Draft Emerging Technologies Whitepaper

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Section 1: Context

Introduction

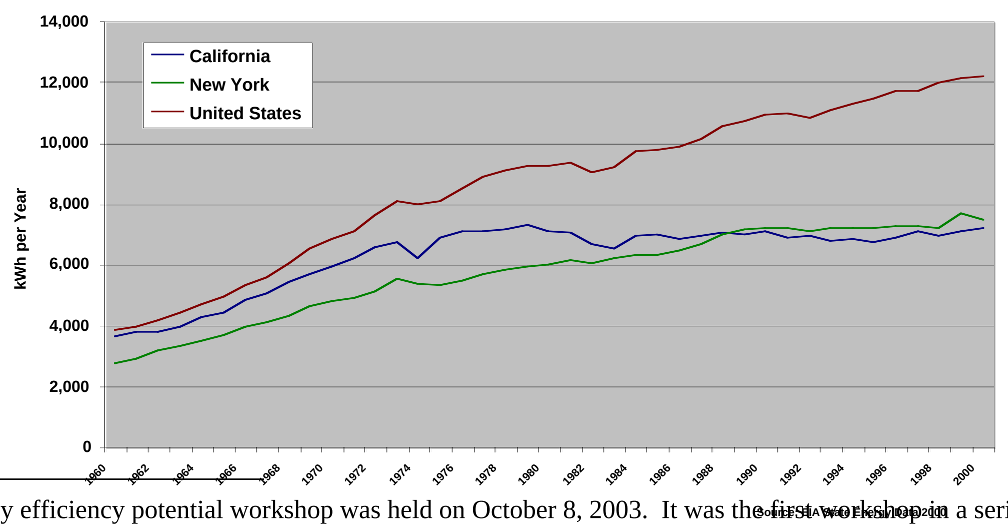
The California Public Utilities Commission (CPUC) issued an Assigned Commissioner's Ruling (ACR) regarding the first and very successful energy efficiency workshop and requesting post-workshop comments regarding steps the CPUC could take to best achieve statewide energy efficiency potential[1]. The ACR identified several conclusions regarding the potential for energy efficiency in California and identified several gaps that need to be addressed, including:

- The state is not currently maximizing its energy savings potential
- The state will need to promote more innovation in emerging energy efficiency technologies
- Some of the CPUC's existing policies should be modified to maximize opportunities to promote energy savings.

In addition, the ACR posited a group of questions regarding how the CPUC could improve development and market adoption of energy efficient emerging technologies. The California Energy Commission (CEC) welcomes the opportunity to provide the CPUC comments regarding emerging technologies and recommendations regarding potential improvements to state policies and programs in energy efficiency emerging technologies. We have provided responses to specific questions raised in the ACR regarding emerging technologies in the Appendix of this whitepaper.

To gain the proper perspective on the issues that the CPUC has raised, it is useful to review the historical per capita electricity use in the US and compare it to per capita energy use in the two states that have the most aggressive energy efficiency programs in the country, California and New York (see **Figure 1**).

Figure 1: Per Capita Electricity Use



[1] The energy efficiency potential workshop was held on October 8, 2003. It was the first workshop in a series of workshops related to Rulemaking 01-08-028 conducted to determine how the CPUC may make the most of the state's energy efficiency resources in the years following 2005.

It is clear that California's energy efficiency programs have had positive effects. For California, electric use per capita has stayed constant for 29 years from 1975 to 2004 while the U.S. as a whole has grown 2% per year and is now up 50 % over California's per capital use[2]. Overall, we believe that two thirds of the US-California difference is due to California's standards programs and conservation ethic. We further believe that emerging technologies are a necessary ingredient to feed the conservation food chain.

Figure 1 shows that California has avoided 50 % of the annual $32 billion annual electric bill, saving$16 billion per year or $450 per year per capita. Other studies have identified comparable levels of avoided bills in California (Rufo and Coito 2002). Without the historic energy efficiency programs, the state's energy consumption per capita would have grown more rapidly and could have equaled or surpassed the national average. Likewise, New York's strong energy efficiency programs have resulted in a per capita electric use much less than the national average and similar to California's. However, even with those significant benefits, there are large, remaining opportunities for increasing the level of energy efficiency in the state (see **Table 1,** adapted from Rufo and Coito 2002).

