LIGHTING THE WAY TO ENERGY SAVINGS

HOW CAN WE TRANSFORM RESIDENTIAL LIGHTING MARKETS?

Volume 2
Background and Reference

NATURAL RESOURCES DEFENSE COUNCIL

Project Manager:

Noah Horowitz
Natural Resources Defense Council

Authors:

Chris Calwell, Chris Granda
Lois Gordon, My Ton
Ecos Consulting

An NRDC Report
December, 1999
(second printing)

Table of Contents Volume 2

1 INTRODUCTION TO VOLUME 2 1

2 BACKGROUND 1

2.1 THE EARLY HISTORY OF LIGHTING 1
2.2 ANOTHER WAY OF LIGHTING 2
2.3 OTHER LIGHT SOURCES 3
2.4 EFFORTS TO CHANGE THE MARKET 4

3 THE COMPACT FLUORESCENT LAMP (CFL) 5

3.1 BACKGROUND 5
3.2 TECHNICAL CHARACTERISTICS 5
3.3 ECONOMICS 6
3.4 NEW AND IMPROVED 7
3.5 APPLICATIONS 8
3.6 THE US CFL MARKET 9
3.7 WHO INFLUENCES PURCHASERS? 12
3.8 MAJOR MARKET BARRIERS 14

4 DEDICATED FLUORESCENT FIXTURES 20

4.1 BACKGROUND 20
4.2 OUTDOOR FIXTURES 21
4.3 INDOOR PORTABLE FIXTURES 21
4.4 INDOOR HARD-WIRED FIXTURES 23
4.5 ENERGY USE AND POTENTIAL SAVINGS 26
4.6 WHO USES FIXTURES? 27
4.7 HOW AND WHERE ARE FIXTURES SOLD? 27
4.8 WHO BUYS AND WHO INFLUENCES? 29
4.9 MAJOR MARKET BARRIERS 29

5 EMERGING RESIDENTIAL LIGHTING TECHNOLOGIES 34

5.1 NEW PRODUCTS FOR HOME LIGHTING 34
5.2 THE WILD FRONTIER 36

6 NOTES VOLUME 2 38

1 Introduction to Volume 2

This is the second volume of a two-volume paper funded by a pollution prevention grant from the U.S. Environmental Protection Agency to the Natural Resources Defense Council (NRDC). NRDC contracted Ecos Consulting with the tasks of reviewing the status of energy efficient residential lighting in the U.S., exploring the reasons for current residential lighting energy consumption, drawing lessons from past efforts to improve residential lighting efficiency, and making recommendations regarding future ones.

Volume 1 deals primarily with policy and programmatic aspects of the topic and contains specific recommendations for action for different stakeholders. Volume 2 is intended to serve as a stand-alone reference for the historical, technological, and market research undertaken to inform the policy recommendations. Volume 2 will be useful to those who are relatively new to the field of efficient residential lighting, and to those wishing to explore unfamiliar dimensions of it.

2 Background

2.1 The Early History of Lighting

For most of recorded history, humans have used *incandescence*—the emission of visible light by a hot object—to illuminate dwellings. For a long time, lighting meant flame from torches and cooking fires. The first candles were invented almost 5,000 years ago, and were a major leap forward in efficiency and performance. Various refinements such as glass lanterns and lamps employing candles became popular in the 1700s, and then the 1800s saw a progression first to oil and then gas lamps, reducing smoke, increasing light output, and improving convenience.

Electric arc lamps, developed in the mid-1800s, were the first non-combustion light sources. Arc lamps were inefficient and very expensive to build and maintain. The next leap forward came with the commercial development of the first practical incandescent or carbon-filament lamp by Thomas Edison in the late 1870s. In an incandescent light bulb, an electric current heats a conducting filament until it glows "white hot." In other words, electrical energy is converted to heat, so that some may be radiated as visible light. Early light bulbs were very short-lived because the filaments used would quickly burn up in the presence of oxygen. With the invention of more durable filaments and vacuum pumps capable of evacuating the air from glass bulbs, the standard light bulb was born. In 1910, General Electric invented the tungsten filament, which could withstand higher operating temperatures. It increased light output without dramatically shortening product life.[1] This incandescent light bulb remains, in revised form, the dominant residential light source in the U.S. today.

The primary cause of incandescent bulb failure was (and continues to be) the thinning of the filament, as tungsten atoms evaporate from it. In response, engineers devised thicker, longer-lived filaments, and began using halogen gases within the bulb to encourage the re-deposition of tungsten on the filament. These improvements increased lamp life and raised filament operating temperature, which led to higher visible light output. In fact, improvement in incandescent lighting has always been achieved by finding a means of making the light source run hotter. We should hardly be surprised that Americans tend to incorrectly equate light output with wattage. Wattage measures power consumption, not light generated, but this is what a century of incandescent lamp usage has taught us to do.

2.2 Another Way of Lighting

The development of fluorescent lighting technology opened a new chapter in the history of lighting. Scientists had long known that when an electric current was passed through a glass tube containing neon, mercury, or sodium gas there was a discharge of a particular color of light. The first neon lamp utilizing this new discharge approach was placed in public service in 1910, but neon lamps only produced individual colors of light, not white (the combination of all colors).

The first useful fluorescent lamp was developed when scientists discovered that it was possible to generate white light through a two step process. An electric charge was passed through mercury vapor in a tube, which then discharged ultraviolet (UV) light. The UV light struck chemical phosphors coating the wall of the glass tube. These phosphors absorbed the UV light and re-emitted white light through the process known as *fluorescence* (see Figure 1) The first commercial fluorescent lamps were installed in cities in 1933 and made available for wider sale in 1939. Discharge lamps (whether neon, sodium, or fluorescent) are much more efficient at converting electrical energy consumption into visible light than incandescent bulbs, and therefore offer substantial energy savings (see Figure 2).

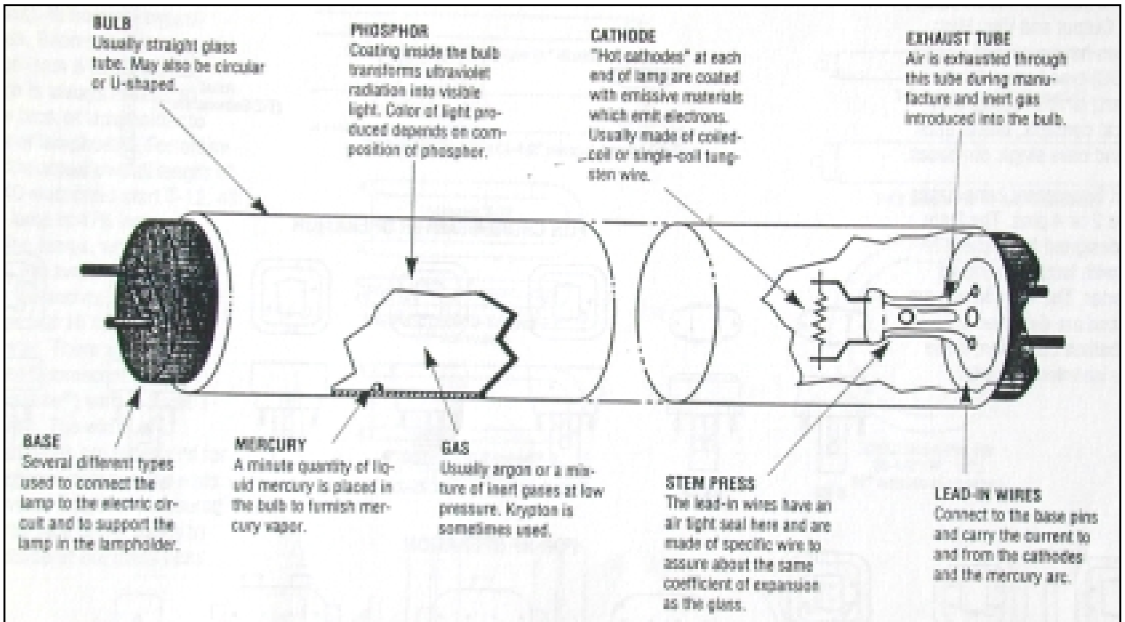

Figure 1 - The basic design of a fluorescent lamp (Osram Sylvania Product Catalog, 1996)

American utilities in the early part of the century were very aware of the potential impact of a new, energy efficient lighting technology on the consumption of electricity. Electricity demand for lighting drove the growth of utilities in the early years of the industry. The legacy of this period can be seen in the frequency with which the word “Light” still appears in utility company names. In the early part of the century, fluorescent lighting represented a real threat to utility sales and growth.

In the years prior to World War II, U.S. utilities persuaded the major lighting manufacturers to focus their development efforts on high output fluorescent sources for commercial and industrial applications, where incandescent lamps were limited by size and heat generation, as a way to encourage demand for electricity. As a result, attention was diverted from the development of fluorescent lamps designed to compete with incandescent lamps in residential applications.[2] As discussed later in this paper, utility interests have continued to shape U.S. residential lighting ever since.

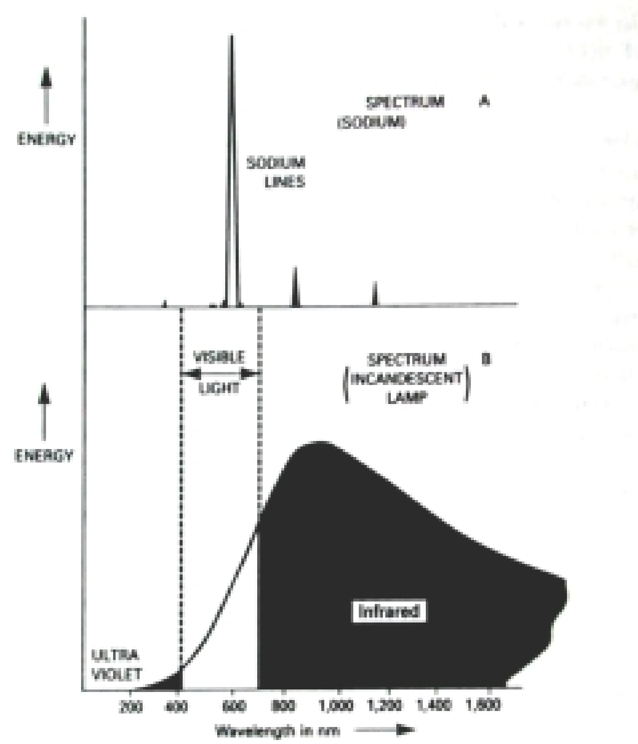

Figure 2 – Virtually all of the light emitted by a sodium lamp is in the visible range of the spectrum, while an incandescent lamp emits mostly infrared light, or heat (*The Majesty of Daylight)*

Fluorescent lamps did make modest in-roads in the residential sector between the 1940's and 60's, primarily in kitchens and bathrooms, where the tasks conducted required high light levels. The diffuse, continuous nature of fluorescent lighting allowed for attractive lighting designs that could not be replicated with incandescent sources.[3] Fluorescent technology continued to improve incrementally as well.

However, fluorescent lighting remained an unappealing choice to most homeowners. Until the early 80's, commercially available fluorescent lamps provided cool, blue-tinged light that contrasted starkly with the familiar, warmer reddish glow emitted by incandescent lamps. Although the associated electricity savings were substantial, fluorescent lamps were more expensive to purchase and install than incandescent lamps. There were other technical barriers, such as the need for magnetic starting circuits (ballasts) that buzzed or hummed, required a few seconds to start, or could cause the lamps to visibly flicker. Fluorescent fixtures also tended towards a commercial or institutional aesthetic, utilizing bare lamps to maximize light output instead of diffusers or decorative covers.

Today, most if not all of these barriers have been overcome. Two breakthroughs were particularly critical to preparing fluorescent lighting for widespread application in residences. First, manufacturers developed "rare earth" phosphors that emitted a warmer color of light, improved the appearance of colors lit by fluorescent lamps, and increased the absolute light output for a given lamp size and power level. Simply put, these new phosphors did a better job of converting ultraviolet light from the mercury discharge into useful, visible light. Secondly, high frequency electronic ballasts lamps allowed fluorescent lamps to be started more rapidly and operated more efficiently. Electronic ballasts eliminated virtually all of the hum and flicker that characterized their magnetic predecessors. When these improved lamps and ballasts were combined in compact packages, the modern compact fluorescent lamp (CFL) was born. For the first time there was a rival to the incandescent light bulb that could be used in many of the same applications, but was three to four times as efficient at converting electricity to light. The rise of the CFL is discussed in Volume 2, Section 3.1, below.

2.3 Other Light Sources

Linear and compact fluorescents are not the only energy efficient lighting choices that have become available to consumers in recent years. Especially in outdoor fixtures, high intensity discharge (HID) lamps using metal halide or high-pressure sodium technology have also become popular. These products can be even more energy efficient than fluorescent sources, but with a light color not always suitable to indoor residential use. Subsequent refinements have improved the color characteristics of these sources, but it remains difficult and expensive to start and re-start the lamps rapidly, limiting their usefulness as an indoor residential product.[4]

Each of these advances has made significant reductions in energy consumption possible, helping to break the age-old link between heat and light. At each juncture, scientists have found a way to convert more of the incoming electricity to visible light, reducing heat output, extending product lifetime, and cutting energy bills. Indeed, the progress from candles to today's most efficient light sources represents a 600-fold improvement in efficiency and about a 6,000-fold improvement in product lifetime.[5]

2.4 Efforts to Change the Market

The first major efforts to reduce lighting energy consumption in the US came in the wake of the oil crises in the mid-1970s. These were usually conservation programs that focused on turning off unnecessary lights and did not address the long-term potential of changes in installed lighting technology. While there were some substantial efforts by electric utilities to encourage the purchase of energy efficient residential lighting prior to the 1990s, most utility energy efficiency programs were small and driven largely by simple regulatory conservation mandates.[6] Beginning in the last decade, incentive regulation allowed many utilities for the first time to make money by implementing successful energy efficiency programs, which helped spur major innovations in program design and expansions of program scope (see Volume 1, section 3.4.4). The California utilities' investments in efficiency programs ramped up sharply in the early 1990s, for example, and each of the utilities launched or expanded an existing residential lighting program built around CFLs. Similar trends played out in the Northeast, upper Midwest, and Northwest. Utilities began cooperating in the design and marketing of their residential lighting programs, sometimes joining forces to stimulate regional markets for efficient lighting.

