Findings and "Gaps" in CFL Evaluation Research: Review of the Existing Literature

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Abstract
For a variety of recent residential evaluation projects, the authors were responsible for reviewing a wide range of literature and research on CFLs. The research covered topics including:

- Market characterization, research with manufacturers, distribution channels, and market shares;
- Program and marketing practices and trends;
- Retention effects, including results of measure lifetime studies, operating hours research, and patterns of CFL usage in homes;
- Program lessons, including results and "best practices" from giveaway, rebate, retail, "branding", and outreach / advertising programs;
- Net effects and impacts examined through the net-to-gross ratio; and
- Other factors and effects, including: non-energy benefits, price points and price differentials, and features affecting consumer selection of CFLs, and other factors.

The literature review examines topics that have existing research and highlights those areas with important "gaps" to allow targeting future rounds of qualitative and quantitative research relevant to program evaluation, and computation of benefit cost and scenario work. This paper presents a summary and review of the existing data and industry studies, augmented with information from new research conducted in the Midwest, Northeast, and California. The work provides a valuable assessment of information with existing research, and highlights important "gaps" in research and understanding of decisionmaking and impacts related to CFLs.

Introduction[1]

A fair bit of attention has been paid to CFLs in the US. The dramatic electricity and cost savings, the extended lifetimes, and technological improvements have made CFLs a more attractive lighting option than standard bulbs for households (and businesses); however, sales have remained fairly low. Significant potential remains for CFL installations due to low saturations and associated energy savings. As a consequence, CFLs have been the focus of many utility-sponsored programs. Also, as a consequence, considerable and increasing evaluation and research attention has been paid to CFL equipment. This paper provides a summary and update of the status of research on a number of key topics, points out "lessons learned" and identifies a number of important gaps in the evaluation and market research on this key lighting equipment.

Technology And Manufacture Of CFLs

Technology, Evolution, and Manufacture
CFLs were invented 25 years ago at Royal Philips Electronics. Compared to standard incandescent light bulbs, CFLs provide several key advantages: they use less energy, generate less heat,[2] and last up to 10 times longer than standard bulbs. However, in the year 2000, after 20 years in the market, they still made up less than 0.5% of the market for light bulb sales – even with program efforts by utilities.[3] Noting bulb size and shape as a significant barrier to adoption, the Department of Energy

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[1] This paper was written based on a combination of work conducted for several clients, augmented with in-house research and analyses by the authors. Portions of this work derive from research conducted for Xcel Energy, Minneapolis, Minnesota, NYSERDA (New York State Energy Research and Development Authority, Albany, NY), the California Public Utilities Commission, San Francisco, CA, and others.

[2] By some measures it saves 90% of heat; in other work, total heat energy in building is 20-30% as much as an incandescent depending on the CFL and the baseline.

[3] Including significant market transformation efforts by California utilities in the 1990s.

developed a program to encourage development of a "subcompact" CFL by manufacturers. Several other technology changes have also taken place over the last 5-10 years:[4]

- Improved phosphor coating,
- Electronic instead of magnetic ballast,
- Higher industry performance standards, and
- Other improvements.[5] [6][7]

Manufacturer interviews conducted by the authors indicate that important past problems with CFLs have been overcome.[8] In particular, they mention reductions in hum, flicker, and warm-up time. Price improvements are also mentioned as an important CFL improvement; efficacy (lumens per Watt) improvements are also noted. Surveys indicate that CFL purchasers are becoming more satisfied with the products, in large part because CFLs have undergone a continual series of significant improvements in technology and features that have resolved prior problems hum, flicker, start-up times, and improved the quality of the light.[9] These changes, coupled with improvements in the flexibility of subcompact CFLs as retrofit equipment in existing sockets, the US energy crisis, and US national and regional Energy Star® quality and promotion initiatives have helped stimulate CFL sales. By 2001, CFLs represented 2.1% of retail sales, with higher shares in some areas of the country. A large number of firms manufacture CFLs, some under their own manufacture, and other with the assistance of subcontractors producing equipment meeting defined specifications. The Asian market has reportedly gained a foothold in CFLs in the last several years. Manufacturers that construct their own units but also purchase a portion from OEM (original equipment manufacturers) report that, in the last few years, the Asian supply market has gained a foothold in both lighting equipment and, presumably, CFLs (Skumatz, et. al., 2004 [22], Skumatz, et. al., 2005 [19]).[10]

