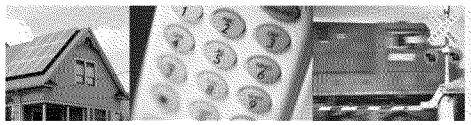

Realizing Lower Bills through Improved Standards & Technology

California Public Utilities Commission

Policy & Planning Division

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Contents

Executive Summary

As residential energy users in California have faced higher rates for regulated electric service over the years, there has been much discussion about how, with increases in energy efficiency, total customer bills have not risen as much. This paper extends the discussion beyond residential customers' utility bills to consider the overall cost of the ultimate services customers purchase through their energy bills. Two examples are presented: household refrigerators and household light bulbs. New refrigerators in 2013 were substantially less expensive to operate and less expensive to buy and own than were similar models in 1980. Similarly, not only the energy-bill cost of household lighting but also the total cost of owning a light bulb has declined with the introduction of more efficient compact-fluorescent bulbs and light-emitting diode bulbs even as utility electric rates have risen.

Introduction & Background

Over the years from 1980 to 2013, changes in technology have resulted in a substantial decrease in the total energy required to operate new household refrigerators and new light bulbs, two examples of major energy-consuming household items. This paper reviews those reductions in energy requirements and extends the analysis to consider whether they are associated with a reduction in the overall cost of owning and operating such household appliances. The result, taking into account not only the energy efficiency gains, but also changes in the cost of electric service, changes in the prices of refrigerators and light bulbs themselves, and other economic variables, is that the total cost of owning and operating these two types of energy-consuming appliances found in nearly all households decreased substantially over the period from 1980 to 2013. For refrigerators, the 2013 total annual cost of ownership and operation is down more than three-fifths from the cost in 1980. For light bulbs, the change has been even more dramatic – more than 70-percent. These results occur even with a substantial increase over the same time period in the cost of the electric energy that powers them.

Energy efficiency has increased for many types of products, and this is not the first research to so report.[1] This paper's research confirms the results reported by others that today's modern refrigerators and light bulbs use much less energy than those of previous decades. It extends the research in two ways: First it includes not only energy costs, but also capital costs, the costs of owning refrigerators and light bulbs; And second, it makes the comparison particular to the circumstances of Californians by incorporating the residential electric rates of Pacific Gas & Electric Company (PG&E, or the Company), one of the three large electric utility companies that serve the Golden State. The analysis measures energy costs as reflected in the third-tier rate within PG&E's residential electric tariffs. Unlike national average rates, or even average revenue-per-kilowatt-hour (kWh) figures that are often used in such

[1] See, for example, Joanna Mauer, Andrew deLaski, Steven Nadel, Anthony Fryer, and Rachel Young, "Better Appliances, An Analysis of Performance, Features, and Price, as Efficiency has Improved," Report No. A-132 of the American Council for an Energy-Efficient Economy and the Appliance Standards Awareness Project, May 2013. For a long-term perspective, see William D Nordhaus, "Do Real-Output and Real-Wage Capture Reality? The History of Lighting Suggests Not," Cowles Foundation Paper No. 957, Cowles Foundation for Research in Economics at Yale University, 1998.

analyses, PG&E's Tier-III rates reflect actual prices faced by many Californians in their home energy consumption.[2] They are the consumers' cost of more energy use and the savings from using less.

It is an oft-repeated California boast that while our rates for electric service are high, our electric bills are not so high, for we have invested in energy efficiency. Energy use per person in California has remained about constant over several decades, in sharp contrast with the substantial increase over the Nation as a whole.[3] The California Public Utilities Commission's web site states it very clearly: "Due to the State's efficiency programs, per capita energy use has remained flat...."[4] Savings from efficiency is valuable to Californians not only for its economic benefit to consumers. Conservation of electric energy, particularly electric energy produced from fossil sources, is a primary method for reducing greenhouse gas emissions and mitigating, to the extent possible, global warming.[5]

The research shows that refrigerators have been changing over the years in at least two ways. First and most obvious to purchasers is the proliferation of alternative door designs. In the 1980s most household refrigerators were two-door top-freezer models; now there are many more choices. Second and more important to this research, refrigerators have been getting much more efficient in their use of electricity. New top-freezer models in 1980 consumed more than 1,400 kWh over a year, according to a review in Consumer Reports magazine.[6] In 2013, top-freezer models consumed less than 500 kWh per year, nearly a two-thirds reduction. Overall, ownership costs have been declining while energy use also has been declining. The only part of refrigerator costs that is rising is the cost of the electric service itself.

For light bulbs, the change has not developed from incremental improvements from year to year. Instead, the entire technology of light production changed and is in the process of changing a second time. In the 1980s, almost all electric light bulbs were incandescent bulbs. In the 1990s, compact fluorescent bulbs (CFLs) were introduced. Now, in the 2010s, Light-Emitting Diode bulbs (LEDs) are becoming an even more efficient choice. The reduction in energy consumption for a similar amount of light has been dramatic. A traditional 60-watt bulb – the standard choice in 1980 – might consume over 100 kWh over a year in normal operation.[7] A new LED bulb available in 2013 that provides the same amount of illumination would consume only about 20 kWh, a four-fifths decrease in consumption. The old incandescent bulbs were inexpensive to purchase. The new LED models are, by comparison, expensive to buy. But because of their long life, the cost of owning them is spread out over many years. And the cost of operation is comparatively very low.

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[2] About one-third of residential customers of the three large investor-owned electric utilities in California face the third tier for at least a portion of their monthly electric consumption according to an estimate provided by the CPUC Energy Division.

[3] A graph of the California and National trends appears in the California Public Utilities Commission's "Primer on Energy Efficiency," or "CPUC Energy Efficiency Policies and Investor-Owned Utility (IOU) Programs," December 11, 2012, page 3. It can be accessed here: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/.

[4] California Public Utilities Commission web site: http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/.

[5] California's Global Warming Solutions Act of 2006, also known as "AB-32," provided and discussed on the website of the California Air Resources Board, http://www.arb.ca.gov/cc/ab32/ab32.htm.

[6] In fact, while the statistics presented in this paper are for annual energy consumption, the February 1980 Consumer Reports review of refrigerators reports energy use in kWh/month.

[7] The specific assumptions about light-bulb operating hours are discussed later.

The developments have occurred at different rates and in different rates for these two types of appliances. For refrigerators, the results show a steep decline in total costs from 1980 to 2000, followed by a more-or-less flat total cost since then. For light bulbs, the decline is associated with the changes in technology beginning in 1992, with the first Consumer Reports discussion of Compact Fluorescent bulbs and continuing with the introduction of LED bulbs, first reviewed in 2011. The purchase price of new refrigerators has declined over the year. In contrast, with light bulbs, the savings in energy use have come with increases in the initial cost of buying the bulbs. Even so, while the initial costs of buying the newest form of light bulbs is higher than the initial cost of the old incandescent bulbs, the overall costs of ownership have declined with greater longevity of the new bulbs.

This paper is based on reviews of the new household refrigerators and new lighting sources published by Consumers Union, a reputable consumer organization from 1980 through 2013, with the results recalculated to show total annual costs of ownership and operation, all in dollars of 2013 value. Both capital costs and electric rates are applied to the Consumer Reports' test results. Capital costs are related to national economic conditions, and the electric costs are calculated at electric rates in place in northern California at the time. Specifically the CPUC-approved just and reasonable residential tariffs of the PG&E were applied to the electric consumption figures in the Consumer Reports reviews. PG&E's tariffs include a "tiered" rate schedule, i.e., a schedule that charges a low rate for a prescribed quantity, or block, of energy followed by higher rates for additional consumption.[8] For this analysis, we rely on PG&E's third-tier rate – a rate that is likely to be on the margin for a substantial portion of residential customers. By choosing a rate that is on the margin, we focus on a customer's potential savings or additional costs associated with changes in consumption, such as by changing out an old light bulb for a new, more efficient bulb, or by changing out an old refrigerator for a new one.[9]

The empirical finding of this paper is that efficiency gains in domestic refrigerators and in household lighting have come faster and stronger than have California's increases in electric rates. So, yes, it appears to be justified to claim that our rates are high, but our bills are low.

Can these benefits in lower costs be attributed to California's efficiency programs? There may be some connection, and some would argue that without action in California, there would not have been nearly as much improvement in the efficiency of either refrigerators or light bulbs. Certainly, the California Energy Commission can claim to have adopted refrigerator standards very early, in 1976, and that those regulations were then followed upon at the federal level.[10] The Appliance Standards Awareness Project gives some credit to California as well:

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[8] The structure of CPUC residential energy tariffs is under review in CPUC docket R.12-06-013. There is a review of the concepts embedded in energy tariffs, including those of PG&E, prepared by Energy Division Staff and available on the CPUC web site at: http://www.cpuc.ca.gov/PUC/energy/Electric+Rates/. See "Rate Design Elements, Concepts and Definitions – PowerPoint."

[9] It is beyond the scope of this paper to discuss the benefits and dra wbacks of tiered rates except to note that one of the benefits is their ability to provide a sharp price signal to users without also delivering a very high bill. For a discussio n, see Stephen St Marie, "Implications of High Marginal Rates in Utility Service Tariffs," for presentation to the 20th Annual Western Conference, Center for Research in Regulated Industries, Monterey, CA, June 28, 2007.