Finally, Earth Day 1990 represented something of a turning point in the national consciousness regarding energy efficiency in the home. After a decade of environmental retrenchment in the 1980s, the public was primed by 1990 for a message of individual awareness and action, especially to tackle global problems like ozone depletion and climate change. Curbside recycling began to sweep the nation. Books like *50 Simple Things You Can Do to Save the Earth*, *Consumer Guide to Home Energy Savings*, and *The Green Consumer* sold millions of copies, and each recommended that consumers purchase CFLs.

2.4.1 Utility Program Approaches

Residential lighting efficiency programs have been popular because they can be extended to almost all residential utility customers. Many early programs were simply product giveaways intended to familiarize customers with efficient residential lighting technology by distributing free samples. Over time, these giveaways became limited primarily to low-income programs, as utilities sought ways of encouraging most of their customers to make at least a partial investment in efficient lighting products on their own.

By the early 1990s there were a number of program variants. Many utilities mailed coupons to their customers as utility bill stuffers, encouraging the customers to redeem them in participating retailers for discounts off of qualifying products. In an effort to further reduce customer hassle, some utilities made arrangements with retailers to offer in-store price reductions instantly, and then reimbursed the retailers for discounts after the sale. A number of West Coast utilities decided to channel incentives through manufacturers to maximize retail price reductions per rebate dollar. Other utilities established mail order catalog programs so customers could have qualifying products sent directly to their door with embedded utility incentives. Still others conducted direct installation programs, utilizing the experience of trained professionals to ensure that the maximum number of fixtures could be retrofitted with efficient light sources. Some utilities even leased CFLs to their customers, recouping payments on a monthly basis as a bill surcharge.

Each of these programs shared the common objective of reducing the purchase price of residential efficient lighting products. This created a natural tension with manufacturers. They appreciated the additional product sales, but were also worried about losing control of pricing, and thereby consumer perceptions of their product's value.

3 The Compact Fluorescent Lamp (CFL)

Figure 3 – Linear and compact fluorescent lamps and two types of incandescent bulbs (Calwell)

3.1 Background

Decades after large, linear fluorescent lamps had become established products, the lighting industry began to explore ways to miniaturize fluorescent technology to improve its versatility and usefulness. In 1979, Philips unveiled a fluorescent lamp that was small and efficient and could be used in the same sockets as incandescent light bulbs (see Figure 3). General Electric introduced a competing CFL product in 1985, but sales of all CFLs remained quite low throughout the 1980's. It seemed for a time that only Amory Lovins and a handful of other efficiency advocates owned such products. CFLs would be unveiled with a flourish from specially designed suitcases, demonstrated to admiring crowds, and then whisked away to the next presentation, like rare artifacts. Few consumers knew where to buy one or how much it might cost. Gradually, CFLs began to appear in a limited number of retail and mail order channels.

Figure 4 – Full color, consumer - oriented CFL packaging (Calwell)

CFLs remained very difficult to find in retail stores in the U.S. before 1990, selling in simple packaging primarily to commercial and industrial customers through wholesale channels. However, at the beginning of the decade, major manufacturers began explicitly marketing CFLs to the mass market with full-color packaging (Figure 4) instead . The revised packaging worked to merchandise the products to new customers, rather than presume purchasers already knew what they wanted to buy. At the same time, manufacturers began offering specialized designs, such as globe-shaped and reflector-equipped versions of CFLs, which had an appearance similar to their incandescent equivalents.

3.2 Technical Characteristics

There is no longer a "typical" CFL, but rather a series of specialized products offered by more than a dozen manufacturers. These include the largest international lighting manufacturers — Philips Lighting, General Electric Lighting, and Osram Sylvania — along with a growing number of manufacturers specializing in fluorescent technology, including Lights of America, Maxlite, Feit Electric, and TCP. Only one manufacturer produces CFL products in the U.S.; but factories in Mexico, Asia, and Europe produce substantial quantities for the US market.

Most CFLs have rated lives of 6,000 to 10,000 hours, significantly longer than the 750 to 1,000 hours common to incandescent bulbs. Efficiency is also much higher. An incandescent light bulb usually generates 13 to 17 lumens of visible light for every watt of electricity consumed. Most CFLs generate from 45 to 65 lumens per watt. In the typical CFL, compact fluorescent tubes with a diameter of ½ to 5/8 inch are fitted to an adapter containing a compact ballast and a standard, Edison threaded screwbase. In most currently available CFLs this connection between the lamp and adapter is permanent, in which case the product is called an *integrally ballasted* or *unitary* CFL. As Figure 5 illustrates however, some CFL designs have a separable lamp and ballast. These are *two piece* or *modular* CFLs. A CFL ballast can last more than 20,000 hours, for the

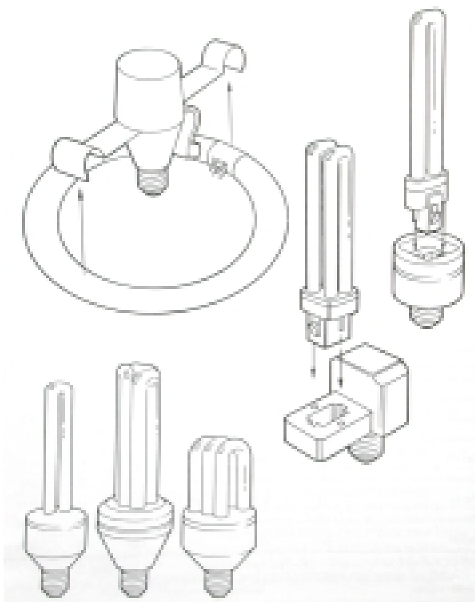

Figure 5 – Basic CFL types
(*The Lighting Pattern Book for Homes*, 1993)

life of two or more CFL tubes. Modular CFLs allow the consumer to replace the relatively inexpensive tube without replacing the ballast and can therefore be more economic than unitary CFLs in the long run. However, because they have separable components, modular CFLs cannot normally be made as compact as unitary models and unitary CFL prices have also tended to be lower.

The popular "circline", lamp is sometimes not regarded as a CFL because it uses a larger diameter (1.5 inch) tube. However the circline does include a ballast and a base that can be screwed into a regular socket. The circline does not attempt to mimic an incandescent bulb, but curves into a larger, open design. The tube lies in a narrow horizontal plane, typically outside the space occupied by a table lamp harp or within the circular volume of a ceiling fixture. Figure 6 contrasts a horizontally oriented circline with a more vertically oriented spiral CFL.

When CFL tubes are sold alone they are called *pin-based* lamps because they attach to the ballast with a socket and pin arrangement. Pin-based lamps utilize an enormous variety of base types to ensure that they can only be fitted with a ballast properly equipped to operate them. However, some ballasts are emerging that have the ability to drive multiple lamp types automatically, which may yield important advantages in future lighting products (see section 5.1.2, below).

3.3 Economics

While a CFL costs significantly more than an incandescent bulb, the energy savings and extended life more than make up the difference in most cases. In fact, a typical CFL will save its purchaser $40-50 over its lifetime. In the case of a 23-watt CFL, which will normally provide equivalent or greater light output than a 75-watt incandescent bulb, Table 1 identifies the expected payback times for a variety of CFL price and usage combinations. It assumes an electricity cost of 8 cents per kwh—the national average for residential customers – and includes consideration of replacement bulb savings.

Figure 6 – Spiral CFL and Circline (Calwell)

Table 1 illustrates that payback times of two to three years are now routinely achievable at common CFL prices. Some CFLs are so affordable that paybacks are possible within one year with normal product use.[7] It is also worth noting that a 3 year payback equates to a better rate of return on investment than the long term performance of the U.S. stock market, and with substantially less uncertainty, provided that the CFL lasts as long as it should.

The more relevant issue to many consumers may be the payback in terms of replacement light bulbs alone.[8] For example, if the average consumer determines that a CFL lasts 10 times as long as a regular light bulb, he or she would be inclined to buy it if it costs less than 10 regular light bulbs. The value of the energy savings of a single bulb might never enter in the picture, because it is impossible to detect on a monthly utility bill.

The retail prices of CFLs have declined sharply over the last several years, and are projected to decrease

Table 1 – Expected Payback Time in Years for a Typical CFL Purchase

	CFL Purchase Price					
Hours used per day	$3	$6	$9	$12	$15	$18
1	2.0	4.0	5.9	7.9	9.9	11.9
2	1.0	2.0	3.0	4.0	4.9	5.9
3	0.6	1.2	1.8	2.4	3.0	3.6
4	0.5	0.9	1.4	1.8	2.3	2.7
5	0.3	0.7	1.0	1.4	1.7	2.1
6	0.3	0.6	0.9	1.2	1.5	1.8
7	0.2	0.5	0.7	1.0	1.2	1.5
8	0.2	0.4	0.7	0.9	1.1	1.3

further with a new generation of "consumer" (shorter rated life) models. However, actual cash register sales data show how wide the price spread between CFLs and incandescents still is. The average A-line incandescent bulb now costs $0.44, while the average CFL is approximately $11.32.[9] Thus the CFL costs 26 times as much as the incandescent bulb, but lasts only as long as 10 to 15 incandescents. Moreover, it is common to see four-packs of incandescent bulbs sold for $1.00 or less at home improvement centers, further straining the apparent economics of CFLs (Figure 7). However, consumers also appear to attach some value to the convenience offered by longer lived bulbs. Philips' Halogena halogen incandescent bulb is selling well at prices of $4 with a rated lifetime of 3,000 hours and no real energy savings over an incandescent.[10] Since four incandescent bulbs will provide the same total lifetime but cost only $1 to $2, it is logical to conclude that the convenience highlighted in Halogena's advertising is valuable to consumers and would also help to increase sales of CFLs.

Figure 7 – Incandescent bulbs commonly sell for less than $0.25 apiece during promotions (Calwell)

3.4 New and Improved

Early CFLs were frequently too large and heavy to find use in all but the most determined households. The ballasts were often larger than the lamps themselves, making it difficult to utilize the products in existing fixtures without various adapters and socket extenders. With advances in solid state electronics, ballasts have continued to shrink in size and weight, while light output has improved. As Figure 8 illustrates, the progress made by CFLs is truly remarkable. The newest designs are virtually identical in size and shape to incandescent bulbs, at least at the 25-watt equivalency level.[11]

Such products are triumphs of geometric ingenuity, finding ever more clever ways to concentrate the maximum possible fluorescent tube surface area within the smallest possible volume. Unlike incandescent lamps, CFL light output is generally proportional to size, making it easier to shrink low-light-output CFLs than brighter models (Figure 9). In the brightest products, heat output can also become a significant challenge, which limits size reductions as well.

Another very recent trend with CFLs has been the development of more compact alternatives to the older Circline style. By utilizing a far thinner tube, manufacturers have been able to achieve high light output in a

Figure 8 – Progress in CFL size and shape from the late 1980s (upper left) to present (lower right) (Calwell)

Figure 9 – How CFLs with similar light output have shrunk over time (Calwell)

very slender, symmetrical package, ideally suited to low profile wall and ceiling mounted fixtures. Thorn Lighting introduced the first such product. Thorn was later purchased by GE which reintroduced the product. It is now available in two piece designs ranging from 15 to 55 watts (Figure 10). Other manufacturers are now introducing circular twin lamp designs that can provide even higher lighting levels. Both types of products are reaching the marketplace first in torchieres, and are expected in a variety of other fixture types in the months and years ahead.

Figure 10 – A square lamp or "2D" modular CFL (Penny Cody)

3.5 Applications

Indoors, CFLs can be used in a variety of surface mount and hanging fixtures, as well as portables. As new products become available, some consumers are installing CFLs in recessed lighting, and other fixtures. Some consumers replace globe-shaped decorative incandescent light bulbs common in bathroom vanity fixtures with globe-shaped CFLs. CFLs also are now available with integrated reflectors that allow them to be used for directional lighting. Most recently, CFLs have become available that can be dimmed using conventional dimmers, though prices for these models can still be quite high.

Because outdoor lights are often on for long periods of time, CFLs are a natural choice. Porch and post lights, exterior garage lighting, and flood light replacements are all common uses. CFLs used in outdoor applications usually function well if installed in a fixture with a daylight sensor, but motion sensors can frequently cause premature failure of CFLs, either from rapid switching or from the presence of a continuous, low level current flow (see Volume 1, section 3.7.2). It is also important to note that in cold weather many CFLs may take longer to start, take more time to reach full brightness, and may ultimately provide less light than they would indoors. Nevertheless, CFLs are now available which can provide outdoor service in the winter temperatures experienced by most of the continental U.S.