CFL Distribution and Market Share

Distribution

An important aspect of CFL adoption is the ease in which consumers can obtain bulbs. Although manufacturers have made inroads in compatibility between CFL and standard bulb fixtures, consumers may have had difficulties finding CFLs in locations where they normally purchase incandescent bulbs.[11] One study has shown that while the greatest share of incandescent light bulbs are sold in grocery stores (31%),[12] only 1.3% of CFLs are sold in the same location. Rather, the vast majority of CFLs (57%) are sold in home centers, with the next-largest share sold in hardware stores (NRDC 2004 [13]). Other data (Skumatz 2004 [22]) finds that in New York State, more than half of CFL purchases were made at "big box" retailers like Home Depot, Lowes, and Sears. Since most (83.4%) of the purchasers of CFLs are residents of the home in which the bulb will be installed, an increased presence of CFLs in grocery stores, where consumers are accustomed to purchasing bulbs for home use, may make CFL purchases more likely and more convenient (Skumatz et al. 2004 [22]). Surveys conducted by the authors with manufacturers agree, and indicate that manufacturers report that the largest share of CFL sales are conducted through "big box" stores and home centers. Distributors and intermediaries (including buying clubs) are responsible for the next largest share of

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[4] The California utilities note a significant change in the quality of CFLs promoted before vs. after 1998, perhaps representing a watershed year in CFL performance and characteristics. Some also suggest that much of this technological transformation has been due to initiatives undertaken by utilities, which set out to broaden the range of uses for CFL bulbs under the direction of the California Public Utilities Commission (SDG&E 2005 [16]).

[5] One study (LRC 2005 [10]) found that screwbase bulbs are achieving even longer lifetimes than manufacturers are promising, although some fail very soon after installation. The average median life, or the time after which 50% of the lamps have failed, was 12,500 hours.

[6] Lamp life was not significantly affected when enclosed in fixtures at 90 degrees Fahrenheit. Another source on CFL efficacy, color rendering, color temperature, and long-term tests of life and light output is the Lighting Research Center, which runs the Program for Evaluation and Analysis of Residential Lighting (PEARL), note improvements in bulb features and performance. http://www.lrc.rpi.edu/programs/PEARL/index.asp

[7] The value of the PEARL program lies in objective third-party testing, carried out by a NVLAP-accredited laboratory. http://ts.nist.gov/ts/htdocs/210/214/214.htm

[8] And research by the authors also indicated new technologies and innovations are on the way. This includes improvements in 20W screwbase and ceramic metal halide bulbs, LED lamps, and other technologies.

[9] Early problems with this equipment may have left a legacy of concerns about CFLs in the marketplace. The main concerns and recollections / anecdotes seem to focus on early burnouts and poor light quality. NEEA (2004) [12] and KEMA (2005) [8] have examined evidence for this impact.

[10] An inventory of Energy Star® manufacturers can be found on the Energy Star® website- www.energystar.gov, Skumatz, et. al. 2004 [22], Skumatz, et. al. 2005 [19], and other sources

[11] Relatively little quantitative work explores this topic.

[12] Followed by mass market locations followed by home centers.

CFL sales. Once at the distributor location, the vast majority of sales are directly to end-users, and specifically homeowners. Very few are sold independently; large box stores, chain retailers, and buying groups make up the key channels from manufacturer to distributor and end-users. Very few are sold to builders or contractors, and distributors estimate that the majority are used in retrofit. Interviews, surveys, and store-related information collected and conducted by the authors indicate that most CFLs are purchased as retrofit equipment – to fit in existing fixtures in place of incandescent bulbs (or sometimes replace CFLs). According to 2004 survey results from New York, more than 80% are purchased by someone in the home; households reported that contractors (who might be purchasing for new or remodeled applications) purchased only about 2% of CFLs. The current market for CFLs is retrofit, rather than initial installation in new homes. Distributors and manufacturers report they saw opportunities to increase sales and markets through increased variety of CFLs, increased need for conservation, and through continued involvements of US utilities in increasing awareness and usage. Several noted that market share is relatively low, and believed additional marketing and education is needed to further stimulate market share.

Market Share Information: Limited at Best
Estimates of sales, shipments, or market share for CFLs are difficult to obtain; however, the data available indicates that market share has increased since the late 1990s. Several surveys and studies indicate that national sales figures increased from about 0.5% in 2000 to about 2% by 2002 or 2003 (SCE 2004 [25], NEEA 2004 [14], KEMA 2003 [9]). Some areas, such as California and the Northwest, have seen higher shares, on the order of 5-7%. In California, sales by 2002 or 2003 may have increased to 3-5% of bulb sales.[13] Nationally, it is estimated that CFLs comprised about 2% of screwbase lamp sales in 2004. Several studies indicate sales share increased by perhaps 50%-60% annually since 1998 (Southern California Edison 2004 [25], and Megdal and Associates 2003 [11]). However, these increases are expanding from a very small base and would not be expected to continue, especially since the long life of CFLs means that parity with incandescents (in terms of usage) would be achieved with a market share of about 15%. Data from the Northwest indicate the average person purchases 0.3 CFLs per year.[14] Table 1 below summarizes the results from several recent studies examining the extent to which households purchase CFLs relative to standard bulbs.

