**DWR**	**Participated in inter-agency committee which formed INFORM's scope in 2000, also OIC Phase I member.**
Chief	**NOAA, NWS, Office of Hydrologic Development, Hydrology Laboratory**	**Interacted with HRC, provided early work on weather forecasting, and informally reviewed INFORM status updates.**

6.5.1. Results of the In-Depth Attribution Interviews

The attribution survey consisted of three open-ended questions about the PIER program's role in the development of INFORM. The first question asked respondents to characterize PIER's role in developing INFORM methods and software. Respondents credited PIER with making a significant contribution to advancing technical aspects of the project. Aris Georgakakos, co-Principal Investigator, described PIER funding as "very critical" to technical development. In particular, Georgakakos stated that PIER support was essential to inclusion of the Bay Delta in the model, without which the model would have been fundamentally incomplete. Art Hinojosa of DWR considered PIER "invaluable" to refining the INFORM model. According to Hinojosa, PIER funding accelerated the technical development of INFORM by at least 4-5 years.

A second survey question focused on the extent to which PIER promoted cooperation among the many agencies involved with INFORM. The main thrust of the responses was that, although PIER staff provided limited direct support to enhance interagency collaboration, cooperation ultimately hinged on the third-party funding provided by PIER and its partners. Principal Investigator Konstantine Georgakakos asserted that PIER support was "instrumental" in promoting cooperation among the disparate agencies collaborating on INFORM. Maury Roos of DWR also stressed the importance of PIER funding.

The final question asked respondents to consider what the status of INFORM would be today if PIER had not supported the project. Respondents from DWR stated that INFORM's present level of development is directly tied to PIER efforts. Roos argued that in the absence of PIER support, the INFORM project "definitely would be going at a slower pace." Hinojosa emphasized that system operators are conservative in their decision-making, and would not have committed to INFORM without PIER backing. From a project perspective, Aris Georgakakos stated flatly that, "If the CEC hadn't been there, the project would not have gone forward." Konstantine Georgakakos echoed the views of others associated with the project that outside funding was integral to the development of INFORM, and that all three funding agencies (CALFED, NOAA, and Energy Commission-PIER) contributed in roughly equal measure.

6.5.2. Attribution Analysis

Taken together, results from the attribution survey support the conclusion that PIER support has been essential to the INFORM project. Respondents considered PIER a key driver of the technical development of the INFORM model. Respondents also cited PIER funding as a precondition of interagency cooperation in building and implementing INFORM. Lastly, interviewees shared the view that INFORM would not exist in its present state without the financial support given to the project, including funds provided by PIER.

Based on this evidence, KEMA concludes that a significant portion of the benefits produced by INFORM is attributable to the PIER program. Given the respondents' consensus that all three project funding partners are jointly responsible for the success of INFORM, PIER's share of the benefits deriving from INFORM can be calculated by applying the percentage of total project funding contributed by PIER to the gross benefits estimated above. This percentage is 31 percent ($400,000/$1,300,000). Therefore, average net benefits attributable to PIER over the period 2006-2008 were $14.9 million, while maximum net benefits were $81.5 million. See Table 17 for a summary of these calculations.

Table 17. Benefit Calculations for PIER INFORM Project

	2008 $ million			
	2006	**2007**	**2008**	**Total**
Benefits from Increased Generation				
Average INFORM	$0.0	$30.0	$12.0	$42.0
Maximum INFORM	$48.0	$108.0	$72.0	$228.0
Benefits from Increased Carry-over				
Average INFORM	($7.0)	$9.0	$4.0	$6.0

	2008 $ million			
	2006	2007	2008	Total
Maximum INFORM	1	$18.0	$16.0	$35.0
Total Benefits				
Average INFORM	($7.0)	$39.0	$16.0	$48.0
Maximum INFORM	$49.0	$126.0	$88.0	$263.0
Net Benefits				
Average INFORM	($2.2)	$12.1	$5.0	$14.9
Maximum INFORM	$15.2	$39.1	$27.3	$81.5

It is important to note the limitations of these estimates. Because the INFORM system has not yet been implemented, benefit estimates at this stage must be treated as provisional. In order to realize the benefits of INFORM and confirm their scale, at least one more round of comparable project funding will be required. At this point in time it is not clear whether development of the INFORM system will progress at all. Therefore, we use cost of the project to PIER - $400,000 – as the lower bound of the project's net present value.

7.0 Case Study – Advanced Thermostats

This chapter presents the benefit-cost analysis of the PIER program's Advanced Thermostats project. The objectives of the project were to develop a reference design for advanced thermostats. These devices control residential and small commercial HVAC equipment use in response to signals issued by electric companies or system operators to mitigate demand conditions that could lead to high market prices or network emergencies. The reference design was intended to be used by manufacturers to adopt a feature set specified to promote flexible use of PCTs and to reduce their unit prices through standardization. Both these outcomes would then facilitate the broader use of PCTs in demand response and energy efficiency applications. This chapter begins with a brief description of PCT technology and PIER project activities. This is followed by detailed benefit-cost calculations and results for California.

7.1. Product Description

Advanced thermostats have the ability to receive demand response signals and, in response, reduce space conditioning use by adjusting temperature set-points. Several types of PCTs are on the market today, with a variety of capabilities and communication methods available. At its most basic, an advanced thermostat consists of a customer interface, a HVAC interface, and demand response communications capability. The customer interface allows users to define temperature set-points throughout the day and, in some versions, define temperature offsets for when space conditioning is reduced. The HVAC system interface is the equipment controller which interacts with the HVAC unit based on unit settings and responds to demand response signals. Finally, the demand response communications component provides the means for receiving price or curtailment signals from utilities, aggregators or grid operators, indicating when to reduce space conditioning.

The ability to ***receive*** communications is core to the functionality of an advanced thermostat. The means for two-way communications, to transmit HVAC usage data to utilities for example, is an optional feature. Many utilities in the U.S. are expecting advanced thermostats to be used in conjunction with their Advanced Metering Infrastructure (AMI).[44] Under this scheme, advanced thermostats interact with smart metering devices. The metering devices, in turn, act as gateway devices, handling multiple communications protocols to coordinate the home area network (HAN) with the utility communications system, delivering price and emergency signals to the appliances while sending real-time energy usage back to the utility.[45,46] Utilities

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44 AMI includes: (1) interval meters; (2) a near real-time communications system that connects the meter to the utility; and (3) software bridges that link back-office software for billing, operations and maintenance, outage management, and other utility activities.

45 HAN refers to a network within a residential building that connects multiple digital devices, including smart meters and appliances.

46 The HAN and utility system communications protocols are not the same – it is analogous to how a personal computer is the "gateway" device which uses an Internet connection to communicate with data

that are currently deploying AMI have tended to use one of three communications systems: radio frequency point-to-point, radio frequency in a mesh network, and broadband over powerline. Where no AMI is deployed, HAN appliances such as advanced thermostats can also be used. However, another means is required to communicate price and emergency signals to customer equipment controls. Under this latter scenario, an advanced thermostat can, for example, receive demand response signals directly through an internal interface that receives wireless communications sent via a non-AMI system (such as radio broadcast data signals).

In this early stage of AMI development, approaches to system deployment have proliferated, along with communications protocols governing the AMI/Smart Grid and HAN spaces. In California, the investor-owned utilities (IOUs) are expected to complete their AMI deployment between 2011 and 2012. A number of California's municipal utilities, however, are not considering AMI at this time. One approach to addressing the variety of communications protocols and lack of standardization has been the development of an expansion port for advanced thermostats. Briefly, an expansion port is a modular expansion interface that can accommodate multiple forms of communications, including various broadband and radio signals, and which contains memory capacity to store data from logging devices. An advanced thermostat built with an expansion port could have one-way or two-way communications capabilities and could interact with a variety of systems. The expansion port as designed allows the advanced thermostat to work with any type of AMI as well as unforeseen legacy technologies and communications protocols. Advanced thermostats specified in the reference design can also operate in areas not served by AMI. In California, this would allow the same advanced thermostats to function as a viable demand response technology for both municipal and investor-owned utilities.

7.2. Project Overview

7.2.1. Background

Since the energy crises of 2000 and 2001, California government agencies have sought to support and facilitate the widespread adoption of demand response through technical support and pricing programs. The California Public Utilities Commission articulated a comprehensive demand response policy in its 2003 Vision Statement.[47] In that statement, the Commission stated that electric customers should have "the ability to increase the value derived from their electricity expenditures by choosing to adjust usage in response to price signals" as customers are equipped with advanced meters as a result of the Commission's Advanced Metering Infrastructure (AMI) decisions.

Prior to the 2003 Vision Statement, virtually all large customers had moved to time-of-use (TOU) rates. TOU rates consist of several pre-defined time periods and charge customers different pre-determined rates during each time period. For example, during the summer the

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server "utilities", but uses a USB cable or an infrared beam to send data to a printer on a "home area network".

47 California Public Utilities Commission, *California Demand Response: A Vision for the Future*, June 5, 2003.

rate charged during the afternoon is generally higher than the rate charged at night. The different rates reflect the fact that it is generally more expensive to serve customers during some time periods. TOU rates do not change based on current market conditions. In the 2003 Vision Statement, the Commission recognized the value of moving beyond TOU rates to truly dynamic rates that change based on actual system prices and conditions.

The Energy Action Plan II (EAP II), developed and adopted jointly by the CPUC and California Energy Commission (Energy Commission) in 2005, sets out key actions that both agencies intend to pursue. The EAP II identifies demand response, along with energy efficiency, as the State's "preferred means of meeting growing energy needs."[48] The EAP II concludes that "[w]ith the implementation of well-designed dynamic pricing tariffs and demand response programs for all customer classes, California can lower consumer costs and increase electricity system reliability."

One of the key activities identified for the CPUC and Energy Commission in the EAP II was to: "Identify and adopt new programs and revise current programs as necessary to achieve the goal to meet five percent demand response by 2007 and to make dynamic pricing tariffs available for all customers. Dynamic pricing rates include.

- Real-Time Pricing (RTP): A dynamic rate that allows prices to be adjusted frequently, typically on an hourly basis, to reflect real-time system conditions.
- Critical Peak Pricing (CPP): A dynamic rate that allows a short-term price increase to a predetermined level (or levels) to reflect real-time system conditions. Typically, the time and duration of the price increase are predetermined, but the days are not predetermined."

At roughly the same time as the development of EAP II, the Energy Commission, CPUC, and California's three investor-owned utilities (IOUs) conducted and sponsored extensive evaluations of statewide pilot pricing programs that featured various approaches to critical peak pricing program design, as well as other voluntary load reduction schemes.

Based in part on the outcomes of some of the statewide pricing pilots, the Energy Commission issued an Order Instituting Investigation/Order Instituting Rulemaking (OII/OIR) in January 2008 to develop so-called "Load Management Standards".[49] The basic objectives of the process were to:

- Assess which rates, tariffs, equipment, software, protocols, and other measures would be most effective in achieving demand response;

48 California Energy Commission and California Public Utilities Commission, *Energy Action Plan II: Implementation Roadmap for Energy Policies*, October 2005.

49 California Energy Commission, "Load Management Standards: Efficiency Committee Scoping Order," Docket No. 08-DR-01, January 2, 2008.

- Adopt regulations and take other appropriate actions to achieve a responsive electricity market;
- Explore the potential of peak load reduction and load shifting strategies; and
- Explore the coordination of regulatory authority of demand response efforts across investor-owned and publicly-owned utilities in the state.

One of the standards to emerge from this process was for programmable communicating thermostats. The Energy Commission had initiated work in this area earlier in the decade as part of an effort to establish long-term demand response capability, as opposed to shorter-term programs promoted in reaction to emergency situations. This led to a 2001 report which proposed an Energy Commission-directed research project to "establish a commercially viable remotely controlled thermostat suitable for residential and small commercial and industrial business applications."[50] This, in turn, led to the development of the reference design for advanced thermostats. The standard proposed by the Energy Commission included a feature that would disable the home or business owner's control over the device in case of a system emergency. The Energy Commission proposed to include this standard as a requirement for new construction in the 2008 revisions to the Title 24 construction code. However, public opposition to the non-override feature persuaded the Commissioners heading up the process to withdraw the code change proposal.

According to Ron Hoffman, prior to the initiation of the PIER advanced thermostat project, research found that widespread use of advanced thermostats in the context of utility-sponsored demand response programs would be cost-effective only if those advanced thermostats were available to the utilities for a unit cost less than $150. In addition, according to Ron Hoffman, advanced thermostats from the top three vendors cost utilities which purchased them for use in demand response programs between $225 and $350 depending on features and volume purchased. Thus, the PIER program's objective of reducing cost through standardization to a reference specification was critical for gaining regulatory support for programs involving advanced thermostats. Moreover, if the price of advanced thermostats could be reduced very significantly, researchers associated with the program believed that consumers would be willing to purchase and install the devices on their own in order to take part in time-of-use tariffs and other demand response-oriented pricing programs.

7.2.2. Regulatory Environment

In conjunction with research into demand responsive technologies, California has also pursued dynamic pricing options. Recent decisions by the CPUC direct the IOUs to establish default and optional dynamic pricing rates for all sectors. Currently, residential electricity rates in California are based on a tiered system. The system provides residential electric customers with a baseline energy allowance for basic energy needs at a lower rate. If usage exceeds the baseline

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50 Rosen and Levy, Mandating Demand Responsiveness in Appliance Standards through Controllable Thermostats (2001)

allowance, a higher rate is charged. Most California utilities have four or five tiers, with rates increasing at each tier. This pricing design is intended to discourage high use. During the California Energy Crisis, the state passed legislation capping residential electricity rates at 130 percent of baseline use. This legislation is significant because it effectively precludes default dynamic rates for residential customers. One expert interviewed described the formula used to calculate electricity bills under the legislation as "mathematically incompatible" with dynamic rates, since higher rates can only be charged after the customer has exceeded their baseline use.

The current conditions in the regulatory arenas that are relevant to the development of markets for advanced thermostats are as follows.

- Demand Response. On August 20, 2009, the CPUC approved demand response programs for the remainder of 2009 through December 31, 2011 for Pacific Gas and Electric Company (PG&E), Southern California Edison Company (SCE), and San Diego Gas and Electric Company (SDG&E). The CPUC also authorized several demand response pilot programs to test new demand response-related technologies and integration of demand response with AMI systems.
- AMI and Dynamic Pricing. Based on recent CPUC decisions, AMI should be widely deployed by the California IOUs by 2012 and critical peak pricing (CPP) will be the default rate for all of their commercial customers. CPP will be offered (on an opt-in basis) to residential customers as well. Default rates for residential customers are effectively prohibited by legislation currently. In the decisions ordering SCE and PG&E to propose dynamic rates, the CPUC has ordered that each propose default TOU/CPP rates after the legislative rate protections end.
- Title 24 Building Code. California's Title 24 building code is revised every three years, with the next revisions in 2011 and 2014. The experts KEMA interviewed felt that advanced thermostats were only somewhat likely to be included in the 2011 standard, given the obstacles encountered in 2008. However, most thought that those obstacles would be overcome by 2014 and that advanced thermostats would likely be included in the standard at that time. This schedule is consistent with the timeline for the adoption of CPP in California, which will provide an incentive for customers to adopt advanced thermostats and other enabling technologies.

  It was the judgment of experts on demand response regulation and markets in California that the Commission is unlikely to include the non-override language in future proposals. Even without such language, a significant effort in terms of education and marketing may be required to overcome the resistance to the technology, particularly given the negative press generated by the 2008 effort.

7.2.3. Project Objectives and Accomplishments

There were two principal motives behind the PIER advanced thermostat RD&D project:

- Support California's goal of accelerating its implementation of demand response programs that signal the actual price of electricity to customers during peak demand periods per the Integrated Energy Policy Report 2004 Update; and
- Make progress in achieving demand reduction and electricity savings per the Integrated Energy Policy Report 2003.

More specifically, the purpose of the PIER advanced thermostat effort was to facilitate the development of new reference designs for sensors, meters and thermostats that would make demand response infrastructure cost-effective for residential consumers in California, and adaptive to changes in communications capabilities and protocols over time.

The PIER program sponsored the development of a reference design for advanced thermostats and tasked a team of researchers at the University of California, Berkeley with addressing technical questions associated with implementing residential advanced thermostats in California. Principal investigators at the Center for Environmental Design Research (CEDR) at the University of California, Berkeley included D. Auslander, R. White, and P. Wright. The project coordinator was Alex Do. Researchers included B. Burke and L. Vaynberg. Ron Hofman continued to advise for the project as a PIER contractor. Additional advisors on the projects included Gaymond Yee of CIEE. Work on the reference design was begun in 2005 and completed in 2007. The advanced thermostat reference design was developed over twenty months in which manufacturers, utilities, and consultants participated in public workshops and conference calls.

The primary contracts under the CEDR initiative were two basic ordering agreements, which totaled less than one million dollars (exact budget amounts were unavailable). In addition to the two basic ordering agreements, Energy Commission staff expended effort on the project. Documentation of these additional costs was not readily available either and the costs were difficult to reconstruct. Based on conversations with Energy Commission staff and others, KEMA estimated the total likely cost of the PIER advanced thermostat efforts at $ 1 million.

Confidential CEDR project materials identify nine goals for the project, which were completed in two phases over 20 months:

- Investigate advanced thermostat system interfaces
- Publish a bill of materials for a minimum functionality advanced thermostat
- Develop an advanced thermostat proof-of-concept
- Demonstrate radio data system (RDS) one-way communications with advanced thermostat
- Demonstrate two-way wireless communications with advanced thermostats via an expansion port
- Develop an RDS site survey tool
- Develop a methodology to study systemic control of advanced thermostats

- Support the Title 24 Advanced Thermostat Technical Working Group
- Issue a recommendation for a one-way communications interface

As noted earlier, the Energy Commission's vision for a statewide demand response system entailed a minimum functionality advanced thermostat with flexible communications capability. The Energy Commission provided guidance on what the minimum functionality of an advanced thermostat should be according to four interfaces it defined: consumer interface, HVAC system interface, demand response communications and an expansion port. The consumer interface was to augment that of a standard thermostat by presenting information related to signal reception. In other words, at a minimum, the design should be able to inform the consumer of signal reception, operating status and function. The goal of HVAC interface was to enable the advanced thermostat to work with a variety of HVAC equipment. With regard to communications capabilities, the advanced thermostat was to be able to receive broadcast signals, such as that provided by a statewide communications system. Finally, the CEDR was tasked with investigating the addition of an expansion port which would enable two-way communications, data downloads and other relevant functionalities. In particular, "the minimum set of applications to be explored should include audit trail downloads, enabling WAN and LAN options, and sensor-network extensions." (CEDR, 2007)

CEDR investigated the feasibility of such requirements, and developed a basic design and bill of materials. This basic design would serve as a starting point for the reference design to be developed for the Title 24 Building Standards. In particular, it would contain "detailed functional information to allow vendors to map their interface specifications to their designs." CEDR then tested the design by building a proof-of-concept (POC) with off-the-shelf hardware. The POC served as a way to test various advanced thermostat technologies as well as to demonstrate that a minimum functionality design was technically feasible. Furthermore, it demonstrated that it was possible to add minimum communications capabilities (with the option for added communications capabilities) while containing the advanced thermostat costs below $100. Table 18 summarizes the bill of materials published by CEDR for a advanced thermostat with minimum functionality as defined above.