3.6 The US CFL Market

Existing homes represent an enormous potential for the use of CFLs and remain the focus of many utility programs. As noted earlier, some utility data exist to approximate CFL installation rates for this market. Other segments of the residential lighting market are also viable for CFLs, but little or no information is available describing CFL saturations. These segments include hospitality (hotel/motel), multi-family, low income housing, and assisted living centers. In these market segments, the purchaser of lighting products is normally not the end-user, and in some cases may not even be responsible for the energy bill. This creates two challenges: either the purchaser will buy the cheapest light source (incandescent) and let the tenant pay its electricity costs, or the purchaser will buy a very inexpensive, low quality CFL to save energy at minimal expense, obligating the tenant to live with an unattractive, undesirable light source.[12]

3.6.1 How Many CFLs are Sold, and Where?

CFLs are now widely distributed though a variety of market channels including home improvement centers, hardware stores, grocery stores, drug stores, discount department stores, specialty lighting stores, mail order catalogs, the internet, and electrical wholesalers. But even in parts of the country where utilities have funded efficient residential lighting programs for nearly a decade, CFLs still occupy only 4 to 7% of the retail shelf space for household light bulbs. Even that estimate overstates the products' presence in grocery stores.[13]

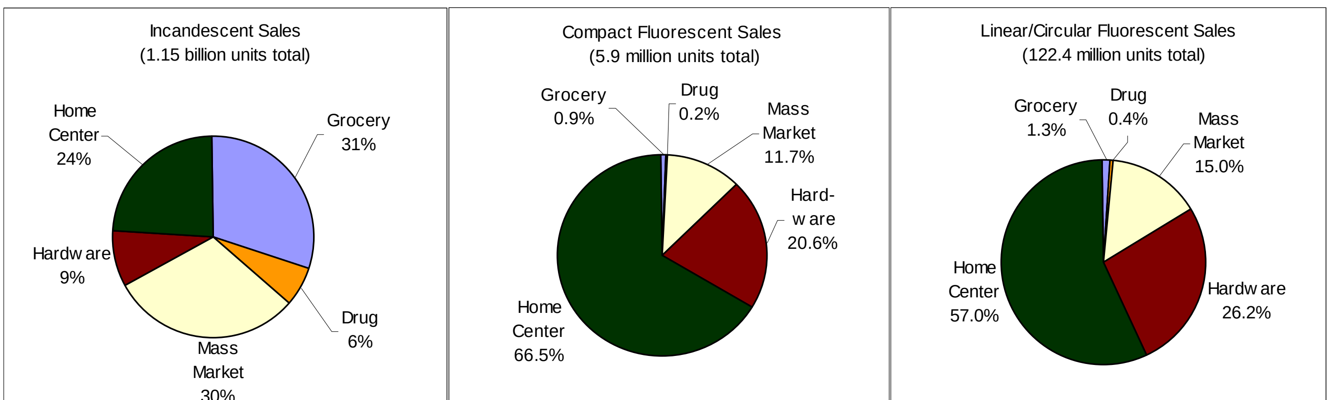

Figure 11 – Point of sale information showing lamp sales by retailer, 12 months ending April 1999
(Analysis of AC Nielsen and Triad POS data)

Attempts to characterize total CFL sales to the residential marketplace are notoriously difficult. The AC Nielsen and Triad Point of Sale (POS) data described in Volume 1 provide a useful glimpse of sales through five major retail channels (Figure 11). In the figure, grocery stores include retailers like Safeway and Vons; drug stores include retailers like Walgreens and Rite-Aid; mass market retailers include discounters like Target and Wal-Mart; home improvement centers include do-it-yourself stores like Home Depot, Home Base, and Lowes; and hardware stores include retailers like Ace Hardware. However, both hardware stores and home centers also sell to contractors, which in some cases purchase CFLs for commercial jobs. Unfortunately there are virtually no data on CFL sales by electrical wholesalers, and no reliable means of apportioning those sales between residential and non-residential projects. In short, we have a fairly precise picture of how many CFLs are sold through the major consumer lighting sales channels, but very poor information about how many CFLs, in total, reach residences each year, including new construction and renovation.

Within the three key product families for residential lighting (incandescent, linear/circular fluorescent, and compact fluorescent), the roles of various retailers in fulfilling consumer demand vary substantially. Point of sale data suggest evolving roles for the major families of retailers, with home improvement centers like Home Depot and mass market retailers like Wal-Mart increasing their shares substantially. Perhaps the strongest evidence for the high degree of concentration in the incandescent bulb market is the fact that Wal-Mart and Home Depot alone now account for more than 50% of all light bulb sales in the U.S. on a units basis.[14] Home improvement centers control an incredible two-thirds of the compact fluorescent market and 57% of the circular/linear fluorescent market. Hardware stores still sell a fifth to a quarter of fluorescent lamps, while mass market discounters manage only 12 to 15 percent. Grocery stores and drug stores are virtually irrelevant to both markets at present. Indeed, only 55,000 CFLs are sold in grocery stores per year, vs. nearly 350 million incandescent bulbs.

Estimates of overall sales of CFLs provide an interesting contrast to the retail sales data. General Electric furnished one set of overall sales data, including aggregated estimates for U.S. CFL sales by all of the National Electrical Manufacturers Association's (NEMA) members. This primarily includes General Electric, Osram Sylvania, and Philips, but not companies like Lights of America, Feit Electric, TCP, Panasonic, MaxLite, and SunPark.[15] Other aggregated national sales estimates were provided by Nils Borg of the International Association for Energy Efficient Lighting (IAEEL). The IAEEL data were compiled from undisclosed industry sources as the North American portion (U.S. and Canada) of a worldwide sales forecast.[16]

Table 2 – Estimates of Annual CFL Sales (millions of units)

Region	Lamp Type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999 (est)
U.S. (NEMA mfrs only) Source: GE	Pin base	19.5	30.7	39.2	41.7	40.9	40.0	39.1	40.8	44.6	47.5
	Screw base	3.9	10.9	14.1	14.4	13.8	13.4	12.4	14.1	14.5	15.1
	TOTAL	23.4	41.6	53.3	56.1	54.7	53.4	51.5	54.9	59.1	62.6
North America (all mfrs) Source: IAEEL	Pin base	12.5	15.0	19.0	28.0	33.0	35.5	37.0	38.0		
	Screw base	5.5	15.5	17.5	21.5	22.0	26.0	28.0	32.0		
	TOTAL	18.0	30.5	36.5	49.5	55.0	61.5	65.0	70.0		

Because of discrepancies in these data sets (Table 2), it is difficult to draw clear conclusions from them. However, it does appear that screw base CFLs exhibited a dramatic increase in sales in the early 1990s, which flattened considerably by the middle of the decade. This is consistent with the ramp-up of utility programs and consumer interest noted earlier, as well as the subsequent flattening or decline of utility investments in efficient lighting (residential and commercial).

A second set of data provided by GE allocates the NEMA-member CFL sales for 1997, 1998 and 1999 among three sales channels.[17]

Table 3 – NEMA CFL sales by channel (millions)

Sales Channel	1997	1998	1999 (est)
Commercial/Industrial	32.4	38.8	41.4
OEM (final CFL and fixture assemblers)	12.2	10.1	10.7
Consumer	10.3	10.2	10.5
TOTAL	54.9	59.1	62.6

Sales growth for the three large lighting manufacturers has continued to be strong overall. However, CFL sales to commercial and OEM customers appear to have been largely responsible, while retail customer sales have stayed mostly flat. The three largest lamp manufacturers may actually be losing CFL market share in the consumer market to some of the smaller companies mentioned above that often focus primarily or exclusively on retail CFL sales and are not members of NEMA. The three largest lighting manufacturers have an estimated 85% share of the entire market for light sources. By contrast, Lights of America may account for only a few percent of the entire lamp market, but its share of residential CFL sales is much higher.[18]

The above estimate of consumer sales of CFLs at approximately 10 to 11 million units per year is consistent with the cash register data currently available. The Nielsen and Triad data identify 5.9 million CFLs sold through all retail channels and at least another 3 million circular fluorescents sold through home improvement centers and hardware stores alone. These data do not provide enough detail yet to ascribe circular fluorescent sales to grocery, drug, and mass market discount stores.

3.6.2 National Retail Channels

Among the largest national chain retailers, the purchasing patterns for lighting are fairly consistent. GE, Osram, or Philips is normally chosen to provide a complete line of lighting products, including incandescent, halogen, CFLs, and linear fluorescents. These extremely valuable contracts are for a minimum of a year, giving the winning manufacturer the opportunity to dominate shelf space within that retailer. The manufacturer also receives the responsibility of "facing" that area—keeping it stocked with products, organized attractively, and decorated with various point-of-purchase displays and other shelf-based advertising designed to attract consumer interest. While some variation may occur at the store or regional level, most of the relevant decisions about this retailer/manufacturer relationship are made at corporate headquarters.

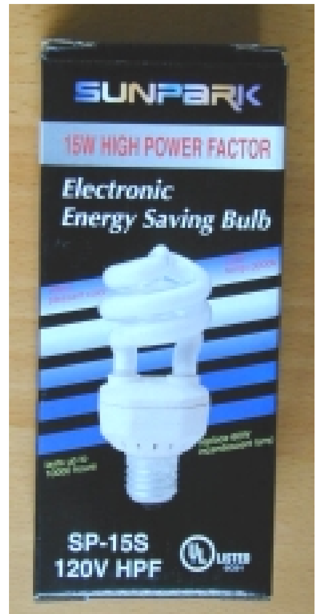

Figure 12 – Typical CFL from small niche manufacturer (Calwell)

Niche CFL manufacturers can often gain a foothold in these stores as well, but only if they offer types of products not already provided by the full-line manufacturers (Figure 12). They compete fiercely for a small amount of additional shelf space, normally segregated from the rest of the lighting display area in a fluorescent-only section. Lights of America, Feit Electric, and Panasonic are perhaps the most familiar examples of such niche manufacturers. Indeed, niche manufacturers have been able to garner substantial market share because of their ability to sell next to products made by General Electric, Osram Sylvania, or Philips in stores that would otherwise rarely carry products by two of the Big Three.

3.6.3 Independent Retail Channels

Beyond the national chain stores, franchised and independent retailers represent an important channel for CFL sales as well. Franchised hardware stores like Ace and TruServ have the ability to purchase CFLs through a company sponsored distributor. This allows a smaller store to take advantage of volume purchasing and offer improved pricing to the customer. The second group, the independent retailers, typically cannot reach the minimum order volume required to purchase directly from a manufacturer, and are left to other avenues, usually a local electrical distributor. Margins are high, sometimes up to 40 percent, in both the independent and the franchise store, and when added to the price of a CFL, can result in slow sales. On the other hand, many of these smaller retailers' sales are not captured by the POS cash register data mentioned earlier, so it is very difficult to know how significant they are.

3.6.4 Non-traditional Retail Channels

A few other non-traditional sales channels offer CFLs, including mail order catalogs, Internet sites, a bulk procurement program for sub-compact fluorescent lamps sponsored by DOE, through the Pacific Northwest National Laboratory (PNNL), and a discounted federal procurement channel operated by the Federal Energy Management Program (FEMP). PNNL's program achieved sales of approximately 230,000 units between June 1998 and April 1999, mostly to commercial and institutional customers.[19] Mail order catalogs like Grainger and GrayBar serve commercial customers almost exclusively, so their sales, even if substantial, are not counted here. However, Energy Federation Inc. (EFI), Real Goods Trading Company, and a number of smaller mail-order firms place a heavy emphasis on residential customers. Interviews with those companies suggest that residential mail order sales of CFLs are perhaps 0.5 to 1 million units per year – greater than grocery, drug, and mass market retailer sales combined. EFI's products are routinely bundled with utility incentives, while Real Goods' and most other mail order firms' are not.

3.6.5 Electrical Wholesale Channels

Electrical wholesalers typically sell products to the construction industry and to maintenance staff of commercial and industrial buildings. For most electrical wholesalers, sales to residential construction (single family, multifamily/condo) are a small fraction of their overall business, perhaps 10 percent. These wholesalers often serve as franchised or exclusive suppliers for one of the Big Three bulb manufacturers, and tend to carry a substantial variety of that manufacturer's CFLs, but not others. Utility program efforts to date to encourage major increases in electrical contractor CFL sales have not been as successful as retail-based programs. Contractors are generally constrained by very tight project budgets, and derive no up-front benefit from lower future energy bills.

3.7 Who Influences Purchasers?

Ultimately, the consumer places the final vote on the success or failure of a product such as CFLs. However, many players are responsible for influencing consumer decisions, or constraining the range of possible choices consumers have.

3.7.1 National Chains

In recent years national chains, particularly home improvement centers, have grown tremendously in market share and influence. The national chains now decide what products will be made available, and effectively marketed, to a large percentage of potential purchasers. Companies like Home Depot even have an on-staff energy manager, who helps keep the company's own energy bills low while promoting the benefits of energy efficiency to customers and retail staff as well.[20] Significant opportunities to reach and influence national chains are trade shows and events such as the Dallas Market and the Chicago Housewares and Hardware Shows, where buyers for retailers are actively seeking to learn about new developments in lighting and select new products.

Home Depot, for example, makes many of its buying decisions through regional "team captains." These people share a dual responsibility within the company: to make all lighting buying decisions for the stores within their region, and to make recommendations to the other team captains on a particular category of lighting products within their area of expertise. As a result, conducting a successful program to promote Energy Star CFLs within one region can increase the chances of such programs succeeding in other regions if the particular team captain involved is responsible for fluorescent lighting expertise within the company. Other retailers often entrust these decisions to a single national lighting buyer.

3.7.2 Buyers Groups

Buyers groups were formed to help smaller retailers obtain a greater variety of products and improved pricing. For example, True-Value stores typically purchase lighting and other products from one buyers group. The buyers group functions similar to the large chain, with manufacturers given exclusive contracts to supply products for a minimum amount of time. Because buyers groups influence many smaller retailers (there are 750 TruServ stores in the Northwest alone), they can have a significant influence on the success of CFLs, yet have not been the focus of programmatic efforts relating to CFLs.

3.7.3 Utilities

During the past three years, many parts of the electric utility community have positioned themselves to move in a more coordinated fashion to transform the market for CFLs. Rather than focusing solely on activities within the boundaries of their own service territories, these utilities have banded together to act across media and retail markets that span multiple cities, counties and even states. In the Pacific Northwest, 120 electric utilities joined forces under the Northwest Energy Efficiency Alliance. In the Northeast, Northern Lights and then the Northeast Energy Efficiency Partnership were formed to coordinate activities in multiple states. In California, the California Compact was created in 1990 to facilitate cooperation among the state's five major electric utilities on residential lighting programs. Now the state's three major investor-owned electric utilities are cooperating to implement a somewhat uniform CFL program model across the state. Wisconsin Energy Conservation Corporation (WECC) has had some success developing a similarly uniform program concept across multiple utilities in Wisconsin. At the same time, energy officials from eight states in the upper Midwest (Minnesota, Wisconsin, Illinois, Michigan, Indiana, Ohio, Iowa and Missouri), have recently launched the Midwest Energy Efficiency Alliance (MEEA), which is formulating new efficiency initiatives for the region.

According to the information presented at CEE's June 1999 meeting in Chicago and subsequent research, about $23 million is being invested annually by the nation's electric utilities in residential lighting programs (CFLs and fixtures). We conclude that perhaps 1 to 1.5 million CFLs bearing utility incentives sell to residential customers per year.[21] This number varies significantly from year to year, but constitutes a sizeable and influential share for the total residential retail CFL sales identified above.