Table 1: CFL Sales / Screwbase Lamp Sales
Sources:** **(NEEA 2004 [14], Xenergy 2002 [28], Megdal and Associates 2003 [11], Kema-Xenergy 2005 [8])

Study/Date	National	California	Northwest
SCE 2004	1.8% (2003)	3.1% (2003)	-
NEEA 2004	2.1% (2002)	-	7% (2002)
Kema 2004	0.5% (2000) 1.5% (2001) 2.1% (2002)	1.0% (2000) 5.6% (2001) 5.1% (2002) ~8% (2005)[15]	-

Another indicator of CFL usage is saturation, which can be measured by the percentage of lamps with screwbase sockets that contain CFL rather than incandescent bulbs, or the total number of CFLs per household. In studies by Megdal and Associates (2003) [11] and Xenergy (2002) [27], a range of 49-55% of households had at least one CFL, and a range of 5.8-7% of screwbase sockets contained a CFL. A study by Northern States Power (1996) [15] showed an average of 0.8 CFLs per household in Minnesota, compared with 0.27 per household in North and South Dakota.

Awareness and Satisfaction

The literature indicates that key sources for information on bulbs and lighting equipment are: Advice from a friend; consumer reports / consumer magazines; advice from retailers / salespersons; or the internet (Skumatz 2005 [21], CEE 2004 [1]). Electronic sources for information on lighting and

[13] One study in the Northwest indicates the sales share may be as much as 7% by 2002 (NEEA 2004 [11]).
[14] Kema-Xenergy (2005) [8] has also found that several other factors play an important role in CFL purchase and use behavior. Specifically, the study finds that household owners are more likely to purchase CFL bulbs than renters, and that residents of single-family homes are more likely to make CFL purchases than those that live in multifamily buildings. However, other factors such as annual earnings and location in an urban or rural environment were not related to purchasing behavior.
[15] Reported by anonymous reviewer, and attributed to 2006 California Residential Appliance Saturation Survey conducted by RLW Analytics.

consumer products are cited as product manufacturer web sites, consumer organization websites, and retailer websites. Utility websites were used about half as frequently as retailer websites. Although CFL awareness started to increase around 2001, it remains low. On a 1-10 scale, where 1 corresponds to “not at all knowledgeable” and 10 means “extremely knowledgeable”, awareness in California increased from 6.7 to 7.6 between 1998 an 2001, and decreased to 7.2 in 2003 (Kema-Xenergy 2003 [9]). During the same period, consumer awareness of Energy Star® labels increased from 42% to 54%, and awareness of the meaning of Energy Star® increased from 60% to 76%.

Positive and Negative Features and Satisfaction

Users report the most important characteristics of light bulbs include brightness, equivalent light output, and warm color. They expect color consistency and predictability from CFLs (Rensselaer, 2003 [3]). A study in the Northeast found purchasers’ reasons for buying CFLs included: savings, longer life; to try them out, and to help the environment / the right thing to do (Skumatz 2005 [19], CEE 2004 [1]). The main reasons CFLs are not purchased included: high cost[16], could not find right “fit”, not available at the store, and quality of light / color (NEEA 2004 [14]). Retailer perceptions of the key advantages of CFLs align with those of householders. According to a study in California, they include: lower operating cost / energy savings, longer life, lower life-cycle costs, and less damage to the environment (Xenergy 2002 [28]).

Eighty percent of CFL purchasers reported they were at least as satisfied with the CFLs they purchased as with purchases of incandescents (NEEA 2004 [14]). More than one-third said they were more satisfied. The main reasons for dissatisfaction were:

- the lamps were not as bright as they were led to expect, or
- they didn’t like the lighting (a high percentage).

CFL purchasers are becoming more satisfied over time. One study (KEMA 2005 [8]) noted that 28% of purchasers are more satisfied with newer CFLs than earlier purchases, and only 5% were less satisfied. Reasons for higher satisfaction were related to the shape and size of the CFL; reasons for remaining dissatisfaction included early burnout, cost, and product style. Satisfaction levels and the percentage of purchasers that indicated they would purchase CFLs without a discount (NEEA 2004 [14], KEMA 2005 [8]) have decreased over the last several years. Studies speculate this may be because purchasers are moving from early adopters to a broader market.[17]