[10] The California Energy Commission's "Regulations for Appliance Efficiency Standards Relating to Refrigerators, Refrigerator-Freezers and Freezers and Air Conditioners, were adopted on November 3, 1976. See the Energy Commission's web page, http://www.energy.ca.gov/appliances/.

> The story of residential refrigerator efficiency since the mid-1970s is one of the greatest success stories of appliance efficiency standards. Six iterations of standards (three adopted by California and then by other states, and three adopted nationally) have driven the energy use of a typical new refrigerator from about 1,800 kWh/yr. in 1972 to less than 500 kWh/yr. today.[11]

California has also been critically involved in the search for developments in lighting and in regulation of electric lighting. California's standards for efficiency in lighting are stronger than federal standards.[12] Certainly, it is true that there is federal law, and federal lighting standards are the result of the 2007 Energy Independence and Security Act (EISA).[13] But the EISA only began to take effect in 2012 and therefore cannot take credit for the benefits of lighting efficiency improvements beginning in the 1990s when CFLs first appeared.

Finally, California utilities, under the sponsorship of the CPUC and with compensation from customer payments, have developed and operated programs designed to promote the dissemination and use of efficient lighting. These programs have included rebates for the purchase of new energy-star appliances, buy-back programs for older, inefficient appliances, and buy-down programs designed to provide retail consumers with lower prices for efficient items at retail stores. The CPUC allocates large budgets to these programs, and has done so at least since the adoption of the Long Term Energy Efficiency Strategic Plan in 2008.[14] The budget for 2013-14 is over $69 million.[15] The CPUC maintains a website for Californians called "Lower My Utility Bill."[16]

This paper does not evaluate California's development of standards or the State's programs to promote energy efficiency. It does not posit that the gains in efficiency that have been achieved would not have occurred without the standards and efficiency programs. Still, given the fact of California's actions over the years it is hardly possible to deny that California has made investments. This analysis shows that substantial gains have been achieved, and it provides no reason not to continue California's boast that at least some of the benefits of increased efficiency have come from those investments.

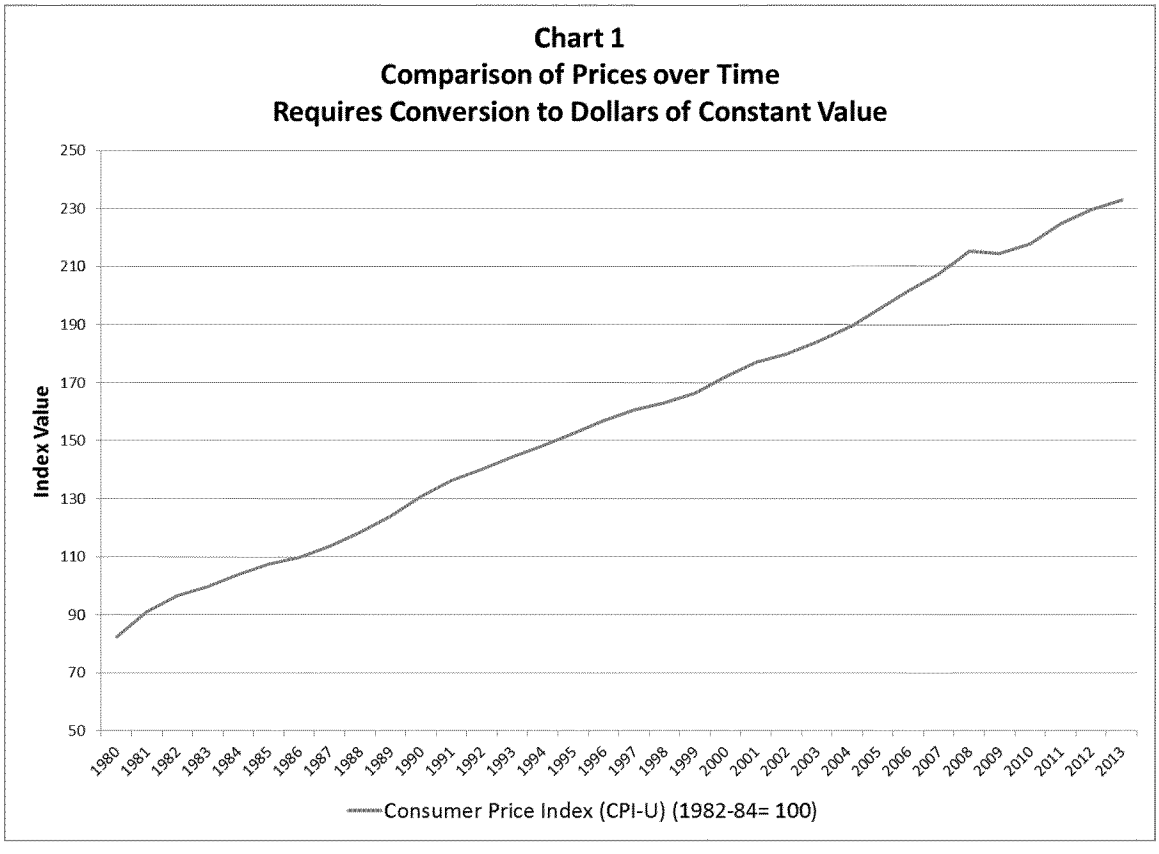
Data Sources & Methods

I reviewed a series of articles in Consumer Reports magazine from 1980 through 2013. For refrigerators, I analyzed the reviews in five-year intervals from 1980 through 2010, and then annual articles from 2010 forward through the end of 2013. Reviews of refrigerators were not always done in every fifth year over the period, so in some cases I relied on adjacent years. For light bulbs, there were very few articles in

[11] ASAP web site, Refrigerators and Freezers, "Key Facts." http://www.appliance-standards.org/product/refrigerators-and-freezers.
[12] See California Energy Commission 2010 Appliance Efficiency Standards, adopted November 18, 2009. Available at http://www.energy.ca.gov/appliances/previous_regulations.html.
[13] The EISA is administered by the U.S. Department of Energy. Information is here. http://energy.gov/eere/femp/energy-independence-and-security-act.
[14] California Public Utilities Commission, 2010-2011 Energy Efficiency Annual Progress Evaluation Report, September 2012.
[15] CPUC Fact Sheet, Statewide Lighting Program (2013-2014), July 2013.
[16] CPUC web site: http://www.cpuc.ca.gov/puc/cec/d_lowerbill.htm.

the early years. Since 2007, there was an article almost every year. In each case, I took the purchase prices as given in the articles. For example, in the June 2000 Consumer Reports evaluation of refrigerators, there were 14 top-freezer models evaluated. The article also reviewed another 19 models with other door configurations, but I kept those numbers separate. Another seven top-freezer refrigerators were evaluated in the October 2000 issue. I combined the results of both Consumer Reports analyses together and found that the prices of the 21 top-freezer models ranged from $525 to $1,100. I calculated the average, $725, and used that number for the analysis.

I used the US Bureau of Labor Statistics' Consumer Price Index for All Urban Consumers (CPI-U) to convert all years' data to 2013-value dollars, for the overall price level nearly tripled from 1980 through 2013. The original $725 average price among refrigerators evaluated in 2000, for example, converts to $980 in dollars of 2013 value.



Energy cost is only part of the cost of owning and operating a refrigerator or a lighting device in a home. Other costs include the cost of purchasing and owning. Those costs can be further broken down into the cost of depreciation over time and the opportunity cost of the capital associated with the item. For depreciation of refrigerators, I used 15 years as a standard, a number that appears in some of the

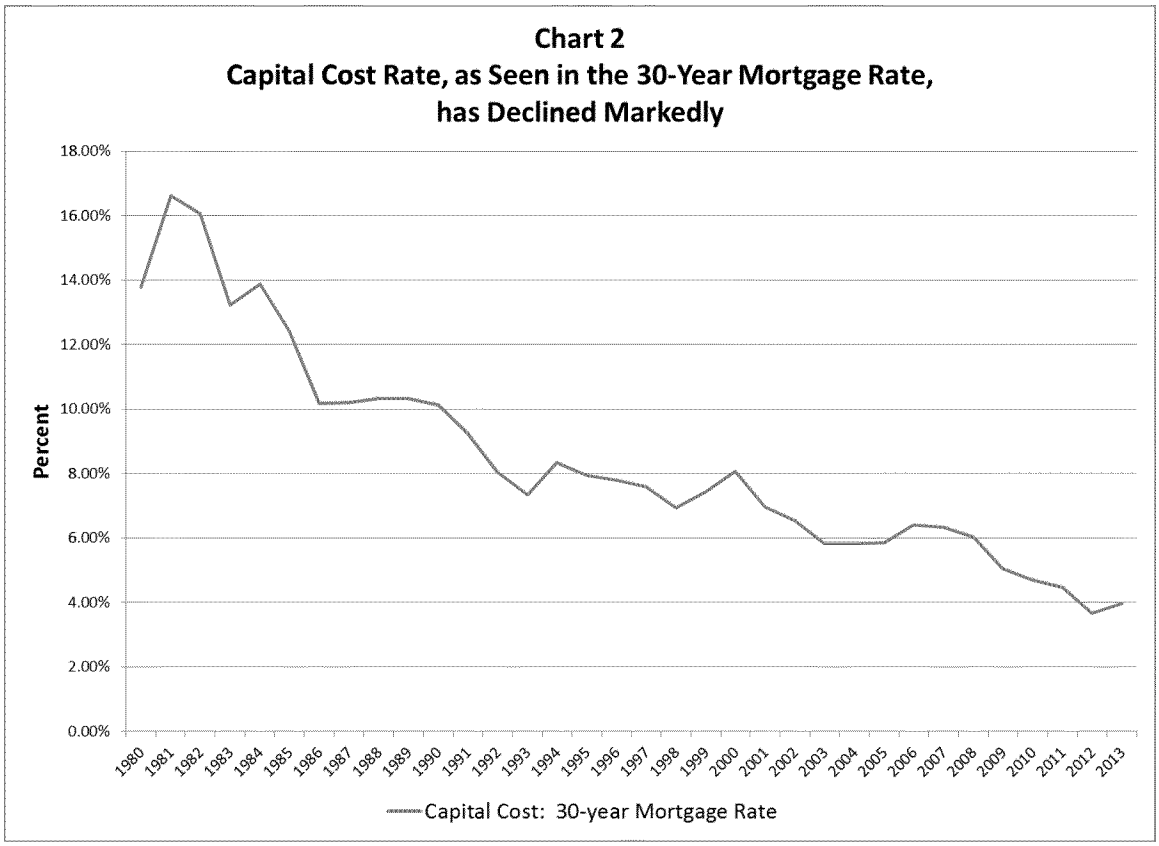
Consumer Reports articles.[17] For light bulbs, I calculated a lifetime based on the claimed lifetimes of the bulbs as reported in the Consumer Reports articles and an assumption about annual usage.