3.7.4 Government/Energy Star®

The U.S. federal government has a variety of programs to inform the public about the need to conserve energy and reduce air pollution. Over the past 10 years, the Department of Energy (DOE) has conducted awareness campaigns, offered financial incentives, and funded education. Likewise, the Environmental Protection Agency (EPA) has been conducting consumer awareness campaigns on energy efficient lighting since March of 1997, when it launched the ENERGY STAR residential light fixtures program. In May 1999, DOE and EPA jointly launched the ENERGY STAR CFL program to encourage consumers to try the latest CFL technology and provide a common marketing platform for interested manufacturers, retailers, and utilities. The components of ENERGY STAR include a complete public awareness campaign and broad education for all players in the distribution channels of covered products.

Perhaps the key feature of the ENERGY STAR programs are the technical specification for qualifying products.[22] For the first time, manufacturers will be able to design products to meet one overarching specification for all participating utilities, rather than varying specifications for different utility programs (see Volume 1, section 3.6). This should largely remove the difficulties manufacturers have faced in the past conforming to different utility requirements for power factor and total harmonic distortion, for example. In addition, ENERGY STAR will develop testing protocols and other mechanisms to monitor product quality and meet consumer expectations. This program has enormous potential to quickly influence the CFL market, especially if well-coordinated with regional market transformation efforts.

3.7.5 Media

In 1979, Philips unveiled its first electronically ballasted CFL at a well-attended press conference at Paul Revere's home in Boston, dubbing it the "Revolutionary Light Bulb." A flurry of additional articles and books mentioning CFLs appeared in 1990, coincident with Earth Day. Though CFLs continue to appear occasionally in magazine and newspaper articles, they are not the "news" they once were. *Consumer Reports* did publish a very widely read article on CFLs in January 1999 that had unquestionable influence with numerous utilities, manufacturers, retailers, and government agencies. The article identified inconsistencies in product performance relative to claims made on product packaging, and urged purchasers to be selective in their choices. It is likely to influence a number of changes in the design and content of product packaging, and has already helped stimulate national discourse about systematic testing of CFL performance.

3.8 Major Market Barriers

CFL technology has continued to advance and many of the technical barriers to market acceptance that initially plagued these products have been removed or substantially reduced. Advanced electronic ballasts have greatly reduced problems with ballast size, noise, flicker, and starting. A range of CFLs are widely available today that:

- are compact enough to fit into most fixtures,
- start immediately when switched on and come to full brightness quickly,
- have an attractive, warm light color,
- produce no audible hum,
- produce no perceptible flicker,
- do not interfer with remote controls,
- produce consistent light in different positions and at different operating temperature,
- generate enough light to meet consumer expectations.
- can start and operate brightly at cold outdoor temperatures

Other marketing and distribution barriers have been reduced by increased competition between manufacturers and as a result of attention from consumers and market transformation program managers.

- Most CFL product packaging clearly provides an accurate assessment of product performance
- A range of CFLs are now available through retail outlets almost everywhere in the country
- There are CFLs in enough different sizes, shapes and levels of brightness to meet almost all needs

However, several barriers still generally prevent greater penetration of the residential market including:

- high prices
- a lack of consumer familiarity with the product
- general consumer fear of health effects of fluorescent light
- lack of assurance that will last long enough to pay for the initial investment required
- incompatibility with normal dimmers,
- incompatibility with many timers or photocells

Prices have fallen considerably and will probably fall further as discussed below. The first CFLs are now available that offer multiple levels of light with standard incandescent dimmers.[23] However, less than half of all consumers are familiar with CFLs and there remains much work to be done in broadening their appeal, and to educating consumers about energy efficient lighting in general[24]. In addition, not all the technical barriers have been overcome for all products and it is difficult for consumers to assess the quality if individual CFLs prior to purchase.

3.8.1 Price Point

Until recently, the price of a CFL intended to replace a typical 75-watt incandescent bulb was in the range of $15 to $20, with higher light-output products priced over $20. At this price, few consumers were willing to invest in a CFL. Over the past three years, a number of CFL manufacturers have been able to achieve retail price point of about $10. Including utility incentives, this has occasionally led to remarkably low product prices in the $2.00 – $3.00 range (Figure 13). As a new generation of products becomes available in the near future that are rated for 5,000 to 6,000 hours of life instead of 9,000 to 12,000 hours, prices will trend even lower.

Some manufacturers have conducted consumer-based market research indicating that the normal price point most likely to attract significant demand is approximately $5.00.[25] Currently, IKEA, a Swedish discount housewares store, is successfully selling CFLs in their stores in this price range without rebates.[26]

Figure 13 – Promotional prices for CFLs in August 1999 in Wisconsin (Calwell)

3.8.2 Product Value

In the late 1980s and early 1990s, in an effort to overcome the price point barrier and get consumers to try CFLs, many utilities ran programs offering them free-of-charge. Unfortunately, many of those products were not up to consumer expectations of quality and performance. These early programs hampered subsequent marketing efforts by establishing a low perceived value for CFLs. It is difficult to convince consumers to purchase something that was once given to them for free, and that did not provide a positive experience.

Customers seem to have a much better sense of the cost of standard incandescent bulbs and linear fluorescent lamps than they do of CFLs. When asked about the cost of incandescent bulbs, most Southern California Edison customers correctly guessed prices of about $2.00 for a pack of four. Likewise, most correctly guessed that the cost of a typical four-foot fluorescent tube would be $3.00 to $5.00. However, when the researchers questioned those already familiar with CFLs about the typical cost of a CFL, more than half of those surveyed did not know.[27]

The lesson here is a powerful one: products that sell at the market price over a long period of time are understood by consumers to cost a particular amount. If that amount is higher than for a competing product, as is the case with CFLs vs. incandescents, customers begin to assemble a comparative value rationale for the products. One example might be: "They cost $10 more but they last as long as 10 regular light bulbs and save about $50 worth of electricity."

But CFLs are subject to highly variable utility incentives that stop and start at seemingly random times throughout the year. Today there are a number of programs administered by utilities that reduce the price paid by consumers for CFLs by 50% or even 75%. Moreover, retailers apply varying margins to their price, and manufacturers appear to be lowering their price as sales volumes increase. As a result, CFLs do not seem to cost any one particular amount to consumers. Because they are confused by the *cost* of these products, they have difficulty assigning a *value* to them, or knowing when they are getting a good price and when they are paying too much.

3.8.3 Fluorescent Phobia

Based on anecdotal information from utility programs, it appears that some percentage of consumers are simply unwilling to have fluorescent lighting in their homes, virtually without regard to product price, size, brightness, or energy savings. These consumers believe that fluorescent lighting is somehow hazardous to their health, and they are very difficult to convince otherwise. Such consumers are targeted by the makers of incandescent "full spectrum" lamps and other products that advertise a connection between health, mood, or well-being and certain types of lighting. While full-spectrum lighting products were initially only offered by niche manufacturers, competing products have now been introduced by General Electric under the "Neodymium - Enrich" brand and Westinghouse under the "Realite" brand. These products often sell for many times the price of standard incandescent bulbs but are less energy efficient. Full spectrum incandescents utilize a special coating to block yellow or red portions of the light spectrum and may use modified filaments or internal gases to emphasize the blue and purple portions of the spectrum. The resulting light spectrum has a color temperature in excess of 5000 K and is more similar to sunlight than standard incandescent or fluorescent light sources.

A good deal of research has been conducted in the field of full-spectrum lighting, but the findings remain controversial and often conflicting.[28] What seems clear, however, is that the energy efficient lighting community has given this issue insufficient attention, and that consumer health fears about fluorescent lighting need to be addressed head-on before certain consumers will even consider buying a CFL. Efforts by manufacturers to refer to their CFLs on packaging as "electronic light bulbs" or "energy saving bulbs" may help near-term sales, but do nothing to dispel accumulated fears about fluorescent lighting once consumers get the products home and realize they are indeed fluorescent.

Interestingly enough, there is some evidence to suggest that rapid changes in the intensity or brightness of light (as opposed to the specific color or spectrum of light emitted) can have negative effects on the human nervous system. The brightness of both incandescent bulbs and magnetically ballasted fluorescents actually fluctuates 120 times per second along with the 60 Hz voltage cycle of household alternating current. For various reasons, this change in brightness or "flicker" is about 5-10% for incandescent bulbs, up to 20% for older (T12) fluorescent tubes with magnetic ballasts and up to 40% for T8 tubes with magnetic ballasts. Researchers in Sweden have discovered that a small percentage of people are bothered by this level of light fluctuation to the point that they find working under magnetically ballasted fluorescent lighting to be uncomfortable. However, another benefit of high frequency electronic ballasts is that they reduce flicker from all kinds of fluorescent tubes to below 1%.[29]

3.8.4 Product Longevity

The residential lighting archives are full of tales of short-lived CFLs, and the evidence is far from anecdotal: program evaluations have noted the extent to which early burn-out of CFLs has led to negative consumer attitudes. A telephone survey of CFL buyers in the Northwest within the first year of purchase revealed that 8% of purchasers had removed a CFL already because of failure[30]. These products were still under manufacturer warranty and should not have failed within the first year. Early burnout was the second most common source of dissatisfaction among customers surveyed by phone, accounting for 22% of the complaints received.[31]

As discussed, longevity may be the single most desirable feature of a CFL to the average consumer, or at least the attribute for which consumers are most likely to pay more than the price of a standard incandescent bulb.[32] Indeed, Philips has recorded significant success with its marketing of Halogena incandescent bulb replacements and their two year warranty. Even though a significant percentage of these products might fail within two years if used heavily, the longer warranty apparently encourages enough new sales to justify its cost. Most CFLs only offer a one year warranty, though Philips has moved toward five and seven year limited warranties on its compact fluorescents.

In addition, the Energy Star labeling program and nascent testing efforts associated with it should help to address this barrier by providing some assurance that at least ENERGY STAR compliant CFLs will last long enough to justify their higher purchase price. The Energy Star program for CFLs requires a minimum product lifetime of 6,000 hours of rated life and a warranty of 12 months from date of purchase, responding to manufacturers' assertions that this lifetime would still meet consumer expectations for longevity, but at a lower product cost. Some manufacturers remain dissatisfied with this outcome, however, and continue to tout longer product lifetimes and warranties as one of the main means of encouraging greater CFL sales.[33]

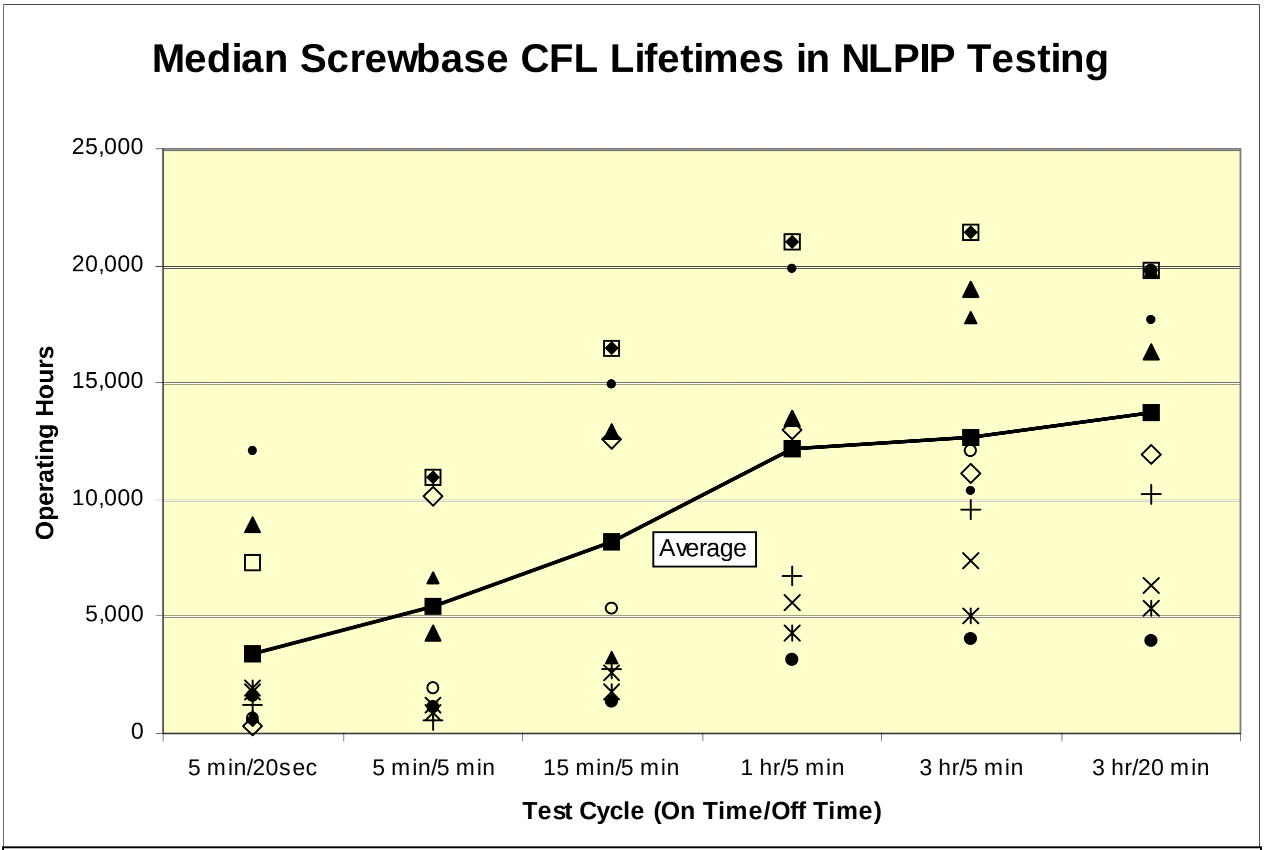

Figure 14 – CFL product lifetimes appear to rise sharply with the frequency of on/off cycles, but variation by manufacturer around the average is quite high. (NLPIP, *Screwbase Fluorescent Products*)

Figure 14 illustrates the results of recent testing of screw base CFL lifetime by the National Lighting Product Information Program.[34] The median lifetimes for each product in each test cycle are plotted in Figure 14, with the average of all the products depicted by the line. The enormous variation around the average is intriguing. It shows that some products last roughly twice as long as the average, while others last less than a third of the average in particular test cycles.