Price Issues

One of the major factors affecting acceptance and purchase of CFLs is the fact that CFLs have higher prices than standard incandescent bulbs. CFL prices vary by wattage and features; the DEER study in California indicates the incremental cost of CFLs ranges from $4.90 to more than $8, depending on CFL type.[18] However, studies indicate that average CFL prices have fallen over the last five years. Average retail prices in California fell from $6 in the year 2000 to $2 in 2005 (KEMA-Xenergy 2005 [8]). The literature also suggests prices in California are lower than Wisconsin or the Northwest. This pattern of falling prices and increasing purchase can help manufactures reach improved economies of scale, lowering prices and further stimulating demand. However, the program factor has also been very important in increasing demand for CFLs. Beyond efforts to increase awareness and knowledge about the equipment, many programs are offering discounted CFLs, and are finding that with a $1-$2 price differential as compared with standard bulbs, CFLs “fly off the shelves”. (Skumatz 2005 [18])

Utility CFL Programs: Approaches and Results

Program Marketing

Early CFL programs tended to be give-aways and coupon programs. Now, utilities have transitioned toward partnerships with retailers to help stimulate development of and changes in market infrastructure and increase the value that residents place on the CFLs. Most CFL programs distribute CFLs from one or more manufacturers through a variety of large retail stores; a few work with one manufacturer and retail distributor (e.g. the Midwest Energy Efficiency Alliance, MEEA 2004 [12]). CFL programs are consistent in the marketing methods they use. Most use print ads, radio campaigns, and point-of-purchase merchandising while a few (e.g. California, New York) use TV

[16] A KEMA-Xenergy (2005) [8] study found the importance of the barrier of high cost fell from 41% in 2001 to 15% in 2003.

[17] Other information (on awareness of CFLs, KEMA-Xenergy 2003 [9]) notes an increase in awareness between 1998 and 2001, and a decrease to 2003). It may be that the energy crisis around 2001 led to a spike in awareness, purchase, and satisfaction with CFLs.

[18] and installed incremental costs range from $8 to more than $12 depending on assumptions

promotions also. Almost all of these campaigns promote the societal benefits of energy efficiency, and the financial value of those efficiency improvements to the consumer. Regardless of marketing tactics, ICF (2000) [6] found that “Introducing new products to consumers requires substantial educational and promotional outreach” working "to achieve the goal of informing and motivating the general public.” However, several studies suggest that many current CFL programs do not adequately address this need. Further, ICF found that different messages are required to motivate different types of customer – regionally and demographically. This diversity is required as purchasers move beyond environmentally-aware “early adopters.” Furthermore, Megdal and Associates (2003) [11] found that “Product improvements and . . . selection have increased . . . [but m]arketing and education on these improvements needs to occur” in order to overcome previous barriers to adoption.

Program Process

There are several sources on information about the success of CFL programs and their administration and delivery (process evaluations). Several of the evaluation studies that are most relevant for comparison include the 2004 Annual Report of the MEEA “Change the World, Change a Light” program (MEEA 2004 [12]), feedback from retailers and manufacturers on the California Statewide Crosscutting Residential Lighting Program (Kema-Xenergy 2005 [8]), and the findings of Quantum Consulting’s Best Practices Survey (Quantum 2004 [26]).

The MEEA “Change the World, Change a Light”, conducted in coordination with EPA Energy Star® efforts, offers discounted CFLs at selected retailers.[19] The program evaluation reported strong satisfaction and sales; however, it also noted that the program could have been improved by adding additional retailers to provide better sales coverage, improving communication with retailers, and events need strong publicity up-front.

Kema-Xenergy (2005) [8] found that retailers and manufacturers had a high level of overall satisfaction with a retailer-based program, but areas of dissatisfaction existed. Two key suggestions were to allow larger allocations of incentive money to be made available and to provide advance notice of program funding and other program details. In 2002, Xenergy conducted another study of retailers and found that there were few barriers to the sale of CFLs; the product sold quickly, brought people into the stores, and attracted repeat customers; and CFL sales were not expected to ever make up a significant proportion of overall lighting sales. (KEMA-Xenergy 2003 [9])

Best Practices

More detailed evaluation work – especially work focusing on the identification of “best practives” -- has also been conducted. The authors reviewed a number of “best practices” studies that include broad suggestions that serve as useful reminders to those designing “next” programs..[20] [21]

Program Design and Process: The studies emphasize conducting market research sufficient to develop a sound program plan with multi-pronged, inclusive participation strategies. Other positive features include links between design and tactics to program theory and logic, and developing measurable indicators with clear sources of data (and buy-in from regulators where needed). Measurement of progress needs a clear baseline and accurate data collection process, an appropriate, periodic verification process (tracking and computations), and detailed and well documented evaluation process linking to program goals. The evaluation work should provide a feedback loop for integration into program refinement / management. Programs with clear responsibilities (but with flexibility) perform better, and implementation using an RFP process is recommended. Of course, quality CFLs (potentially independently tested) are key to program satisfaction, and the “best practices” reports recommend avoiding give-away programs that devalue the product. .

Marketing Suggestions: Marketing should address bulb cost, energy use, and a compelling message on the energy savings and other benefits for the home provided by CFLs – but the marketing must use simple, clear language that avoids industry jargon. However, where there are

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[19] With retailers / manufacturers selected through an RFP process, etc.