The rate of capital cost facing consumers varies depending on their circumstances. It is arguable that credit-card rates – which can be over 20-percent – may be appropriate for some consumers. Others without debts may face only the opportunity cost of purchasing certificates of deposit – which may yield 1-percent or less. Purchasing a refrigerator may be a substantial household expense and may be done on credit. It is unlikely that light bulbs are purchased on credit except on revolving credit arrangements or through credit cards. There is a substantial literature in economics regarding the appropriate rate of discount for different analytical purposes.[18] For this analysis, I did not attempt to use a social discount rate that would be appropriate for analysis of cost-benefit of public investment projects. Rather, I wish to evaluate consumer costs based on a number from a householder's point of view. Plus, I wanted a number that is simple and available. I used the 30-year mortgage initiation rate, a series available from the Federal Reserve Board on a relatively consistent basis over the entire time period from 1980 forward.

Mortgage rates declined from over 15-percent in the early 1980s to less than four-percent in 2012-13. This change results in a substantial decrease in ownership costs for both refrigerators and light bulbs that is not at all related to energy efficiency, purchase price, or electric rates. This fact is discussed later.

[17] The use of 15 years as a standard life for refrigerators may be too conservative. Changing the expected life from 15 years t o 20 years lowers the cost of ownership by a small amount, but it does not affect the character of the results. Appendix 1 presents a version of Table 2 using a 20-year life.

[18] For a recent review of the literature, see Juzhong Zhuang, Zhihong Liang, Tun Lin, and Franklin De Guzman, "Theory and Practice in the Choice of Social Discount Rate for Cost-Benefit Analysis: A Survey," ERD Working Paper No. 94, Asian Development Bank, May 2007.



Finally, there is the operating and maintenance cost. Energy consumption is the only operating cost I considered. For light bulbs, energy consumption is the only operating cost, for light bulbs are not maintained or repaired. They are merely replaced at the end of their useful lives. For refrigerators, there may be some other maintenance costs besides electric service, such as cleaning and repair. I have not discovered information about the non-electric operating and maintenance costs of household refrigerators, and so they are not included in this analysis.

Most of the Consumer Reports articles reported either the kWh consumed or a dollar equivalent, based on national average utility rates. I used the information provided in the articles to calculate average annual kWh energy consumption for each type of refrigerator for each year analyzed. I then applied the third-tier rate of the tariffs of PG&E that were in effect on July 1 of the years of observation, adjusted to dollars of 2013 value. In 1980 and 1985, and in the years after 2000, PG&E's rates had at least three tiers. In 1990, 1995, and 2000, Tier II was the highest rate. In those cases I used the second tier, of course. The purpose of using a specific rate instead of the more typical average revenue-per-kWh is that the rates provide the actual marginal cost or marginal savings associated with operating a particular appliance or light bulb.[19]

[19] According to information provided by the CPUC's Energy Division, in the most recent years, approximately one-third of residential customers faced the third tier for at least a portion of monthly consumption. The remainder of residential customers either use less energy (thereby avoiding high-tier consumption) or subscribe to CARE low-income rates.

Chart 3 presents PG&E's third-tier rates in five-year increments from 1980 to 2010 and annually for the years 2011, 2012, and 2013. In cases where rates changed during the year, I used the rate that was in place on July 1. Though the rates as filed (shown in by the blue line) increased rapidly over the years, much of the increase is matched by inflation in the price level generally. The rates restated in dollars of 2013 value show the rates in constant value. In real terms, the rate declined nearly one-third from 1980 to 2000, and then increased after 2000.

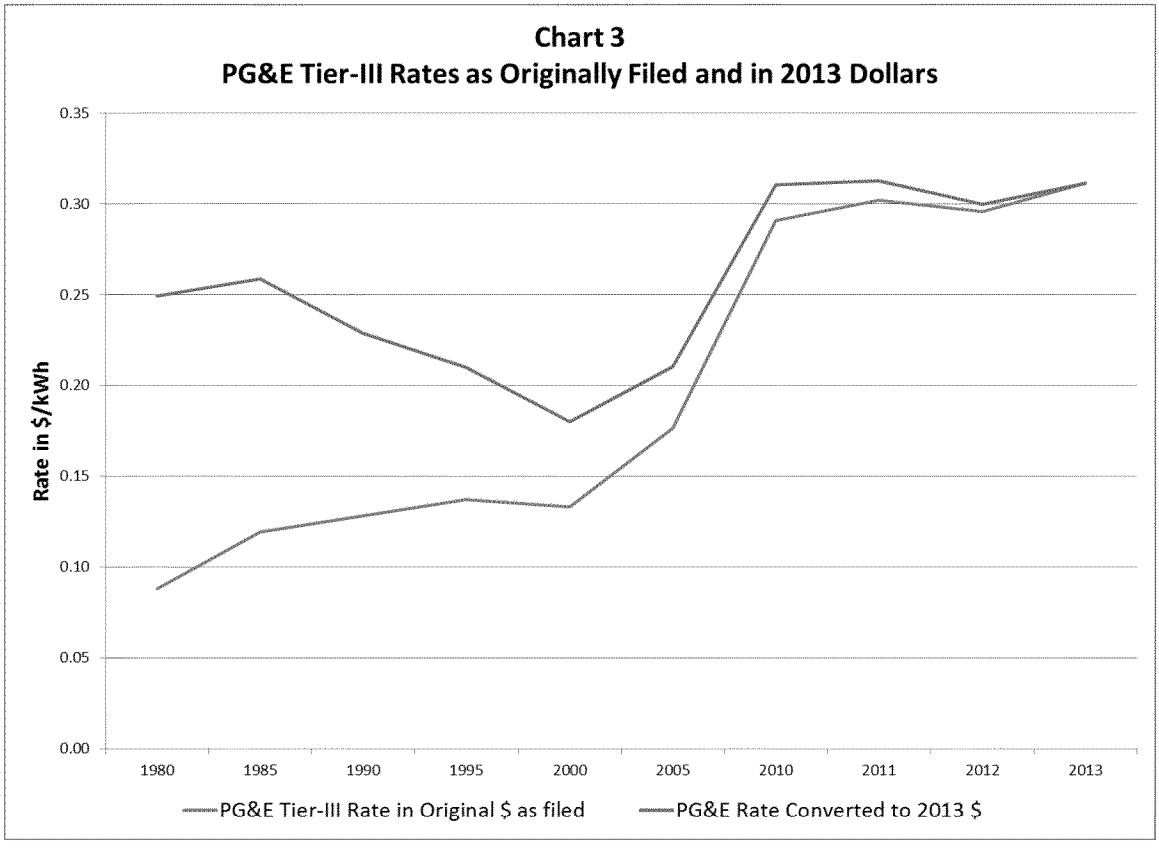
It is arguable that electric rates are not an appropriate price signal to use to measure consumers' trade-off between energy consumption and capital investment in new refrigerators or light bulbs. First, while the electric tariffs in effect on any day reflect the immediate trade-off faced by consumers, we should be aware that they do not reflect the change in utility costs that result from reduced consumption. A utility may save only a fraction of the amount removed from a residential customer's bill from reduced consumption, particularly from consumption at the third tier. In this analysis, the customer saves about $0.31 per kWh reduced from consumption. The utility's generating savings may be half that amount or even less. An analysis from society's point of view would take into account that the customer's savings may be short-lived, for future rates will have to reflect the smaller change in the utility's total cost of service. According to this argument, an analysis based purely on bill savings overstates customers' savings.

Second, there is an argument that goes beyond today's rates and even beyond today's electric utility costs. It is that the savings from reduced kWh consumption to the extent that they can be counted on to persist in the future – such as the benefits from more efficient refrigerators and better light bulbs – represent an opportunity for the utility to avoid major infrastructure investment. According to this argument, it is not only generating savings, or even bill reductions that are important. It is the savings possible in the longer run as new power plant construction is avoided, new transmission line upgrades and whole new transmission corridors are avoided, and even local distribution system upgrades are avoided. According to this argument, the savings to consumers from investment in more efficient refrigerators and lighting systems may be substantially larger than the savings in their current bills. Therefore, an analysis based on bill savings would understate consumers' total benefit from more efficient refrigerators and lighting systems.