Table 18. Minimum Functionality Advanced Thermostat Bill of Materials Summary

Material Cost Elements		Unit Cost
Equivalent Advanced Thermostat		**$12.70**
Added Interfaces	**Communications**	**$3.40**
	Human-Machine	**$0.15**
	HVAC	**$2.15**
	Expansion	**$1.75**
Total Bill of Materials		**$20.20**

Source: CEDR, 2007

The POC work was done in both phases of the project. The first POC was made public in April 2006 and demonstrated a 1-way device that provided demand reductions in response to a radio broadcast. In the project's second phase, the POC was upgraded to closer approximate a production PCT, a test communications protocol was developed, the computing platform was revised to a cheaper alternative and a two-way communications interface was added. Ultimately, the Phase 2 POC was installed at the California ISO, along with a commercial-grade FM radio transmitter in a long-term demonstration of California demand response technologies.

In the end, PIER was successful in developing a reference design. The CEDR report confirmed the Energy Commission's vision of a minimum functionality advanced thermostat capable of receiving statewide broadcasts and adaptable for additional communications, available for retail at under $100. Furthermore, this work laid the groundwork for the development of the reference design. Continued input from stakeholders in the Title 24 Standards, including the Advanced Thermostat Technical Working Group, helped to form the reference design drafted for the building standards.

The key implications of these program accomplishments, in terms of increasing the pace of participation in CPP and RTP programs, the magnitude of demand reduction achieved, and the cost-effectiveness of public investment in DR programs, are as follows:

- Utility-sponsored DR programs are more likely to pass standard cost-effectiveness tests and generate higher levels of net benefits.
- The low cost of the advanced thermostats, their modular design, and the potential to communicate via long-distance wireless technologies opens up a retail channel for participation in RTP, without the intermediary of a demand response service provider.
- This capability presents a potential low-cost competitor to hard-wired technologies such as AMI for at least some of the proposed functions of AMI, in particular delivery of DR resources. This affects the regulatory rationale and benefit-cost assessment of AMI. Hence, utilities view these developments with some concern.
- The standardized, low-cost communications port and platform reduces the technology risks that manufacturers face in building smart grid capabilities into their products.

7.2.4. Follow-up activities

The Commission included an advanced thermostat requirement for residential and small commercial new buildings in the proposed 2008 revisions to California's Title 24 building code. Specifically, the reference design specified key features and functions in four categories:

- Customer Interface:
    - o Adjustable temperature set-points for heating and cooling, for a minimum of four defined periods per day.
    - o Adjustable temperature offsets for heating and cooling, with defaults for 4 degrees.
- HVAC System Interface:

- o Standardized HVAC equipment controller that can also accommodate heat pumps with resistance heat strips.
- Demand Response Communications:
  - o One-way communications capability with default to statewide demand response communications system for receipt of price and emergency signals.
  - o Clock mechanisms to manage temperature transitions and system recovery.
- Expansion Ports:
  - o Modular expansion interface that can accommodate other forms of communications, including various broadband and radio signals, and memory storage data logging devices.

However, another element of the proposed 2008 Building Efficiency Standards appeared to lead to their rejection. Specifically, the proposed 2008 Title 24 Building Standards stated:

> Upon receiving an emergency signal, the advanced thermostat shall respond to commands contained in the emergency signal, including changing the setpoint by any number of degrees or to a specific temperature setpoint. *The advanced thermostat shall not allow customer changes to thermostat settings during emergency events*. [51] [emphasis added]

On January 4, 2008 an article titled "Who will control your thermostat?" by Joseph Somsel appeared in the Internet publication *American Thinker*.[52] The article was critical of the level of government control suggested by the proposed language, a criticism which was picked up and given a wide audience by radio personality Rush Limbaugh and resonated with some members of the public. The Commission was unprepared for the response, and the advanced thermostat

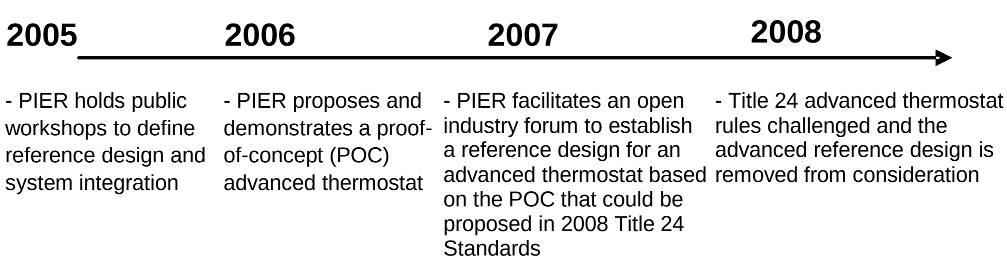

Figure 15. Events Timeline

51 California Energy Commission, 2007. 2008 Building Energy Efficiency Standards for Residential and Commercial Buildings, Express Terms—45 day language. November 2007, p 64.

52 http://www.americanthinker.com/2008/01/who_will_control_your_thermost.html

requirement was dropped from subsequent versions of the proposed standards.

The rapid implementation of AMI by utilities nationwide means that manufacturers of HAN equipment may confront and need to interface their equipment with a patchwork of utility communications protocols. Building separate equipment designed for each communications protocol deployed would be cumbersome and expensive. As such, major appliance manufacturers are currently engaging in public-private partnerships to develop global protocols for demand response appliances. Whirlpool, for example, publicly anticipates all such appliances will be HAN-enabled by 2015. These include refrigerators, stoves, microwaves, clothes washers and dryers, and dishwashers. In addition, building on the reference design concept of an expansion port for interoperability, an open industry forum was created to promote an interoperable communications card standard for connecting home area network devices to Smart Meters. Called the U-SNAP Alliance (for Utility Smart Network Access Port), its stated mission is to "create a protocol independent serial interface standard that enables any HAN standard, present and future, to use any vendor's Smart Meter as a gateway into the home, without adding additional hardware in the Smart Meter."[53]

7.3. Benefit-Cost Calculations: Methods

7.3.1. Introduction

An appropriate benefit-cost assessment of PIER's activities in support of the advanced thermostat requires a clear definition of the baseline scenario for the development of the markets for advanced thermostats in California in the absence of PIER's efforts, as well as definitions of one or more plausible alternatives that the reference design may enable. The project description above identifies two major markets for advanced thermostats:

- **The Program Market.** The program market consists of utilities and demand service providers who purchase advanced thermostats in bulk for use in programs for which cost recovery is authorized by utility regulators. These advanced thermostats are then bundled into a package of equipment and services that enable residential and small commercial customers to participate in the programs.
- **The Retail Market.** The retail market consists of sales directly to end-users via standard retail and mail-order channels. At the moment, sales through this channel are negligible. However, they could grow rapidly when critical peak pricing and other time-of-use rates become available to small commercial and residential customers. In order to facilitate this growth, customers would need to have access to price and system emergency signals through some technologically simple and relatively inexpensive medium. This could include internet connection, radio frequency messaging, or direct connection to an AMI-enabled meter.

53 http://www.usnap.org/mission.aspx.

Developing baseline and alternative scenarios for the program and retail markets for advanced thermostats is complicated by the fact that both are and will continue to be driven by regulatory decisions and utility company actions in response to those decisions. For example, it is up to utilities to propose the design and target volume of demand response programs, as well as the extent to which load reductions are implemented year to year. On the retail side, the design and roll-out of pricing programs continues to be a matter of regulatory deliberation. Moreover, regulatory action would be needed to require utilities or California ISO to make pricing signals available over public media. Both the outcomes and the timing of these decisions remain highly uncertain. Much of the research that KEMA conducted for this case study consisted of gathering information from regulators, utility program staff, demand service providers, and other market actors regarding their organizations' policies and strategies in regard to demand response, dynamic pricing, and advanced thermostats, as well as their views on the likely course of events in those markets.

7.3.2. Common Elements in All Scenarios

Based on our research into the market and regulatory environment for advanced thermostats summarized above, we developed the following basic assumptions to structure the benefit-cost analysis.

Regulatory Policy and CPUC Decisions. We assume that the policies and activities of the CPUC in terms of requiring and authorizing financial compensation for utility deployment of AMI, demand response programs, and dynamic pricing would have occurred largely as they did in the past and would continue through the end of the analysis horizon (2020) in the absence of the PIER activity. Based on interviews with CPUC staff, the PIER advanced thermostat reference design seemed to have limited to no impact on the CPUC and utility decisions to move forward with default commercial dynamic pricing and optional residential dynamic pricing. Additional research by KEMA is consistent with this assertion. In particular,

- Initiatives to move forward with dynamic pricing in California had already begun, starting with a statewide pilot launched in 2003.
- California had already begun examining the potential savings of dynamic pricing with enabling technology like advanced thermostats through the Statewide Pricing Pilot (SPP), begun in 2003, and
- Alternatives to advanced thermostats, including direct load control, were already available as were advanced thermostats not designed with the reference design in mind.

Our forecast of the pace of adoption of advanced thermostats under the various scenarios assumes that:

- Some form of critical peak pricing will be the default rate for commercial and industrial customers of the IOUs by 2012.
- Residential customers will have the opportunity to opt into critical peak pricing or other forms of time-of-use rates by 2012.

Utility response to CPUC Regulation. With one small exception noted below, we assume that utility offers of demand response and dynamic pricing programs, as well as roll-out of AMI, would have proceeded as they have in the absence of PIER activity. Specifically, we assume that:

- The California Investor-Owned Utilities (IOUs) will complete wide-scale, but not universal, deployment of AMI by 2012.
- The California IOUs will continue to offer demand response programs that use advanced thermostats to their commercial customers.

Direct effects of the PIER Project. We assume that PIER efforts to develop the reference design and to support incorporation of that design into Title 24 had the following direct effects.

- Reduction in price of advanced thermostats purchased by utilities and other demand response program operators.
- Expansion of supply of low-cost advanced thermostats to residential and small commercial customers.
- Enabling of communications through a wider variety of media and signaling systems via the implementation of the expansion port.

Customer response to demand response and dynamic pricing opportunities. We assume that patterns of customer response to the opportunities created by expanded demand response and dynamic pricing will be similar to those experienced in the statewide pilots of those programs.

7.3.3. Structure of the Analysis

Definition of Scenarios. KEMA developed three scenarios to structure the benefit-cost assessment of PIER's activities in support of advanced thermostats. These are as follows:

- **Baseline Scenario.** The baseline scenario assumes that the PIER project did not occur. The principal consequence of this assumption in terms of benefit-cost forecasts is that the price of advanced thermostats remains high, with some adjustments over time for the effects of manufacturer learning and competition. In the face of continued high prices for advanced thermostats, we assume no development in the retail market.
- **PIER Project Scenario.** Under this scenario, we forecast increased volumes of activity in the program market and the development of a retail market in response to the reduced prices and enhanced communications capabilities associated with the PIER efforts, as well as implementation of dynamic rates. Here, we assume that the reference design advanced thermostat is not incorporated into Title 24 prior to 2020.
- **PIER Project plus Title 24 Scenario.** This is essentially the same as the PIER Project Scenario except that we assume that the Title 24 energy code will incorporate the advanced thermostat reference design, with its mandatory non-override feature. Based on interviews with market observers, we assumed that the next round of Title 24 revisions would not include this change, but that the 2014 revision would. This assumption leads to higher levels of forecasted adoption of advanced thermostats as well as slightly higher unit savings given that mandatory emergency response will be enabled.

Table 19 summarizes the structure of the scenarios. The far right-hand column "Unit Savings" indicates that we undertook the benefit-cost assessments for each scenario using two sets of assumptions concerning unit savings, both of which were drawn from the Code and Standards Enhancement (CASE) study conducted for advanced thermostats. The "base" and "pessimistic" cases differ largely in the assumptions they incorporate concerning the temperature and climate conditions in effect when real-time prices increase. The more extreme the assumed conditions, the higher the level of modeled demand and energy reductions.

Table 19. TRC Scenarios Summary

Variable / Scenario	AT Price Forecast	Market Volume			Dynamic Pricing	Unit Savings
		Program	Retail	Title 24		
Baseline	Baseline	No impact	No impact	No change	In effect	CASE "base case" CASE "pessimisitic case"
PIER Project Scenario	Price decrease	Volume increase	Retail market created	No change	In effect	CASE "base case" CASE "pessimisitic case"
PIER Project Scenario w/ Codes	Price decrease	Volume increase	Retail market created	2004 PCT requirement	In effect	CASE "base case" CASE "pessimisitic case"

Structure of the analysis. Benefit-cost assessments of market interventions are typically structured in two modes: a baseline that involves no program and a program case. The benefit-cost analysis of PIER activities in support of advanced thermostats differs from the typical approach in that all three scenarios feature a program of some type to promote the use of advanced thermostats to facilitate demand and price response. Therefore, we use the difference between the Baseline and PIER Project Scenarios in the NPV of net benefits over the analysis horizon as the key indicator of the societal value of PIER's advanced thermostat support activities.

7.4. Benefit-Cost Calculations: Inputs and Results

7.4.1. Inputs

The following paragraphs identify the key variables in the benefit-cost assessments of the three scenarios defined in the previous section; the sources used to estimate their value; the input values selected; and the rationale for their selection. Generally, KEMA used information from documents developed in support of 2008 Title 24 Buildings Standards amendments, CPUC proceedings, ex post and ex ante program evaluations and in-depth interviews. This work identified areas of uncertainty in regard to variables that exercised a large influence on net benefits and benefit-cost ratios, and it helped identify which areas PIER likely had an impact.

PCT savings. The use of advanced thermostats has the potential to both save energy and reduce demand. Such reductions have associated financial benefits. KEMA used estimated average annual unit energy savings for advanced thermostats from the CASE study.[54] As a sensitivity check on the estimates, KEMA used savings estimates from CASE's base case and pessimistic

54 Southern California Edison and California Energy Commission. Draft Report, Demand Responsive Control of Air Conditioning via Programmable Communicating Thermostats. 2006.

case, by sector. Both are non-emergency savings, meaning that the savings are associated with voluntary HVAC use reductions and participants have full override capability. Table 20 illustrates the average per unit energy and demand values selected from the CASE study. The same savings estimate was used for advanced thermostats distributed through the program or retail channels. Though it is possible that the advanced thermostats savings from the channels would be different (in part because the incentives for advanced thermostats use may differ), KEMA believes that the range of values used in the sensitivity analysis already account for such differences. Table 21 presents CASE average per unit annual savings in financial terms.

Table 20. PCT per Unit Energy and Demand Savings Sensitivity

Sector	Energy Savings (kWh/unit)		Demand Savings (kW/unit)	
	Residential	Commercial	Residential	Commercial
"Base case" unit savings	19.4	40.0	0.4	0.8
"Pessimistic case" unit savings	1.6	3.6	0.1	0.4

Table 21. Advanced thermostat - per Unit Financial Savings

Sector	Financial Savings (kWh/unit)	
	Residential	Commercial
"Base case" unit savings	$32	$39
"Pessimistic case" unit savings	$2	$3

Forecast of advanced thermostat installations: Baseline. KEMA developed annual forecasts of the number of advanced thermostat installed in the service areas of the three investor-owned utilities – PG&E, SCE, and SDG&E, as well as for the Sacramento Municipal Utility District (SMUD). We then combined these forecasts into annual statewide forecast totals from 2006 through 2020. We developed separate forecasts for residential and small commercial customers, and for the program and retail market channels. The following paragraphs summarize the approach, key assumptions, and sources referenced in developing the residential forecast. Similar approaches and sources were used to develop the forecast for small commercial customers.

The development of the forecast of residential advanced thermostat installations for each of the utility service areas proceeded in the following steps.

- *Estimate the total population of eligible customers*. We defined the eligible population as all residential customers with central air conditioning (CAC) installed. For most of the utilities these statistics were taken from demand response program plans filed with the CPUC. In our forecast, the annual population of existing households is adjusted for new construction and demolition using factors taken from a variety of sources. In the PG&E

service area for example, we estimated that there were 5.4 million such customers in 2009.

- *Forecast the number of customers participating in utility-sponsored demand response programs.* Our forecast of the number of customers participating in utility-sponsored demand response programs that use CPTs was based primarily on one or more of the following kinds of documents filed by the investor-owned utilities with the CPUC: demand response program plans; rate case documents seeking settlements for AMI deployment; filings in support of dynamic rate plans. We reviewed filed plans for the following programs:
    a. PG&E SmartAC – a direct load control program using advanced thermostats to cycle CAC units or to reset their thermostats in response to or in anticipation of emergency conditions, with limitations on the duration of single events and total hours in a single cooling season. The program is scheduled to run from its inception in 2007 through 2020.
    b. SCE Summer Discount Plan – started as a direct load control program. In SCE's 2009 – 2011 application, the company noted its intent to convert participants to PCTs to assess savings with critical peak pricing (CPP) and advanced thermostats.
    c. SDG&E Peak Time Rebate Program – an event-driven pricing program scheduled to run beyond from 2008 to an unspecified date beyond 2011. Advanced thermostats will not be provided through the program, but SDG&E staff anticipate that participants will likely use advanced thermostats, along with other enabling technologies, to reduce demand during program events.

Forecast the number of customers installing advanced thermostats to benefit from critical peak pricing and similar pricing offers. To forecast the number of customers who will purchase advanced thermostats on their own to take advantage of CPP and similar rate plans, KEMA relied heavily on the results of a May 2009 Freeman, Sullivan & Co. (FSC) study commissioned by PG&E.[55] Using the results of stated preference analysis of mail surveys from 3,064 residential customers, FSC forecasted participation in the following initiatives in SmartAC, a CPP program known as SmartRate[56], and a number of existing TOU tariffs.

Based on the results of the stated-preference analysis, FSC forecasted that the following levels of enrollment by December 2011:

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55 Freeman, Sullivan & Co. 2009. 2008 Load Impact Evaluation for Pacific Gas & Electric Company's SmartRate™, Smart AC and Residential TOU Programs: Final Report. San Francisco: Pacific Gas & Electric Company.

56 The current version of SmartRate is a voluntary CPP tariff in which critical peak prices are $0.65 per kWh higher than otherwise applicable on a limited number of days during the summer season in exchange for a credit during non-high price usage periods. It will be replaced in 2010 by a new rate (Peak Day Pricing) with an underlying TOU structure throughout the year and higher critical peak prices during events that can be called throughout the year, not only during the summer.

a. Peak Day Pricing – 277,060

b. Smart AC – 227,627[57]

c. Enrollment in both programs 26, 274.

The study forecasts that enrollment in these programs will remain constant from 2012 through 2020.

KEMA used the participation rates implied in these findings to transfer them to the other utility service areas. Based on review of evaluations of the statewide pricing programs, we assumed that two-thirds of the customers with CAC who enroll in CPP or TOU rates will choose to purchase advanced thermostats, as opposed to other enabling technologies to take advantage of savings opportunities offered by CPP and similar programs.[58]

Combining the results of Steps 2 and 3, KEMA projected baseline installations of advanced thermostats increasing from roughly 109,000 in 2010 to 267,000 in 2020. This represents an increase in the saturation of thermostats in homes with CAC from 1.63 to 2.96.