[20] The sources include Andrew Goett's (HBRS Inc.) 1994 [5] investigation of the degree to which aggressive promoting measures affected the residential CFL programs of Southern California Edison, Pacific Gas & Electric Company, and Orange & Rockland Utilities based on their program evaluations; Quantum Consulting's 2004 [26] summary of national best practices in residential CFL programs which studied in detail six programs from different areas of the country; and a 2003 study conducted by Rensselaer [3].

[21] A few suggestions were also made related to equipment (Goett [5]), including: Investigate the best physical size for typical residential fixtures; develop new Energy Star® metric: specify lamp / ballast dimensions and improve communication of color; and shorten requirements for a maximum warm-up time of three minutes for non-amalgam lamps

differences with the CFLs (longer start-up time), marketing may be needed to “reset” customer expectations. Simplified (less “busy”) packaging will help improve communication, and improvements are needed in the communication of color issues associated with CFLs (CCT does not work well). Buy-in and leveraging with manufacturing partnerships, and retail outreach and support will aid the program (and its cost-effectiveness), and help assure that the product is stocked and advertised; however, the program should take care not to “over-market” a limited supply. The studies suggest that programs should allow participation strategies to evolve or change with time and success, but keep them simple.

Distribution Suggestions: The studies suggest that awareness is a limiting factor. Information and education need to be central to any promotional program. Retail delivery channels seem to be superior to direct mail due to higher installed rates and groundwork laid to promote adoption, and use of barcodes can significantly simply redemption for retailers.[22] However, retailer agreements need to be short and clear, ideally not more than one page, and assure correct use of logo.

Cost Effectiveness

CFL programs typically have limited funds available to influence a very large number of consumers to buy CFLs through various retail outlets. This desire to affect purchases broadly often requires CFL program managers to make decisions that narrow the target market or targeted product ranges. Table 2 presents estimates of the cost-effectiveness of prominent CFL incentive programs (based on information from MEEA (2004) [12] and Quantum Consulting 2004 [26]).

Table 2: Cost-Effectiveness of Best Practices for Residential CFL Incentive Programs
(Source: Quantum Consulting, 2004 [26]; Units = Cents per kWh saved)

	CA Utilities	Efficiency Vermont	Mass. Electric	Midwest Energy Efficiency Alliance	NW EEA[23]	United Illuminating
Total Resource Cost/Societal Test	3.5	2.3 (B/C ratio)	2.4	8.34 (B/C ratio)	1.62	1.77
Incentive Cents per kWh	45	6	12	3	N/A	8
Non-Incentive Cents per kWh	13	86	6	3	1	11
TOTAL Cents per kWh	58	92	18	6	>1	19

Elements of CFL Program Energy Savings

Energy Savings

Energy savings computations for CFLs are fairly straightforward; detailed analyses of energy savings found that kWh savings vary with:[24]

- Watt of new CFL
- Watt of bulb replaced
- Climate zone, and
- Vintage of bulb.

Results indicate that energy savings vary from 20-80 kWh per unit, depending on the situation (above), and the peak savings in watt per unit range from 2 to more than 5 watts per unit. Residential CFL loads peak at 20:00 to 21:00 and generally do not contribute to overall load during peak periods (KEMA, 2005 [8]). There have been few studies examining interaction effects with other equipment in the buildings and CFLs produce minimal heat output compared to standard fixtures.
However, of course, program savings, or the savings attributable to a program, are not solely a function of the bulbs installed and replaced. Consideration must be taken of several other key inputs to the computation, including:

- Net to gross ratios that account for the savings impacts above and beyond what would have occurred without the program;
- Technical degradation of the CFLs, if any;

[22] The studies also suggest that due diligence requirements from regulators can put undue burden on retailers regarding risk of ineligible customers, especially where utility territories do not well-match marketing, distribution, or other record-keeping or sales boundaries. In addition, as the price for CFLs decreases, the proportional cost of coupon redemption may become burdensome.
[23] Northwest Energy Efficiency Alliance 2004 [14]
[24] Found in DEER – the Database for Energy Efficient Resources, www.energy.ca.gov/deer/

- Hours of use; and
- Measure lifetimes and the length of time the CFLs remain in place.

Research related to these topics is presented in the following sections.

Net To Gross Ratio, Free Riders, and Spillover

The net-to-gross ratio (NTG) is an indicator of the share of the program's gross energy savings that can be properly attributed to the program's influence, above and beyond what would have occurred without the program. The ratio consists of two main elements:

- Free ridership, which acts to decrease the gross savings by accounting for the fact that some participants would likely have installed the CFLs and realized the savings, even if the program had not been in place.
- Spillover, which acts to increase the gross savings by accounting for the influence the program has had on the market. This influence is a combination of three types of spillover:[25]
  - Within project spillover: participants purchased through program
  - Outside project spillover: participants purchased additional CFLs though other outlets
  - On-participant spillover: Non-participants were induced to purchase CFLs because of suggestions from participants, greater availability in the marketplace, etc.