Finally, there is the argument that energy consumption results in a reduction of negative externalities including reduced greenhouse gas production. The benefits of less global warming may not be calculable, but they may be sizable and may constitute a reason for society to take a strong interest in more efficient refrigerators and lighting fixtures regardless of savings on current bills.

None of these arguments shall be addressed here, and this analysis does not account for reduced greenhouse gas emissions or the effect on future rates of today's savings. This analysis is calculated from rates on consumers' bills and from what some may consider a short-sighted consumers' point of view.[20]

[20] Issues involving pricing for energy efficiency compared to the cost of generation and externality costs are discussed in a well titled article, "Energy Efficiency Policy Puzzles," by Timothy J Brennan, *The Energy Journal*, Vol 34, No 2, 2013.



Household Refrigerators

Household refrigerators are often tested by Consumer Reports magazine. For this research, I reviewed the articles published over five-year intervals from 1980 forward through 2010, and all articles for 2011 through 2013. In total it is over 20 articles. In each article, the magazine conveniently separated the results into groups of top-freezer models and others by type, allowing tracking of similar types of refrigerators over time.[21]

There were two Consumer Reports refrigerator reviews in 1980. In February, six top-freezer and 10 bottom-freezer models were reviewed. In September, an additional 13 top-freezer models were reviewed. The average of the 19 top-freezer units cost $570 (in 1980 $), while the average bottom-freezer unit sold for $606. The articles reported kWh consumption of the refrigerators, with the annual averages being 1,454 kWh for top-freezer models and 1,975 kWh for bottom-freezer models. A PG&E customer, paying slightly less than 9¢ per kWh on the third tier of the tariff, would have paid about $128

[21] Refrigerator models are not strictly comparable from year to year, and have changed in other ways besides becoming more efficient in their use of electricity. One change is that the newer units are larger. The top-freezer models reviewed in the 1980 Consumer Reports article averaged 17.5 cubic feet (claimed by manufacturers) and 14.0 cubic feet (usable space measured by Consumer Reports). The "similar" top-freezer 2013 models averaged 21.1 cubic feet (claimed) and 17.1 cubic feet (usable measured), an increase of a bit more than 20-percent.

for electricity to run the average top-freezer model for a year. A buyer of an average bottom-freezer unit would have paid $174 for electric service for the refrigerator.

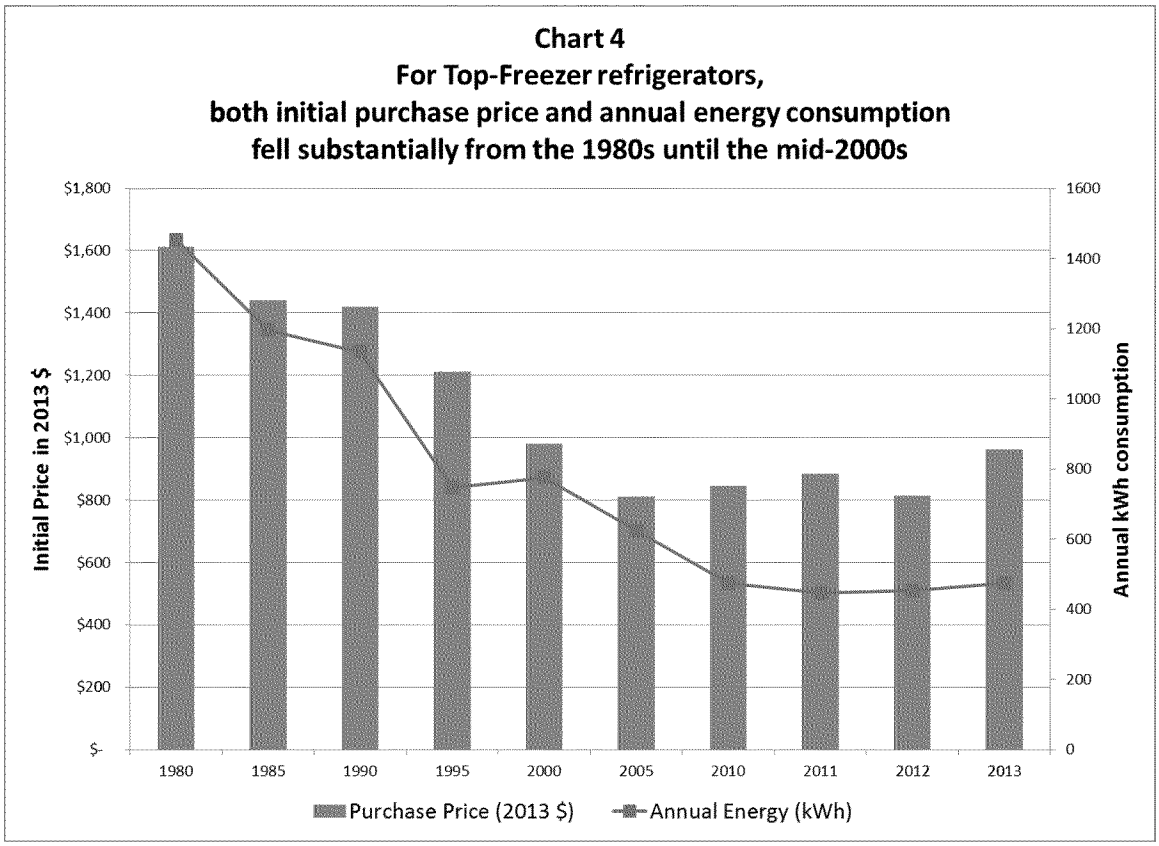
By 2013, prices had changed and, after translating the 1980 numbers into 2013 dollar values, it is clear that the modern units are much less expensive to buy and less expensive to operate. Six top-freezer models and four bottom-freezer models were analyzed in the Consumer Reports magazine of July 2013. The average purchase prices were $962 and $1,200, and the annual electric consumption levels were 474 kWh and 434 kWh, respectively. At PG&E's third-tier rate, annual operation would cost be about $147 and $135. (The article also analyzed 19 French-door bottom-freezer units and seven side-by-side-door models.) Table 1 presents a simple review of the cost to buy a refrigerator and the cost to run it for a year.

Table 1

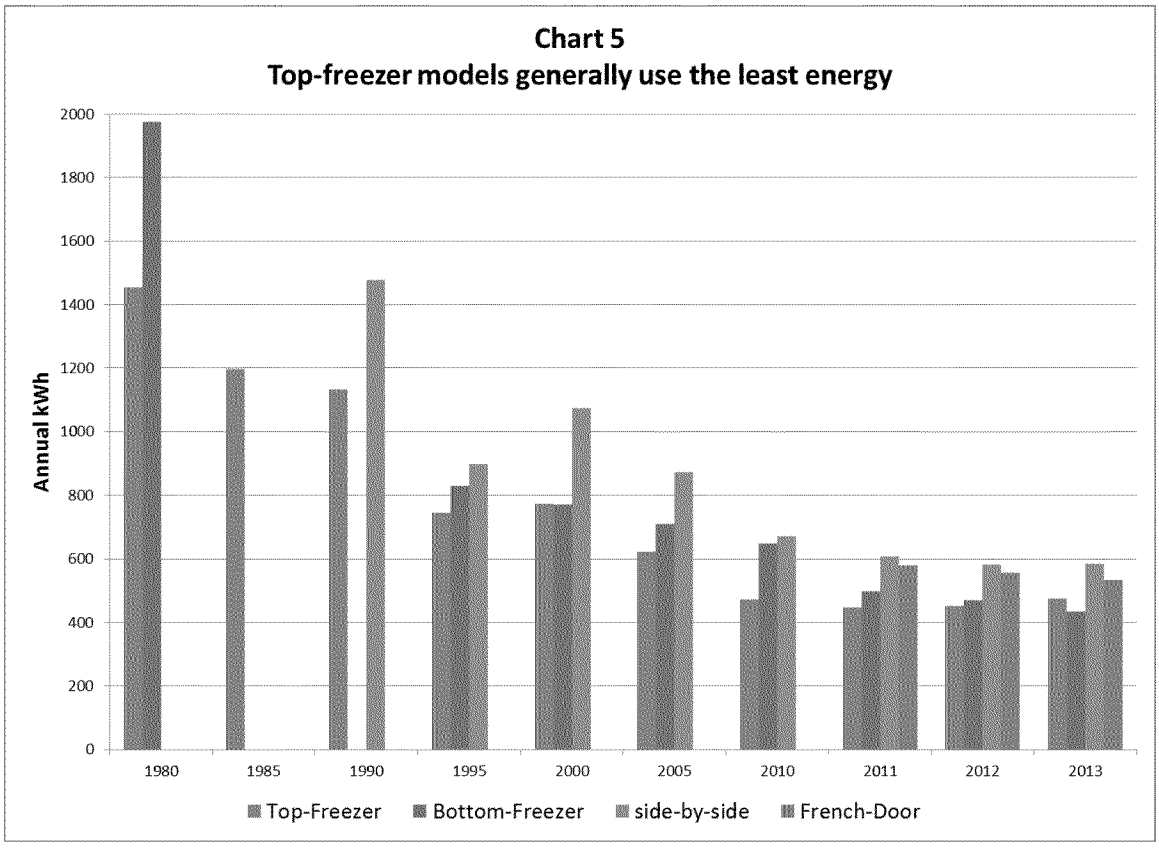
Modern refrigerators are less expensive to buy and to operate

	Purchase Price ($)	Electric Consumption (kWh)	Electricity Cost ($)
1980 models *in 1980 dollars*			
Top-freezer models	570	1,454	128
Bottom-freezer models	606	1,975	174
1980 models in *2013 dollars*			
Top-freezer models	1,611	1,454	362
Bottom-freezer models	1,713	1,975	492
2013 models			
Top-freezer models	962	474	147
Percent of 1980 value	*60%*	*33%*	*41%*
Bottom-freezer models	1,200	434	135
Percent of 1980 value	*70%*	*22%*	*27%*
French-door models	2,584	533	166
Side-by-side models	1,843	586	182

Chart 4 presents in graphical form the progress of energy usage declines along with the decline in initial purchase costs of top-freezer refrigerators from 1980 through 2013. The progress has been remarkable, at least through approximately 2005.