Forecast of Advanced Thermostats Installations: PIER Project Scenario. KEMA built separate forecasts for each utility and market channel to reflect increases in advanced thermostat adoption in response to the availability of cheaper and more capable advanced thermostats due to the development of the reference design. For the program channel we assumed that the utilities would increase their deployment of advanced thermostats by 10 percent over the period ending 2020, based on conversations with utility program managers. For the retail channels, we applied the results of the statewide pilot program evaluations and rate program participation forecasts referenced above to the forecasts of growth in the eligible populations over the analysis horizon. The results of these calculations are shown in Table 22.

Table 22. Participation Rates for Advanced Thermostat Forecast Scenarios: 2020

	Residential % of HH with CAC			Small Commercial % of Floor Space with CAC		
Scenario	Program Channel	Retail Channel	Code Related	Program Channel	Retail Channel	Code Related
Baseline	**1.0%**	**0%**	**0%**	**19.6%**	**0%**	**0%**
PIER Project	**1.1%**	**4%**	**0%**	**21.6%**	**17.5%**	**0%**
PIER Project with Code	**1.1%**	**4%**	**7.0%**	**21.6%**	**17.5%**	**7.0%**

57 Updated per Pacific Gas & Electric Company, 2010 – 2011 SmartAC Program and Budget: Prepared Testimony. August 28, 2009.

58 See, for example, Faruqui, Ahmad and Sanem Sergici, "The Power of Experimentation: New evidence on residential demand response." San Francisco: The Brattle Group. May 11, 2008.

Forecast of PCT Installations: PIER Project plus Title 24 Scenario. To estimate advanced thermostat volume in the PIER Project plus Title 24 Scenario, KEMA assumed that in 2014, all new construction would have advanced thermostat. In addition, KEMA assumed a spillover effect for existing buildings. In particular, KEMA assumed that thermostat installations would likely be prompted by the installation of new air conditioning systems. Of these new installations, a growing percentage would install an advanced thermostat over a programmable thermostat (5 to 20 percent between 2014 and 2020). Prior to 2014, the advanced thermostat volume equates to that of the PIER Project Scenario. The results for 2020 are shown in Table 22.

Figure 16 illustrates projected market share of advanced thermostats over time in the Baseline scenario, PIER Project Scenario and PIER Project with Codes Scenario. Baseline advanced thermostats are assumed to increase gradually over time. The PIER Project Scenario sees an increase in volume after 2009, attributable to the PIER project and due to growth in the retail channel and through C&I programs. A larger increase in advanced thermostat market volume is evident in the PIER Project Scenario with Codes due to forced adoption in new construction and a slight increase in adoption in existing buildings.

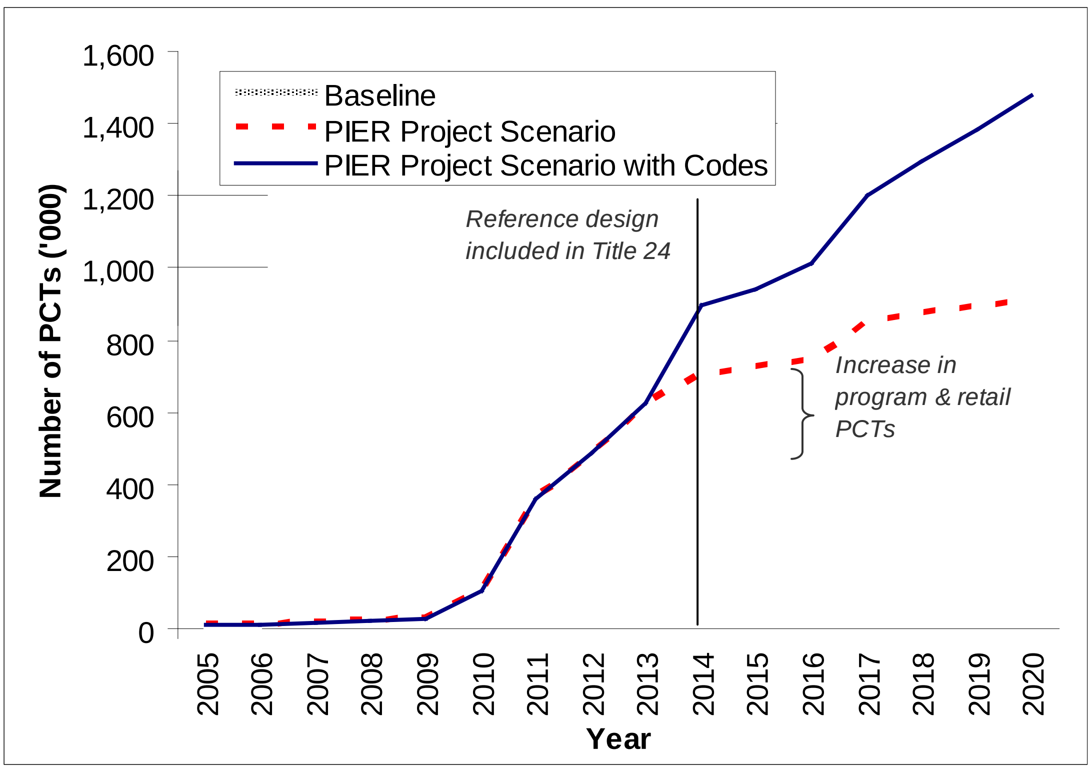

Figure 16. Effect of PIER Activities on Annual Market Shares

advanced thermostat prices. KEMA used information from the CASE study and from expert interviews to forecast advanced thermostat prices over time. Regardless of PIER activities, KEMA assumed advanced thermostat price reductions due to manufacturer learning, competition and slight increases in volume. In the PIER Project Scenario, KEMA assumed advanced thermostat prices drop at a quicker pace, attributable to PIER and increased volumes. This effect starts to be seen in 2010 product offerings. Price reductions in the PIER Project Scenario with Codes are greater than those in the PIER Project Scenario given the large increase in volume from the Title 24 building energy code, occurring around 2014. Figure 17 shows the results of these calculations.

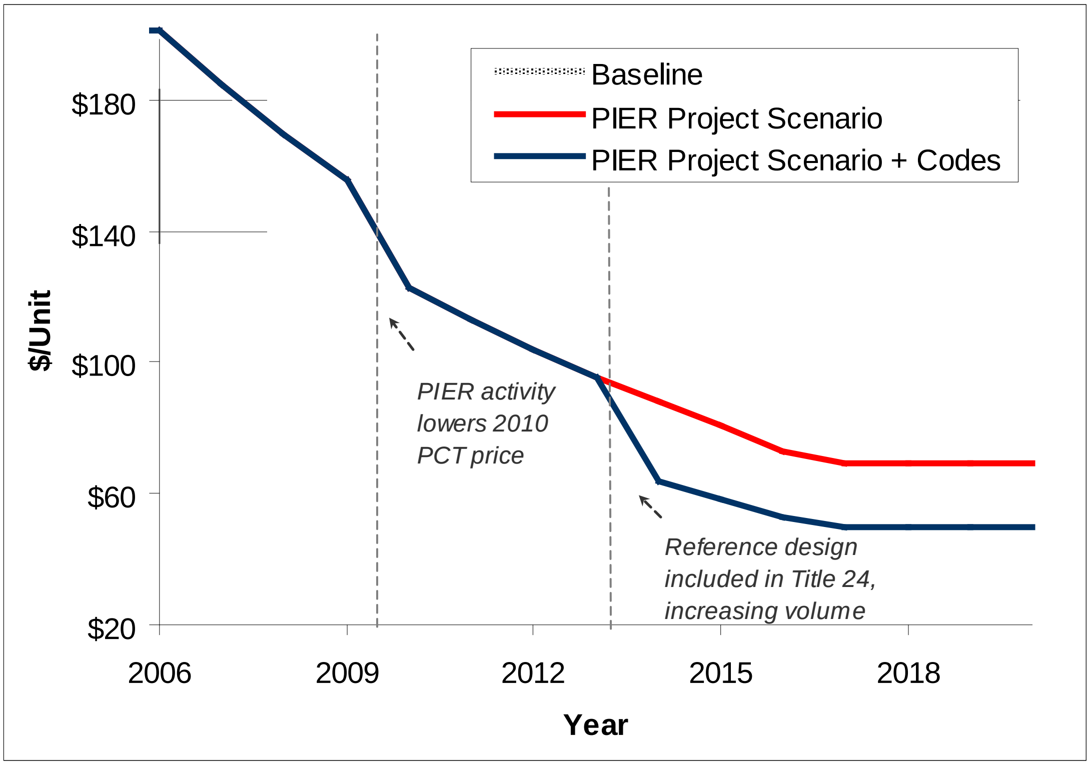

Figure 17. PIER Project Impact on Advanced Thermostat Pricing

7.5. Results

The following paragraphs identify the cost-benefit results for each of the scenarios analyzed. As noted earlier, KEMA uses the difference between the baseline and PIER Project Scenarios in the NPV of net benefits over the analysis horizon as the key indicator of the societal value of PIER's advanced thermostat support activities.

Figure 18 illustrates the estimated savings over time for each of the scenarios. Savings are calculated as the per unit savings multiplied by the number of advanced thermostat in the market. The high and low estimates are presented for each of the three scenarios. The shapes of the curves reflect assumptions about advanced thermostat market share. The size of the savings reflects per unit savings estimates.

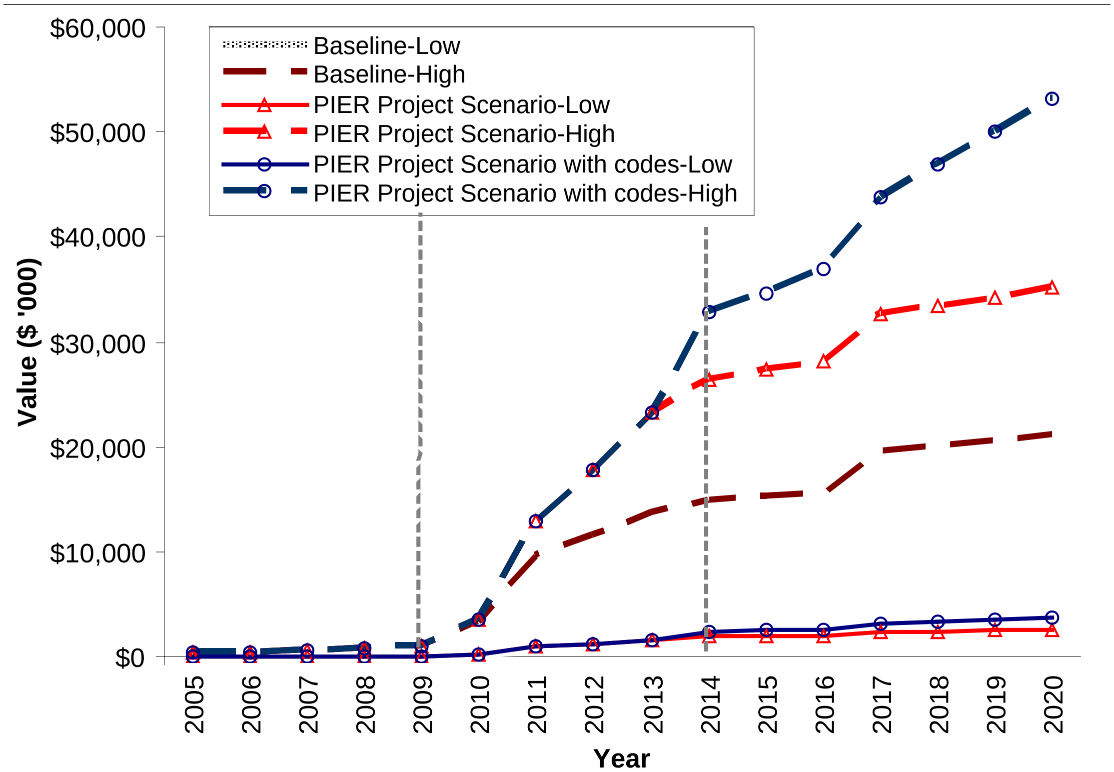

Figure 18. Advanced Thermostat Savings by Scenario

The price of a advanced thermostat determines the cost of obtaining savings for an individual consumer and via utility programs. To estimate costs in the Baseline scenario, KEMA multiplied advanced thermostat volume by advanced thermostat prices. The PIER Project scenarios do the same, but also include the costs associated with the program. KEMA estimated PIER program costs at $1 million. Figure 19 illustrates advanced thermostat costs over time, by scenario. In the years 2005 to 2009, the impact of the PIER project is not yet realized. Therefore, costs run in line with one another. The PIER Project scenarios reflect the PIER program costs, with a slightly higher total cost in 2005.

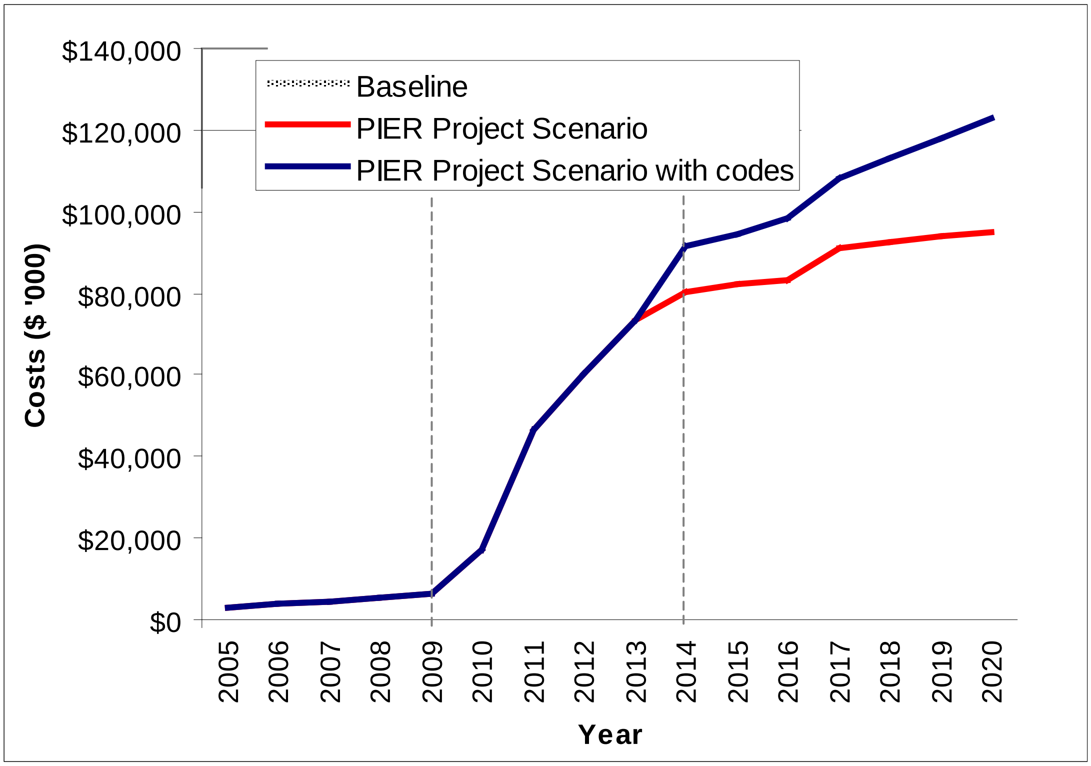

Figure 19. Advanced Thermostat Costs by Scenario

Using the inputs described above, KEMA calculated the net present value of benefits for each scenario and for the residential and C&I sectors. The figures in Table 23 show the difference in net benefits between the baseline scenario on the one hand and the PIER Project and PIER Project with Code scenarios on the other. In this case the base case includes deployment of advanced thermostat over time through utility programs, which creates a net benefit over a strictly "no program" case.

Table 23. Summary of Net Present Value Calculations by Scenario and Customer Segment

Scenario	Per Unit Savings	Residential	C&I	Total
PIER Project Scenario	Pessimistic			-$1.0
	Base	$3.7	$24.8	$28.4
PIER Project Scenario w/ Codes	Pessimistic			-$1.0
	Base	$14.1	$31.6	$45.7

Under the base case assumptions concerning energy savings and demand reductions per unit, the increased adoption of advanced thermostat associated with the PIER project lead to a gain of $28.4 million in net present value over the baseline scenario. Additional adoptions in new construction due to the effect of incorporation of advanced thermostat into Title 24 building codes yield a gain of $45.7 million in net present value. Under pessimistic assumptions regarding energy savings and demand reductions per unit, advanced thermostat are not cost-effective within the TRC framework and their deployment leads to substantial costs in excess benefits. As discussed in Section 2, we treat this situation by assigning a low net present value equal to the cost of the PIER project.

7.6. Conclusions

This benefit-cost assessment illustrates that PIER program activities in support of the advanced thermostat reference design and deployment are likely to be cost-effective. However, the ultimate assessment of cost-effectiveness awaits empirical observation of customer behavior and equipment performance in the context of pricing programs that will soon come into effect.

Regardless, continued indirect impacts from the PIER program are likely to be observed in the near future. The experts interviewed uniformly agreed that they had not seen any trends toward standardization of advanced thermostat prior to the reference design, and that it was extremely unlikely that the industry would have developed interoperability standards on its own, at least for the foreseeable future. The formation of U-SNAP is but one example of this project's impact. According to the group's website:

> *The initial idea for U-SNAP emerged in 2007 when the California Energy Commission (CEC) was considering the concept of Advanced Thermostats as part of its Title 24 energy efficiency program.*[59]

Although the spillover effects of device interoperability are difficult to characterize and quantify at this point, the technical advances made through this project will help utilities and customers exploit the opportunities for financial savings and load control offered by the deployment of AMI and other communication channels between energy suppliers and users.

[59] U-SNAP. About. Viewed 2009. Available online at: http://www.usnap.org/about.aspx

8.0 Case Study: NightBreeze

This chapter presents the benefit-cost analysis conducted on PIER program support for NightBreeze night ventilation technology. It begins with a brief description of NightBreeze technology and of the two PIER projects designed to promote its development and adoption. The chapter continues with detailed benefit-cost calculations and results, and ends with concluding remarks about PIER and the NightBreeze system.

8.1. Product Description

Night ventilation, also known as ventilation cooling, is a relatively simple method of reducing air temperatures in residential buildings and decreasing air conditioning loads in warm climates. During nighttime hours, when outdoor air temperatures fall below indoor temperatures, residents circulate cool outdoor air throughout the home. This has the effect of "pre-cooling" the home in anticipation of hot weather the following day. In the morning, homeowners seal cooler air inside, causing indoor temperatures to rise less rapidly than they otherwise would as the day grows hotter. Pre-cooling delays the need to activate residential air conditioning, and does so during periods of peak demand.

Traditionally, homeowners have encouraged night ventilation by opening windows at night. However, leaving windows open may pose security problems, and unfiltered outdoor air may introduce allergens and pollutants into the home. Another alternative is to use whole house fans, but these typically require manual operation by residents. In 2002, Davis Energy Group (DEG) introduced NightBreeze, an intelligent night ventilation system that seeks to maximize the benefits of ventilation cooling while avoiding the drawbacks associated with other modes of night ventilation.