Results from a nationwide study of CFL programs (Skumatz, et.al. 2004 [23], Skumatz, et. al. 2005 [20])[26] show the average Net to Gross (NTG) ratios for CFL programs have a common range of 80-90%, with an average of 87%. The same nationwide study showed a wide range of results for free ridership and spillover.

- **Free ridership** from programs around the country ranged from 1-50%, with an average of 29%. These results indicate that, on average, about one out of four of the CFLs purchased under programs studied would have been bought without the influence of the program. This figure represents naturally occurring adoption from the purchases made under the program.
- **Spillover estimates** ranged from 8-32%, depending on program design. These results indicate that for every 10 CFLs purchased (and incentivized) through the program, another 0.8 to three CFLs were purchased outside of the program incentives.
- **Net-to-gross ratio** estimates ranged from 80-91% (average 87%). This indicates that, on average, almost 90% of the CFLs purchased – or the savings achieved – occurred due to the influence of the program. These are savings and CFL adoption changes that are attributable to the program.

Certainly, these results vary by type of program, and there was some tendency for give-away programs to result in higher free ridership than other designs.

Installation Rates

CFL Installations and Lifetimes

More than 90% of the "first" two CFLs purchased are installed; installation rates for additional bulbs decrease to 75-87% for the 3rd through 5th CFLs, and 52-62% of the 7th and 8th CFLs (KEMA-Xenergy 2005 [8]). Early distribution was by direct mail promotions; later distribution was through regular retail channels. Although the number of sales per purchase was slightly lower, the installed rate was higher for retail distribution as compared to direct mail (Goett, 1994 [5]).

Another factor that affects the computations of program-attributable savings is effective useful lifetime for CFLs. In California, where a great deal of work has been conducted on measure lifetimes, CFLs historically been assigned a lifetime of 5.8 years for residential applications. A recent detailed analysis of more than 100 measure lifetime studies by Skumatz and Dimetrosky (2004) [23] updated the measure lifetimes to about 9.4 years for indoor screw in CFLs (based on 2.34 hours of use per day), and 7.1 years for outdoor installations (based on 3.1 hours of use per day).

CFL Usage

The literature indicates average hours of use of CFLs is about 2.28 hours per day. Including outdoor CFLs increases the average to 2.34 hours in California (KEMA-Xenergy 2005 [8]). A Massachusetts study (Megdal 2003 [11]) found average daily use for CFLs was 4 hours. High usage and low usage

[25] Although these brief definitions presented here were more complex given this was an outreach / advertising program.

[26] The analysis in this section was based on a database of free ridership, spillover, and net to gross findings assembled by Skumatz Economic Research Associates, Inc. (SERA), gathering data from well over 100 residential, commercial, and industrial programs from across the US. (www.serainc.com).

factors are summarized in Table 3. The study also summarizes average hours of use by room from several studies. Other findings by the Kema (2005) [8] study include:[27]

- On average, daily hours of use varied by 0.7 hours per day between winter and summer.
- Hours of use varied by about 1.5 hours from summer to winter in "sensitive" rooms (i.e. those with day-lighting that are used during daylight hours).
- Multi-family buildings had higher daily hours of use than single-family homes.
- Homes with children had higher daily hours of use than homes without children.
- Homes with seniors had the lowest usage.

Studies by Kema (2005) [8], Xenergy (2002) [27] and Megdal and Associates (2003) [11], all found similar results regarding the average CFL hours of use and the percentage of room types with CFLs installed The greatest potential for future savings may lie in kitchens, family rooms and garages,[28] all of which have high usage but a comparatively small percentage of CFLs.

Table 3. Average CFL Hours of Use per Room Type, Program Participants (Source: Various studies)

Room type	CFL hours per day[29] (Kema 2005) [8]	Percentage of rooms with CFLs		
		California (Kema 2005) [8]	Vermont (Xenergy 2002) [27]	Massachusetts (Megdal and Associates 2003) [11]
Kitchen	3.5	11%	8.7%	17%
Living room	3.3	17%	6.9%	17%
Outdoor	3.1	23%	10.8%	6%
Family room	2.5	8%	4.7%	3%
Garage	2.5	2%	No data	No data
Bedroom	1.6	18%	2.6%	18%
Bathroom	1.5	11%	3.8%	5%
Hall/entry	1.5	5%	5.2%	9%
Laundry room	1.2	3%	7.1%	No data
Basement	No data	No data	No data	11%

Retention, Measure Lifetimes, and Persistence of Savings

Several studies have looked at CFL retention: [30]

- Kema (2005) [8] found that of CFLs purchased between January 2001 and June 2004, 65.5% were being used at the time of the survey (March-September 2004)..
- NEEA (2004) [14] found that retention rates in the Northwest were around less than 50%. However, over the two years of the survey (2002-2003) retention rates improved significantly.