Not only have the top-freezer models declined in energy use; the other types have also shown progress. Still, except for 2013, all of the other years show that the top-freezer models used the least energy among the types tested.



Of course, refrigerators are not purchased every year, nor are they consumed in a year. For a more comprehensive review, we should take into account that refrigerators have a life of 15 years or more. The entire purchase price may be paid in one year, but the cost of owning and operating it should take into account that only 1/15th of its output is consumed in any one year. This analysis has counted a year's ownership cost as a combination of depreciation of 1/15th of the purchase price plus the capital carrying cost of 14/15^{ths} of the purchase price. Table 2 presents the results for all years and for all of the types of refrigerators reported. For top-freezer refrigerator models, the decline in ownership cost has been remarkable – from $677 to $247, a drop of about 64-percent.

Appendix 1 presents a modified version of Table 2 based on a 20-year refrigerator life. The results present a slightly lower cost of ownership but no change in the character of the result.

The major factors driving down the costs shown in the results in Table 2 are greater energy efficiency and lower initial purchase prices. But there is another factor – the decline in the capital cost rate – that significantly affects the outcome. With the decline in mortgage rates from about 14-percent in 1980 to about 4-percent in 2013, the opportunity cost of holding capital in the form of a refrigerator also has declined. Applying the 1980 cost of capital to the 2013 results raises the 2013 annual total cost of owning and operating a top-freezer refrigerator from $247 as shown in Table 2 to $335, an increase of $88. So, even excluding the benefits of a lower cost of capital, modern refrigerators, at $335 per year,

still would be less than half as costly to own and operate as those of 1980, which cost $677 per year as shown on Table 2.

Table 2

Refrigerator Cost of Ownership and Operation, 1980-2013

	1980	1985	1990	1995	2000	2005	2010	2011	2012	2013
	--- All Values shown in 2013 Dollars ---									
Top-freezer models										
One-Year Ownership Cost	$315	$263	$229	$171	$139	$99	$93	$96	$82	$100
One-Year Operating Cost	$362	$310	$259	$157	$140	$131	$147	$140	$136	$147
Total Cost of Owning and Operating	$677	$573	$488	$328	$279	$230	$241	$235	$218	$247
Bottom-freezer models										
One-Year Ownership Cost	$334			$209	$167	$189	$232	$116	$111	$125
One-Year Operating Cost	$492			$174	$139	$149	$202	$156	$141	$135
Total Cost of Owning and Operating	$827			$383	$306	$338	$434	$271	$252	$260
Cost compared to top-freezer	*122%*			*117%*	*110%*	*147%*	*180%*	*115%*	*116%*	*105%*
Side-by-side models										
One-Year Ownership Cost			$392	$277	$277	$226	$192	$177	$169	$191
One-Year Operating Cost			$338	$189	$194	$184	$208	$190	$175	$182
Total Cost of Owning and Operating			$730	$466	$471	$410	$400	$367	$344	$374
Cost compared to top-freezer			*150%*	*142%*	*169%*	*178%*	*166%*	*156%*	*158%*	*151%*
French-door models										
One-Year Ownership Cost								$231	$211	$268
One-Year Operating Cost								$181	$167	$166
Total Cost of Owning and Operating								$412	$378	$434
Cost compared to top-freezer								*175%*	*173%*	*176%*

The results clearly show that the total costs of owning and operating new top-freezer refrigerators declined sharply over the years from 1980 through 2005. The results for more recent years are about flat. Chart 6 shows the decline in the total ownership and operating costs of top-freezer refrigerators in graphical form. That the values vary from year to year may be the result of the particular choices of refrigerator models chosen by Consumer Reports to review and less related to changes in overall cost of ownership or operation of refrigerators generally.

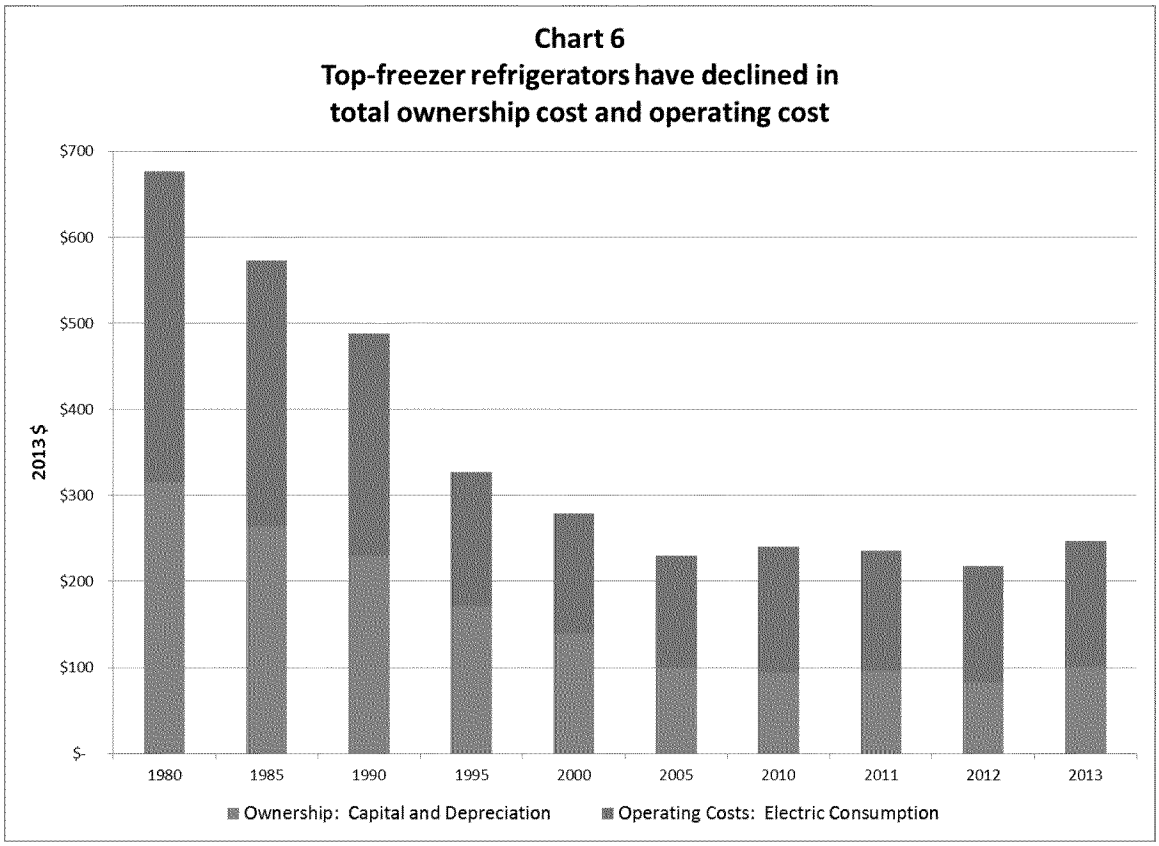


Table 2 also shows the same general pattern of declining costs for the bottom-freezer models and the side-by-side models of refrigerator. French-door models, if they were available at all, were not presented in the Consumer Reports articles in the years searched. Still, the increasing popularity of the side-by-side models and the French-door models has occurred despite the clearly higher costs associated with owning and operating them. Apparently, consumers have other values besides minimizing energy use and ownership cost. It may be that at least some customers are willing to trade-off some of the energy and ownership cost savings in favor of greater convenience or other aesthetic values.

Finally, the decline in overall costs for refrigerators seems to have paused, or perhaps ended, after 2005. It could be that new refrigerator standards will provide substantial further declines after 2015. In August, 2011, the US Department of Energy issued updated standards for refrigerators and freezers. The rules contained a three-year lead time and will become effective in August of this year.[22]

Household Light Bulbs

The technology of household light bulbs has undergone two major changes since 1980. While it is true that fluorescent bulbs have been commercially available for many years, and they found their way into domestic kitchens and baths in many homes, most domestic lighting has been from incandescent light

[22] U.S. Department of Energy, 10 CFR Part 430, (Docket Number EE-2008-BT-STD-0012), RIN: 1904-AB79.

bulbs. Bulbs, or lamps, come in many sizes and shapes and many have special characteristics, such as reflectors or three-way filaments. This analysis is based on a review of traditional 60-watt, 800-lumen household lamps. They turn on and off instantly; they are "dimmable," and they emit a light color that many consider pleasant (so pleasant, in fact, that the makers of the newer types of bulbs have worked to emulate the light color of incandescent bulbs). Consumer Reports magazine did not spend much effort in reviewing incandescent bulbs. There were review articles in 1982 and 1990. Incandescent bulbs were included in a 2007 analysis that reviewed their performance against that of compact fluorescent bulbs.