Table 1: 10-year Achievable Potential Results (2002-2011) by Scenario*

(Compared to 2011 Business as Usual baseline of 310,000 GWh, 61,000 MW and $37 Billion)

Scenario	Result	Business-As-Usual	Advanced Efficiency	Max Efficiency
Base	GWh Savings	9,637	19,445	30,090
	Net Savings, millions dollars	9,604	15,949	23,203
	MW Savings	1,788	3,480	5,902
Low	GWh Savings	7,569	15,949	23,203
	Net Savings, millions dollars	4,454	7,436	10,542
	MW Savings	1,408	2,725	4,415
High	GWh Savings	11,733	21,146	29,199
	Net Savings, millions dollars	15,649	23,036	29,972
	MW Savings	2,178	3,824	5,862

[2] Approximately half of this 2% per year relative gain in electric efficiency (California versus the U.S.) is directly explained by California's codes and standards and utility-administered energy efficiency programs. The other half of the 2% per year gain is explained by structural differences and a mild climate.

* *GWh and MW savings are in the year 2011. Dollar savings are net of annual cost or more efficient products, calculated using nominal discount rate = 8 percent, inflation rate = 3 percent and the service life of the product*

Achieving additional energy savings will not happen automatically and the bridging of energy efficient emerging technologies into the market will be one of the key factors in achieving and sustaining future energy savings.

Framework for Successful Development and Market Adoption of Emerging Technologies

The overall framework for bringing innovation to the marketplace can be envisioned as a system of linked activities that create value.

- Innovations (i.e., new technologies and advances in design, construction, and operational tools and methodologies) typically flow from a conceptual stage of development to full adoption in the commercial arena via a series of linked activities. These specific activities in the innovation process are idea generation and selection, research and development (R&D), pre-commercial demonstration and promotion, and adoption into commercial arena.

- Poor linkage between these activities results in decreased delivery of innovations and value to the commercial arena. One of the key determinants for successful innovation is "institutions for collaboration" that effectively link upstream R&D with commercial deployment (Porter and Stern 2001). Without strong linkages, innovations will not be transferred effectively to the marketplace, the full value from the R&D investment will not be captured and the advances may diffuse to other regions before they are used by the region that created them.

- Without proper linkages to the commercial market, innovations are in effect warehoused (i.e., shelved or stored without being put to use). Warehoused technologies do not have unlimited shelf life—they are perishable and eventually become worthless. However, deployment of new technologies does not happen unassisted. In a colloquium of leading innovation practitioners, 50 major companies exchanged knowledge and best practices regarding innovation and they identified linking R&D activities to commercialization as one of the major historic barriers affecting innovation success (Arthur D. Little 2000).

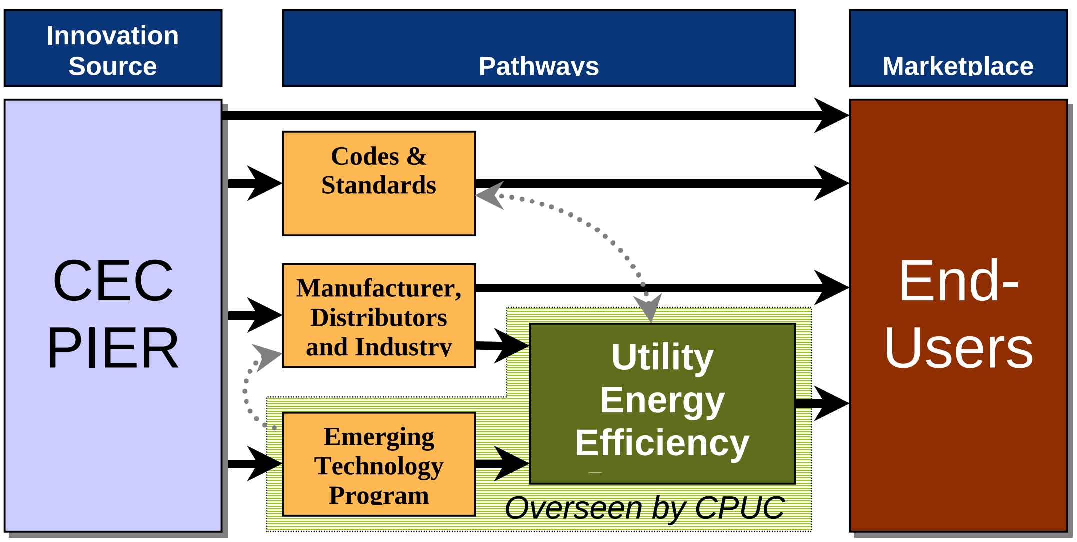
Therefore, to capture the full potential of the value created by investments in upstream R&D, it is necessary to invest especially in the linkages between upstream R&D and the commercialization market.