The NightBreeze system combines heating, ventilation cooling, and air conditioning functions in an energy-efficient, user-friendly control system. In essence, NightBreeze supplements standard HVAC systems with ventilation cooling functionality, and places all aspects of residential climate control under a single set of controls. A central system controller uses climate and usage data to predict future daytime cooling demand. Based on these predictions, the controller ventilates the house with cool, filtered outside air overnight in order to lower indoor air temperature. In the morning, NightBreeze closes off the house from outside to preserve the cool indoor air mass. As the day grows hotter, temperatures inside the pre-cooled home will rise slowly compared to homes without night ventilation, and less air conditioning will be needed to achieve an identical level of comfort. NightBreeze is most effective in hot, dry climates and transition zones.

Major components of the NightBreeze system include the following:

- Integrated controls that allow residents to set minimum and maximum indoor temperatures. Within this range, NightBreeze logic optimizes resident comfort and energy savings.

- An air handler powered by a variable-speed electronically-commutated motor (ECM). This permits precise airflow control while providing enhanced energy efficiency relative to conventional permanent split capacitator (PSC) motors.
- A damper equipped with variable controls for normal HVAC operation or ventilation cooling.

Figure 20 offers a general schematic of the NightBreeze system.

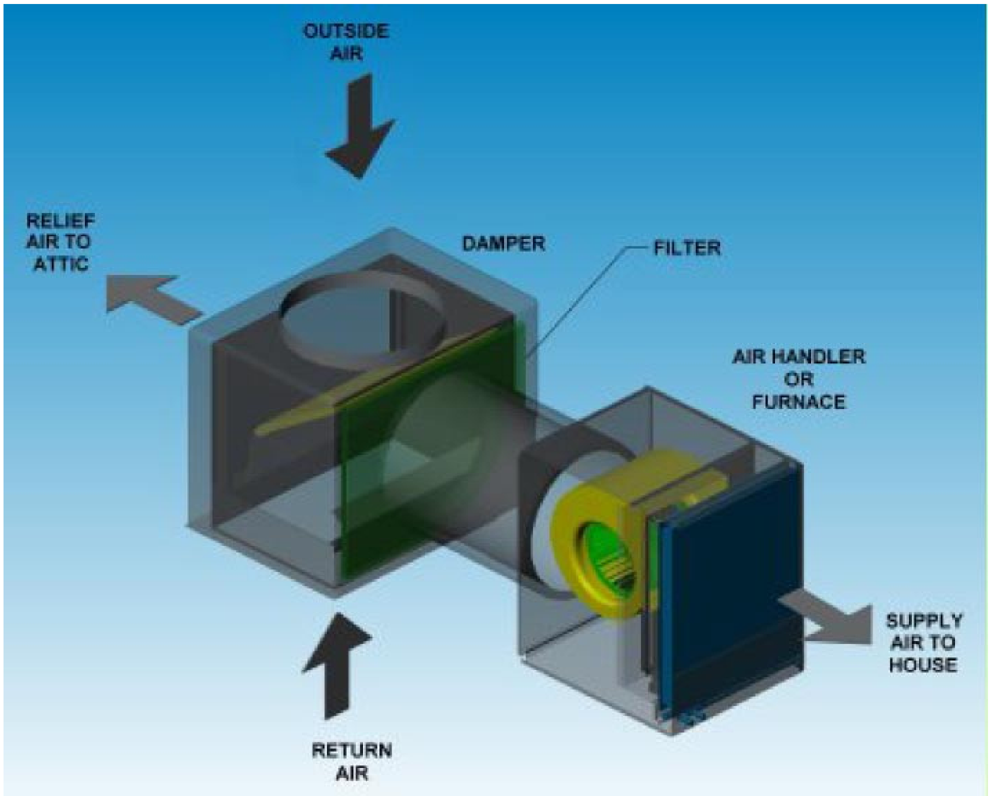

Figure 20. NightBreeze System Overview

Source: DEG.

NightBreeze works using a unique algorithm to set the ventilation rate. Sensors monitor indoor and outdoor temperatures, and the controller utilizes these data to predict temperature ranges for the following day. Based on these temperature predictions, the controller derives values for vent target temperature and anticipated cooling demand. In turn, the system utilizes cooling demand values to calculate fan airflow overnight and into the morning.

The NightBreeze system offers two primary benefits. First, pre-cooling a home reduces indoor air temperatures and postpones the need to operate an air conditioner condenser unit as outdoor daytime temperatures rise. Decreased load means decreased energy consumption, resulting in lower energy bills. Second, because residential air conditioning is a key driver of peak energy use, reducing air conditioning load cuts peak demand, thereby easing strain on the power grid. The magnitude of benefits associated with NightBreeze is contingent on several factors external to the system itself. These include size of household, indoor climate settings and preferences, energy use patterns, rate structures/tiers, and local climate and weather.

8.2. Project Overview

PIER has delivered support for the NightBreeze system through two separate projects. Researchers carried out the first project under the umbrella of the Alternatives to Compressor Cooling (ACC) program launched by the California Institute for Energy Efficiency (CIEE) in 1994. PIER took over the administration of ACC in 1999. For the fifth stage of the program, PIER decided to help develop a night ventilation system. In addition to the benefits noted above, PIER staff believed that ventilation cooling had the potential to completely eliminate the need for residential air conditioning in certain California climate zones.

The primary goal of this project, known formally as "Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling" (1998-2004), was to develop, test, and demonstrate an integrated HVAC night ventilation system.[60] To accomplish this goal, PIER contracted with DEG to build and evaluate the system, which was named NightBreeze. DEG subcontracted with RCS/ZTECH to help construct the control unit. The original NightBreeze was a single-zone "hydronic" system, or one in which heat is derived from a water heater or boiler. The project team deployed NightBreeze at two separate sites in California, Watsonville and Livermore. Researchers confirmed that the NightBreeze system was functional and effective, and that its adoption across the state would likely result in significant energy savings and demand reduction.

Widespread deployment, however, was hampered by the system's hydronic design. Most new homes in California are equipped with gas furnaces rather than hydronic air handlers. This is especially true in the production home market, which accounts for 85 percent of the California residential market.[61] In order to gain market share and have meaningful impacts in terms of energy savings and demand reduction, proponents of ventilation cooling needed to develop a furnace version of the NightBreeze.

This was the principal objective of the second PIER project in support of ventilation cooling.[62] Like ACC Phase V, this follow-up project, known as "NightBreeze Products Development Project" (2002-2007), also relied primarily on DEG to carry out essential tasks. DEG successfully designed and built a furnace version of the NightBreeze ("NB2") to complement the original hydronic version ("NB1"). Project engineers also improved upon the NB1 model by furnishing

60 David Springer, Alternatives to Compressor Cooling, Phase V: Integrated Ventilation Cooling: Consultant Report, prepared for California Energy Commission, February 2004.

61 KEMA et al., Residential New Construction (Single Family Home) Market Effects Study, prepared for California Public Utilities Commission, May 21, 2009.

62 David Springer, NightBreeze Products Development Project, Davis Energy Group for the California Energy Commission, 2006.

NB2 with multi-zone controls. Figure 21 depicts the evolution of NightBreeze from hydronic to furnace system configuration.[63]

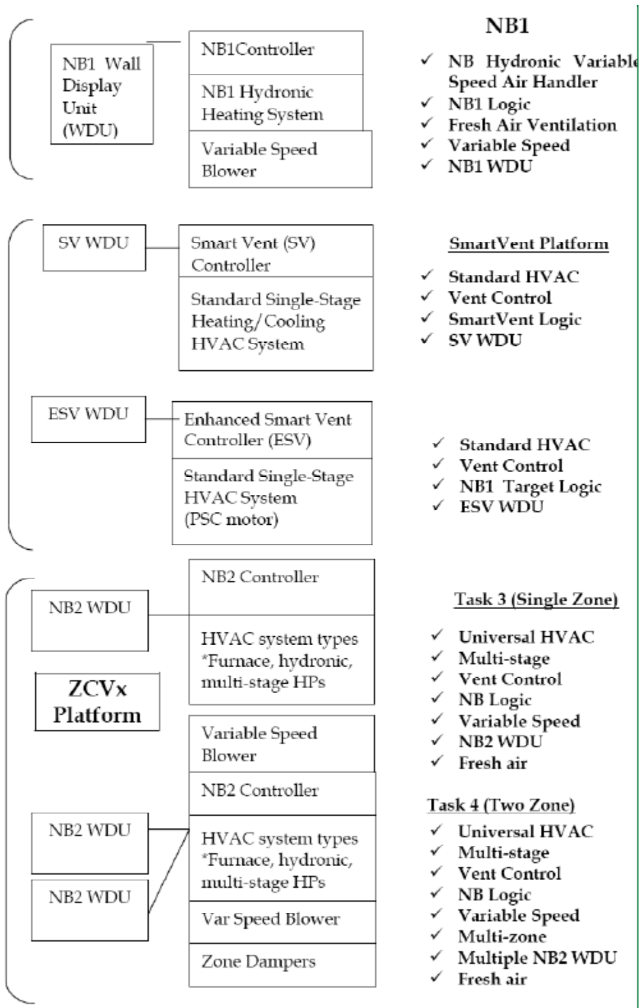

Figure 21. NightBreeze System Evolution

Source: David Springer, *NightBreeze Products Development Project*, Davis Energy Group for the California Energy Commission, 2006, 14.

This deployment project sought to promote commercialization of NightBreeze technology in other ways as well:

- Project staff submitted NightBreeze to the Electric Testing Laboratory (ETL) for safety evaluation and product listing. Advocates of NightBreeze believed that ETL certification was critical to gaining traction in California's heating and cooling market. The project team successfully obtained ETL certification in 2006, and DEG subsequently launched its first significant sales effort in support of NightBreeze.

63 Although DEG designed NB1 and NB2 for use with different heating systems, their price and performance are comparable, and DEG makes no distinction between the two versions when reporting sales volumes. Following this practice, the remainder of this report treats these models as interchangeable and refers to them jointly as "NightBreeze systems."

- Researchers incorporated NightBreeze logic into SmartVent systems, a competing night ventilation technology distributed by Beutler Corporation.[64] SmartVent systems operate with furnaces, yet use less sophisticated controls and less efficient PSC motors compared to NightBreeze. Beutler had partnered with PIER on previous research projects, and was amenable to working with DEG to stimulate growth in the ventilation cooling market. This collaboration resulted in the "Enhanced SmartVent," featuring advanced NightBreeze algorithms.
- The project team established a more direct role for itself in California's residential building sector. Specifically, DEG set up a new company called Advanced Energy Products Corporation (AEP), intended to sell NightBreeze technology and other efficient cooling and heating products. AEP's initial strategy was to market both hydronic and furnace models throughout California as well as in Nevada.

As the second, market development project ended, PG&E and SCE each launched rebate programs in support of night ventilation technology. Despite the promise of consumer cost savings and the availability of utility incentives, the market for NightBreeze systems has lagged in the context of a severe downturn in the California housing sector. Currently, advocates of night ventilation technology are working to incorporate ventilation cooling systems as a compliance credit under California Title 24. Supporters believe this would promote wider adoption of NightBreeze.

8.3. Benefit-Cost Calculations: Methods

KEMA conducted a cost-effectiveness assessment of PIER's involvement in support of NightBreeze technology using the California Total Resource Cost Test framework. The assessment proceeded in the following steps.

- Identify key variables. KEMA used information from project documents, independent research on ventilation cooling, and in-depth interviews with project participants and market actors to develop a set of initial scenarios for cost-effectiveness testing within the TRC framework. This work identified key areas of uncertainty in regard to variables that exercise a large influence on net benefits and benefit-cost ratios.
    - **Quantity of NightBreeze systems sold.** Since the introduction of the NightBreeze system, industry observers and participants report that sales have been low and market penetration minimal. Precise sales data, however, do not exist. Furthermore, predictions regarding future trends, for example, expected Compound Annual Growth Rates (CAGR), are not available. KEMA employed in-depth interviews to develop estimates of NightBreeze sales. We discuss these interviews below.

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64 NightBreeze systems work only with variable-speed blowers, while SmartVent systems work with both variable-speed and single-speed blowers. This market differentiation created the conditions for a "gentlemen's agreement" between DEG and Beutler to collaborate on ventilation cooling technology development.

- o **Replacement savings produced by NightBreeze.** Replacement savings associated with NightBreeze systems take the form of energy savings attributable to reduced consumption. KEMA referred to project materials and associated research to calculate replacement savings.
- o **Influence of PIER activities.** In assessing benefits and costs of PIER projects, the central question is the extent to which PIER activities influenced market and regulatory outcomes. Determining program attribution in this instance relies primarily on qualitative assessments made by multiple experts distinguished by broad experience and diverse points of view. KEMA assessed expert perspectives on the effects of PIER by conducting structured interviews, described below.
- o **Incremental cost of NightBreeze**. Incremental cost data are critical to calculating program cost in relation to benefits. KEMA gathered information on the incremental costs of NightBreeze systems during in-depth interviews with industry participants and observers.

Estimate value ranges for key variables. KEMA estimated the plausible range of values for the variables identified above using the following sources:

- o **In-depth interviews.** KEMA conducted in-depth interviews with 10 individuals who have extensive professional involvement with and knowledge of the market and technology for night ventilation systems. Table 24 provides a list of these experts and their backgrounds.

Table 24. Interviewees for NightBreeze Case Study

Interviewee	Affiliation	Background
Mark Berman	**DEG**	**Oversees product development for DEG; helped manage PIER NightBreeze development project**
Jerry Best	**AEP**	**Oversees NightBreeze sales for DEG/AEP**
Marc Hoeschele	**DEG**	**Worked on NightBreeze market development project**
Jeff Jacobs	**Building Advisory Group**	**Green builder; installed first NightBreeze system in Livermore, CA**
Nancy Jenkins	**SCE**	**Former Manager, CEC-PIER Energy Efficiency Research Office; oversaw NightBreeze projects**
Cliff Murley	**SMUD**	**Participated in PIER off-peak pre-cooling project**
Bob Radcliff	**Beutler Corporation**	**Collaborated with PIER and DEG in developing NightBreeze and SmartVent**
Chris Scruton	**PIER**	**Managed NightBreeze market development project**
Charlene Spoor	**PG&E**	**Managed PG&E evaluation of NightBreeze**

Interviewee	Affiliation	Background
Bruce Wilcox	**Bruce A Wilcox, PE**	**Residential energy efficiency and building codes consultant**

These interviews covered a wide range of subjects relating to NightBreeze, including the following key issues:

- Barriers to night ventilation technology
- PIER support for NightBreeze
- Market features and trends
- Program attribution

KEMA also questioned interviewees about their overall views related to the costs and benefits associated with both PIER projects.

- **PIER project materials.** PIER staff provided KEMA with various NightBreeze project materials. These included project reports, planning documents, and scopes of work. These sources furnished information regarding key variables as well as other benefit-cost data, such as PIER program costs.

As mentioned earlier, many socioeconomic and environmental factors, such as energy consumption patterns and climate characteristics, affect NightBreeze performance. This is especially relevant to replacement savings, which have the potential to vary widely according to causes unrelated to NightBreeze technology. To take account of this variation, KEMA conducted a sensitivity test using a range of estimated values for energy savings. KEMA also carried out a sensitivity test using different values for incremental cost. We describe these analyses in greater detail below.

Formulate scenarios and estimate TRC net benefits and benefit-cost ratios. Using the results of Step 2 above, KEMA developed specifications for scenarios that we believe reflect the possible effects of PIER involvement in support of NightBreeze technology. We then used those scenarios to calculate a range of TRC cost-effectiveness indices.

8.4. Benefit-Cost Calculations: Inputs and Results

KEMA developed benefit-cost ratios, discounted net benefits, and net present value figures associated with PIER support for NightBreeze night ventilation technology through the following steps.

8.4.1. Estimate Benefits

- Establish avoided costs for California. We obtained data on California avoided costs from the CPUC Avoided Cost Database used for assessing cost-effectiveness of proposed 2009 – 2011 energy efficiency programs. The time-dependent values for residential air conditioner measures ranged from $0.15 per kWh to $0.17 per kWh depending on utility and climate zone. For purposes of this analysis we use the mid-point of the range - $0.16 per kWh.

- Develop estimates of quantity of NightBreeze systems sold annually. Since its introduction, sales of NightBreeze systems have been minimal by industry standards. Given the limited availability of information about NightBreeze sales, KEMA asked experienced individuals with knowledge of the California heating and cooling market for their best estimates of units sold for three specific years, 2006, 2009, and 2015. Responses were aggregated and synthesized by KEMA, and Table 25 presents the results. Table 25 also notes the reasons for selecting these particular years.

Table 25. Estimated Quantity of NightBreeze Systems Sold Annually, for selected years

Year	Number of Units Sold	Reason for Year Selection
2006	**100**	**DEG launched first serious sales push after obtaining ETL certification**
2009	**50**	**Current market assessment**
2015	**1,000**	**Medium-term market assessment under variable conditions**

Note: According to DEG, the ratio of NB2 sales to NB1 sales is approximately two to one.

Respondents identified a number of factors that could significantly affect NightBreeze sales in the next several years. These included:

- The state of the California housing market, and the California economy more generally. Between 2005 and 2008, the number of estimated single-family homes completed in California decreased to 32,018 from 152,871. Observers of the California housing market anticipate that the number of new homes completed will not rise above 70,000 per year over the next few years due to continuing economic difficulties and the large number of unsold and vacant foreclosed homes in the inventory.[65]
- The availability of additional outside funding for DEG activities. Respondents identified prior PIER funding as essential to the development of NightBreeze technology. However, the end of the second PIER market development project left DEG with no substantial funding support for further refinement of the NightBreeze system. Without additional funding, DEG will lack the resources necessary to achieve full commercialization of the NightBreeze system. In particular, the company will be unable to develop a retrofit model for existing homes. (DEG is currently awaiting word on recent applications for funding submitted to the Energy Commission and DOE.)

65 http://realtytimes.com/rtpages/20080715_newhomes.htm

- o Possible cooperative agreements with major manufacturers. An alliance with one or more major HVAC manufacturers would permit DEG to achieve significant reductions in production cost. Process efficiencies, advanced production methods, and economies of scale would all contribute to a lower cost, more competitive version of the NightBreeze system. Cooperative agreements with established manufacturers would also make existing marketing and distribution networks available for promoting NightBreeze.
- o Utility incentive programs. Both PG&E and SCE provided incentives for NightBreeze systems in previous years, but neither IOU currently operates such a program. Several respondents argued that renewed rebates for night ventilation technology would stimulate a measurable increase in NightBreeze sales. However, these respondents were unaware of specific proposals to amend residential energy efficiency programs to support ventilation cooling systems.
- o The wider adoption of TOU rate structures. TOU rate structures reflect the high cost of peak power generation relative to off-peak generation. Because NightBreeze produces disproportionate reductions in peak energy consumption, many interviewees viewed NightBreeze technology as ideally situated to take advantage of dynamic pricing schemes for residential customers. Expanded use of TOU structures in California would likely result in higher NightBreeze sales volumes.
- o Inclusion of NightBreeze as a Title 24 compliance credit. Energy efficiency advocates are currently lobbying for inclusion of night ventilation technology as a compliance credit in the next round of Title 24 revisions. Such a modification would allow builders, architects, and others to utilize NightBreeze technology in meeting energy budgets under the dominant performance approach to Title 24 compliance. Respondents believed that the Energy Commission is almost certain to adopt this amendment. They also believed that this amendment is likely to be the most significant driver of future NightBreeze sales.