A detailed study (Skumatz, Gardner, et.al. 2005 [20]) examined more than 100 measure lifetime or estimated useful lifetime (EUL) studies that had been conducted in California over the last decade to derive new EULs. The updated DEER measure lifetimes compared with the California Protocol EULs are presented below.

Table 4: Updated DEER Measure Lifetimes (Source: Skumatz and Dimetrosky 2004 [23])

Identification / Information		Years		
Measure Name from EUL Study	Sector	DEER Newly Adopted EUL (2005)	Interim / previous DEER EUL	*A Priori* Protocols EULs
CFL Bulbs	CIA	Varies based on operating hours	Varies	5.8
CFL Fixture: no add'l description	C	12	16	12
CFL Fixture: no add'l description	R	16	16	N/A

[27] Characteristics that are not associated with variations in CFL usage are: geographic location (e.g., northern v. southern latitudes), dwelling type, household composition, size of home, electric utility service territory, CFL base type and wattage category, and customer experience with CFLs.

[28] Note that many garages may already have linear fluorescent lamps installed.

[29] The current DEER hours of operation estimates are derived from the CFL metering study executed by KEMA. The KEMA study was conducted between July 2003 and October 2004. For it, 369 homes considered to be in the territory of PG&E, SCE and SDG&E were monitored using time-of-use loggers.

[30] One additional study looked into the issue; however, we were unable to determine the elapsed time between installation and the study to use to judge the removal figures. Northern States Power (1996) [15] found that removal rates were 2.0% for rebate participants, 12.1% for non-participants; a difference that was suggested as possibly due to the increased quality of CFLs offered through the rebate program compared to the general market.

A summary of EUL revisions based on operating hours from a logger study[31] is as follows:

- Indoor screw in, 2.34 average daily operating hours: 9.4 years EUL
- Outdoor screw in, 3.1 average daily operating hours: 7.1 years EUL[32]

Energy and Load Savings

Friedman (2000) [4], in a review of lessons from past CFL program experience in Latin America, noted that residential CFL programs save electricity and reduce peak load demand.[33] Furthermore, Kema (2005) [8] showed that residential CFL loads peak strongly at 20:00-21:00 hours (i.e. that CFLs do not contribute to overall load at peak times).

A comprehensive DEER dataset with analysis of incremental energy savings associate with CFLs includes information on both energy and load savings at a very detailed level.[34] The database includes the following estimated energy and demand savings values:

- The estimated energy savings values range from 20 – over 80 kWh per unit, depending on the assumptions and conditions.
- The estimated peak load savings (in watts per unit) range from 2 to more than 5 watts per unit, depending on specific CFLs and other assumptions.

Other Issues and Effects

Non-Energy Benefits

Non-energy benefits represent often-omitted effects from energy efficiency measures. A significant body of work has been developing around recognizing and measuring non-energy benefits (NEBs), and the discussion in this section is derived from Imbierowicz and Skumatz 2004 [7]. NEBs include a variety of positive and negative program impacts of hard-to-measure effects (e.g. comfort). The literature[35] sorts these benefits into three "perspectives":

- Utility / Agency NEBs: Benefits accruing to the utilities or program-sponsoring agency
- Societal NEBs: Benefits beyond those for the utilities / agencies or participants
- Participant NEBs: Impacts that are realized and recognized by program participants

The NEB analyses indicates that Energy Star® CFL marketing and outreach programs have led to significant benefits that are recognized by participants, but not recognized by the program (Imbierowicz and Skumatz 2004, p.95 [7]).

- The results demonstrate that the estimate of net non-energy benefits totals up to 90% of the energy savings associated with CFLs.
- The NEBs show that owners value the program's benefits in terms of factors like better CFL performance, as well as less tangible benefits like environmental impacts and personal satisfaction from the system.
- The results corroborate that features of the CFLs beyond the energy savings are important to the purchase (and value) decision surrounding CFLs, including lower maintenance, doing good for the environment, and a host of other "features".

The NEB results imply that CFL payback years to the household are nearly halved when NEBs are considered in the assessment. Clearly, this matches with focus groups and other work that note that longer times between replacement can be very valuable – especially in difficult-to-reach installations. Further, the NEB information may be useful to utilities trying to assess the wide range of impacts provided by utility programs.