Development and Market Adoption of Energy Efficient Innovations in California

The CEC's Public Interest Energy Research Program (PIER), funded at $62.5 million annually, is the largest public interest energy research program in California and one of the largest in the country. PIER has been in existence since 1998 and an array of promising innovations are emerging from the research investments made over the past six years. PIER has played a critical part in developing energy efficiency innovations and has successfully facilitated the introduction of many of these innovations into the market. PIER uses multiple paths to facilitate innovations (see **Figure 2**). These include bringing innovations directly from the CEC PIER program to the end users for adoption and use; affecting the marketplace via codes and standards (both California T-24 and T-20 and via national codes); and linking to the end user via the multitude of manufacturers, distributors and to the overall building industry (i.e., highly fragmented group of architects, designers, developers and contractors).

The utility emerging technology (ET) programs, funded by Public Good Charges at approximately $4-5 million annually, contribute a considerable role in making many of these market connections possible, particularly when additional actions are needed to bridge from research and development to the marketplace. The intent of the ET program is to help accelerate the introduction of innovative energy efficient technologies, applications, and analytical tools that are not widely adopted in California through a variety of approaches, but mainly by reducing the performance uncertainties associated with new products and applications. For example, in some cases, performance validation is critical in order to increase market familiarity, reduce resistance to the innovation, and influence industry adoption of technologies. In other cases, end users need to see these emerging technologies in real applications before they are willing to adopt the technology. In still other cases, larger scale pilot demonstrations are necessary before industry and consumers have the confidence that the technology will perform well under various operating and climate conditions.

Figure 2: CEC PIER's Pathways to the Marketplace Showing the Function of the ET Program