Generally speaking, the respondents believed that the pace of growth in sales of NightBreeze and similar systems would be low. The primary reasons for this assessment included the following:

- **The market for night ventilation systems has been hampered by high cost and a lack of information.** The cost of NightBreeze technology relative to a conventional system has been an obstacle to wider deployment (see discussion of incremental cost below). In addition, a lack of information about night ventilation in the heating and cooling market has minimized participants' awareness of product availability, benefits, and operation. Ignorance about NightBreeze extends from homebuilders and contractors to homeowners and consumers.
- **PIER has failed to overcome these barriers.** The cost of NightBreeze systems remains high, especially in the retrofit market. With respect to information, respondents

criticized PIER for restricting its focus to a narrow audience of specialty builders and contractors.

- **Without additional effort, the market for NightBreeze and other ventilation cooling systems is likely to remain sluggish.** Currently, sales, market share, and margins are all very low for NightBreeze. In the absence of additional funding sources, from PIER or another organization, the future of NightBreeze technology is uncertain. Favorable revisions to Title 24 would help stimulate demand for ventilation cooling systems.

To carry out cost-effectiveness calculations, KEMA assumed constant rates of change in sales volume between 2006 and 2009, and between 2009 and 2015. We used the resulting slopes to approximate units sold for each intervening year.

- Estimate energy savings for NightBreeze systems. There were three different estimates of energy savings available for use in benefit-cost calculations. KEMA calculated the first of these using data from the first PIER NightBreeze project. Project researchers estimated that statewide adoption of NightBreeze technology would produce total energy savings (across all climate zones) of 97.6 GWh per year.[66] The research team also assembled data on the 2002 new residential construction market in California (including housing starts), broken down by climate zone.[67] Combining these figures resulted in a weighted average energy savings estimate of 900 kWh per NightBreeze system per year.

  A second estimate derived from the PG&E study, which monitored six homes located in California climate zone 12. Climate zone 12 is located in the Northern California Central Valley, with Stockton as its reference city. Zone 12 has a "moderate inland valley" climate. The study concluded that the average peak energy savings produced by a NightBreeze system was 47.8 percent.[68] These savings were attributable to reduced use of central air conditioners in residential buildings. The Energy Information Administration's (EIA) 2005 Residential Energy Consumption Survey (RECS) found that the average electric consumption by a California household for cooling using central air systems was 1,637 kWh.[69] Combining PG&E test results with average cooling energy use data produced a NightBreeze energy savings estimate of 782 kWh.

  A final estimate of energy savings was calculated by project researchers as part of PIER's NightBreeze market development project. In the project report, DEG estimated that a NightBreeze system saves approximately 400 kWh per year.[70] Specifically, DEG assumed 400 kWh as the weighted average for all climate zones per estimates of new home construction.

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66 Springer, 54.

67 Ibid.

68 Matrix Energy Services, *Residential Night Ventilation Monitoring and Evaluation*, prepared for Pacific Gas and Electric Company, November 2007, 46.

69 http://www.eia.doe.gov/emeu/recs/recs2005/c&e/airconditioning/excel/tableac5.xls.

70 See Springer, *Alternatives*, 40.

Given the differences among these estimates, KEMA conducted a sensitivity analysis using the following three values for estimates of energy savings: 400 kWh, 650 kWh, and 900 kWh. This range of estimates accommodates the array of energy savings values that are likely to obtain across different California households in different climates.

- Estimate cost savings associated with NightBreeze. Three different estimates of cost savings were available. The first two derived from research conducted as part of the original PIER NightBreeze project. Using data collected from the Livermore demonstration site, researchers calculated a range of annual cost savings estimates across all sixteen California climate zones under both flat rate and TOU rate scenarios.[71] Combining these figures with data on the new residential construction market (see above) resulted in two separate estimates, each weighted for all climate zones: under flat rates, NightBreeze produced annual savings of $12 per unit, while under TOU rates, average annual cost savings were $285 per system.

A third estimate derived from a 2007 study commissioned by PG&E. As part of this study, researchers conducted rigorous tests of NightBreeze systems and determined that homes equipped with NightBreeze averaged cost savings of 1.7 percent.[72] According to the 2005 RECS survey, average energy expenditure per California household was $1,396.[73] Combining these figures produced cost savings per NightBreeze unit of $24.

8.4.2. Estimate Costs

- **Quantify PIER program costs.** KEMA derived information about program administrative costs from program documents provided by PIER.[74] The project budget for ACC Phase V was approximately $715,000, and the budget for the market development project was approximately $280,000.
- **Determine incremental cost of NightBreeze.** In multiple interviews, KEMA asked market participants and observers to estimate incremental cost. Most responses fell between $1,500 and $2,000 per unit. We adopted this range as representative of NightBreeze incremental costs. KEMA conducted a sensitivity test using $1,500 and $2,000 per unit to assess the effects of different incremental cost values.

Given the generally low economic return on investment predicted for the NightBreeze system, we assume that the system as well as similar night ventilation systems will only be considered for use in new construction.

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71 Ibid., 46. Flat rates correspond to E-1 rates. TOU rates correspond to E-7 rates.

72 Matrix Energy Services.

73 http://www.eia.doe.gov/emeu/recs/recs2005/c&e/summary/excel/tableus1part1.xls.

74 *Public Interest Energy Research: 2003 Annual Report*, March 2004.

Assessment of the effect of PIER activities on NightBreeze development. In multiple interviews with experts on night ventilation technology, markets, and associated regulatory issues, KEMA asked interviewees a series of questions relating to PIER's support of NightBreeze and the broader ventilation cooling market. The interviewers agreed that PIER has been essential to the development of NightBreeze technology. Virtually all respondents viewed PIER support as indispensable to the design, manufacture, and commercialization of NightBreeze systems. Given the paucity of funding sources available to small companies like DEG for unconventional projects like NightBreeze, funding by PIER was crucial to product development and deployment. Most interviewees agreed that without PIER, NightBreeze would not exist. We therefore attribute all energy benefits generated by the forecasted sales of the NightBreeze and similar devices to the effects of PIER, as well as all customer costs associated with those projected sales.

Calculate Benefit-Cost Ratios and Net Benefits. Table 26 shows the results of benefit cost calculations using the Total Resource Cost test formulas. Additional assumptions incorporated into the benefit-calculations include the following:

- **Discount Rate:** 8.15 percent, per the *Standard Practices Manual*.
- **Effective Useful Life:** 12 years. This is the effective useful life assigned to all residential HVAC control measures in the Database of Energy Efficiency Resources (DEER).
- **Measure cost inflation:** One percent per year.
- **Benefit-cost assessment horizon:** 20 years.

Table 26. Results of TRC Benefit-Cost Calculations

	NPV in 2009 $000s			
Cost Assumptions/ Annual Savings	**Benefits**	**Costs**	**Net Benefits**	**TRC B/C Ratio**
Low Cost				
400 kWh/Year/unit	$1,496	$5,472	($3,976)	0.273
650 kWh/Year/unit	$2,430	$5,472	($3,042)	0.444
900 kWh/Year/unit	$3,365	$5,472	($2,107)	0.615
High Cost				
400 kWh/Year/unit	$1,496	$6,989	($5,494)	0.214
650 kWh/Year/unit	$2,430	$6,989	($4,559)	0.348
900 kWh/Year/unit	$3,365	$6,989	($3,624)	0.481

As Table 26 shows, PIER's investment in the NightBreeze technology does not yield positive net present values or benefit-cost ratios greater than 1.00 under any of the sets of assumptions concerning unit savings and cost described above. The maximum TRC benefit-cost ratio achieved is 0.615. Given these results, we set the net present value of the project at PIER's project cost, namely: -$995,000.

Conduct sensitivity analysis. KEMA conducted a "break-even" analysis to identify market conditions under which PIER's investment in the NightBreeze technology would become cost effective. To do this we varied the values of each of the following assumptions or inputs:

- Unit costs;
- Time-dependent avoided costs; and,
- Volume of units sold.

To assess the relative influence of each of these factors, we varied them individually until the TRC benefit-cost ratio attained the value of 1.00, while holding the other two values constant. Table 27 displays the results of this exercise.

Table 27. Assumed v. Break-Even Values for Key Benefit-Cost Inputs

Benefit-Cost Analysis Input	Documented Assumption	Break-Even Value
Unit Cost	$1500 - $2,000	$805
Time-differentiated avoided cost	$0.16/kWh	$0.27/kWh

Because the energy cost savings associated with the implementation of NightBreeze technology are low compared to its cost, we found that there was no volume of sales that could drive the TRC benefit-cost ratio to 1.00 while holding assumptions concerning unit cost and time-dependent avoided costs constant. Table 27 shows the break-even values for unit costs and avoided electricity costs at which the TRC benefit-cost ratio equals one, as well as the assumptions used for the benefit-cost analysis. The results displayed in Table 27 suggest that the simple payback relationship between measure costs and savings would need to improve by roughly 40 percent – either through decreases in measure costs, increases in avoided costs, or some combination of the two – if the NightBreeze technology is to become cost-effective within the benefit-cost framework that is most commonly used in the California regulatory and policy arena.

Currently, supporters of night ventilation technology are focused on revising Title 24 in order to qualify NightBreeze as a compliance credit eligible to help meet residential building codes. In the course of conducting other case studies and reviewing additional PIER projects for potential case study development, we have found that qualification of a technology or measures for compliance credit does not necessarily lead to significant market penetration. For example, the LED nightlight/sensor discussed in the final case study of this report is qualified for compliance credit but has sold very few units. Similarly, KEMA reviewed residential green roofs for a potential case study, but found that this technology had experienced little adoption despite being qualified for compliance credit. Given NightBreeze technology's marginal economic value to homebuyers, we believe it is unlikely that qualification for compliance credit will greatly increase the volume of units installed.

In any case, as the sensitivity analysis described above showed, even significant increases in volume installed will not lead to a benefit-cost ratio greater than 1.00. Rather, the problem lies with the relatively high cost of the measure compared to its potential energy savings. The NightBreeze is a complicated measure, consisting of many diverse components, including an additional plenum and vent damper, jumper ducts between the room in which the main return duct is located and other rooms, and HVAC controls that are much more sophisticated and difficult to set up than those with which the typical residential HVAC technician is familiar. Given this product configuration, it is difficult to imagine circumstances under which installation costs could be reduced significantly or large numbers of HVAC contractors would invest in the training needed to install these devices in significant volumes.

9.0 Case Study: Hotel Bathroom LED Night Lighting

This chapter presents the benefit-cost analysis conducted on PIER support for Hotel Bathroom LED Night Lighting technology development. It begins with a brief description of the Hotel Bathroom LED Night Lighting technology and of the PIER work designed to promote its development and adoption. The chapter continues with detailed benefit-cost calculations and results, and ends with concluding remarks about PIER and the Hotel Bathroom LED Night Lighting technologies.

9.1. Product Descriptions

The PIER Hotel Bathroom LED Night Lighting project developed two technologies: a Lighting Control System and a Smart Light Fixture. Both the Lighting Control System and the Smart Light Fixture include a LED night light and an occupancy sensor in their design. Both technologies save power by simultaneously turning on an LED night-light and turning off the vanity fixture lighting when the occupancy sensor fails to detect an occupant for a pre-determined period of time. Turning on the LED nightlight protects motionless occupants (long bath takers) from being plunged into complete darkness while saving electricity when the lights are left on either accidentally or to serve as a night light. The time-out for the occupancy sensor is typically set to an hour or more to minimize the chance of turning off the lights with an occupant in the room (a “false-off”). This hour time-period is much longer than normal occupancy sensors’ time-out of 15 to 30 minutes. This time setting is a compromise between energy savings and hotel operator’s fear of inconveniencing guests.

These products were developed as a response to earlier research which showed most hotel bathroom energy use occurred when the lights were left on for more than two hours at a time.[75] This can occur when occupants or staff forget to turn off lights when they exit a room.[76] In addition, many hotel guests leave the bathroom lights on at night with the door slightly open to serve as a nightlight.[77] This practice eases the discomfort of being in an unfamiliar setting, but increases electricity usage. The Hotel Bathroom LED Night Lighting technologies provide a night light to ease the guest’s discomfort in an unfamiliar setting, while also reducing power consumption in hotels.

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75 Page, Erik and Siminovitch, Michael, 2000. “Lighting Energy Savings Opportunities in Hotel Guestrooms: Results from a scoping study at the Redondo Beach Crown Plaza” *Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings*, August 20-25, 2000, Pacific Grove, CA

76 Page, Erik and Siminovitch, Michael, 2004. “Performance Analysis of Hotel Lighting Control System” ACEEE Conference Paper on the WN-100 Technology. 2004

77 Page, Erik and Siminovitch, Michael, 2005. “Project 4.1 Hotel and Institutional Bathroom Lighting” California Energy Commission Public Interest Energy Research Program, CEC-500-2005-141-A10, October 2005.

Traditionally, hotels have been averse to placing occupancy sensors in bathrooms. Despite the potential utility-bill savings, hotels fear guest reactions when the sensor does not correctly determine room occupancy because of minimal occupant movement, such as when a guest takes a long bath. In an industry sensitive to client perception of comfort, unintentionally plunging guests into darkness would likely result in negative guest experiences. The Lighting Control System and Smart Light Fixture explicitly address this concern by setting the occupancy sensors time-out to one hour. This minimizes the risk that guests will have the lights turned off on them while in the bathroom.

Major components of both products developed for the Hotel Bathroom LED Night Lighting project include:

- An LED nightlight consuming less than one watt.
- Switching logic that turns on the LED nightlight when the overhead light is turned off.
- An occupancy sensor with a variable timeout that can be set between 15 minutes and two hours. The project tested both products with the time-out set to one hour.

The two products vary in the placement of these components: the Lighting Control System, which replaces a standard wall switch, houses both the occupancy sensor and the LED nightlight in the Lighting Control System while the Smart Light Fixture houses the occupancy sensor and LED nightlight in the vanity fixture. The final project report indicates the Smart Light Fixture should have slightly fewer false-offs since the occupancy sensor in the vanity fixture should have a better "view" of the room.

9.2. Project Overview

9.2.1. Product Development and Testing

PIER delivered support for the Hotel Bathroom LED Night Lighting through funding under an umbrella program: the Lighting Research Program. The Lighting Research Program "was a R&D program focused on developing and introducing new energy efficient lighting technologies into the marketplace."[78] It was funded by the California Energy Commission and managed by Architectural Energy Corporation. The Hotel Bathroom LED Night Light project was one of 18 projects funded under the Lighting Research Program umbrella contract. The Lighting Control System was developed in phase I of the project and Smart Light Fixture was developed in phase II of the project.

Funding totaled $440,000.[79] The California Energy Commission provided $220,000 and matching funds of $220,000 were provided by third parties. Watt Stopper provided the majority of money but Double Tree and SMUD also provided financial support.

78 http://www.archenergy.com/lrp/index.htm

79 Pers. Comm. Sandra Fromm, October 15, 2009

According to the project website[80], the primary goals of the project were to develop both a switch retrofit controller (Lighting Control System) and a vanity light fixture (Smart Light Fixture) that resulted in quantifiable savings. The technology was expected to reduce bathroom-lighting electricity use by at least 50%. Goals stated on the project website are:

- Conserve energy and improve safety in hotel bathrooms and similar institutional applications.
- Create two lighting technologies suitable for hotel and institutional bathroom lighting that would reduce energy use by 50 to 75%.
- Cost payback period of three years or less for at least one of the systems.
- Develop a retrofit lighting-control system in Phase 1.
- Develop a "smart" luminaire in Phase 2 (smart refers to the ability to shut off lights when the room is unoccupied).
- Improve effectiveness of hotel bathroom lighting by reducing overall costs.

The Hotel Bathroom LED Nightlight project built on earlier research showing significant energy saving opportunities existed in hotel bathrooms. Since California currently has 5,489 hotels and 496,023 rooms,[81] PIER began research believing this represented a significant market that could be transformed by new technologies. Representatives of Watt Stopper report that the firm had become aware of these data through its own market research activities and had begun product development on the Lighting Control System (model # WN-100) in coordination with LBNL researchers. This development began before the PIER funding was made available.

PIER funding brought Watt Stopper's and LBNL's R&D efforts together along with fixture manufacturing expertise from SpecLight, and additional funding from SMUD. This allowed Watt Stopper to finish development of the product, partner with a lighting manufacturer to prototype the Smart Light Fixture, and run field trials with Lighting Control Systems and Smart Light Fixtures. Watt Stopper representatives report that PIER initiated its support early in the product development cycle. This is supported by goals and baseline conditions[82] detailed on the project website.

Watt Stopper successfully developed a Lighting Control System device in Phase 1 of the project: the WN-100. The WN-100 was deployed in a field study at the Double Tree hotel in Sacramento, CA. Published results show an average savings of 46.5% in light "burn-time." Project reports and interviews with SMUD employees involved with the project indicate the device was favorably received by both hotel guests and staff.

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80 http://www.archenergy.com/lrp/advlight_luminaires/project_4_1.htm

81 Pers. Comm. Erin Hannigan, STR Global, September 1, 2009. http://www.strglobal.com

82 http://www.archenergy.com/lrp/advlight_luminaires/project_4_1_baseline.htm

The published results for the Lighting Control System indicate researchers relied on data from only five rooms. More rooms were monitored, but data quality issues reduced the sample size to five. Four of these rooms were scheduled for high-occupancy (nearly 100%) at the request of the researchers. The fifth room was occupied approximately 80% of the time. Neither high-occupancy nor 80% occupancy is representative of reported hotel occupancy – the industry averages 65% occupancy.

Energy savings varied by room occupancy. Energy savings were higher in the room occupied 80% of the time (70%) than the average for the five rooms (46.5%). The researchers suggested that the greater savings were related to longer periods of vacancy when guests or staff left lights on and the room was then unoccupied for one or more nights. This resulted in continuous energy consumption until a new guest occupied the room.

Watt Stopper and SpecLight developed a Smart Light Fixture in Phase 2 of the project. It was field tested at three locations: one hotel (Red Lion Hotel Sacramento at Arden Village), one assisted living facility (Emerald Gardens), and one nursing facility (Regency Place). SMUD project staff report that the results were similar to those obtained for the Lighting Control System. However, these results were never published because the Smart Light Fixture went out of production. SMUD, who funded these studies, did not see any point in publishing results for a product that could not be purchased. SMUD employees thought this would create undue confusion for hotel operators whom they were trying to influence.