"Gaps" And Lessons In CFL Research

The review indicates that CFL technology has advanced and provides products with appealing features including performance similar to standard bulbs, good fit in fixtures, long lifetimes, and excellent savings. Early technical problems have been overcome for the most part, and price

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[31] Source: Gary Cullen, Itron, Personal communication with Skumatz, (CFL_EUL.xls), 5/12/05 [2] (info based on 8,000 hour manufacturer rated bulb life)

[32] The California Public Utilities Commission (CPUC) expects that these figures may be further revised, because they are largely based on operating hours from one study; however, it represents the best information on CFL lifetimes to date.

[33] Specifically, he notes that the energy savings have been cheaper than expanding electricity supply, and that CFLs have been an important component because residential lighting (mostly with incandescent bulbs) is usually the main component of evening peak electricity demand in Latin America.

[34] This comprehensive database includes an analysis of CFLs under the tables headed "residential non-weather sensitive measures". The extract of information related to CFLs is attached in Appendix B. The web link for the full database is found at "www. Energy. Ca.gov/deer/", and the dataset is found at "http: // eega. Cpuc. Ca. gov". Other versions of the dataset are also found at the energy.ca site.

[35] Skumatz, Lisa A., Chris Ann Dickerson, 1997 [24], and the studies cited therein.

differentials are falling. However, prices in most areas still seem to be higher than most residents are willing to spend. Areas with CFL programs and retailer partnerships have found dramatic increases in sales when residents are stimulated by promotions and price breaks. Energy Star® branding seems to provide extra confidence in quality, and customers recognize and value a number of non-energy benefits related to CFL performance and features. Several studies have provided information on "best practices" for CFL programs.

However, there are a number of areas in which research is lacking.

- CFL market share and market sales figures are not widely available and are expensive to obtain, but are very important to program evaluation. This makes it difficult to track program progress, and complicates identifying whether exit strategies are needed for programs.
- The other area in which continuing research would be useful includes price point and willingness to pay. Identifying the threshold price at which CFL purchases would increase would help programs identify optimal rebate levels.

The best practices identified in the report provide useful tips for the design and operation of programs related to residential CFLs. In addition, the research indicates that there are a number of opportunities for increasing sales of CFLs for residential applications:

- **Technology**: Continuing technology improvements to provide high quality applications beyond the widely-accepted small 13-23 watt applications. Energy Star® CFLs for recessed fixtures, as well as CFLs that will work well in outdoor applications, and with dimmers and photo cells would likely help expand the market.
- **Labeling**: Residents find labeling on the packaging to be confusing. They particularly report problems with the (EPA) match or equivalencies stated between CFL watts and incandescent watts; many report the lights are dimmer than the bulb it replaced. EPA may want to re-work these equivalencies to minimize disappointment. Poor or disappointing performance of a bulb has a long memory in the marketplace, and should be avoided wherever possible. There have been some efforts to cite lumen equivalents instead of wattage equivalents to account for the fact that a CFL watt is not necessarily perceived the same as an incandescent watt.
- **Beyond retrofit**: Virtually all the CFLs are sold to homeowners for retrofit in existing fixtures. To continue to expand the adoption of CFLs – and to help prevent backsliding to incandescent bulbs – programs may want to focus on CFL fixtures, and on developing programs to interest builders and contractors in CFLs. In some areas of the US, codes and standards are being used, requiring new homes to have a certain number of CFL / Energy Star® fixtures; however, the market still needs considerable attention.
- **Additional rooms**: There are several opportunities to expand use of CFLs. Although CFLs are most commonly installed in kitchens, living rooms, and bedrooms (and outdoors in California), not all fixtures in these areas have CFLs. In addition, expanding capabilities of CFLs so they can withstand cold outdoor temperatures would expand applications of CFLs. Greatest future potential may lie in family rooms and garages that have high usage and fewer CFLs.
- **Marketing using NEBs**: Non-energy benefits analysis shows households with CFLs report they particularly value the lifetimes and environmental benefits, but a significant share also state the value high quality lighting from CFL. Given this information comes from CFL owners, using this information in marketing may help appeal to new purchasers. Cooperative marketing efforts, sponsorship from CFL manufacturers, and local / regional / national coordination in promoting CFLs provides an opportunity to leverage program dollars and capitalize on awareness opportunities for CFLs.
- **Retailers**: Capitalizing on feedback from retailers, an education program assuring retailers that CFLs have the same or fewer complaints as other products may help add allies in increasing CFL market share. Retailers are a key ally in increasing both awareness and sales, through efforts in marketing and point of purchase, good placement in stores, promotions, and other activities. Finally, considering whether it is possible to gain higher penetration (and decent aisle placement) for CFLs in grocery stores may provide another opportunity for increasing market share. This would make parallel access for CFLs and traditional bulbs; however, it may be that the CFLs would sell poorly because of higher price

unless knowledgeable staff are readily available, which is more practical in hardware and box stores.[36]

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