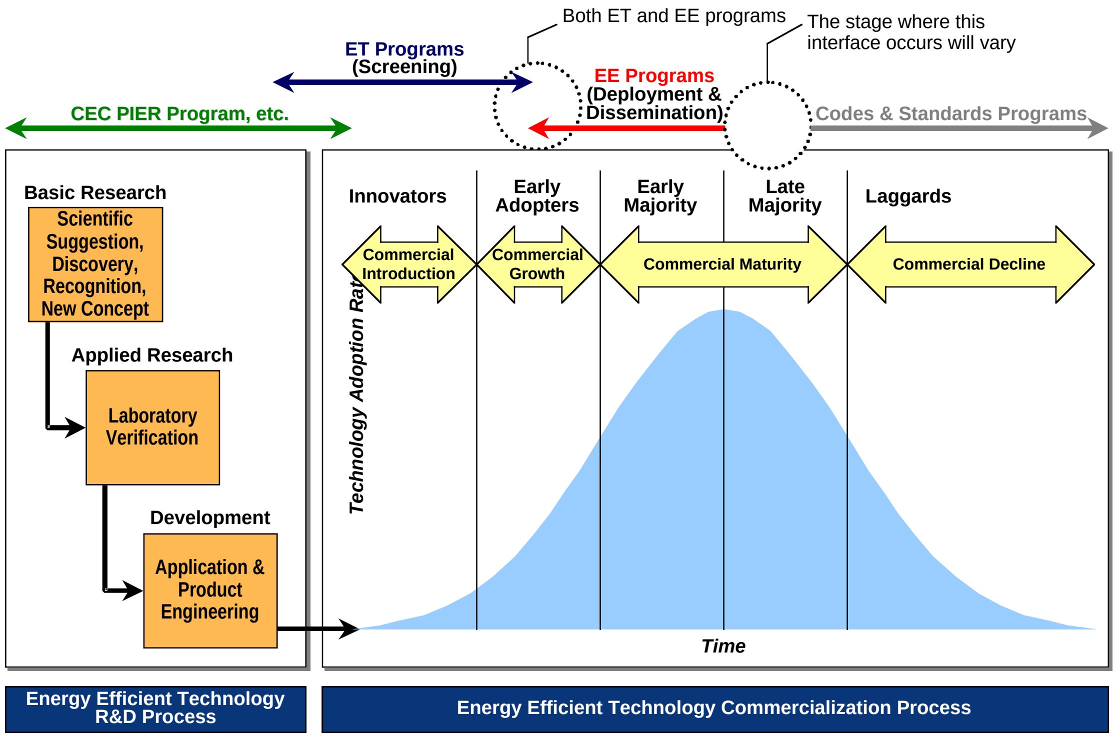


The ET programs address three sectors --commercial, residential, and industrial-- and in each of these three sectors, the potential for energy savings varies significantly by end use application. For example in the residential sector, air conditioning represents a major opportunity. It is estimated that air conditioning accounts for approximately 70% of the potential peak demand savings (Rufo and Coito 2002).

CEC PIER's mandate focuses PIER's activities on R&D. AB 1890, Article 7, established PIER to provide "Public interest research and development not adequately provided by competitive and regulated markets" and to provide for "the future market utilization of projects funded through the program." While PIER's primary focus and expenditure of funds has been in the R&D arena, the program recognizes the importance of "providing for future market utilization" of the research products and strives to continuously build bridges to the market either directly or through other public purpose programs such as those funded through the California utilities. The ET program at the utilities has been an important channel for bridging PIER research products to the market (see **Figure 3**).

By validating performance of new innovations and introducing them to end users, the ET program reduces unacceptable uncertainties and risk to the end user and serves a critical bridging function. The ET program's activities also influence the manufacturers, distributors and overall industry regarding viable approaches to improve energy efficiency. In this manner, the ET program and CEC PIER work hand-in-hand to encourage adoption of emerging technologies, provide a vital pathway

Figure 3: Energy Efficiency Technology R&D and Commercialization Process



Source: Adapted from Southern California Edison

to the marketplace that other direct paths do not address, and support CPUC in achieving the statewide energy efficiency potential.

Recommendation for Increased Funding

The CPUC should provide for higher levels of funding for emerging technologies because of the significant benefits that would accrue to the state's energy efficiency program and attainment of the kWh savings goal. Increased levels of funding for the ET programs are prudent because at the current levels of funding there are a large number of potentially beneficial innovations developed at CEC PIER that will not receive funding for pre-commercial demonstration. In general, of the 10-15 energy efficiency technologies that typically emerge annually from PIER research, approximately 75% are typically in jeopardy of not being bridged to the market place because of insufficient ET program funding. The implication is that potentially important opportunities for future energy savings in the state are being lost because of insufficient funding.

For example, to make this issue more tangible, we have identified a number of promising ET opportunities that have emerged or are in the process of emerging from PIER that could become lost, warehoused or severely diminished in the future if additional investments are not made via the ETCC (see **Table 2**). This list is not intended to be comprehensive (because there will be many more ET opportunities available), but it serves to simply illustrate the types of opportunities that exist.

Emerging technologies identified on this table include a sample of hardware, software, demand responsive strategies/tools, and design tools that are emerging from the public interest research stream.

The utility ET programs have successfully bridged some hardware technologies to the market through limited demonstrations. However, to validate performance and determine viability for future efficiency incentives, larger scale demonstrations are necessary.