9.2.2. Support for Product Deployment

In the course of product testing and the development of a Technology Transfer Plan for the Lighting Control System[83] the project team identified a number of potential barriers to widespread adoption of the system and related products. The most important of these were:

- **Marginal customer cost-effectiveness.** The Technology Transfer Plan identified installation costs of nearly $35 and $58 for the WN-100. At this price, the lighting power controlled would need to exceed 100 watts in order for the device to be cost-effective to the customer. The Technology Transfer Plan also noted that the small sample of rooms monitored to estimate savings added uncertainty to the assessment of cost-effectiveness.
- **Incompatibility with applicable provisions of the Title 24 Energy Code.** Under California's Building Energy Efficiency Standards (Title 24), hotels are required to follow residential lighting requirements for guest rooms. Two applicable criteria of Title 24 were problematic for deploying the Lighting Control System and Smart Light Fixture in California:
    - The lumens/watt efficacy of the LED did not meet the lighting efficacy requirements of Table 150-C of Title 24. Thus, Title 24 would require the use of a motion sensor to control the LED and defeat its purpose.

83 Architectural Energy Corporation, *Technology Transfer Plan For Project 4.1 Motion Sensor Nightlight, Deliverable 4.1.5.a,* California Energy Commission Contract #500-01-041, June 5, 2003

  - The studied time-out of one hour exceeded the maximum allowable time-out under Title 24: 30 minutes.
- **Competing products in the market.** The Technology Transfer Plan lists several technologies that compete with this product. Products such as hair-dryer nightlights discourage guests from leaving the lights on overnight but do not capture other savings. Other systems can control energy throughout a guest room and reap more energy savings at a lower price. The Technology Transfer Plan emphasizes the need to clarify to hotel operators how the night lighting devices save energy.

Thus, the main message conveyed in the Technology Transfer Plan was that the Lighting Control System and related devices embodied an excellent technology for high-wattage lighting, and marketing should target chains with high-wattage lighting.

To support the broader deployment and adoption of bathroom night lighting devices, the PIER project undertook the following activities:

- Developed and submitted a code change proposal to the Energy Commission that would resolve the conflicts noted above between code requirements and the operation of the lighting controls.
- Approached the California Investor-Owned Utilities (IOUs) to request that they provide incentives for the adoption of hotel night lighting devices.
- Manufacturer-planned targeted rebates to stimulate demand for these products.

9.2.3. Current Status

Code change efforts. The December 2008 draft of "2008 Residential Compliance Manual" contains neither an allowance for the one-hour time delay in bathrooms nor rules to regulate hotel bathrooms separately from residential bathrooms and so we concluded that this portion of the proposal was rejected. However, Table 150-C was revised to require a lower efficacy of 30 lumens/watt for lamps under 5 watts, which allowed this technology to be code-compliant.

Utility program support. Direct incentives for the Lighting Control System and Smart Light Fixture are not offered by the California investor-owned utilities. Pacific Gas and Electric Company (PG&E), SMUD, and San Diego Gas and Electric Company (SDG&E) program administrators indicated that the Lighting Control System and Smart Light Fixture can receive incentives for a kWh reduction due to the occupancy sensor. However, there are no hotel-centric or device-centric incentives to encourage these specific technologies in California. It appears the only utility offering direct incentives for these devices is Seattle City Light.

Most surveyed parties indicated they did not know the Energy Commission funded development of these technologies through PIER. PG&E and SDG&E program administrators were unaware of the Energy Commission efforts and project reports. The program designer for Seattle City Light attributed his knowledge of the device primarily to SMUD's Emerging

Technology website containing study results and Watt Stopper technology advertising. When questioned pointedly on the matter, he mentioned he probably read something that indicated the research and development was funded by the Energy Commission from the SMUD website.

Product Availability. Manufacturers continue to use data from the Energy Commission-sponsored studies to support marketing of occupancy sensor-related products for bathrooms in hotels and other residential facilities. Watt Stopper highlights results from the Double Tree monitoring study on their website.[84] Memorytime – another controls manufacturer – has issued a press release for their competing product, the "Lite-A-Switch",[85] which specifically mentions that "[d]evelopment of the Lite-A-Switch was inspired by studies in the hotel sector showing that 55% of hotel guests use the bathroom light as a nightlight." The research is not explicitly cited but is most likely a reference to the PIER Hotel and Institutional Bathroom Lighting project report since it uses one of the strategies developed in the project. However, it is possible Memorytime independently developed the "Lite-A-Switch" based on an earlier LBNL study that inspired the PIER project.

Many manufacturers offer products that fit the Lighting Control System description; these products are available for both residential and commercial applications. Watt Stopper currently sells the WN-100, FS-205HN, RS-250-N, and RS-150BA-N. Sensor Switch sells the WSD-NL. MemoryTime sells the Lite-A-Switch. Leviton sells the OSSNL-IDW. Hubbel Wiring Devices sells the RMS101ILI.

These products are available at a variety of outlets. The Leviton OSSNL-IDW is available on Amazon.com. Grainger Industrial Supply sells the lighting control system by Hubbel Wiring Devices. Dale Electric Supply Co. sells the Hubbel Wiring device as well. Watt Stopper has sold their devices through Home Depot in the past.

Sales. Manufacturers report that they expect to sell approximately 10,000 commercial devices in 2009. This is a significant reduction in sales from their peak of 20,000 devices in 2007. They attributed this to the downturn in the economy. Sales of residential devices are also down. This is partially due to economic conditions, but also results from the expiration of a Home Depot promotion.

9.3. Benefit-Cost Calculations: Methods

HMG conducted a cost-effectiveness assessment of PIER's involvement in support of Bathroom LED Night Lighting technology using the California Total Resource Cost Test framework. The assessment proceeded in the following steps.

- **Identify key variables.** HMG used information from project documents, independent research on market penetration and factors, and in-depth interviews with project

84 http://www.wattstopper.com/getdoc/426/DoubleTreeCaseStudy.pdf

85 http://www.prlog.org/10227808-new-energy-efficient-led-night-light-enhances-guest-safety-saves-hotels-money-on-every-room.html

participants and market actors to develop a set of initial scenarios for cost-effectiveness testing within the TRC framework. This work identified key areas of uncertainty in regard to variables that exercise a large influence on net benefits and benefit-cost ratios.

- **Quantity of Lighting Control Systems and Smart Light Fixtures sold.** Since the introduction of the Lighting Control Systems and Smart Light Fixtures technologies, industry observers and participants report that sales have been low and market penetration minimal. Precise sales data, however, do not exist although some device manufacturers provided limited sales data. Predictions regarding future trends such as expected Compound Annual Growth Rates (CAGR) are not available. To address this, HMG combined manufacturer sales numbers with in-depth interviews to develop estimates of Lighting Control System and Smart Light Fixture sales. We discuss the interviews below.
- **Replacement savings produced by Lighting Control System and Smart Light Fixture.** Replacement savings associated with Lighting Control System and Smart Light Fixture systems take the form of energy savings attributable to reduced consumption. HMG referred to project materials and associated research to calculate replacement savings.
- **Influence of PIER activities.** In assessing benefits and costs of PIER projects, the central question is: to what extent did PIER activities influence market and regulatory outcomes? Determining program attribution in this instance relies primarily on qualitative assessments made by multiple experts distinguished by broad experience and diverse points of view. HMG assessed expert perspectives on the effects of PIER through structured interviews, described below.
- **Incremental cost of Lighting Control Systems and Smart Light Fixtures**. Incremental cost data are critical to calculating program cost in relation to benefits. HMG gathered information on the incremental costs of Lighting Control System and Smart Light Fixture systems during in-depth interviews with industry participants and observers.

Estimate value ranges for key variables. HMG estimated the plausible range of values for the variables identified above using the following sources:

- **In-depth interviews.** HMG conducted in-depth interviews with 10 individuals who have extensive professional involvement with and knowledge of the market and technology for bathroom lighting systems. Table 28 provides a list of these experts and their backgrounds.

Table 28. Interviewees for Hotel Bathroom LED Night Lighting Case Study

Interviewee	Affiliation	Background
Darren Nix	**Pacific Gas and Electric subcontractor: Ecology Action**	**Lodging Savers third-party program manager.**
Michelle Sivertsen	**Sempra program subcontractor at Intergy**	**Lodging Energy Efficiency Program third-party program manager.**
Dave Bisbee	**SMUD**	**Technology Development; former program manager for Hotel LED Night Light project.**
Michael Brozena	**Seattle City Light**	**Program Implementer: Hotel Efficiency**
Jon Null	**Watt Stopper**	**Technical Development manager for Hotel LED Night Light project; now a Product Line Manager**
Christopher Schrader	**Choice Hotels**	**Brand organization. Business Strategy. Green Strategy.**
Patrick Maher	**The Maher Group**	**AHLA Green Task Force Member; Hotel Efficiency Consultant**
Starwood Hotels	**Gus Newburry**	**Engineer; Head of Field Operations**

Additional hotel industry professionals were contacted. Three members of the AHLA green task force referred us to Patrick Maher as their spokesperson; an additional 12 members did not respond to requests for an interview. The California Lodging Association added a note to their monthly newsletter advertising the survey but none of that organization's members responded. No members of the Green Hotel Association responded. Eight Best Western franchises were contacted, but all declined to take part in the interview.

All manufacturers with a Lighting Control System product were contacted. Only Watt Stopper and Sensor Switch responded. An interview was conducted with Watt Stopper, but the interview with Sensor Switch fell through due to scheduling difficulties. However, Watt Stopper is licensing their technology to Leviton and was able to give us an estimate of their market share and the market as a whole.

We attempted to contact all California Investor-Owned Utilities and succeeded with two of the three. The utility contacts from PG&E and SDG&E were specifically for hotel lodging energy efficiency programs. The eight interviews were fruitful. These interviews covered a wide range of subjects relating to Hotel Bathroom LED Night Lighting, including the following key issues:

- Barriers to Lighting Control System and Smart Light Fixture adoption

- o PIER support for Hotel Bathroom LED Night Lighting
- o Lighting and bathroom retrofit schedules
- o Market features and trends
- o Program attribution

HMG also questioned interviewees about their overall views related to the costs and benefits associated with the PIER project

- o **PIER project materials.** PIER reports and data were obtained from Architectural Energy's and the Energy Commission's websites. This data provided HMG with various project materials. These included project reports, planning documents, and scopes of work. These sources furnished information regarding key variables such as PIER program costs.

Formulate scenarios and estimate TRC net benefits and benefit-cost ratios. Using the results of Step 2 above, HMG developed specifications for scenarios that we believe reflect the possible effects of PIER involvement in support of Hotel Bathroom LED Night Lighting technology. We then used those scenarios to calculate a range of TRC cost-effectiveness indices.

Assessment of the effect of PIER activities on Hotel Bathroom LED Night Lighting development. In multiple interviews with experts on hotel bathroom technology, HMG asked interviewees a series of questions relating to PIER's support of Hotel Bathroom LED Night Lighting. The interviews included questions about hotel bathroom lighting technology, markets, and associated regulatory issues.

Widespread deployment has been hampered by hotel operator skepticism and bigger energy savings opportunities elsewhere in hotels. Despite the favorable outcomes documented at the Double Tree in Sacramento, hotel industry professionals interviewed for this report indicated they would be unlikely to install the devices. Especially with higher-end chains, the professionals specifically stated that once a guest was in a room, they should have complete control over their experience. Adding an occupancy sensor to the bathroom would remove this control and so they would be unlikely to install these devices.

Other professionals noted that they could get more energy savings with other technologies. Over half of the surveyed respondents, including hotel industry professionals, utility representatives, and lighting manufacturer representatives indicated hotels were more likely to chase larger savings from other technologies than to look into energy savings in bathrooms. Multiple alternatives were mentioned, however, controlling guest-room HVAC with a key-card system was mentioned most frequently.

Spec Light's decision to withdraw the Smart Light Fixture from production has further hampered deployment. Watt Stopper sells a kit with the occupancy sensor and LED nightlight included which fixture manufacturers could incorporate in their products. However, they do not have any current contracts with lighting manufacturers to sell this kit. Watt Stopper attributed this to lack of experience among lighting manufacturers in promoting the energy efficiency aspects of their products.

However, other interviewees suggested that Metal Optics, the owner of Spec Light, may have quit manufacturing the Smart Light Fixture for reasons other than trouble marketing the device. These interviewees reported that a dispute over the intellectual property rights occurred after field trials of the Smart Light Fixture began. They believed this dispute deterred Spec Light from supporting the product. Representatives from Metal Optics, the owner of Spec Light, could not be reached for comment as to why they no longer produce the Lighting Control System.

Currently, sales and market share are low for Hotel Bathroom LED Night Lighting products. Both manufacturers and utility representatives expressed frustration that these technologies have not had better market penetration. They believe that Hotel Bathroom LED Night Lighting will remain a niche technology in the absence of additional funding sources or incentives. Alternately, they noted that a requirement for Hotel Bathroom LED Night Lighting in Title 24 would stimulate demand for these systems.

Even with increased utility support and alterations to Title 24, the results of our interviews suggest that not all hotels are likely to voluntarily adopt this technology. Hospitality professionals and utility program representatives indicated that lower-end to mid-range chains were most likely to install these devices as a cost-cutting measure. High-end hotels indicated their desire to protect their guests' ability to have complete control over the lights in their room. While none were interviewed directly, it was indicated that small, independent hotels are unlikely to install these devices. Most interviewees agreed these types of establishments do not typically have the expertise or time to learn about and adopt new technologies.

The interviewees outside the original project team were generally unaware that PIER had funded development of Hotel Bathroom LED Night Lighting products. Virtually all respondents viewed PIER support as a positive factor that, now that they were aware of it, would increase their interest in utilizing the technology.

Watt Stopper indicated that it would likely have pursued Hotel Bathroom LED Night Lighting technology in the absence of PIER support. Discussions with Architectural Energy Corporation[86] revealed Watt Stopper provided matching funds totaling about $120,000 or 35% of the project budget. The Watt Stopper representative stated that PIER support reduced development time, increased collaboration with researchers in the field, increased their opportunities for field trials of the product, and contributed case study material that is still in use to market the products. They viewed the PIER involvement as very helpful although not essential to their development of the Hotel Bathroom LED Night Lighting products they currently offer.

9.4. Benefit-Cost Calculations: Inputs and Results

HMG developed benefit-cost ratios, discounted net benefits, and net present value figures associated with PIER support for Hotel Bathroom LED Night Lighting technology through the following steps.

86 Pers. Comm. Judie Porter, Architectural Energy Corporation, Oct 16, 2009

9.4.1. Estimate Benefits

- Establish avoided costs for California. We utilized the E3 calculator for 2009 planning purposes to establish avoided costs. The E3 calculator contains the CPUC-accepted avoided cost values.
- Develop estimates of quantity of Lighting Control Systems and Smart Light Fixtures sold annually. Since its introduction, sales of Lighting Control System and Smart Light Fixture systems have been minimal by industry standards. Given the manufacturers' willingness to provide information on sales, HMG asked experienced individuals with knowledge of the California hotel lighting market for their best estimates of future sales. Responses were aggregated and synthesized by HMG, and Table 29 presents the results. Table 29 also notes the reasons for selecting these particular years.

Table 29. Estimated Quantity of Lighting Control Systems and Smart Light Fixtures Sold Annually, for selected years

Year	Number of Units Sold	Reason for Year Selection
2005	**0**	**Case study ended**
2007	**20,000 (US); ~2600(CA)**	**Per Watt Stopper actual national sales figures combined with estimate of other manufacturers, CA estimates per hotel room share**
2009	**10,000 (US); ~1300(CA)**	**Per Watt Stopper estimate national sales figures combined with estimate of other manufacturers, CA estimates per hotel room share**
2012	**~1400 (CA)**	**2009 estimates with 3% annual increase**
2015	**~1530 (CA)**	**2009 estimates with 3% annual increase**

Respondents identified a number of factors that could significantly affect Lighting Control System and Smart Light Fixture sales in the next several years. These included:

- The state of the California market, and the California economy more generally. According to the Wall Street Journal, average debt per hotel room has risen to $5,083 making it difficult to build new hotels or renovate existing hotels.[87] The number of new hotels completed or renovated is likely to remain low over the next few years due to continuing economic difficulties.
- Utilities do not offer targeted incentives for these devices.
- The Smart Light Fixture is not currently in production. The utility companies or the California Energy Commission could offset the price of the occupancy sensor and LED nightlight to push the Smart Light Fixture back into the marketplace. SMUD has study results showing these fixtures were well received and save energy at rates

87 http://online.wsj.com/article/SB10001424052748703790404574469120027986600.html?mod=WSJ_hpp_MIDDLENexttoWhatsNewsForth

similar to the Lighting Control System. SMUD employees expressed dismay that these products were no longer available.

Generally speaking, the respondents believed that the pace of growth in sales of Lighting Control Systems and Smart Light Fixtures would be low. The primary reasons for this assessment included the following:

- o The market for Lighting Control Systems and Smart Light Fixtures has been hampered by industry concerns about guest comfort and control. The cost of the Lighting Control System was not named as an obstacle to wider deployment during interviews. However, all interviewees expressed concern that hotel guests would react negatively to these devices.
- o PIER research and guest feedback were not relayed to industry professionals. The PIER-sponsored research showed guests were receptive to the new devices. Double Tree employees reported some guests were so happy they requested information on how to acquire one for their own home. Despite this, manufacturers have been unable to keep the Smart Light Fixture in production or significantly transform the hotel bathroom lighting market with the Lighting Control System.
- o Without additional effort, the market for Hotel Bathroom LED Night Lighting is likely to remain sluggish. Currently, sales and market share are low for Hotel Bathroom LED Night Lighting. Both manufacturers and utility representatives expressed their belief that Hotel Bathroom LED Night Lighting will remain a niche technology in the absence of additional funding sources or incentives. To carry out cost-effectiveness calculations, HMG assumed a 3% annual increase in product adoption after 2009. Sales estimates for 2009 were obtained from manufacturers and scaled up at this rate until 2015. We assumed California sales of 1300 units in 2009 and 1550 units in 2015.

- Estimate energy savings for Hotel Bathroom LED Night Lighting systems. There are several different factors affecting estimates of energy savings available for use in benefit-cost calculations: room occupancy rates, lighting technology type, hotel type, and lighting intensity.
  - o The Double Tree study results indicated more savings from unoccupied rooms than from occupied rooms. This surprising finding was attributed to guests or staff leaving the lights on when exiting the room. Because the room was unoccupied for one or more days after this, lamp burn-time was reduced from one or more days to just one hour resulting in significant savings.
  - o Furthermore, the savings values published in the Double Tree study were from rooms artificially skewed toward high-occupancy conditions. Hotel room occupancy hovers around 65% over time and none of the published results are from a room that is representative of this average. Even the least occupied room was occupied 85% of the time, but it amassed savings of 70% compared to 47% for rooms occupied nearly 100% of the time. This implies the previous PIER report may have underestimated potential savings per unit. Thus, we conducted sensitivity analysis to test the effects

on cost-effectiveness of variations in unit savings. We used unit savings associated with 100 percent and 80 percent occupancy.