The chart also confirms another important principle of CFL lifetime. CFLs tend, on average, to last longer if left burning for longer periods of time. Leaving them off for longer periods of time between cycles also increases average lifetime. The message that emerges from these tests is that rated life is an imperfect predictor of actual life, and that the average CFL can last 10,000 hours or more if used at least an hour at a time. By the same token, consumers should not use CFLs in sockets that are switched on and off frequently. Moreover, continued testing and follow-up are needed to help reduce the enormous variation among different products and ensure that most CFLs last as long as promised. Utilities and market transformation organizations should work closely with testing laboratories and manufacturers to devise a consensus-based means of systematically testing CFLs with frequent switching cycles and public reporting of results.

3.8.5 Product Size and Shape

As noted earlier, CFL technology has made great advances in reducing lamp and ballast size. With the introduction of sub-compact products, the consumer can at last find a CFL to fit in most applications. While

Figure 15 – Overhead view of high output CFLs (Penny Cody)

further reductions in product size are possible, they do not always yield proportional increases in light output. It is a limitation of CFL design that as the total fluorescent tube surface area rises within a given volume, the opportunity for light to be reabsorbed by the tubes rather than emitted from the CFL rises as well (Figure 15). In short, the tubes get in each others' way. As a result, it may be difficult for manufacturers to continue making the same progress with CFL size reduction in the future as they have made over the previous decade.

Ballast width once prevented CFLs from having the familiar pear shape of incandescent bulbs. As ballasts have shrunken, manufacturers are coming closer to that objective. But they will never fully mimic the shape of the light source within the bulb—the filament. Incandescent and halogen sources will continue to be superior for highly directional, focused lighting applications, whenever an extremely small, intense light source is needed.

3.8.6 Light Color

Early CFL technology emitted a bluish light that most consumers found unattractive. While there continues to be a greater preference for cool (blue) fluorescent colors in the southern U.S., the general preference is for warmer (red) color temperatures—2700 K to 3000 K. This is completely understandable within the context of Kruithof's research on human vision. Cooler colors appear more natural to the human eye at very high lighting levels (often obtained with daylight or linear fluorescent sources), while warmer colors appear more natural at lower lighting levels (often obtained with incandescent or CFLs).[35]

Indeed, virtually all residential CFLs today operate between 2700 and 3000 K, though other colors can be special-ordered. A color rendering index (CRI) greater than 80 is also the norm with CFLs, which means that colors appear more natural when illuminated by CFLs than previously. The notion that these new CFLs provide a light color very close to incandescents is still quite new to most consumers, who have the enduring perception of fluorescent light as cold and institutional. However, ongoing research to make additional improvements in the appearance of fluorescent light should help as well. Philips Lighting and Osram Sylvania have invested particular effort in clearly labeling their products to help consumers distinguish between cool and warm sources, and between high CRI and low CRI alternatives.

3.8.7 Education

Inadequate consumer education remains one of the greatest barriers to further success by CFLs. Generally, neither consumers nor retail salespeople have a good sense of how long a CFL lasts, what it costs to operate, or what product is best for what application. Without this information, the persuasive case for CFLs remains unheard.

Given that the principal financial benefits of CFLs stem from their reduced energy use and longer lifetime, it is interesting to see the response of Southern California Edison customers to questions about their relative electricity use and lifetime compared to incandescents. Despite an extensive history of CFL promotions, only 30% of respondents correctly perceived CFLs to use one-third to one-quarter of the electricity of incandescent bulbs. As a result, they consistently underestimated the benefits of making the switch to these higher cost products. Likewise, only 11% of customers understood that CFLs last at least 10 times longer than incandescents.[36]

Electric utilities are natural purveyors of consumer education because of their independent credibility and direct access to the consumer. Unfortunately, utilities have not always provided consumers with appropriate information about CFLs. First, as noted above, utilities have sometimes promoted CFLs that did not last as long as customers expected. During the period when most utilities maintained their own technical specifications for CFLs, they sometimes promoted products that were optimized from the utility's perspective, but were unattractive to consumers. Finally, in their zeal to maximize penetration, some utility programs used direct-install program approaches, sending trained staff door-to-door to physically install CFLs. These approaches gave customers CFLs, but did not necessarily give them reasons to like them and abrogated the process of customer choice altogether. Experience has since shown that residential utility customers are not at all hesitant to remove CFLs that they do not like. At least one direct-install program in New England in the early 1990s experienced removal rates of over 30% within the first year of installation.[37]

Retailers are enthusiastic about the future of CFLs, and some have acted on this confidence by increasing shelf space dedicated to the products. In the Northwest's LightWise program, 80% of participating retailers stated a belief that demand for CFLs will increase with growing consumer familiarity. However, 60% of the retailers interviewed did not feel they had enough information about CFLs to adequately sell the product. Overall they felt unprepared to explain CFL benefits, wattage conversions, power quality and differences in ballasts. Retailers suggested that in addition to staff training, they would like to offer consumer education classes, informative point of sale materials, demonstration models and other display tools.[38]

Retailers traditionally look to the manufacturer to provide training about product features and point of sale materials. Clearly this role needs to be reinforced. Field staff for utility programs can augment these efforts, especially in the context of ENERGY STAR. Examples of major retailer training efforts can be found occupying central roles in several of the regional programs.

3.8.8 Product Availability

CFL availability has improved dramatically in recent years, but remains uneven. Retailers remember their past experiences of having ordered too many CFLs and being left with unsold inventory or needing to resort to deep discounting to move product. Product availability can also be a serious issue during "stop and start" utility promotions unless special effort is taken to coordinate with retailers and manufacturers.

There is also a concern with modular CFLs, because if the customer is to benefit from the ability to change the lamp upon burn-out while keeping the ballast, lamps of appropriate types and pin configurations must be available long after the initial sale. If the ballasts last as long as advertised (3 to 5 lamp lives), the matching lamp may no longer even be manufactured at a future date when the customer wishes to replace it.

4 Dedicated Fluorescent Fixtures

4.1 Background

Light fixtures or *luminaires* are vehicles for the delivery of light.[39] *Dedicated* fluorescent fixtures are light fixtures that are internally wired to accept only fluorescent sources. In other words, they provide no threaded socket for use with an Edison based lamp, and typically include an internal ballast. This ballast is designed to mate with pin-based compact or linear fluorescent lamps, allowing the user to replace only the light source when it eventually burns out.

Dedicated fluorescent fixtures confer a number of energy efficiency advantages over the use of screw base CFLs in existing fixtures:

- They can be (but are not always) optimized optically and thermally for use with fluorescent lamps, resulting in fewer performance compromises and frequently offering a more attractive appearance.
- They offer more predictable long term energy savings to utilities than screw base CFLs, which temporarily "capture" a socket during their lifetime, but may be replaced by incandescent lamps upon burnout.
- Many utilize linear fluorescent lamps, which are longer-lived and usually more energy efficient than CFLs.
- They combine a décor choice with an energy efficiency choice, usually eliminating the need for the purchaser who prefers energy efficient lamps to locate a suitable CFL for a particular fixture style.
- Their prices are often closer to those of standard incandescent light fixtures than CFLs are to standard incandescent lamps. This may reduce the "sticker shock" often experienced by first time buyers of efficient lighting.

The launch of the ENERGY STAR fixture labeling program in 1997 helped bring to prominence a family of dedicated fluorescent fixtures that largely meet the aesthetic demands of typical residential applications. These fixtures usually employ electronic ballasts and high quality lamps, achieving a level of performance that was once the sole province of the commercial lighting marketplace. The products include a warranty of at least two years—conveying a level of manufacturer confidence in the product not typical of the residential lighting marketplace. Today a growing number of manufacturers produce hard-wired fluorescent fixtures in styles and finishes that are indistinguishable from the most popular incandescent fixtures.

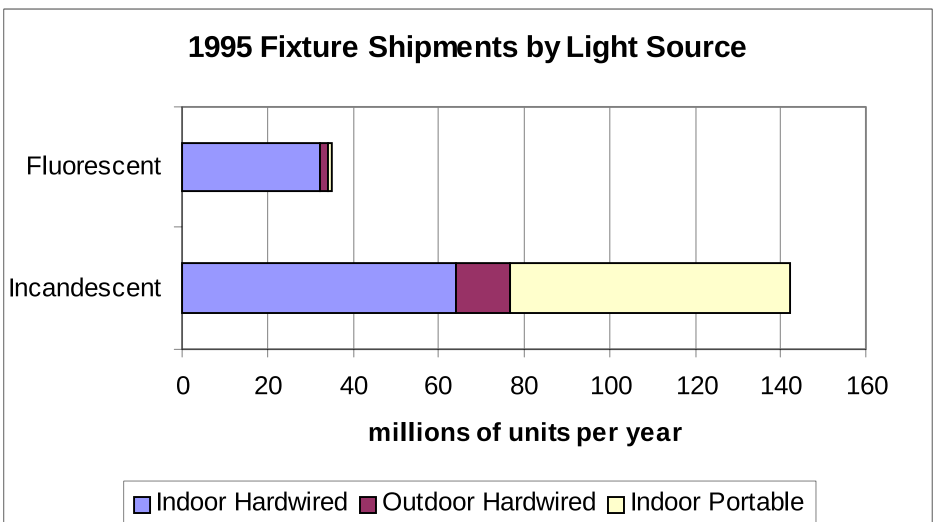

Figure 16 – Fluorescent lighting had only made substantial headway with indoor hard-wired fixtures in 1995, however, ENERGY STAR is beginning to broaden its role (Economic Industry Reports).

Residential light fixtures can be readily divided into two major families: outdoor and indoor, and further subdivided by technology and type within those families (see Figure 16).

4.2 Outdoor fixtures

Outdoor fixtures are typically wired directly to household wiring, controlled by an indoor switch, and mounted either on the building exterior or on a freestanding pole. They often include built-in photocells to shut the light source off automatically during daylight hours, and may also incorporate motion detectors. In outdoor fixtures in particular, the ability to control hours of use may be even more important than the energy efficiency of the light source. Outdoor fixtures generally serve one or more of three purposes: façade illumination (directed at the home), pathway lighting (directed at the ground), or security (facing outward, toward possible intruders). They represent approximately 10% of residential lighting energy use.[40]

Because color quality needs are often less restrictive for outdoor fixtures than indoor fixtures and hours of operation are high, other light sources in addition to fluorescent and incandescent are popular as well. The majority of Energy Star outdoor fixtures are compact fluorescent, although the specification permits metal halide and high-pressure sodium alternatives. Though utilitarian models have been available for years, decorative designs are relatively new in the market, and may benefit from added attention by market transformation organizations. Other designs powered by solar panels and batteries are also of particular interest to the energy efficiency community, since they draw no utility current at all.

4.3 Indoor Portable Fixtures

Indoor fixtures are divided into two primary types: portable (about 30% of the installed number) and hard-wired (about 70 %). Portable fixtures provide both an electrical cord and plug for connection to a standard household outlet, as well as an integrated switch or dimmer to control the light source. They represent about 20% to 25% of the lighting energy use in a typical home.[41]

There are seven principal types of portable fixtures: table lamps, wall lamps, floor lamps, strip lights, desk lamps, work lights, and night lights.

Figure 17 - Cutaway view of a typical fluorescent table lamp employing a screw base CFL (Lights of America)

4.3.1 Table Lamps

Table lamps are perhaps the most common type of portable fixture, combining a decorative base, mounting harp, and shade to direct light upward and downward (Figure 17). Some utilize translucent shades to disperse the light more broadly. Table lamps still account for the greatest single share of new portable fixture purchases, equal to the number of ceiling fixtures purchased per year. They consume about 12% of residential lighting energy, most commonly in living rooms.[42] These fixtures very commonly utilize three-way switches, and would normally be fitted with a three-way incandescent bulb using 50-100-150 watts or up to 250 watts in reading lamps. Aesthetic considerations are paramount with table lamps which are often considered furniture. Table lamps are normally purchased in discount department stores, furniture stores, and lighting specialty stores.

Table lamps normally utilize a translucent shade to direct light vertically into a room. As a result, the fluorescent sources that are best suited to this application distribute their light symmetrically and vertically. Some CFLs also have adapters that tilt the lamps 90 degrees from their socket orientation, which can be satisfactory for this purpose but are not symmetrical (see Volume 1, Figure 5). Because of the enormous variety of styles and shapes of table lamps, and the fact that purchasers are accustomed to being able to select the most suitable light source (and level of brightness) after their purchase, table lamps have rarely been sold as dedicated, pin-based fixtures. A small number of table lamps are frequently converted to dedicated fixtures for hotel and motel applications with special screw base adapters that lock in place and cannot be removed by guests.

4.3.2 Wall Lamps

Equally popular with the hospitality industry are portable fixtures intended to hang on walls, often above or next to beds. As with table lamps, because of the endless variety of styles, it is still far more common to see wall lamps with screw base CFLs than dedicated fluorescent models. Portable wall fixtures account for an almost negligible share of residential lighting energy use (see Volume 2, Section 4.6.4).

4.3.3 Floor Lamps

Some floor lamps are very similar in style to table lamps, but free-standing. Others, known as torchieres, direct light primarily upwards, and are usually described as indirect fixtures, because their light is intended to bounce off the ceiling or walls before reaching the surfaces to be illuminated. Most torchieres employ a pin-based halogen bulb, though screw base incandescent versions are also increasingly widely sold. In either case, the light source sits in a reflective dish at the top of a pole. Given its low cost, ($10 to $15 in many cases), ease of installation and availability, the halogen torchiere has quickly become one of the most popular and affordable portable fixtures in the market. Compact fluorescent floor lamps were extremely rare until recently, when compact fluorescent torchieres began to capture market share from halogen models. Floor lamps accounted for about 7% of all household lighting energy use in the mid-90's, but their share may have grown in recent years with the spread of the halogen torchiere.[43]

4.3.4 Strip Lights

Strip lights are very simple linear fluorescent fixtures often used to illuminate cabinets, shelves, countertops, or even artwork. These fixtures are widely available at low cost in discount stores and home improvement centers, and are often the building blocks for various types of architectural fixtures (see Figure 23). Their energy use as a share of total residential lighting is minimal.