Compact Fluorescent bulbs were first reviewed in Consumer Reports in October 1992. That article noted not only that customers could achieve savings on electric bills from using CFLs, but also pointed out the electric utilities' desire that customers should use them. It said:

> "Utility companies want their customers to replace their incandescent bulbs with newer compact fluorescents. If enough households use compact fluorescents, the overall demand for electricity will drop. Utility companies could then postpone or forgo the construction of new generating plants, the rate increases to pay for them, and the associated environmental impacts."[23]

That 1992 article noted several problems with the new CFLs. First, it pointed out that some of the bulbs "touted as replacements for 60-watt incandescent … were more than 300 lumens shy of the usual 850 or so that soft-white 60-watt bulbs put out." The article mentioned the high cost of the CFLs, but even at those high purchase costs, the bulbs would pay for themselves in lower electric bills. The article found that some of the CFLs it tested had lives much short of the claims. The article noted that standard fluorescent tubes are generally unsuited to living areas in a home because of the color of the light they emit. Would the new CFLs be better? The article state, "Not always." In a section entitled "Quirks and cautions," the article noted that CFLs should not be used with a dimmer switch, that some models contain tiny amounts of radioactive material to help them start up, that many CFLs are hard to fit into standard fixtures, that some manufacturers say they should not be used outdoors, that they may flicker, and that they are heavy, perhaps making some lighting fixtures tippy, and that some staffers "reported that their television set's remote-control unit wouldn't function in a room lit by an electronic-ballast bulb."[24]

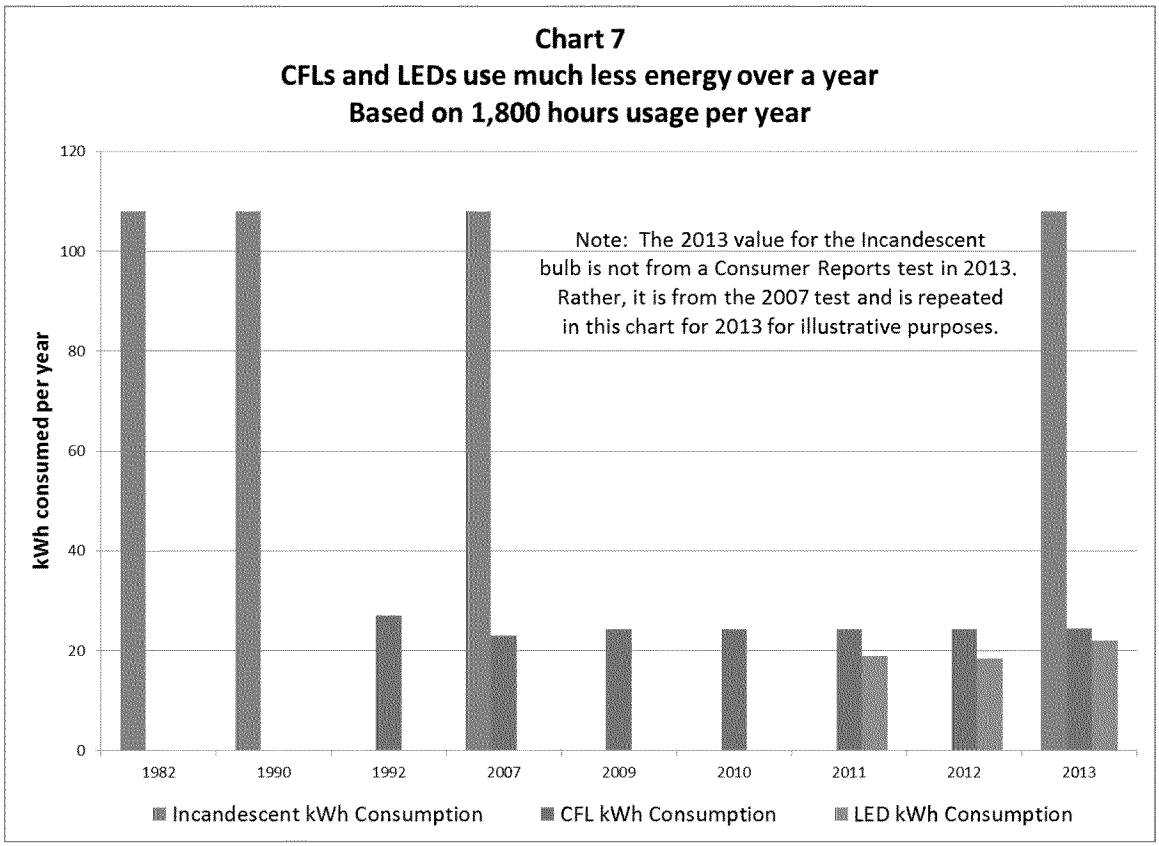
The next Consumer Reports review of CFLs, in 2007, was much more positive. Only a few deficiencies were highlighted: They were slow to reach full brightness, their lives would be shortened by frequent cycling, and recycling efforts (needed because of mercury) were lagging.[25] A 2009 review was subtitled "Energy-saving bulbs look good and save money."[26]

While CFLs continue to be sold, a second lighting revolution has begun with LEDs, which are even more efficient than CFLs in their production of light. The first Consumer Reports review of LEDs was in

[23] Consumer Reports, "Bright Ideas in Light Bulbs," October 1992, page 664.
[24] Consumer Reports, "Bright Ideas in Light Bulbs," October 1992, pp 664-668.
[25] Consumer Reports, "Lighting, New twists in savings," October 2007, pp 28-29.
[26] Consumer Reports, "Compact Fluorescents," October 2009, pp 29-31.

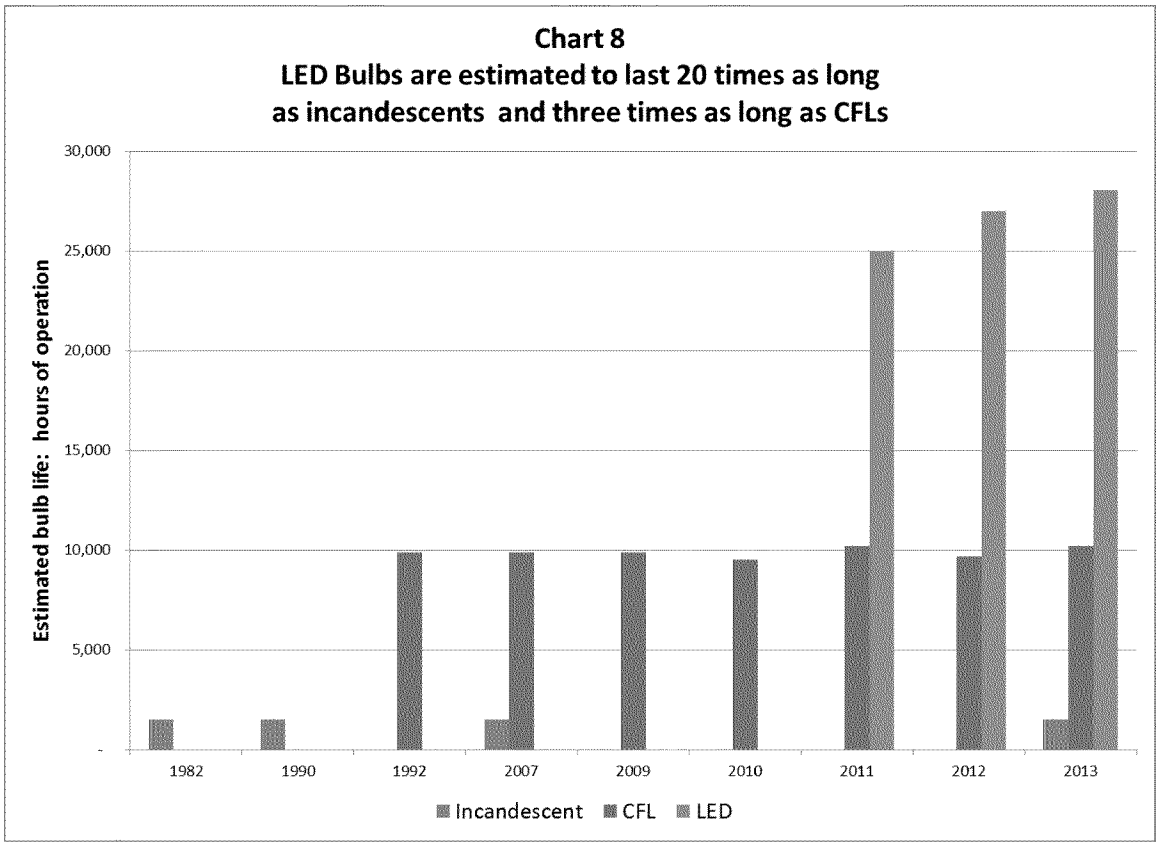
October 2011.[27] At that time, the consumer prices for LED bulbs were very high, and the article noted that without rebates, the new bulbs "can take four to 10 years to pay for themselves." And "you probably won't save money by switching from a CFL to an LED until the price of LEDs comes down."

Certainly, CFL bulbs and LED bulbs use less electric energy to produce the same light. The question of this analysis is about the total cost of ownership, including the cost of bulbs as well as the cost of the electric service required to power them. In fact, the benefits of the new types of bulbs are even more dramatic in terms of total cost reduction than are the benefits of new refrigerators. Chart 7 presents an illustration of the energy consumed by the three types of bulbs should they be used 1,800 hours per year, that is, five hours per day, 360 days per year.