- o Bathroom lighting technology type affects savings estimates. When more efficient fluorescent is used, Hotel Bathroom LED Night Lighting systems offer a lower return on investment. The savings estimates contained in the Double Tree case study appear to be for a vanity fixture containing five 40-watt incandescent bulbs. While incandescent bulbs are currently allowable in hotel bathrooms provided they are controlled by an occupancy sensor, federal law will phase out incandescent bulbs starting in 2012.[88] This implies the long-term savings should be calculated using fluorescent rather than incandescent lighting. In addition, many hotels have already installed fluorescent lighting, which significantly reduces potential energy savings from lighting controls. Thus, we provide savings estimates taking into account the deployment of more efficient lighting in hotel bathrooms.
- o Lower-end and mid-range hotel chains are most likely to adopt this technology. High-end hotels will protect their guests' ability to choose how to control the lights, and small, independent hotels are unlikely to install these devices.
- o A reduction in total light could reduce power consumption. However, we assumed hotels are already providing what they consider to be an "optimal" quantity of light and that this is unlikely to change in the foreseeable future.

9.4.2. Estimate Costs

- **Quantify PIER program costs.** HMG acquired program budget information from the Energy Commission. The project budget for Task 4.1 was approximately $220,000 and $220,000 in matching funds was provided by a consortium including SMUD, Watt Stopper, and the Double Tree hotel; the primary contributor was Watt Stopper who provided approximately $120,000 in matching funds.
- **Determine incremental cost of Hotel Bathroom LED Night Lighting.** HMG estimated incremental costs based on information in manufacturer interviews. We assume the incremental cost of a Lighting Control System would be $20 for new construction and $39 for bathroom retrofits. We assumed $10 represented the labor cost of removing the old wall switch and installing the Lighting Control System.[89] We did not develop cost estimates for the Smart Light Fixture as it is no longer sold.

Given the generally high economic return on investment predicted for the Hotel Bathroom LED Night Lighting system, we assume that it will be considered for use in both new construction and retrofits, especially to control incandescent lighting.

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[88] http://www.nytimes.com/2007/12/22/business/22light.html

89 This differs from numbers presented in the Technology Transfer Plan. The price of the unit itself came down significantly and we assumed hotel chains would have maintenance staff that could replace the switches in 15 minutes at a cost of $10. This is comparable to the Double Tree's reported time and cost presented in the case study.

Calculate Benefit-Cost Ratios and Net Benefits.

Table 31 shows the results of benefit-cost calculations using the Total Resource Cost test formulas. Additional assumptions incorporated into the benefit calculations include the following:

- **Discount Rate:** 8.15 percent, per the *Standard Practices Manual*.
- **Effective Useful Life:** 7 years. This is the effective useful life assigned to all hotel guest room lighting measures in the Database of Energy Efficiency Resources (DEER).
- **Measure cost inflation:** No increase per year. From 2005 to 2009, the unit cost has decreased by 50%.
- **Benefit-cost assessment horizon:** 20 years.
- **PIER project costs:** $340,000 in the first year.
- **Administrative costs:** $20,000 in overhead and G&A, $3,000 for market outreach, and $10,000 for rebate processing and inspection.
- **Incentive:** $10.00 per device as recommended in the technology transfer plan.
- **Express Efficiency Rebate Program NTG Default:** Net to gross of 0.96.

Electricity savings as follows:

Table 30. Electricity Savings

Modeled Electricity Savings (kWh / kW)		
	Medium-high occupancy ~ 80%	***High occupancy ~ 100%***
Incandescent	228 kWh / .203 kW	148 kWh / .203 kW
Fluorescent	76 kWh / .068 kW	49 kWh / .068 kW

TRC Results. As Table 31 shows, PIER's investment in the Hotel Bathroom LED Night Lighting technology yields positive net present values only when controlling incandescent lighting. However, it is reasonable to assume that savings are actually greater than this measured across the population of hotel rooms since savings are expected to rise as occupancy goes down to average levels around 65 percent.

Table 31. Results of PIER TRC Benefit-Cost Calculations

Cost Assumptions/ Annual Savings	NPV in 2009 $000s Benefits	Costs	Net Benefits	TRC B/C Ratio
Replacement - Incandescent				
100% occupancy, 148 kWh/Year/unit	$793	$649	$143	1.22
80% occupancy, 228 kWh/Year/unit	$1,218	$649	$568	1.88
Replacement - Fluorescent				
100% occupancy,49 kWh/Year/unit	$263	$649	($387)	0.40
80% occupancy, 76 kWh/Year/unit	$406	$649	($243)	0.63

The products can be offered in utility programs with an incentive and reach a BCR of 1.0 (Table 4). When the PIER investments of $440,000 are dropped from the calculation, as they would be for program design, the BCR values are much more favorable. Comparison of Tables 31 and 32 reveals that a cost reduction drives this change. This indicates a utility incentive program combining the Lighting Control System with fluorescent lighting is cost-effective in spite of the 100% occupancy BCR listed in Table 32.

Table 32. Results of Program TRC Benefit-Cost Calculations

Cost Assumptions/ Annual Savings	NPV in 2009 $000s Benefits	Costs	Net Benefits	TRC B/C Ratio
Replacement - Incandescent				
100% occupancy, 148 kWh/Year/unit	$793	$309	$483	2.56
80% occupancy, 228 kWh/Year/unit	$1,218	$309	$908	3.94
Replacement - Fluorescent				
100% occupancy,49 kWh/Year/unit	$263	$309	($46)	0.85
80% occupancy, 76 kWh/Year/unit	$406	$309	$96	1.31

Conduct sensitivity analysis. HMG conducted a "break-even" analysis to identify market conditions under which PIER's investment in the Hotel Bathroom LED Night Lighting technology would become cost-effective. To do this, we assumed one type of lighting and one occupancy rate and varied the number of units sold annually until a BCR of one was achieved. Our fixed values were:

- Lighting technology: fluorescent or incandescent.
- Room occupancy: high-occupancy or 80% occupancy.[90]

We held the lighting type and occupancy rate constant and used a binary search pattern to find a number of units that yielded a TRC benefit-cost ratio of 1.00. Results in Table 33 show that the PIER program has the potential to achieve a BCR greater than or equal to 1.

Table 33. Unit Volume Necessary for the PIER Project BCR to Be Greater Than One

Benefit-Cost Analysis Input	Fluorescent Lighting	Incandescent Lighting
High-occupancy (nearly 100%)	N/A	1025 units / year
80% occupancy	4060 units / year	560 units / year

Table 33 shows the PIER project is not cost-effective when used to control fluorescent lighting at current sales volumes. If sales volumes were to rise above 5150 units per year the project would be cost-effective since room occupancy is generally below 80% and fluorescent lighting is becoming prevalent. We assume savings would increase with decreased occupancy, but do not present that finding here due to a lack of monitored data to base the result upon. Our results show that if sales volumes had jumped to at least four times their current rate (1300 units / year) and then did not drop for the first seven years then a BCR greater of one would be achieved. Other growth options besides a step change would have led to this result as well.

Our calculations also show that rooms with fluorescent lighting and 100% occupancy can never reach a BCR of one. A sales volume of 100,000, the highest number tested, yielded a BCR less than one. Even if sales did reach 100,000 units per year, all bathrooms with Hotel Bathroom LED Night Lighting would be retrofitted in less than 4.5 years. Thus, retrofit of continuously occupied rooms with fluorescent fixtures cannot result in cost-effectiveness for the Hotel LED Nightlighting project.

9.5. Hotel Bathroom LED Night Lighting Conclusions

The actual results of this PIER project are difficult to assess. Given the BCR ranges from .63 to 1.88 depending on lighting technology and occupancy rates, it is unclear what BCR to assign the project as a whole. Watt Stopper's past sales numbers are sufficient to give this PIER project a BCR greater than one if all purchased devices were installed, and they controlled incandescent

90 These values are higher than those seen across the industry, but data were available to support the analysis. Future monitoring studies could provide more representative values which would be expected to improve the results of the TRC.

lighting. The BCR for high-occupancy (~100%) situations can be discounted as being unlikely since hotel occupancy averages 65%. Thus the BCR lies somewhere between .63 (all fluorescent) and 1.88 (all incandescent).

Watt Stopper reports selling 72,000 units to hotel rooms in the United States since the product line went into production in 2002. It seems reasonable to assume at least 13%, or 9360, of these units ended up in California.[91] This is roughly equal to the number of units we project (9961) for our TRC test above. If half were installed in bathrooms with incandescent lighting (greater savings) and the other half installed in rooms with fluorescent lighting (smaller savings), then the resulting BCR would be 1.25, assuming the rooms were occupied 80% of the time. In another scenario, if all of these devices ended up at energy-conscious chains with fluorescent lighting, then the BCR is only .63. Unfortunately, this lower BCR seems more likely, especially since all interviewees explicitly mentioned they would recommend upgrading to fluorescent lighting before adding advanced lighting controls like occupancy sensors.

Estimates in this evaluation probably underestimate energy savings and net benefits for two reasons: (1) savings should increase with industry average occupancy rates, and (2) some hotels would control incandescent lighting with the lighting control system. Both factors would increase energy savings and net present value attributable to the project. However, we were unable to assess these conditions due to lack of data. Thus, this report represents a conservative estimate of savings. Future monitoring studies could yield more representative savings estimates for future installations. Research to ascertain what lighting technology is typically controlled is unlikely to be cost-effective since incandescent lighting will be phased out after 2012 by federal mandate.

Annual Lighting Control System sales of 4060 units would cause the Hotel Bathroom LED Night Lighting project to become conclusively cost-effective (BCR greater than 1). A net present value near zero would be achieved if all devices controlled fluorescent lighting and the net present value would grow more positive with each additional device that controlled incandescent lighting. This is not an unreasonable target: each year approximately 49,000 hotel bathrooms are remodeled. If only 8.5% of these remodels installed the Lighting Control System, cost-effectiveness would be achieved (Table 6).

Current utility programs addressing a wide range of hotel energy efficiency measures are unlikely to meet these goals. To date, they have not convinced sufficient numbers of hotel operators to install these devices. Pacific Gas & Electric's Lodging Savers recommended these devices to 25% of hotels in their program. They recommend the device to those hotels they believe to be most likely to adopt the technology. Only 20% of hotels receiving the recommendation followed it. In the end, only 5% of hotels in the program adopted LED nightlighting technology.[92] Even if one optimistically assumes 20% of hotels would adopt the technology (if they all received the recommendation), sales numbers from program enrollees

91 Thirteen percent of United States hotel rooms are located in California as mentioned earlier in the report.

92 Pers. Comm. Darren Nix, Ecology Action. Interview September 14, 2009

would remain too low to yield positive net benefits. Unless programs attempt to reach more hotels or drastically improve their ability to convince operators to adopt this technology, the current program enrollment goals are not sufficient to make the Hotel LED Night Lighting project cost effective.

However, utility programs specifically targeting this technology could be added. Pacific Gas & Electric and Sempra provide incentives for this technology on a kWh basis. A program designed to accelerate adoption of these products could more effectively advertise their benefits. Instead of being one of many technologies paired incentives tied to kWh savings, it would be one of a few products with aggressive promotion. We believe this promotion will be necessary to overcome hotel operator skepticism, especially skepticism that guest comfort will not be impaired.

In addition, we could find no mention of lodging incentive programs at Southern California Edison. Addition of a targeted program in Southern California Edison territory could reach a market that appears completely untapped.

The Energy Commission should encourage and provide targets for California's IOUs to pay incentives on these technologies. The Lighting Control System provides cost-effective energy savings as shown by the example utility program examined in this report (Table 4). Increasing Lighting Control System sales will show occupancy sensors can thrive in the hotel bathroom market. This will provide motivation for fixture manufacturers to collaborate with Watt Stopper to revitalize the Smart Lighting Fixture designed in this project.

Current utility incentives are significantly lower than those recommended by the Technology Transfer Plan. The Technology Transfer Plan recommended a $10 incentive. We estimate Sempra offers an incentive of about $5.32 per device.[93] We estimate Pacific Gas & Electric offers incentives of $4.48 per device.[94] Both estimates assume control of fluorescent lighting with a Lighting Control System and 80% room occupancy. These incentive levels are only half of those recommended in the Technology Transfer Plan. The example program detailed in Table 4 shows that a $10 incentive per device results in a BCR of 1.31 and net benefits of $96,000 at current sales levels of 1300 devices. We recommend utilities pay a targeted, express incentive of $10 as recommended in the original Technology Transfer Plan to increase demand.

The California Energy Commission needs to address some barriers to this technology. Higher-end hotels have not installed these devices due to fears of guest inconvenience. Title 24 should be revised to allow a one-hour time-out for hotel bathroom occupancy sensors. The project showed a one-hour time-out resulted in up to 70% energy savings and was acceptable to hotel

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93 This estimate assumes a $0.07 per kWh incentive on a 70% reduction in run-time for a 60W fluorescent fixture. Incentive amount obtained during interview.

94 This estimate assumes a $0.14 per kWh incentive on a 30% reduction in run-time for a 60W fluorescent fixture, based on interview data. Incentive rate obtained from example calculations on program website.

guests.[95,96] While some guests may be comfortable with only a 30-minute or even a 15-minute time-out, it appears hotels would refuse to accept this limitation because it is uncertain territory. Title 24 should be revised to allow a one-hour time-out for occupancy sensors in hotel bathrooms.

It is unfortunate that this technology has been overlooked by utility incentive programs targeting the lodging sector. It offers them an opportunity to accelerate adoption of a technology with proven savings. Utilities in California could be well served by following the lead of Seattle City Light, which plans to offer a targeted incentive for these products to increase acceptance of occupancy sensors in hotel rooms.[97]

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95 Page, Erik and Siminovitch, Michael, 2004. "Performance Analysis of Hotel Lighting Control System" ACEEE Conference Paper on the WN-100 Technology. 2004

96 Page, Erik and Siminovitch, Michael, 2005. "Project 4.1 Hotel and Institutional Bathroom Lighting" California Energy Commission Public Interest Energy Research Program, CEC-500-2005-141-A10, October 2005

97 http://www.seattle.gov/light/Conserve/Business/cv5_cw.htm

10.0 Conclusions and Recommendations

This chapter presents conclusions concerning the overall cost-effectiveness of the PIER program, strategic and operational lessons that can be drawn from the project benefit-cost assessments (case studies), and recommendations for integration of benefits analysis into the day-to-day operations of the program.

10.1. Implications of Findings on Overall Benefit-Cost Assessment of the PIER Program

Even though this study was able to assess only a small portion of the PIER portfolio, the results of the individual case studies strongly suggest that California taxpayers have reaped benefits from the program that significantly exceed its costs. If we lift the focus of the benefits assessment to the United States, the success of the PIER program as a public investment becomes even more apparent.

Table 34 summarizes the benefits and costs of the projects assessed for this report. The projects included were identified by PIER staff as having a high probability of generating energy and environmental benefits over a relatively short time frame. Thus, they are not a representative sample of projects in the PIER portfolio and the results shown in Table 34 cannot be expanded to the portfolio in using statistical procedures or simple scaling.

Table 34. Summary of Project Costs and Benefits

		California		United States	
Project	**PIER Costs**	**Low Benefits**	**High Benefits**	**Low Benefits**	**High Benefits**
Efficient External Power Supplies	$577,082	$58,000,000	$105,000,000	$908,000,000	$1,135,000,000
ThermoSorber	$250,000	$2,600,000	$2,600,000	$2,600,000	$2,600,000
RTDMs	$7,000,000	$2,000,000	$229,600,000	$17,500,000	$629,300,000
INFORM	$400,000	-$400,000	$81,500,000	-$400,000	$82,000,000
PCTs	$1,000,000	-$1,000,000	$45,700,000	-$1,000,000	$45,700,000
NightBreeze	$995,000	-$995,000	-$995,000	-$995,000	-$995,000
LED Bathroom Lighting	$387,000	-$387,000	$568,000	-$387,000	$568,000
Total	**$10,609,082**	**$59,818,000**	**$463,973,000**	**$925,318,000**	**$1,894,173,000**

However, it is important to note that the high estimates of benefits for the seven projects total over $463 million for California citizens alone, and that we applied very conservative assumptions in developing even the high estimates. The most important of these restrictive assumptions are as follows:

- **Omission of key project benefits.** For several of the case studies, restriction in schedule and budget precluded the estimation of certain key benefits. For example, in the RTDMS case, we did not quantify the economic benefits associated with expanded capabilities to integrate large amounts of intermittent resources such as wind and solar into the transmission grid. Similarly, we did not account for the reliability value associated with widespread adoption of demand response devices.

- **Application of steep discounting.** In keeping with the TRC framework we applied a discount rate of 8.15 percent to forecasted annual savings. Evaluations of public sector programs such as PIER typically apply lower discount rates. The U. S. Office of Management and Budget in its Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs[98] recommends the use of a 7 percent discount rate for assessment of programs that supplement or displace private investment. Academic economists generally recommend the use of lower discount rates, especially for programs that have intergenerational effects, such as those that mitigate climate change.[99] If we apply a 6 percent discount rate, the high benefit estimate for California would increase by 14.5 percent to $542 million.
- **Conservative specification of key inputs.** In all of the case studies, where there was a choice among several sources or methods for developing key input assumptions, such as unit energy savings or pace of market acceptance, we chose the most conservative alternatives.
- **Omission of broader program benefits.** Most of the general methodological guides to evaluating R&D programs identify a broad set of potential benefits, including diffusion of technical and market information to other organizations and entrepreneurs, stimulation of private investment that would not otherwise have occurred, and the development of organizational infrastructure to support further innovation.[100] The case studies contain ample evidence of these benefits. For example, permanent working groups and even formal organizations of important market actors have formed around the RTDMS and PCT efforts. Significant private investments were made to support the development of the NightBreeze and ThermoSorber products. All of the knowledge gained through this work has been made very accessible through reports available on the Energy Commission web site and through other market channels.
- **Omission of benefits gained through cooperation in cooperative efforts with other organizations.** In the case studies we attempted to capture the interaction between project staff and awardees on the one hand and other agents of technical and market development such as the organizations working towards national and international adoption of efficient power supply standards. This was primarily to support assessment of the degree to which forecasted market changes could be attributed to PIER activities.

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98 http://www.whitehouse.gov/omb/rewrite/circulars/a094/a094.html#8, Accessed October 28, 2009.

99 See, for example, Mark A. Moore et al. "Just Give Me a Number! Practical Values for the Social Discount Rate." *Journal of Policy Analysis and Management.* **13:4** p. 789 – 812. Fall 2004.

100 See, for example, Ruegg, Rosalie and Irwin Feller, 2003, *A Toolkit for Evaluating Public R&D Investment: Models, Methods, and Findings from ATP's First Decade*. Prepared for the Economic Assessment Office, Advanced Technology Program, National Institute of Standards and Technology, Gaithersburg, MD.

However, we did not attempt to characterize the benefits of less transactional types of cooperation. For example, the California PUC in its Interim Opinion setting objectives for the 2009 – 2011 round of utility-sponsored public benefit energy efficiency programs (CPUC Decision 07-10-032) identifies "the reshaping of the HVAC industry" as one of its three major program initiatives to achieve its ambitious energy savings goals. The technical and market insights developed through the NightBreeze program will very likely contribute to that initiative even if the product itself may not achieve cost effective commercialization.