4.3.5 Desk Lamps

Desk lamps are similar to table lamps, but frequently smaller in size and designed to direct virtually all of their light downward toward the desk surface for reading tasks. They are most commonly found at office supply stores or mass market retailers. Desk lamps represent less than 2% of total residential lighting energy use, but are worth noting because they offer substantial energy-savings. By concentrating light where it can be most useful, they permit overall room lighting levels to be lower. Fluorescent light sources have made some in-roads in the desk lamp category, though typically in magnetically ballasted designs with low-light-output twin lamps (13-watts or less) or short linear fluorescent lamps. A few circular fluorescent designs are also available, those these tend to be somewhat cumbersome and specialized. At least two manufacturers, Adesso and GE, are pursuing high quality Energy Star versions.

4.3.6 Work Lights

Work lights have been largely ignored by the lighting community, so little is known about their total electricity impact. Their connected wattage is astonishingly high—ranging from 300- to 1000-watts, depending on whether they employ one halogen lamp or two, each 300-watts or 500. However, "residential" hours of use may be fairly modest, as many of these products seem to be sold to professional contractors, do-it-yourselfers, mechanics, and so forth, who use them for specific work-related purposes but do not use them for long hours at home. Compact fluorescent alternatives were demonstrated for the first time by General Electric and other manufacturers at the 1999 National Hardware Show, and are already for sale. They offer safety and efficiency advantages over halogen models, but cannot match halogens' combination of compact size, intense brightness, low price, and warmth (when preferred by contractors on cold job sites). Also, contractors rarely if ever pay the energy bills associated with their site-based work, and therefore have little incentive to purchase more efficient work lights.

4.3.7 Night Lights

Typical night lights consume only 4 to 7 watts of power, but are frequently in operation 24 hours a day. A remarkable 76 million night lights and replacement night light bulbs are sold in grocery stores, drug stores, and discount retailers each year.[44] Efficient models can draw as little as 0.03 to 1.5 watts. Some efficient night lights use electroluminescent panels, drawing far less than a watt, while others use a smaller incandescent bulb with a photocell that shuts it off during daylight hours (Figure 18). Either way, these improved products yield typical savings of perhaps 3 to 4 watts each as compared to typical night lights. The national energy savings potential for converting nightlights to more efficient products may be more than 2 billion kwh per year—nearly 2% of total residential lighting demand.[45]

Figure 18 – Consumers wishing to cut night light energy use by 75% to 99% have numerous readily available options to choose from (Calwell)

4.4 Indoor Hard-Wired Fixtures

Hard-wired fixtures are connected permanently to household wiring and often physically mounted into a wall or ceiling. Consumers typically refer to them as permanent fixtures. They have no visible cords or switches, relying on a connection to a separate permanently mounted switch or dimmer for control. As such, they generally require the services of an electrician, though many can be installed by a competent do-it-yourselfer.

Indoor hard-wired fixtures can be subcategorized almost endlessly by style, mounting method, function, and even direction of illumination. It may be sufficient to highlight five major types:[46]

4.4.1 Recessed

The most common type of recessed fixture is a cylindrical "can" up to a foot deep that mounts flush with the ceiling surface. These are known generically as *downlights*, because they usually direct their light straight toward the floor. Other variants can be aimed at an angle and used to illuminate walls or accent particular objects in the room. Other recessed fixtures are more similar to commercial lighting, and utilize linear fluorescent lamps to provide diffuse, ambient light for the room as a whole.

Recessed fixtures represent approximately 12% of installed fixtures and 15% of the total lighting energy use. Their use has grown dramatically in recent years, and the products are favored by electrical contractors for their ease and flexibility of installation, as well as their low cost (Figure 19). It is not uncommon for electricians to employ them as the sole lighting source in many rooms, often in groups of 6 or more. Indeed, the focus of much of the Lighting Research Center's recent residential design work has been on the creation of widely applicable designs that substitute linear fluorescent and compact fluorescent fixtures for the vast arrays of incandescent downlights that have invaded kitchens and other living spaces (Figure 20).[47]

Figure 19 – Typical advertisement for recessed lights, showing extremely low cost and wide range of choices (Eagle Hardware advertising supplement, March 20, 1997)

Recessed cans pose some special challenges as fluorescent fixtures. Because ballast performance and longevity are reduced by high temperatures, the fixture must be designed to dissipate heat build-up during operation. Fluorescent tubes must often be oriented horizontally to deliver maximum light output into the room. In addition, many installations are into insulated ceilings, making it more difficult to manage heat and requiring the fixture to be airtight. Under these conditions, it may be difficult to obtain sufficient light output from the products, encouraging manufacturers to employ innovative reflector materials and other technological advances to solve the problem (Figure 21).

Figure 20 – A typical incandescent downlight-based living room design (*The Lighting Pattern Book for Homes)*

Retrofit kits are available on the commercial market to convert incandescent hard-wired ceiling fixtures and recessed cans to fluorescent. The kits are easily installed and permanently alter the fixture to only accept fluorescent lamps in the future, but are not readily available for the residential market.

The Northeast Energy Efficiency Partnership (NEEP) has started an initiative to encourage fixture manufacturers to produce a fluorescent recessed can fixture that overcomes the design constraints noted above.[48] Responses have been somewhat disappointing, with minimum 6-month lead times and high projected costs. However, the market size and number of units requested are still relatively small, and if efforts to line up parties willing to commit to the purchase of qualifying products, the NEEP effort may still bear fruit.

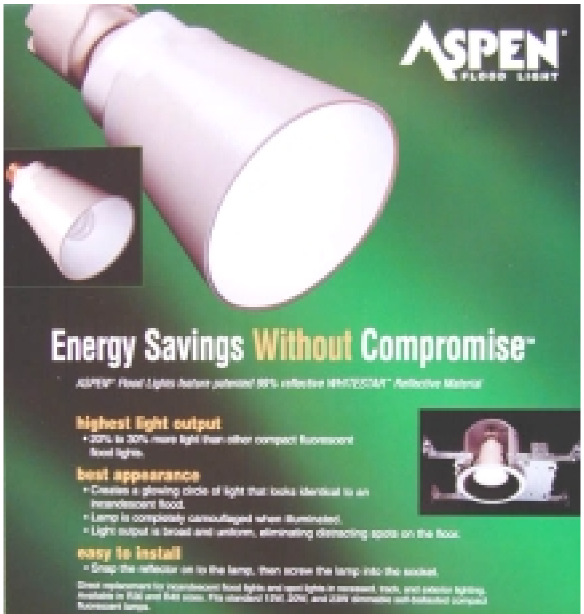

Figure 21 – Sample advertisement for a fluorescent recessed lighting solution. (*Energy User News)*

4.4.2 Surface-Mounted

These fixtures are mounted on the surface of the ceiling and direct their light downward. Most surface mounted fixtures have a single diffuser that disperses light in all directions. These fixtures are now very commonly available with compact fluorescent sources (Figure 22), usually circular lamps, 2D's, or multiple smaller lamps. Linear fluorescent surface-mount fixtures are also widely available, and find use in kitchens, utility rooms and garages. A second major style, the track light, provides a means for multiple light sources in a row to be powered from a single electrical junction box and switch. Compact fluorescent track lighting is relatively rare, because the individual "heads" need to be much larger to accommodate CFLs and their reflectors than they would normally be for reflectorized incandescent or halogen lamps.

4.4.3 Suspended

These fixtures normally hang from a chain, wire or pole from the ceiling place light sources close to eye level and tasks. They can be designed to direct light up, down, sideways, or any combination of the three. These fixtures are commonly found over dining room tables and are often quite decorative. A few compact fluorescent styles are currently available. Linear fluorescent versions, usually for utilitarian purposes, are widely available and known as shop lights (which may also be surface-mounted). Until very recently, shop lights, often fitted with magnetic ballasts and cool white lamps, were one of the few examples of fluorescent technology widely available in the residential marketplace. They remain one of the most widely sold, cheapest residential fluorescent fixtures to this day.[49] Unfortunately, shop lights may still symbolize fluorescent lighting to most residential customers, who remain unaware that more aesthetically desirable suspended fluorescent fixtures are now widely available.

Figure 22 – A range of surface mount fluorescent fixtures (right) exhibited by Good Earth Lighting at the 1999 National Hardware Show (Calwell)

4.4.4 Wall-Mounted

The most common type of wall-mounted fixture is the sconce. These are normally quite compact, and direct light up or down along a wall surface. Some utilize translucent housings to provide general room light as well (see central fixtures in Figure 22). Compact fluorescent sconces are now widely available in the commercial and institutional markets, and can be found (with some effort) for residential applications. Vanity lights are long, thin rectangular fixtures normally found around the mirror in bathrooms. They normally employ 4 to 8 individual light sources to create a diffuse line of light, so are rarely found in dedicated compact fluorescent varieties. Linear fluorescent models are much more common, since the fixture shape and application is an ideal functional and aesthetic match with the characteristics of linear lamps (Figure 23).

4.4.5 Architectural

Figure 23 - Decorative fluorescent vanity fixture (AAMSCO)

These fixtures can be purchased as a unit or constructed onsite of materials that blend with the décor of the room. Permanently attached to the wall or the ceiling, they employ linear fluorescent lamps or a series of long CFLs to graze light along the wall, up onto the ceiling, or horizontally along the plane of the ceiling. These fixtures can be difficult to find with high quality fluorescent sources for residential applications, but can be constructed easily onsite with strip lights.

4.5 Energy Use and Potential Savings

As noted in Volume 1, there are approximately 2 to 3 billion portable and hard-wired light fixtures in U.S. homes. The average number of fixtures per household varies regionally, by age and type of dwelling. A California study found 26 fixtures with 43 sockets for single family households and about half that saturation in multi-family dwelling—13 fixtures and 20 sockets (Table 4).[50]

Table 4: Light Fixture Use and Energy Use in Single-Family and Multi-Family California Residences

Housing Type	Fixtures per household	Annual kwh per household
Single Family	26.2	2076
Multifamily	13.1	1084
Total Population	21.3	1704

Dedicated fluorescent fixtures offer the opportunity to cut lighting energy use by 60 to 80% for each incandescent fixture replaced, and can be targeted toward the highest-use locations for maximum cost effectiveness. Fluorescent light fixtures have barely begun to realize their potential in the residential marketplace, running a distant second to the more popular incandescent alternatives.

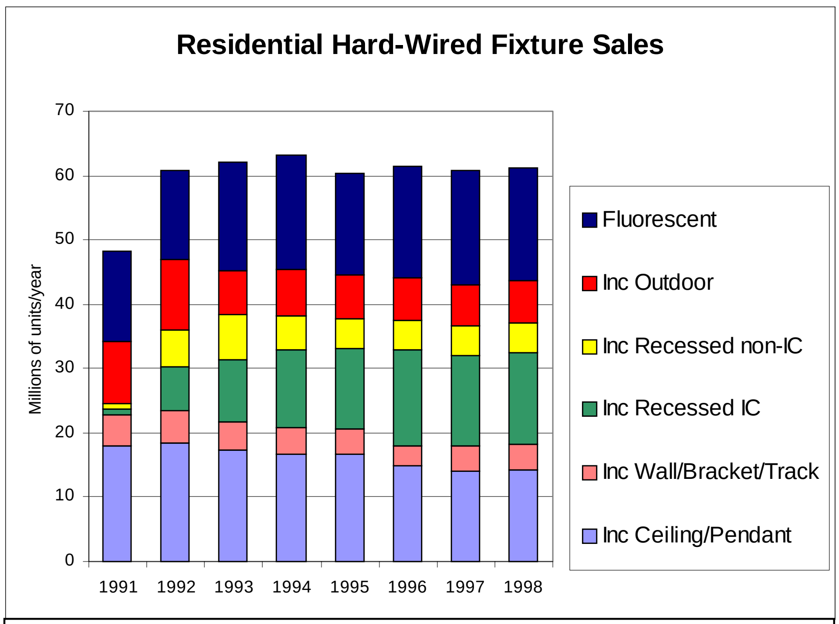

Figure 24 – Recessed incandescent fixtures have gained enormous market share in recent years at the expense of other fixture type sales. (Economic Industry Reports)

Figure 24 shows hard-wired fixture shipments over time, including estimates for 1998.[51] The explosive growth of incandescent recessed fixtures over just a few years is immediately obvious, particularly "IC" type fixtures (those designed to be covered by insulation). At the same time, residential fluorescent fixture sales have been flat over much of the decade.

A similar situation is evident with portable fixtures, even when expressed in total dollars of revenue as opposed to units sold

(Figure 25).[52] From 1967 to 1997, fluorescent portable fixtures recorded essentially no gains in dollar sales, even as the overall market grew more than four-fold. Including the impact of inflation, the fluorescent portable fixture market shrunk significantly.[53]

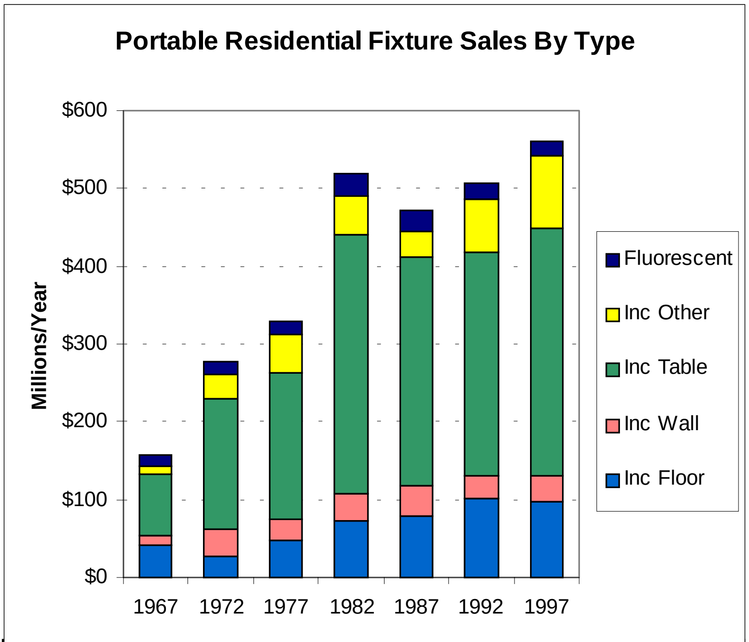

Figure 25 – Fluorescent fixtures have not participated materially in the portable fixture market's growth over the last 20 years (Economic Industry Reports)

4.6 Who Uses Fixtures?

Virtually all residential households use both portable and hard-wired fixtures. As noted in Table 5, single family houses have a greater number of hard-wired fixtures than multifamily or manufactured housing. As a general rule of thumb, builders allocate substantially less than 1% of their construction budget to lighting. This leaves as little as $300 to $700 to provide the lighting for many new homes.