Similarly, software tools that facilitate the design and operation of low energy systems are just emerging out of research but need to have more extensive pilot applications to validate savings and give industry confidence in the energy/cost benefits of the tools.

Demand responsive strategies are also emerging enabling better system reliability and giving consumers more control over their energy costs under time dependent price structures. As these strategies and tools emerge, performance and reliability must be clearly shown in diverse situations and service territories before the tools can be applied on a broad scale.

Finally, while design tools fall out of the traditional definition of emerging technologies, a significant number of such tools are emerging from the research stream and could play an important role in facilitating the design of more efficient HVAC and building systems. However, unless these tools are tested under various building, equipment, and site conditions and the information fully bridged to the design community, they may never be broadly implemented. While validation of design tools has not been a traditional ET role, it is an important bridging function between research and full market deployment that the utility ET programs could contribute a valuable role in.

For these identified innovations alone, it is estimated that annual expenditures in the range of **$12 – $18 million** in utility ET initiatives could play an invaluable role in effectively bridging these products into the marketplace. To be effective in reaching the marketplace, the ET initiatives need to go beyond the current small scale and small quantities of pilots and expand to larger scale projects that include more demonstrations (e.g., demonstrations that clearly validate performance, quantify more precisely the costs and benefits, inform key stakeholders and better inform policy) and provide an effective bridge to the marketplace.

It is difficult to predict the actual benefits of this investment, but we estimate that the overall benefit of commercializing the identified technologies could be in the range of **41-60 GWh** annual electric reduction (Table 2). Our estimate takes into account that not every technology identified in the table would be successful in the market and that successful commercialization is dependent on many factors (e.g. adoption by manufacturers and distributors, changes in codes, standards and standard operating practices) not just the demonstrations via the ET program.

PIER of course covers only a fraction of the available opportunities. Accordingly, we should enlarge the ET budget to be greater than the $12-$18 million of expected costs for the PIER opportunities (Table 2). As a conservative estimate for the years 2006-2008, PIER will contribute approximately half of the innovative ideas to the energy efficiency program, and therefore warrant a total emerging technology annual budget of approximately **$25 million** (i.e., approximately twice the lower-end estimate of $12 million for the PIER costs). The current annual funding level for ET is approximately 1% of the annual energy efficiency budget (the combined PGC and Procurement funds add to approximately $400 million). Raising the funding level to approximately 6% (i.e., $25million)[3] of the annual budget gradually over the next 4-5 years would provide higher levels of bridging between available upstream innovations and the marketplace resulting in better overall return on R&D investment and faster attainment of the kWh savings goal.

The Commission recognizes that policy changes will need to occur in order that the increased funding of ET does not adversely affect the utilities ability to meet their energy goals.

Benchmarks from Successful Programs

We have identified three organizations that have demonstrated the potential value of emerging technologies activities as part of their publicly sponsored energy efficiency R&D programs. These programs provide general benchmarks of the potential benefits of a publicly sponsored program and provide some general guidance for enhancement of the program in California and for closing the gaps identified by the ACR.

The New York State Energy Research and Development Authority (NYSERDA)

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[3] A small part of the proposed $25M/year funding for ET will be handled by the new California Clean Energy Fund, ("CCEF"), a not-for-profit incubator, which PG&E is forming in compliance with the CPUC/PG&E settlement permitting PG&E to emerge from bankruptcy. [CPUC Decision 03-12-035, Dec. 12, 2003]. CCEF will be funded by PG&E at $6M/year (or more) for at least 5 years. However, unlike the ETCC (as part of the Public Goods Charge Energy Efficiency Program), which is not expected to make a profit, the CCEF will function as an incubator and modest venture capital fund, hoping that a fraction of its portfolio will be profitable and will return the $5M/year investment. So by the end of 5 years, CCEF hopes to have a rotating fund of at least $30M. Thus of all the energy efficiency and environmentally friendly opportunities listed in Table I, CCEF will tend to focus on the patentable technologies at the top of the table and pass over the public domain software, design tools, and demonstrations which comprise the majority of the table. Further CCEF will not operate statewide; instead it will focus on helping developers in PG&E's service territory, leaving the ETCC to cover the rest of the state.