The three types of bulbs vary not only in their consumption of electric energy, but also in their useful lives. Chart 8 presents the data as it appeared in the Consumer Reports tests. While traditional incandescent bulbs last about 1,500 hours, CFLs are hovering near 10,000 hours, and LEDs are between 25,000 and 30,000 hours. That total would mean that 20 incandescent bulbs would be required over the lifetime of a single LED bulb. Such longevity makes a difference in the analysis of the total cost of ownership and operation.

[27] Consumer Reports, "Lightbulbs," October 2011, pp 27-29.



As in the case of refrigerators, the total cost of owning and operating an electric light bulb is not only the cost of the electricity to operate it. Nor should the full initial purchase price of a bulb that may last many years be charged to the first year. Therefore, I performed the analysis of ownership costs based on the same principles used in the refrigerator analysis presented earlier. Except, instead of the assumption of 15 years of operation used for refrigerators, I relied on the bulb lifetimes reported in the Consumer Reports articles and shown in Chart 8. Ownership cost is simple to calculate for the use of an incandescent bulb that is expected to last less than one year. Under the assumption of 1,800 hours of operation per year, the cost is the full purchase price of 1.2 bulbs. For bulbs that are estimated to last longer than one year, the analysis is the analogous to the analysis for long-lived refrigerators: Assuming 1,800 hours of operation per year, the first year's depreciation is 1,800/ (hours of life of bulb) X (initial purchase price of bulb). And the holding cost is (annual cost of capital) X (balance after one year of depreciation).

Table 3

Lighting Cost of Ownership and Operation, 1982-2013

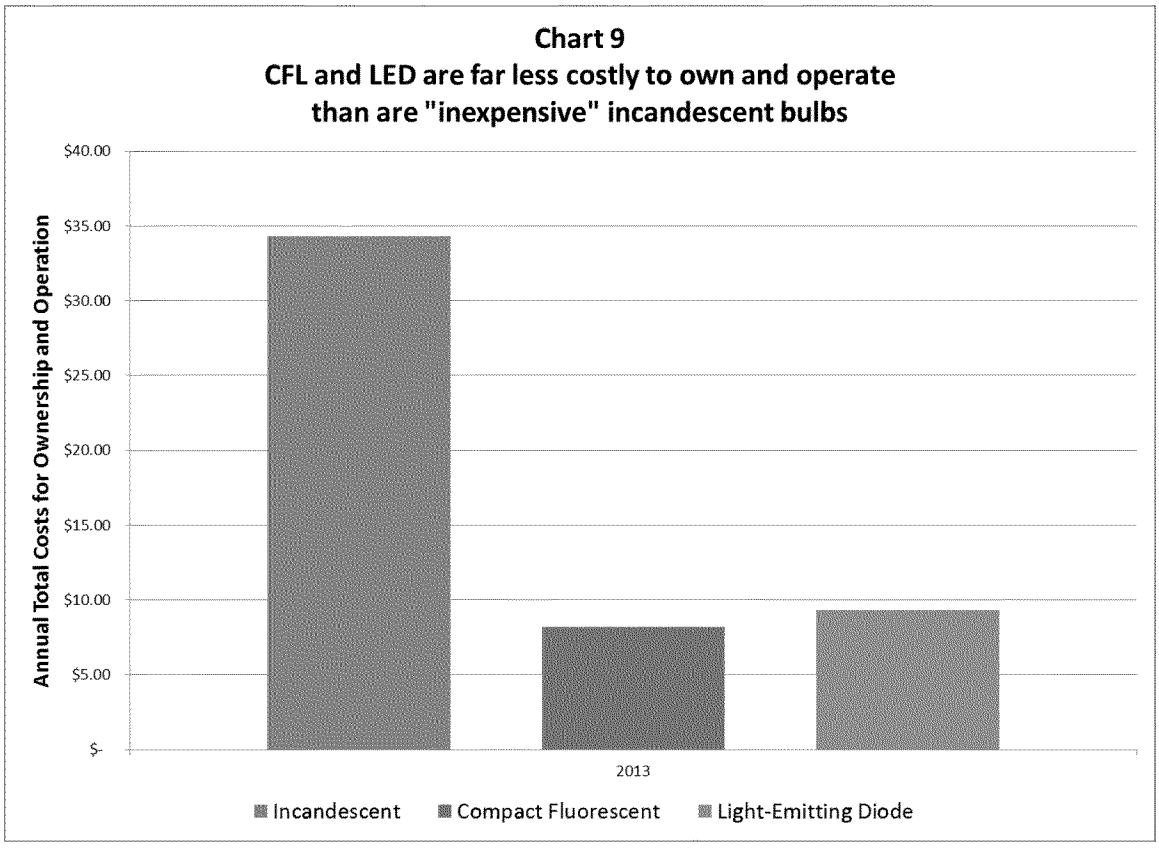
	1982	1990	1992	2007	2009	2010	2011	2012	2013
	--- All values shown in 2013 dollars ---								
Incandescent Bulbs									
One-Year Ownership Cost	$2.89	$2.01		$0.81					$0.72
One-Year Operating Cost	$22.99	$24.72		$21.39					$33.60
Total Cost of Owning and Oprating	$25.89	$26.73		$22.20					$34.32
Compact Fluorescent Bulbs									
One-Year Ownership Cost			$8.60	$0.64	$0.53	$0.52	$0.80	$0.88	$0.60
One-Year Operating Cost			$5.76	$4.54	$7.67	$7.57	$7.62	$7.31	$7.59
Total Cost of Owning and Oprating			$14.36	$5.18	$8.20	$8.09	$8.42	$8.19	$8.19
Cost compared to Incandescent				*23%*					*24%*
Light-Emitting Diode Bulbs									
One-Year Ownership Cost							$4.11	$2.31	$2.51
One-Year Operating Cost							$5.91	$5.56	$6.83
Total Cost of Owning and Oprating							$10.02	$7.87	$9.35
Cost compared to Incandescent									*27%*

Note: 2013 results for Incandescent bulb based on Consumer Reports test of 2007. Not tested in 2013.

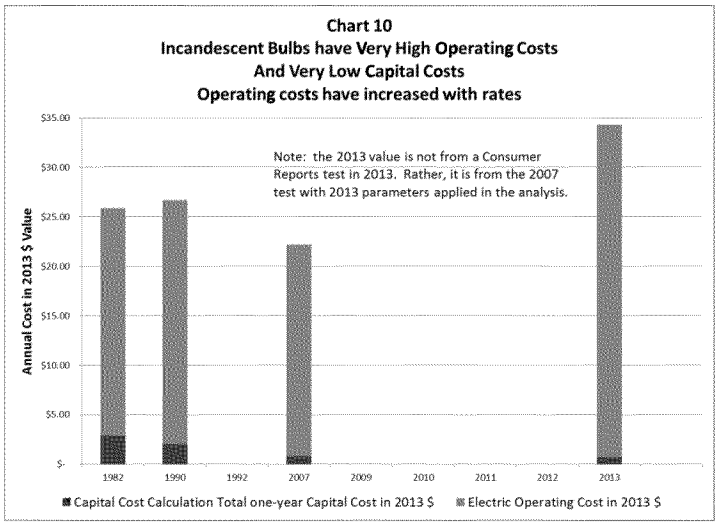
The differences among the three types of light bulbs in their overall cost are dramatic. While incandescent bulbs remain the least expensive to purchase, their short lives make them no less expensive than CFLs to own. For both types of bulbs, the ownership cost is less than a dollar per year. Even LEDs, which in the Consumer Reports 2013 analysis cost nearly $25 to purchase, have an annual cost of ownership of about $2.50 per year.[28] The operating cost of CFLs and LEDs are a small fraction of those of incandescent bulbs. The totals, therefore, are only about a quarter of the total cost of owning and operating incandescent bulbs. These results are shown in Table 3.[29] It is hard to overstate the extent of this change in total costs – a decline of three-quarters in total cost of ownership and operation! Chart 9 presents the total costs of the three types of lighting for the year 2013 in a visual format.

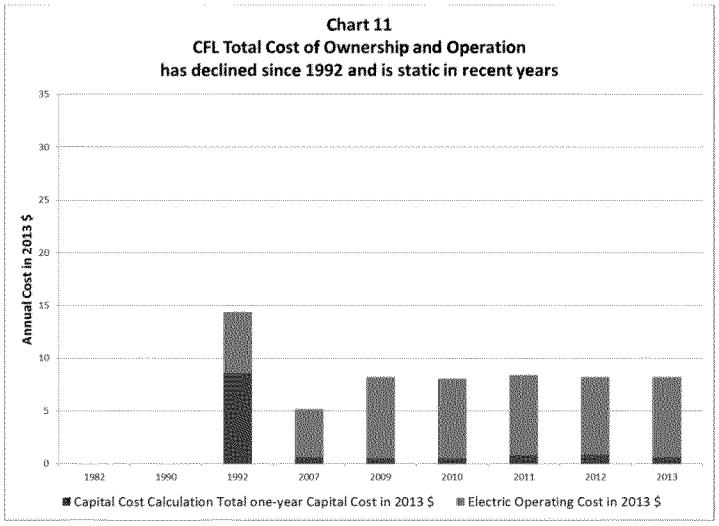
[28] Author's note: It appears that the Consumer Reports analysis of LED bulb costs, published in October, 2013 is already very much out of date. At the local hardware store where I shop, I have found that "soft-white light" dimmable LED bulbs of the "60-watt-equivalent" variety are now selling for less than $10, and special sales can find packages of two bulbs for less than $10. At $5 per bulb, the annual cost of ownership is about $0.51, less than the ownership cost of either Incandescent bulbs or CFLs.