As a result, the lower the price of the home, the more likely it is to provide switched electrical outlets instead of hard-wired light fixtures in bedrooms and living areas. This means the new occupants must purchase portable fixtures, which is partially responsible for the tremendous popularity of halogen torchieres (see below). When fluorescent fixtures are included in new homes, they are frequently the least expensive types available, and are placed in low-occupancy rooms like garages, laundry areas, utility rooms, and even closets.

4.7 How and Where are Fixtures Sold?

Residential light fixtures serve both functional and decorative purposes. They are often purchased to complement existing furniture, wall hangings, carpeting, paint, etc. As a result, light fixtures are sold at an enormous variety of retailers, ranging from home improvement and hardware stores, to home furnishings and department stores, to lighting specialty stores. The specialized metallic finishes that are currently popular are difficult to create domestically at prices competitive with metal-finishing in Asia, which has driven an increasing fraction of manufacturing overseas.

This trend has been partially responsible for a complex dynamic in the marketplace. Many of the latest and most popular lighting fixture styles originate in Europe or the U.S. These fixtures are introduced first at lighting specialty stores and upscale home furnishings boutiques. However, once a particular design became popular, discount stores and home improvement take a sample to an Asian manufacturer, who then replicates it with minor design changes at lower cost. Mass market retailers then offer the design at significantly lower prices than the original models.

As a result, the nation's independently owned lighting specialty stores, though an important source of decorative lighting and design advice, appear to be losing residential lighting market share to the mass market retailers. Lighting specialty stores typically carry margins of 100% to 200% in their retail prices. Even at promotional or sale prices, these retailers find it difficult to compete on price with higher volume discounters, whose markups more commonly range from 20% to 30%, with promotions at 10%.

For national chain stores of various types, portable lighting is at most a few percent of their total sales (Table 5).[54] The greatest volume of fixtures is sold through national home improvement chains such as Home Depot and Lowes, who cater to the remodeling and redecorating market with both portable and hard-wired fixtures. These stores are increasingly targeting the new construction market as well, and now serve a growing contractor clientele. Other national discount chains, such as Target, K-Mart and Wal-Mart primarily stock portable fixtures, maintaining a handful of hard-wired fixtures for do-it-yourselfers. Office supply stores such as Office Max and Office Depot focus almost entirely on portable fixtures like desk lamps and torchieres. Smaller hardware stores, including True Value, aggregate their buying power to compete against the national home improvement chains through the use of a buying collective.

Table 5 – 1998 Portable Light Fixture Sales, by Retailer

Retailer	97 Portable Lighting Sales (millions)	Portable Lighting Share of Total Sales	Annual Growth of Portable Lighting Sales	Lighting Sales Per Store (thousands)	# of Stores
Home Depot	$245	1.01%	22.5%	$392	624
JC Penney	$140	0.70%	6.1%	$117	1,200
Lowes	$125	1.23%	13.6%	$280	446
Wal-Mart	$111	0.13%	11.0%	$42	2,662
Kmart	$67	0.21%	11.7%	$31	2,136
Sears	$62	0.20%	8.8%	$74	833
Target	$60	0.29%	15.4%	$75	796
Office Depot	$56	0.83%	12.0%	$100	560
Meijer	$50	0.76%	10.0%	$446	112
Pier 1	$48	4.46%	20.0%	$67	716
Montgomery Ward	$40	0.70%	-13.0%	$133	300
Staples	$39	0.75%	30.0%	$53	742
Menard	$32	0.98%	28.0%	$237	135
Office Max	$29	0.77%	16.0%	$40	722
Fred Meyer	$28	0.67%	16.7%	$54	518
Costco	$20	0.09%	11.1%	$75	266
HomeBase	$14	0.95%	16.7%	$169	83
TOTAL or AVERAGE	**$1,166**	**0.86%**	**14.2%**	**$91**	**12,853**

In lighting specialty stores, fixture appearance is paramount, and fluorescent products are generally scarce. Prices are higher but salespeople tend to be fairly well-educated in lighting design, and generally better equipped to dispense advice about the kinds of fixtures that are recommended for particular applications. Though they seem like natural locations for the sale of energy efficient fixtures, which often require an explanation of their energy savings and convenience benefits to justify their higher price, specialty retailers have been far smaller players in ENERGY STAR fixture programs to date than home improvement centers.

Electrical wholesalers sell primarily to builders and electricians, focusing almost exclusively on new construction and major renovation projects. Margins in these channels are small (frequently to allow the electrical contractor to mark up the products to the client). The direct purchaser is rarely the end user, encouraging the installation of inexpensive, inefficient products or moderately efficient products with poor aesthetic qualities.[55] Indeed, electricians consciously avoid any fixtures that entail substantial risk or uncertainty, preferring instead to purchase and install familiar products that are very unlikely to require a callback for purposes of adjustment or replacement. Not surprisingly, this can make it difficult for new manufacturers to secure distribution through these channels.

4.8 Who Buys and Who Influences?

It is a commonly held belief in the energy efficiency community that the new construction market is a primary influence in the residential lighting fixture market in terms of design, distribution and pricing. While it is true that new construction influences these aspects, it accounts for only a small portion of overall fixture sales. As shown in Figure 26, the vast majority of fixtures are sold for remodeling and redecorating.[56] Of course every incandescent fixture installed in a new house is a lost opportunity for savings that will not come again until the fixture is replaced, possibly not for decades. In new construction, unless it is a custom project, the party selecting and purchasing lighting fixtures is rarely the end-user. Lighting is typically one of the last items to be installed, at a point where most of the project budget has been expended. There is little incentive for the builder or developer to choose a fixture based on longevity or energy savings.

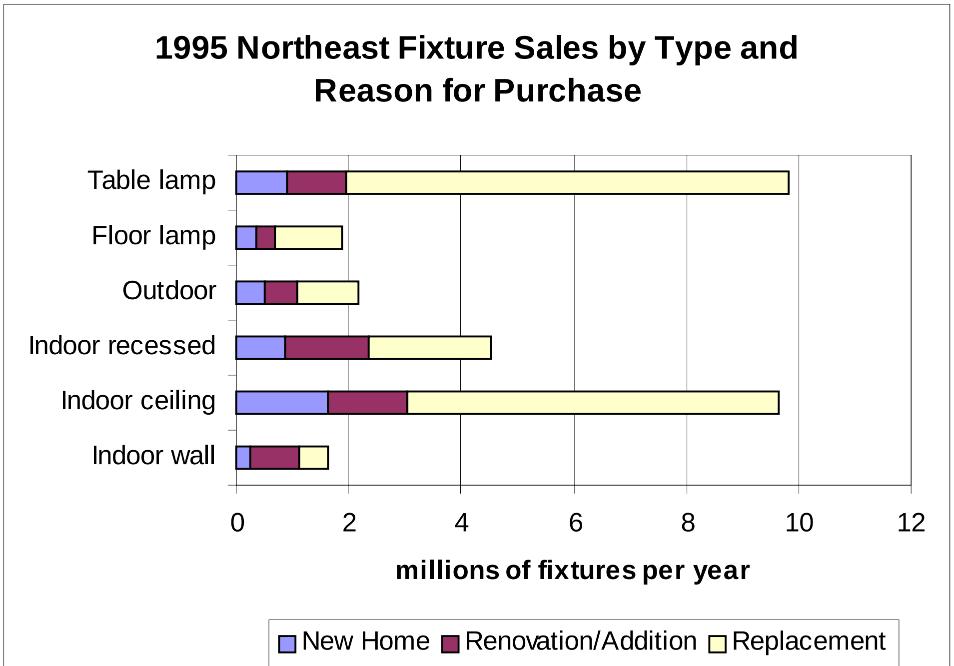

Figure 26 – Table lamps and indoor ceiling fixtures dominate the typical purchase types, and new home construction accounts in most cases for a very small share of the motivating factors for the light purchase. (Opinion Dynamics Corporation)

The more expensive or customized the home, the more likely the homeowner is to be involved in the selection of light fixtures. Ironically, then, the consumer with the best opportunity to express a preference for energy efficient lighting may have the least interest in the resulting energy savings. One case in which the decision-making process is somewhat different is manufactured housing. In the Pacific Northwest, manufactured housing accounts for approximately one-third of all new housing and represents a significant opportunity to address efficient lighting. Manufactured housing assemblers normally seek to minimize the number of fixtures installed in a unit. However, the fixtures that are installed tend to be in high use applications such as outdoor porch lights, the kitchen and the bathroom. They are selected by the assembler and purchased in large quantities directly from the manufacturer. Manufactured housing is not subject to local building codes, but to those established by the federal government through Housing and Urban Development (HUD). Because of this, there are two opportunities to influence the lighting practices of manufactured housing. Voluntary programs have demonstrated substantial success at using incentives and promotions to elevate energy efficiency considerations among manufactured housing assemblers. Likewise, mandatory changes can be achieved through a rewriting of codes established by HUD.

4.9 Major Market Barriers

Many of the same market barriers that apply to CFLs are found in the market for dedicated fluorescent fixtures. In some ways, the hurdles are even higher, since dedicated fixtures require the customer to risk substantially more money than the cost of a screw base CFL that the product they are purchasing will satisfy their needs.

4.9.1 Irreversibility

With a CFL, the purchaser has multiple options after taking it home. The CFL can normally be fitted to any number of different fixtures, and can always be replaced with an inexpensive incandescent bulb in the event that it fails to deliver satisfactory performance. Dedicated fixtures represent more of a commitment to an unknown quantity. They do not generally permit a swap-out to products of higher light output. They can confound purchasers accustomed to the simplicity and flexibility of the screw base Edison bulb. By the same token, that difference can be marketed as a feature or an advantage to the typical customer, who is then able to obtain replacement lamps for the existing and still functional ballast.

4.9.2 Price Point

Efficient fixtures suffer less from the price point barrier than CFLs, because the efficiency upgrade cost is spread over a much larger total cost. For example, a CFL that sells for $15 is about 25 times as expensive as a single incandescent bulb. But a CFL fixture, with included bulb, might sell for $30, compared to an incandescent fixture, without bulb, for $20. The price difference is only 50%, because most of the cost of both fixtures is the metal, the diffuser and the packaging, not the light sources. However, as with a CFL, if the dedicated fluorescent fixture allows price alone to be the determinant in the customer's decision process, it will lose.[57] It must be marketed on value as a superior choice that commands a higher price.

4.9.3 Meeting Real Customer Needs

Consumers want aesthetically pleasing residential light fixtures that provide the same or (preferably) better light output than the incandescent alternative, at a reasonable price. Unfortunately, most consumers' impressions of fluorescent lighting quality were formed before the technology was ready for widespread residential application. Most consumers do not appear to recognize that fluorescent residential lighting has improved dramatically in the last decade.

Linear fluorescent fixtures, as noted earlier, have a decidedly mixed record in residential settings. They have been used in homes for more than 50 years, and are largely responsible for many of the pervasive negative stereotypes about fluorescent color, flicker, hum, and fixture style. Residential linear fluorescent fixtures are common for only a few specific applications like garage and utility room lighting, where a broad area must be lit inexpensively. Their application is not greatly influenced by energy considerations or aesthetics. Indeed, the recent rise in popularity of 300 to 1000 watt halogen shop lights can be attributed to customers' dissatisfaction with typical fluorescent shop light performance, and a disregard for energy consumption. Home Depot is currently introducing an electronically ballasted T8 shop light to compete with halogen shop lights at a price of $30 or less.[58]

However, manufacturers have generally been slow to incorporate technical improvements in residential linear fluorescent fixtures, continuing to rely largely on the least expensive lamp and ballast components to meet particular price points. In fact, wholesale prices for fluorescent fixtures (largely linear) averaged between $15 and $18 from 1981 to 1990—virtually the same as the average price points for incandescent fixtures.[59] The products are sold largely on the basis of price, not value, in spite of the obvious opportunities to convey a message of investment in energy savings, longevity, convenience, or environmental advantages.[60] Consumers would rarely consider spending more money to get a higher performance linear fluorescent fixture, because they buy them with fairly low expectations from the outset.

Most compact fluorescent residential fixtures are marketed on the basis of their similarity to standard incandescent fixtures. They make no claim to light rooms in a fundamentally more attractive way; on the contrary, manufacturers try to persuade customers that traditional lighting aesthetics will not be compromised. As a result, compact fluorescent fixtures are trapped between two often (from the consumer's perspective) more desirable alternatives: less expensive, basic incandescent fixtures, which appeal to bargainhunters; and more attractive and decorative incandescent fixtures, which appeal to style-conscious homeowners willing to pay a little extra for something eye-catching.

Conversely, commercial fixtures have evolved over the last two decades to commonly employ T8 lamps instead of T12s, electronic ballasts instead of magnetic, and high CRI warm color lamps instead of cool white halophosphor lamps.[61] Commercial fluorescent lighting sells explicitly on a message of value, quality and reliability. Of course, in the commercial world, linear fluorescent fixtures are already the default. The labor to replace bulbs is expensive, so long operating life is important. Energy bills can be significant because of long operating hours, and highly efficient light sources are appreciated. Most of the available products are pure commodities, and thus face enormous competitive pressures. To differentiate their products from the competition, manufacturers have innovated continuously, seeking to offer features or performance characteristics not already available. Commercial energy managers understand lifecycle cost issues, and are willing to pay more if it means avoiding high failure rates or operating problems.

Thus, fluorescent fixtures face a difficult time in the residential marketplace, because they try to solve a problem that consumers do not feel they have. The simple claim that these fixtures save energy but are otherwise identical to incandescent versions will generally by itself be insufficient to motivate a purchase. The savings from a single light fixture, though great in a relative sense, is virtually impossible to detect on a typical residential electricity bill.