NYSERDA notes that there are significant barriers that impede realization of the full energy savings potential including limited research and development capabilities of building component and material suppliers; fragmentation of the design and construction industry; institutional barriers that limit adoption of innovative technologies; and lack of market participants due to unavailability of information, inappropriate price signals and market failures. NYSERDA's energy efficiency programs are specifically designed and operated to overcome these barriers (NYSERDA 2000).

NYSERDA spends approximately $15 million annually on its emerging technologies program, or about 50% of the roughly $30 million in annual funding for energy efficiency activities contained in NYSERDA's program.[4] This level of spending for emerging technologies activities is considerably greater than California's. In addition, unlike California, NYSERDA administers both the emerging technologies and incentives programs under a single organization and can seamlessly connect R&D to needed deployment activities, including both emerging technology demonstrations as well as follow-on incentive programs.

[4] The overall NYSERDA program funding is much higher, around $150 million annually; however, this includes significant funding for a several non-efficiency program elements including renewable energy. The NYSERDA estimate of $30 million annual funding for energy efficiency includes the program elements that are comparable to California's energy efficiency program.

Table 2: Utility Emerging Technology Opportunities Flowing From PIER

(Facilitating Actions to Move Promising Emerging Technologies Into the Market)

	Emerging Technology	Examples of Actions Needed to Bridge Technology to the Market	Goal	Estimated Cost of ET Action ($ millions)	Estimated Annual Electric Reduction (GWh)	Estimated Annual Savings ($ Millions)
HARDWARE TECHNOLGIES	Integrated Classroom Lighting System	15-20 Demonstrations in large service territories, 5-10 in smaller service territories (50 total).	Validate energy savings, inform school districts of energy and non-energy benefits via field demonstrations. Determine viability for future incentives.	5 - 6	17 - 20	2 - 2.4
	LED Task Light	Demonstrate technology in diverse occupancy types and user preferences. Determine user behavior within same building and in different building types. (200-300 installations).	Verify energy savings under different operating conditions and energy management scenarios. Determine viability for future incentives.			
	Retrofit Kitchen Down lighting System	Demonstrations to validate functionality and cost savings (lower first cost to builder and operating cost to consumer) (75-100 demonstrations).	Demonstrate energy and non-energy benefits to homebuyers and to builders. Determine viability for future incentives.			
	Colored Cool Roofing Materials	Demonstrate technology with numerous builders in both low-income and custom homes. (Need large-scale demonstrations (75-100) so manufacturer can produce a broad range of products at low cost).	Inform builders and consumers of new aesthetically pleasing and energy efficient roofing materials (tile, asphalt, shake, metal). Determine viability for future incentives.			
	Indirect-Direct Evaporative Cooling	Demonstrate technology in both residential (50) and commercial (50) applications.	Validate energy savings, provide verification to builders and facility managers that maintenance issues are resolved in new technology. Determine viability for future incentives.			
	Night Ventilation Cooling	Demonstrate night ventilation cooling as an energy efficiency alternative to compressor based cooling in coastal and transition zones (50). Demonstrate opportunity to reduce AC usage in inland climates (50).	Validate energy savings and indoor air quality improvements under various climate conditions. Inform builders and consumers of technology. Determine viability for future incentives.			
	Radiant Heating and Cooling	Demonstrate comfort and energy benefits in commercial applications (50).	Validate energy saving. Inform installers of cost effective installation characteristics of new technology. Determine viability for future incentives.			