- **Benefits to households and businesses outside of California.** Due to the international structure of the supply chain for external power supplies and the dominant size of the California market for consumer and office electronics, PIER's contribution to the adoption of efficient power supply standards clearly boosted market share of the efficient devices outside of California. Even if we were to cut our low estimate of the national benefits of this initiative by 40 percent, the resulting net benefits would offset the full cost of the PIER program from inception through 2008. Similarly, the benefits of the RTDMS initiative will be experienced by customers on the entire WECC grid, not just those in California.

Of course, the seven projects assessed here represent only a very small portion of the total PIER portfolio. It is not unreasonable to assume that the portfolio contains a handful of additional "big winners" and that the total net benefits of the portfolio exceed cumulative program costs, even within the stringent requirements of the TRC benefit-cost framework.

10.2. Strategic Lessons from the Case Studies

PIER program staff identified the seven projects assessed in this study as efforts that were likely to produce significant net energy and environmental benefits. We found, however, that not all of these projects are likely to do so. For example, the NightBreeze project is unlikely to generate net benefits due to the technology's high costs of production and installation versus potential energy savings. Similar findings apply to the Hotel LED Bathroom Nightlight technology: deployment is likely to be cost effective only under favorable technical assumptions associated with limited segments of the target market. The net benefits estimate for the INFORM reservoir management system must be characterized as speculative in the project's current state of development, and further progress is contingent on a panoply of policy and management decisions that are beyond Energy Commission control. On the other hand, PIER's involvement in the development of testing methods to support the external power supply standard and grid control technology have yielded very large net benefits, although quantification of the RTDMS benefits is subject to considerable uncertainty.

In the following paragraphs we attempt to identify the circumstances that contributed to these results and to draw the implications of these observations for project selection strategy. We divide these observations into those pertaining primarily to product-oriented projects and to system-oriented projects.

10.2.1. Product-Oriented Projects

The Advantages and Limits of Code-related Strategies. PIER enjoys an unusual advantage over other R&D programs in that its parent organization sets appliance and building energy efficiency standards for the seventh-largest economy in the world, otherwise known as the State of California. Because California accounts for such a large share of international electronics and mechanical equipment markets, standards promulgated there can exercise a significant effect on manufacturers and other standard setting bodies. Similarly, the California construction and renovation markets are so enormous (although subject to cyclical fluctuations) that changes in the building code can greatly accelerate the adoption of efficient products and design approaches.

Many of the projects assessed for this study, as well as some that were reviewed and put aside, contained code-related strategies for diffusion of the technology in question. PIER's efforts to develop a testing procedure for external power supplies were specifically targeted to support the development and manufacturer acceptance of efficiency standards for that class of products. The Hotel LED Nightlight project sought and obtained changes in Title 24 to accommodate the product, which enabled contractors and designers to use it to gain compliance with performance-based lighting requirements. The Energy Commission sought, unsuccessfully, to have PCTs integrated into Title 24, but will try again in upcoming rounds of revisions. Finally, KEMA considered the inclusion of several PIER-supported technologies that have been incorporated in Title 24 as compliance options, but put them aside upon learning from designers, builders, and compliance specialists that those technologies had gained little traction in the market. These included residential cool roofs, self-diagnosing commercial HVAC equipment, and integrated classroom lighting design.

Our review of these cases suggests the following observations in regard to the potential benefits and limits of strategies that rely on code enhancements to support the diffusion of supported technologies.

- **Support of mandatory standards for manufactured products offer the greatest opportunity to leverage technology-oriented R&D.** The large and relatively certain benefits associated with PIER's support of external power supplies illustrate this point. This is a strategy that PIER is clearly well-situated to pursue, with its access to academic institutions, technology companies, utility programs, and standard-setting bodies in California and elsewhere. Flexibility in the use of budget resources also enables PIER to fill gaps in national and international efforts. The external power supply case illustrates effective use of all of these organizational assets.
- **Inclusion of a technology in Title 24 as a compliance option does not necessarily lead to increased adoption.** A number of PIER-supported products and measures that have been incorporated into the Title 24 as compliance options have experienced only minimal levels of adoption. These include the hotel bathroom night lighting system, the NightBreeze ventilation system, residential cool roofs, and classroom integrated lighting controls. The reasons for these outcomes include the following:

- o Less expensive and more familiar products and methods for compliance are already in the market. This appears to be the case for hotel night lighting, NightBreeze, and residential cool roofs.
- o The products are not cost-effective from the customer's point of view. This is the case for NightBreeze and the night lighting system. For manufactured products such as the night lighting system, customer incentives may be an effective method to overcome this barrier and, with sufficient increases in volume, reduce unit costs of manufacture. Given the complexity of the NightBreeze system and its installation, it is less likely that costs would decrease significantly with increased volume.
- o Elements of the product's performance are incompatible with target customers' business practices and strategies. This is the case for the hotel night lighting system for more upscale chains that see automated lighting control as a possible inconvenience for guests.

These examples point out the need to address the issues typically associated with business planning – market sizing, segmentation, characterization of competition and competing products -- early in the project or even in the project selection and contract development process. The prospects of a difficult sell or vigorous competition should not in themselves discourage PIER investment. Rather, investments in technology developments are most likely to yield benefits if all aspects of the project are informed by a realistic assessment of the challenges to be faced in the commercialization phase.

The value of institutional relationships. Several of the projects reviewed for this study contributed to the development of on-going organizations or strategic alliances that will likely support technology diffusion after the project ends. Examples include the following:

- Manufacturers who developed PCTs based on the reference design have joined with other industry players to form an organization dedicated to ensuring interoperability of home area network-enabled appliances and smart meters. This effort should greatly facilitate customer use participation in demand response and pricing programs that involve AMI or other forms of data communication.
- PIER facilitated cooperation between the developers of the NightBreeze system and a large manufacturer/installer of residential furnace and HVAC systems to incorporate elements of the NightBreeze control system into an existing ventilation cooling system.
- PIER contractors worked closely with manufacturers associations in developing testing methods for external power supplies. These relationships will be important if and when standard-setting bodies develop initiatives for product categories not addressed by current standards.

In the projects assessed, PIER did a good job in identifying and cultivating the organizational relationships needed to advance the development and early deployment of the products supported. Our point here is that these relationships can be viewed as enduring assets which can, for example, be used to support future applications for code enhancements to incorporate PCTs.

10.2.2. System-Oriented Projects

The contrasts between the RTDMS and INFORM projects are offer insights into the nature of successful strategies to advance the development of improvements in large infrastructure systems. PIER provided continuous support for the development of synchrophasor-based grid monitoring and control systems for a period of 9 years (at the point the case study was completed). Over that span, PIER supported the full range of activities required to deploy infrastructure control systems: conceptual system development, development and refinement of prototypes for key elements of the system, research and analysis to develop control algorithms, development and deployment of production-level hardware and software, operator training and supervision, and on-going testing and reworking of key hardware, software, and management components. At this point, RTDMS is a fully functional system which has been used successfully to detect faults on the system and to guide operator actions to mitigate potential reliability problems. A number of individuals involved in or close to the project identified the importance of the consistency of PIER support, particularly for system installation and training, as the key factor in advancing RTDMS capabilities well beyond those of similar systems under development elsewhere. We also note that Energy Commission and PIER staff were deeply and consistently involved in the Project Review Committee which shaped the research agenda in response to system needs and the successes and set-backs experienced at successive stages of project development.

By contrast, PIER supported only one round of funding for the INFORM system, which resulted in the development of a prototype and proof-of-concept testing using historical data. Moreover, PIER staff was not actively engaged in the oversight of the project, leaving that function primarily to federal and state water management agencies and NOAA. When funding of successive rounds of the project encountered problems related to conflicting policy objectives, PIER staff was not in position to advance the project by offering either technical or financial support. It basically took the position of waiting for other parties in the project to resolve internal and external obstacles to further support for INFORM. At this point, work on the development of INFORM has been suspended for over three years. The longer this inaction continues, the less likely it is that the work PIER funded will lead to any concrete environmental and economic benefits at all.

PIER’s investment in INFORM has been fairly limited. However, suspension of activity on the project is not the result of a “stage/gate” process in which the project has failed to meet the objectives for next-stage funding. Rather, the first phases of INFORM were successful, but funding was suspended for various organizational reasons.

The strategic lessons to be derived from the project experience summarized above are fairly obvious.

- Major infrastructure systems take a long time and a great deal of effort to develop and deploy. If PIER hopes to generate tangible benefits from investments in these systems it must be prepared to make substantial sums available over a protracted time period.
- Achievement of benefits requires the active cooperation of system managers. To ensure that system operators maintain commitment to the project, PIER staff needs to be actively involved in its oversight and governance. This high level of involvement is required both to ensure that PIER targets its funding to critical project components at various stages of development and to hold system managers accountable for following through on their commitments.

10.3. Recommendations: Integrating Benefits Assessment into Operations

One clear conclusion to be drawn from the case studies is that, for the most part, the benefits of PIER projects can and usually do take a long time to be realized. Moreover, their realization is subject to many contingencies that cannot be predicted at the time funding decisions are made. In light of this reality, we do not believe that evaluation can play exactly the same role for PIER that it does in the technology deployment programs sponsored by utilities. In those programs, impact and market evaluations are used primarily to provide contemporaneous information needed to “true up” preliminary estimates of benefits and market effects, using empirical observations to validate or revise planning assumptions. The long time lags, technical risks, and market uncertainties associated with PIER projects preclude such an approach. Rather, the kinds of prospective benefit-cost analyses presented here can provide insights into the concrete ways in which PIER projects create economic and environmental benefits, which can in turn be used to support more productive project selection and management practices.

The following paragraphs present recommendations for methods to integrate benefits assessment into project selection and management processes, as well as continued evaluation efforts to support those efforts.

10.3.1. Operational Recommendations

- Ensure that project applications and plans contain explicit models of the means and schedule by which economic and environmental benefits will be realized. We found that PIER project managers and awardees shared general concepts about the ways and timeframe in which their projects would generate benefits. However, these ideas were seldom sufficiently detailed to support the development of commercialization strategies or to provide a framework for project or office managers to assess the success of the project. To address this situation, we recommend that applicants for PIER funding be required to include an explicit model of benefits realization that addresses the following:
    - o Nature of the benefits to be achieved: energy use reductions, reliability improvements, etc.

- Specific processes by which the benefits are to be produced: substitution of more efficient equipment, installation of more sophisticated infrastructure control systems, increased flood control, etc.
- Specification of the market actors who will be carrying out the above practices, including their motivations and barriers to adoption of the supported technologies.
- Specification of the population of households and businesses that will experience or reap the benefits.
- Timing of the realization of benefits, including identification of major contingencies and their effect on the timing and magnitude of benefits.
- Measures that the project principals, PIER, and the Energy Commission could take to mitigate the risks posed by the identified contingencies.
- Practical methods for measuring or estimating project benefits.

Much of this information can be summarized in a program logic model similar to the one KEMA developed to summarize information about the PCT project, as shown in Figure 22

Develop metrics to be linked with the benefits realization/logic model, and update these metrics as part of annual project reviews and reporting. We view this process as being similar and complementary to the "stage/gate" process currently used for ongoing program assessment. In this case, however, the assessment would be broadened to address not only the accomplishment of specific milestones but also changes in the market, regulatory environment, or competition that may affect the timing or magnitude of benefits achieved.

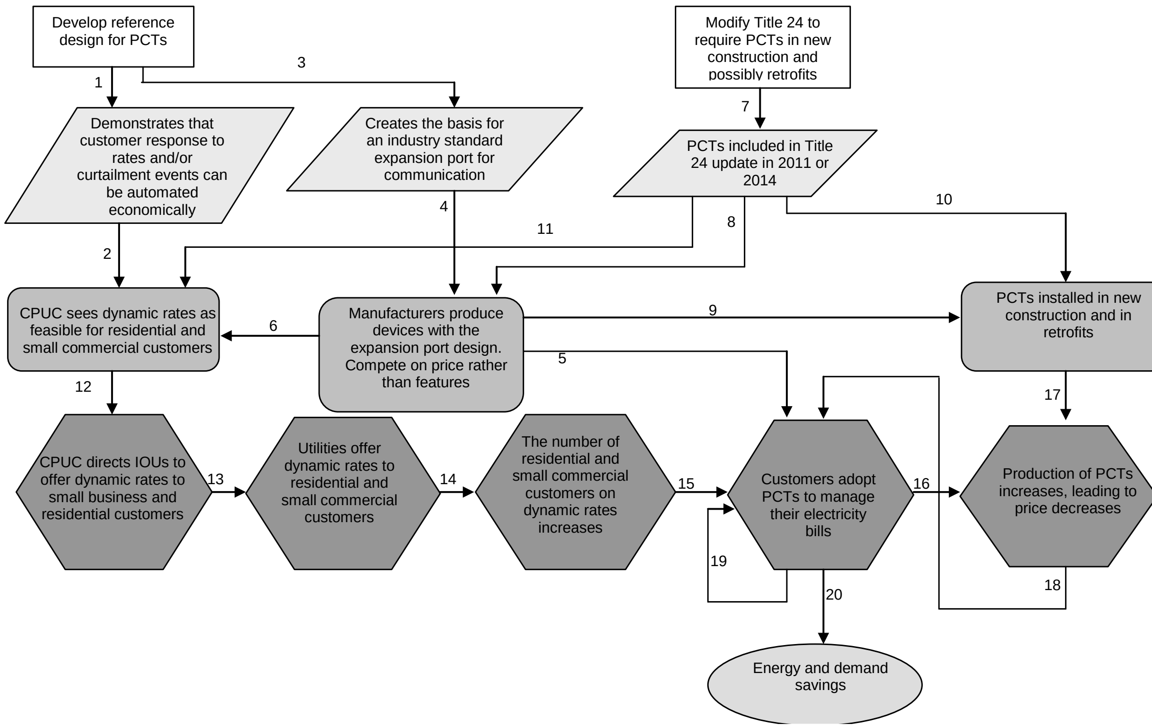

Figure 22. Logic Model for the PCT Project

Pilot the development of the benefits assessment components of project application and management systems. In order to maximize the likelihood that PIER project managers will adopt and use the benefits assessment methods described above, we recommend that they be piloted with a select group of project managers. This will enable PIER to work through the mechanics of the process and use feedback received to make the process as useful and easy to use as possible. Based on our experience in this study, we believe that the forms and methods used will need to be tailored to different kinds of projects – at a minimum the three types identified early on: product, system, and policy.

Roll out the benefits assessment methods to all project managers. Once a workable system is developed, it can be rolled out to project managers for use on all projects. Annual compilations of the project assessments can be used as the basis for a portfolio-level assessment system.

10.3.2. Recommendations for Further Evaluation Efforts

- Conduct a small number of additional project benefit-cost assessments, focusing on project types not addressed by the current study. For various reasons, this study did not undertake assessments of a number of project types that appear frequently in PIER's portfolio. These include basic and applied research in support of major policy initiatives such as A. B. 32, basic environmental science research, and development of new infrastructure systems such as carbon sequestration. We expect that it will be more difficult to quantify the benefits of such projects and to attribute to PIER activities than it was for the first seven projects covered here. However, given the prominence of these projects in the PIER portfolio we believe it will be important to undertake those assessments.

Assess the benefits of PIER's information dissemination activities. Although we have not made a formal assessment of PIER's information dissemination activities, it is our impression as energy efficiency professionals that those activities do generate contribute significant value. Specifically, in the course of preparing the project benefit-cost assessments and in working on projects for clients in California and other jurisdictions, we have used many documents available on the PIER web-site and have found them to be extremely useful for a variety of applications. We recommend that PIER undertake a formal assessment of the use of its web site and other information dissemination activities to characterize the range of users and activities supported by these information resources.

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Appendix A

Master List of PIER Interview Subjects

External Power Supplies

- Arnold Alderman - Anagenesis
- Chris Calwell – Ecos Consulting
- Andrew Fanara - EPA
- Rich Fassler – Power Integrations
- Gary Fernstrom – PG&E
- Brian Fortenberry - EPRI
- Jim Holland - CEC
- Doug Johnson – Consumer Electronics Association (CEA)
- Arshad Mansoor - EPRI
- Alan Meier - LBNL
- Chuck Mullett – ON Semiconductor
- Suzanne Foster Porter – Ecos Consulting
- Leo Rainer – Davis Energy Group
- Harinder Singh – CEC
- John Wilson – Energy Foundation

ThermoSorber

- Mark Curtis – Ammonia Refrigeration Engineering & Safety Co.
- Bob DeVault – Oak Ridge National Laboratory
- Rajesh Dixit - Thermax
- Donald Erickson – Energy Concepts Co.
- Mike Lukasiewicz – MX Roads, Inc.
- Ryan Matley – PG&E
- Jatal Mannaperuma – UC-Davis
- Joseph Orlando – Mid-Atlantic CHP Application Center
- Vikas Patnaik – Trane
- Doug Presney – Clean Tech Partners
- Steve Slayzak – NREL
- Tim Wagner – UTC Power
- Scott Ward - Robur

RTDMS

- Bharat Bhargava – SCE

- Paul Bleuss - CAISO
- Merwin Brown – CIEE
- Jim Cole – CIEE
- Joe Eto – LBNL/CERTS
- Mike Gravely – PIER
- Dave Hawkins – CAISO
- Anita Hoyos – SDG&E
- Lu Kondratunta – SDG&E
- Michael Lopez – SCE
- Niall Mateer – CIEE
- Jim McIntosh - CAISO
- Larry Miller - CIEE
- Jamie Patterson - PIER
- Greg Tillitson - CAISO

INFORM

- Mike Anderson – DWR
- Tom Bordman - San Luis Delta Mendota Water Authority
- Levi Brekke – USBR
- Michael Dettinger – USGS/Scripps Institute of Oceanography
- Pete Fickenscher – NOAA NWS
- Paul Fujitani - USBR
- Aris Georgakakos – Georgia Water Resources Institute
- Konstantine Georgakakos - Hydrologic Research Center
- Peter Gleick – Pacific Institute
- Robert Hartman – NOAA NWS
- Arthur Hinojosa – DWR
- Kathy Jacobs - Arizona Water Research Institute
- Lloyd Peterson – USBR
- Tracy Pettit - DWR
- Maury Roos - DWR
- John Schaake - Hydrologic Ensemble Experiment Project (HEPEX)/NOAA NWS
- George Smith – NOAA NWS
- Michael Tansey - USBR

NightBreeze

- Mark Berman – DEG
- Jerry Best – AEP
- Marc Hoeschele – DEG
- Jeff Jacobs – Building Advisory Group
- Nancy Jenkins – SCE
- Cliff Murley – SMUD
- Bob Radcliff – Beutler Corporation
- Chris Scruton – PIER
- Charlene Spoor – PG&E
- Bruce Wilcox – Bruce A Wilcox, PE

Hotel Bathroom LED Night Lighting

- Dave Bisbee – SMUD
- Michael Brozena – Seattle City Light
- Patrick Maher – The Maher Group
- Gus Newburry – Starwood Hotels
- Darren Nix – Ecology Action
- Jon Null – Watt Stopper
- Christopher Schrader – Choice Hotels
- Michelle Sivertsen - Intergy