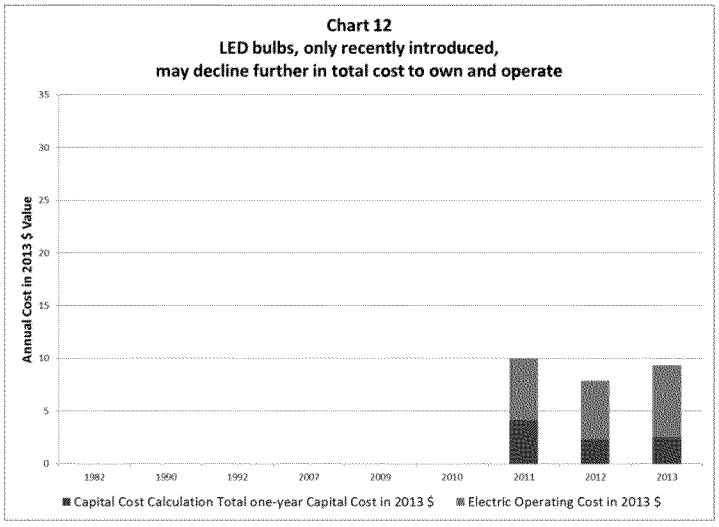
[29] It is possible that the expected life of incandescent bulbs is understated and therefore that their costs of ownership are exaggerated. A modified version of Table 3 based on a 2000-hour life is included as Appendix 2. While there is some reduction in the costs of ownership, that reduction does not change the character of the results. The incandescent bulbs are still the most expensive to own and operate.



Unlike the case of refrigerators, in which the change in costs has been gradual, the change in electric lighting has been due to fundamental technological differences. Incandescent bulbs are of a completely different type and technology from CFLs and LEDs. This point can be seen most clearly, not only from Table 3, but from Charts 10, 11, and 12. These charts present the time trend of the costs of ownership and operation of each of the three technologies. In Chart 10 we see the results for incandescent bulbs. The costs are dominated by the cost of the electric service, and the trend follows PG&E's rates. Both CFL costs (shown in Chart 11) and LED costs (shown in Chart 12) are presented in the same scale as the chart for incandescent bulbs. They show the dramatically lower costs, but they do not present much of a trend themselves except for the initial reduction in purchase costs. There may be further cost reductions in the future.







In most domestic indoor uses, switching from incandescent bulbs to either CFLs or LEDs provides economic benefits. Still, there are advocates for continued use and availability of traditional 60-watt

incandescent bulbs. There are arguments that are still heard often about the superiority of the traditional incandescent bulbs. First is that the slow start-up times of CFLs and the lighting color of both CFLs and LEDs are still drawbacks. The second is that the supposed inefficiency of incandescent bulbs is an illusion. While they use more energy per unit of light produced, the heat they produce may not be lost if it can substitute for heat that otherwise would have to be produced from some other source, such as the furnace. The heat from the bulb allows the furnace to operate less than it otherwise would in the absence of the bulb's operation. So, during heating season, at least, the calculated savings from switching to a more efficient light bulb would need to be netted against savings from less furnace operation. One might think of an incandescent light bulb as a co-generator of light *and* heat.[30] Of course, this argument applies only if other heating can be avoided. During air-conditioning season the co-generated heat from the incandescent bulb becomes an additional load on the cooling system, resulting in a greater total cost. And even in a time when neither heating nor air-conditioning is operating, an incandescent bulb is still consuming power in excess of the amounts consumed by CFLs and LEDs.

The argument that the heat from an incandescent bulb can substitute for furnace heat is most clearly framed in the case where the furnace operation that is avoided would have been produced from electricity, i.e., the same type of resistance heat that is produced by the incandescent bulb itself. In that case, there is a direct substitution of a kWh of electricity in one part of a domicile for an equal (and equally costly) kWh of electricity from another piece of equipment in another part of the domicile. It may be that the heat produced by a lamp can substitute for a multiple of energy if the lamp heat is consumed on the spot whereas to heat that spot from the furnace would require additional heat be distributed throughout the house. That argument is subject to an empirical calculation (and it is beyond the scope of this paper).

Conclusion

The analysis performed in this paper is an extension of the traditional California boast which states that by investing in efficiency we are saving energy. Often that boast extends to the statement that even though our rates are high, our bills are low. This analysis presents no evidence that would refute the claim. In the cases of refrigerators and domestic light bulbs, we can safely say that consumers are not only saving energy, they are also saving money when they switch to new refrigerators and new light bulbs. Our electric rates in the third tier are substantially higher than they were in 1980, even after accounting for changes in the overall price level. Yet the appliances are using substantially less energy to provide the same service, resulting in energy savings. Even accounting not only for the energy costs but also the costs of ownership, which include depreciation and capital costs, in these two example analyses consumers are much better off than they were in the "good old days" of 1980. Efficiency levels increased faster than did rates.

[30] Carl Danner found that consumers who change light bulbs seasonally could gain from using incandescent bulbs for heating depending on the cost of alternative fuels. He found the benefits were greatest for customers who relied on propane heating. See "Squeezing BTUs from Light Bulbs," *Public Utilities Fortnightly*, August 2006, pp 57-60.

What have been California's investments? California propounded early standards for refrigerators. And California rates have provided funds that have been used to promote the purchase and use of better lighting and appliances. California has funded rebate programs for efficient appliances, buy-back programs for old and inefficient appliances, and buy-down programs that lower the retail prices customers see at retail stores for efficient items such as CFL and LED bulbs. Still, all of the new efficient products that have become available in California are also available throughout the nation. The efficient products that are available to Californians could as easily be adopted by residents of other states. Perhaps our high rates have, themselves, been part of the incentive for customers to adopt efficient refrigerators and lights.

This review could be repeated for other energy-consuming devices, such as clothes washers, dish washers, even whole houses, to determine if the total costs of ownership and operation have decreased.

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Appendix 1

This appendix presents the same calculation as Table 2 under the alternative assumption that refrigerators have an expected life of 20 years instead of the standard assumption of 15 years.

Table 2

Refrigerator Cost of Ownership and Operation, 1980-2013

	1980	1985	1990	1995	2000	2005	2010	2011	2012	2013
	--- All Values shown in 2013 Dollars ---									
Top-freezer models										
One-Year Ownership Cost	$291	$242	$208	$152	$124	$86	$80	$82	$69	$84
One-Year Operating Cost	$362	$310	$259	$157	$140	$131	$147	$140	$136	$147
Total Cost of Owning and Operating	$654	$552	$467	$309	$264	$217	$227	$221	$205	$232
Bottom-freezer models										
One-Year Ownership Cost	$310			$186	$149	$165	$199	$99	$93	$105
One-Year Operating Cost	$492			$174	$139	$149	$202	$156	$141	$135
Total Cost of Owning and Operating	$802			$360	$288	$314	$400	$254	$234	$240
Cost compared to top-freezer	*123%*			*117%*	*109%*	*145%*	*176%*	*115%*	*114%*	*104%*
Side-by-side models										
One-Year Ownership Cost			$355	$247	$247	$197	$164	$151	$142	$162
One-Year Operating Cost			$338	$189	$194	$184	$208	$190	$175	$182
Total Cost of Owning and Operating			$694	$436	$441	$380	$373	$341	$317	$344
Cost compared to top-freezer			*149%*	*141%*	*167%*	*175%*	*164%*	*154%*	*155%*	*148%*
French-door models										
One-Year Ownership Cost								$197	$177	$227
One-Year Operating Cost								$181	$167	$166
Total Cost of Owning and Operating								$378	$344	$393
Cost compared to top-freezer								*171%*	*168%*	*169%*

Appendix 2

This appendix presents Table 3 under the alternative assumption that incandescent light bulbs would have a longer life, 2,000 hours instead of the standard assumption of 1,500 hours.

Table 3

Lighting Cost of Ownership and Operation, 1982-2013

	1982	1990	1992	2007	2009	2010	2011	2012	2013
	--- All values shown in 2013 dollars ---								
Incandescent Bulbs									
One-Year Ownership Cost	$2.17	$1.51		$0.61					$0.54
One-Year Operating Cost	$22.99	$24.72		$21.39					$33.60
Total Cost of Owning and Oprating	$25.16	$26.23		$21.99					$34.14
Compact Fluorescent Bulbs									
One-Year Ownership Cost			$8.60	$0.64	$0.53	$0.52	$0.80	$0.88	$0.60
One-Year Operating Cost			$5.76	$4.54	$7.67	$7.57	$7.62	$7.31	$7.59
Total Cost of Owning and Oprating			$14.36	$5.18	$8.20	$8.09	$8.42	$8.19	$8.19
Cost compared to Incandescent				*24%*					*24%*
Light-Emitting Diode Bulbs									
One-Year Ownership Cost							$4.11	$2.31	$2.51
One-Year Operating Cost							$5.91	$5.56	$6.83
Total Cost of Owning and Oprating							$10.02	$7.87	$9.35
Cost compared to Incandescent									*27%*

Note: 2013 results for Incandescent bulb based on Consumer Reports test of 2007. Not tested in 2013.