Utility Emerging Technology Opportunities
(Facilitating Actions to Move Promising Emerging Technologies Into the Marketplace)

Table 2: Utility Emerging Technology Opportunities Flowing From PIER (continued)

(Facilitating Actions to Move Promising Emerging Technologies Into the Market)

	Emerging Technology	Examples of Actions Needed to Bridge Technology to the Market	Goal	Estimated Combined Cost of Utility ET Action ($ millions)	Estimated Annual Electric Reduction (GWh)	Estimated Annual Savings ($ Millions)
SOFTWARE TOOLS	Photo sensor Placement Software	Test software functionality under various room configurations in various occupancy types (50-75 installations).	Inform daylighting designers about the availability of a tool for optimizing photo sensor placement and validate tool functionality. Determine viability for inclusion in future savings by design options.	2 - 3	7 - 10	0.8 - 1.2
	Whole Building Diagnostician	Demonstrate tool to detect and diagnose faults in air handlers (75-100 tests).	Validate performance, quantify energy savings potential, inform service providers and facility operators about the tool, and determine viability for future incentives.			
	Low Energy Cooling System Design	Demonstrate viability of low energy design models in various occupancy types and building sizes (50-75 buildings).	Inform designers about the availability of a tool to facilitate the design of low energy cooling systems through pilot trials in real buildings. Determine viability for future savings by design options.			
DEMAND RESPONSIVE STRATEGIES	Instant Start Electronic Ballast	Test ballast for effectiveness as a demand response technology through dimming T-8 fluorescent lamps. Test in 15-20 buildings.	Determine effectiveness as a demand response technology that utilities could offer to customers. Determine viability for future incentives.	2 - 4	7 - 13	0.8 - 1.6
	DALI Lighting Control	Test protocols in controlling lighting levels beyond simple on/off control in 15-20 buildings.	Determine effectiveness as a demand response technology that utilities could offer to customers. Determine viability for future incentives.			
	Demand Reduction by Pre-Cooling	Test pre-cooling strategies for effectiveness in reducing demand in 20-30 buildings.	Determine effectiveness as a demand response technology that utilities could offer to customers. Determine viability for future savings by design options.			

Table 2: Utility Emerging Technology Opportunities Flowing From PIER (concluded)

(Facilitating Actions to Move Promising Emerging Technologies Into the Market)

	Emerging Technology	Examples of Actions Needed to Bridge Technology to the Market	Goal	Estimated Combined Cost of Utility ET Action ($ millions)	Estimated Annual Electric Reduction (GWh)	Estimated Annual Savings ($ Millions)
DESIGN TOOLS	Large HVAC System Design Guide	Pilot test newly developed design guide under various building sizes and system types for 15-20 buildings	Validate and quantify energy savings potential, inform designers about the energy savings potential when using the guide, and determine viability as a future savings by design option	**3 - 5**	**10 - 17**	**1.2 - 2**
	Small HVAC System Design Guide	Pilot test newly developed design guide under various building sizes and system types for 15-20 buildings	Validate and quantify energy savings potential, inform designers about the energy savings potential when using the guide, and determine viability as a future savings by design option			
	Skylight Design Guide	Pilot test newly developed design guide under various building sizes and system types for 15-20 buildings	Validate and quantify energy savings potential, inform designers about the energy savings potential when using the guide, and determine viability as a future savings by design option			
	Design Guide for Air Handling Systems	Pilot test newly developed design guide under various building sizes and system types for 15-20 buildings	Validate and quantify energy savings potential, inform designers about the energy savings potential when using the guide, and determine viability as a future savings by design option			
	Estimated Total			**$12 - $18 Millions**[5]	**41-60 GWh**	**$5-$7 Millions**

Source: CEC 2004

[5] Based on the estimates in Table 2 and identified opportunities from other non-PIER sources, to fund the full range of available technologies to the ET program would require funding of approximately **$**25 million**.** The expenditures for the identified ET initiatives would typically occur in the near future (i.e., within 1-3 years). It typically requires many years before products saturate the market. The estimated Annual Electric Reduction and the Estimated Annual Savings are assumed to be realized when the product saturates the market after 5-15 years.

Lawrence Berkeley National Laboratories (LBNL)
LBNL provides a link between DOE building R&D activities and deployment initiatives. LBNL focuses a large portion of their R&D budget on demonstrating emerging energy efficiency technologies and transferring the knowledge to the market. Based on their performance self-assessment and the NRC study "*Was it Worth It?*" (NRC 2001) their program has allowed better and faster commercialization of the upstream technologies and advances and achieved high levels of payback.

For example, LBNL claims that their $71 million R&D investment in the 1975-1985 decade in energy efficiency technologies, software and standards has led to significant savings and benefits (see **Table 3**). While some of the assumptions underlying this estimate are open to debate, the estimates provide a useful indication of the order of magnitude of realized energy savings that can be attained when new emerging technologies are not warehoused but, rather, transitioned successfully to the market (Lawrence Berkeley Laboratory 1995).

Table 3: LBNL Net Savings in U.S. from R&D Investment (1975-1985)

	$ Billions	**Multiple of Investment**
Consumer savings achieved as of 1993	$4.96	70
Lifetime savings for technologies installed through 1993	$7.5	106
Lifetime savings for technologies installed through 2015	$155	2,189

DOE Energy Efficiency Research and Development

The National Research Council (NRC) undertook an assessment of the costs and benefits of energy efficiency research undertaken at DOE during the 22-year period from 1978 to 2000. The NRC study found that for the approximately $7 billion (valued in 1999 dollars) spent as part of the DOE energy efficiency program, the estimated net realized economic benefits were approximately $30 billion (valued in 1999 dollars)—approximately a four to one payback ratio. In addition to the realized economic benefits of the R&D, the study identified important environmental and security benefits as well as the creation of important knowledge that provided non-financial and policy benefits (National Research Council 2001).

Implications for California's emerging technologies initiatives

To be successful, upstream R&D often requires pre-commercial deployment activities to build the bridge to the market and encourage market adoption of the emerging technologies. The energy efficiency programs at NYSERDA, LBNL and DOE all incorporate significant levels of pre-commercial bridging activities. In California, the utilities emerging technologies programs coordinate by the ETCC provides the crucial bridge from CEC PIER's energy efficiency R&D to the market and assists in the commercialization of key energy efficiency technologies for the state.

Closing

Raising California's funding level for the ET from 1% to approximately 6% (i.e., $25 million) of the annual energy efficiency budget gradually over the next 4-5 years would provide much higher levels of bridging between of upstream innovations and the marketplace. This would result in better overall return on the R&D investment in energy efficient technologies and faster attainment of the state's energy savings goals.

There is a strong evidence to support the increased investment in emerging energy efficiency technologies in California. First, California's emerging technology and energy efficiency programs have been very effective in reducing electricity demand since 1975. Figure 1 shows that in electricity per capita, the U.S. has grown about 2% per year and California has succeeded in staying constant.

The review of the DOE and LBNL emerging technology programs demonstrates that there is strong, positive payback for RD&D programs of which commercialization is an essential part.

Finally, our assessment of selected emerging technology opportunities has identified important examples of opportunities for capturing additional energy efficiency potential in California. For the selected list of illustrative emerging technologies identified in Table 2, approximately 41-60 GWh annual electric reduction could be realized in the state. The estimated investment by the ET program to bridge only these technologies and emerging technologies from other sources is estimated to be $25 million per year. It is important to note that at the current funding level for the ET program, approximately 75% of the 10-15 energy efficiency technologies that typically emerge annually from PIER research, are in jeopardy of not being adequately bridged to the market place. Bridging those technologies to the marketplace would result in better overall return on PIER's research investment and faster attainment of the kWh savings goal.

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CEC is pleased to have had this opportunity to provide its perspectives and recommendations regarding potential improvements to CPUC's policies and programs in energy efficiency emerging technologies. The CEC desires that this whitepaper provide the basis for collaborative discussions with the CPUC and further exploration of options for improvement.

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Glossary

ACR: Assigned Commissioner's Ruling

CEC: California Energy Commission

CPUC: California Public Utilities Commission

DOE: US Department of Energy

ET: utilities' Emerging Technologies program funded by Public Good Charges

ETCC: Emerging Technologies Coordinating Council

GW: gigawatt

GWh: gigawatt hours

kW: kilowatt

kWh: kilowatt-hours

LBNL: Lawrence Berkeley National Laboratory

MW: megawatt

MWh: megawatt-hours

NRC National Research Council

NYSERDA: New York State Energy Research Development Authority

PIER: Public Interest Energy Research