4.9.4 Learning from Torchieres

Where dedicated fluorescent fixtures have begun to achieve success is in residential applications where *they offer other benefits in addition to simply saving energy*. Compact fluorescent desk lamps, for example, provide more diffuse, even task light than many incandescents, though both appear to be losing market share to sleeker, crisper halogen models. Compact fluorescent outdoor fixtures confer easy-to-understand benefits of convenience, especially given their long hours of operation and the hassle of opening most outdoor fixtures to perform bulb changes. Compact fluorescent torchieres solve a safety problem consumers understand – they do something in a fundamentally better way than the halogen alternative.

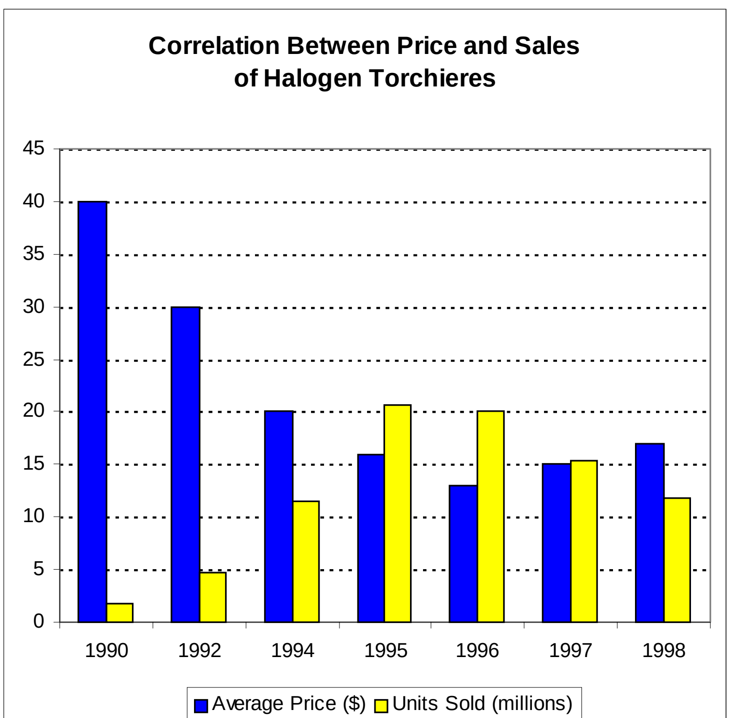

Figure 27 – Halogen torchiere prices and sales trends over time

Indeed, the halogen torchiere's original success is a tribute to that same principle. It solved a genuine problem faced by millions of consumers: the need to light a space brightly and evenly without spending much money up front or hiring an electrician. For millions of renters, these portable, dimmable fixtures made it possible to illuminate almost any room in a home for less than $20. Halogen torchieres also met a basic décor need – they were simple enough to complement, or at least not clash with, most household's interior decors. Besides, many manufacturers, retailers and consumers assumed that halogen torchieres were energy efficient.

Unfortunately, the 300 and 500 watt halogen bulbs in torchieres convert about 90% of their power use immediately to heat, reaching temperatures of 750 to 1100 degrees F.[62] Halogen torchieres have already started at least 435 fires, killed 32 people, injured 114, and caused millions of dollars in property damage.[63] More than 200 safety-related lawsuits are underway against halogen manufacturers and retailers, and television news programs have devoted substantial coverage to the safety problems with the products. Moreover, the safety remedies undertaken by halogen manufacturers are in many cases unattractive and not entirely effective, and have raised the cost of the fixtures. Prominent retailers like Home Depot and Wal-Mart have begun phasing out their sale of halogen torchieres entirely, motivated at least partially by liability exposure. As a result, sales of halogen torchieres have fallen substantially in the last two years and average prices have been rising (Figure 27) – a sign that market transformation is beginning with torchiere floor lamps.[64] Of course, a large share of the decrease in halogen torchiere sales is currently being taken up by torchiere floor lamps that use conventional incandescent bulbs. Although these incandescent torchieres do not have the safety problems of halogen torchieres, they are still very inefficient and represent a large potential for energy savings.

As a result, a safety niche has been opened for ENERGY STAR alternatives. ENERGY STAR compliant torchieres operate at temperatures of only 100 to 200 degrees. They are safer *because* they use energy more efficiently. Compact fluorescent torchieres represent an excellent means of introducing consumers to ENERGY STAR lighting, because they are otherwise almost exact replacements for halogen torchieres, and cost only $30 to $70 without utility incentives. In short, they provide an affordable, low-risk, highly adaptable means for customers to sample ENERGY STAR fixtures prior to undertaking a major investment. And for those customers who are motivated by savings, they offer around $300 of lifetime savings in avoided electricity and replacement bulb costs (Figure 28).

Some measure of the degree to which safety has been important to the success of these products can be derived from a look at the roster of manufacturers currently enrolled in the Energy Star fixture program. Among the most successful, deeply involved manufacturers are the ones marketing Energy Star torchieres: Good Earth Lighting, Energy Federation Inc., Lights of America, Emess, General Electric, Catalina, MaxLite and Technical Consumer Products. Energy Star torchieres have been available in retail stores since the middle of 1998, and have achieved sales of nearly a million units in total since their introduction.[65] Thousands more customers in Wisconsin, New England, Washington, and California have taken advantage of utility-funded opportunities to return their old halogen torchieres for recycling and purchase Energy Star alternatives at discounted prices. When surveyed about the reasons for their participation, customers consistently identified safety as a bigger factor than energy savings or environmental benefits.[66]

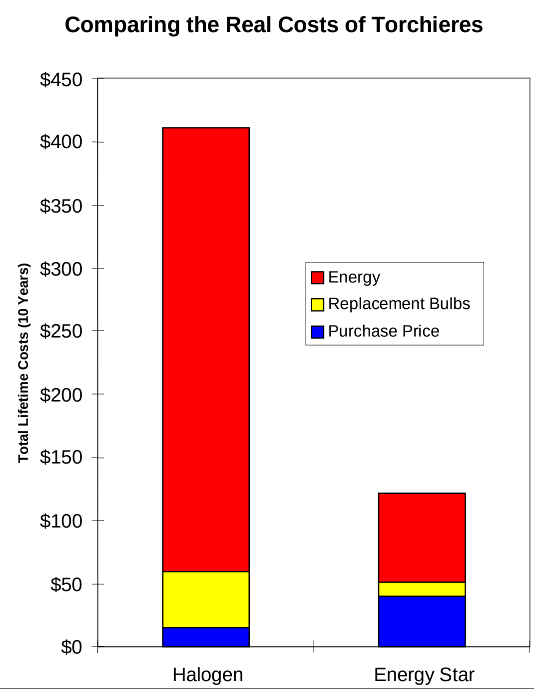

Figure 28 – Lifecycle costs of typical halogen and ENERGY STAR torchieres (www.lightsite.net)

4.9.5 Education

As with CFLs, the need for better education is still paramount. Indeed, recent surveys have shown that as many as a third of all fixture purchasers make their decision while in the store – they were undecided or uninterested in a lighting purchase prior to walking in the door.[67] This greatly increases the importance of educating retail salespeople, providing better point of purchase materials and displays, placing efficient products in eye-catching retail locations, and making ENERGY STAR logos highly visible in the store.

The more widespread, systematic use of the ENERGY STAR logo may also help to solve an educational problem relating to confusing product claims. Even the retailers themselves have acknowledged the difficulty of making informed recommendations to their customers, since they have little on which to base their comments besides the information provided by manufacturers. ENERGY STAR represents a source of independently credible advice or guidance, and is much easier to explain to a customer than the technical aspects of efficient lighting like color rendering index and electronic ballasts.

4.9.6 Product Availability

Fluorescent fixtures bearing the ENERGY STAR label are just beginning to enter the market in significant quantities, and manufacturers are at the early stages of understanding demand. In addition to the Energy Star torchiere sales noted earlier, national sales of indoor hard-wired ENERGY STAR products have reached perhaps 250,000 to 400,000 units to date, while outdoor fixtures may have sold between 200,000 and 350,000 units.[68] Utility program dollars have heavily influenced decisions by manufacturers and retailers about where to begin selling the products in large quantities. Inventory levels for most of the new products remain small, so any localized surges in demand can deplete inventory, leaving empty shelves and disappointed customers.

As discussed earlier, some retailers have begun ordering container-load quantities of efficient fixtures directly from manufacturers' factories in Asia, which significantly reduces per-unit cost. However, due to the distances involved, lead times of 90 days or more are common between the placement of a purchase order and the availability of products on retail shelves. Because fixture manufacturers typically purchase light sources from one supplier, and ballasts from another, while producing fixture housings themselves, it is not uncommon for product component snags to cause significant delays in the production and delivery of finished fixtures. General Electric's 55-watt 2D lamp, the crucial component of at least three manufacturers' ENERGY STAR torchieres, reached OEM assemblers in quantity about two years later than originally forecast. This caused substantial headaches for manufacturers waiting to fulfill retail orders, and for utilities counting on those retail orders to meet program energy savings goals.

5 Emerging Residential Lighting Technologies

5.1 New Products for Home Lighting

In addition to CFLs and dedicated fluorescent fixtures, a new generation of residential lighting technologies is currently undergoing development or being introduced into the market. The most promising technologies and improvements, along with their characteristics and potential applications are summarized below.

5.1.1 Two-wire dimmable fluorescent bulbs and fixtures

Dimmability for CFL lighting systems has been on the "wish list" of consumers and energy-efficiency advocates alike for a number of years. Early products did not meet performance expectations, but a new generation of dimmable products is now gaining acceptance. These products can achieve dimming in discrete steps or continuous dimming across a range of lighting levels, often down to 20% or less.[69] However, one remaining complaint with the current crop of fully dimmable CFL ballasts is their complexity. Fully dimmable CFL ballasts for residential use often require more complex wiring, as they need additional "control wires" to accomplish dimming functions. Although such specialized wiring affords more light level control, it can create a barrier to widespread adoption, raising cost and increasing the chances of incorrect wiring.

Recently, "two-wire" dimming capability has begun to reach the market. These products are designed to be fully compatible with rheostat-operated dimming circuits commonly found in homes, and thus can use the two existing power wires in most residential circuits, without the need for additional control wires. This simplicity has allowed the introduction of dimmable screw base CFLs, and both Philips and TCP have been selling them in the U.S. since 1997. At least nine different manufacturers including SLI Lighting, Janmar, and Lumatech have begun to offer two-wire dimming ballasts for hard-wired fixture applications (linear and compact fluorecent), though these are still quite rare in the residential marketplace.[70] As this technology continues to develop, it promises to increase the usage of fluorescent lighting in homes, particularly as a replacement for banks of dimmable incandescent downlights in semi-custom and custom homes.

5.1.2 Lamp-sensing ballasts

One drawback of the current array of available modular CFL types is the general consumer confusion when selecting lamps, whether for replacement or for first-time use in a new fixture. Unlike screw base lamps, which all fall into one of three main threaded base sizes, a bewildering array of pin and base choices confront the typical purchaser of modular CFLs. While this by itself does not prevent consumers from making a purchase, it does add to the confusion already presented by variations in lamp shape, size, wattage, lumen output, color temperature, and color rendering index. This degree of specialization is intended to ensure that lamps are only used with compatible ballasts. Although manufacturers have now settled on largely standardized base types, more can be done to simplify the processing of purchasing matching components for typical residential consumers.

Perhaps most promising is a new effort by a few ballast manufacturers to greatly increase the number of compact and linear fluorescent lamp types that can be operated by a given ballast. Fulham, for example, has introduced a line of only six "Work Horse" ballasts that can operate 389 different combinations of 71 different fluorescent lamps, including T2, T4, T5, T8, T10, and T12 linear fluorescents, along with the full array of CFL sizes. The ballasts range from a maximum power output of 28 watts all the way up to 140 watts. Likewise, on a more modest scale, Magnetek now offers a ballast designed to operate on a universal input voltage (European or U.S.), and to power CFLs ranging from 26 to 42 watts.

As these "lamp-sensing" ballast technologies become more widely available, they promise to greatly reduce inventory requirements for retailers and electrical distributors, while increasing economies of scale for ballast manufacturers. They should help reduce consumer and specifier confusion regarding the process of finding the right lamp and ballast for a particular application. In principle, the lamp-sensing ballast would be able to accept most modular CFLs through either an adapter or a built-in universal socket/pin receptacle. On-board electronics would sense the type of lamp being used and furnish the correct voltage and current to the lamp, while also being able to correctly sense the lamp's end of life. This would allow consumers to buy a dedicated fluorescent fixture without being locked in to a single level of light output or a particular type of tube. If needs or preferences change, consumers would simply change the pin-based CFL tube in the same way they currently switch incandescent light bulbs.

5.1.3 Metal halide residential products

Metal halide belongs to the high-intensity discharge (HID) lamp family, which is characterized by intense, very high efficiency light sources. Metal halide lamps have been most popular in commercial and industrial applications, because they can illuminate vast areas for very low energy costs. Metal halide light sources are also extremely efficient. They can range from 75 to 100 lumen per watt, depending on lamp wattage, with lifetimes of 40,000 hours or more in commercial service. However, they currently have some limitations that make them problematic in residential applications. For example, lamp start up can take from three to five minutes, and restarting after shutdown can take anywhere from 10 to 20 minutes. Lamp color rendering can also shift dramatically over lifetime. Color temperatures are also cooler than many residential users are accustomed to. Because of their intense light, fixtures must be designed to distribute the light effectively and avoid glare. Finally, additional safeguards may be needed to protect consumers from ultraviolet radiation if the outer lamp envelope fails.

Despite these drawbacks, metal halide lamps have the potential to save a significant amount of energy in residential use, and can already replace CFLs or halogens in applications where an intense point source, long burning hours, or a high lumen output application is needed. Future innovation will make metal halide even more attractive. Electronic and "pulse" ballasts, combined with new lamp designs have proven successful in controlling color shifts, as well as reducing starting and re-strike time. Even dimmable HID ballasts have recently been demonstrated. At least one manufacturer has combined metal halide lamps with incandescents in a residential fixture. The incandescents start immediately when the fixture switches on, then shut off automatically as the metal halide sources reach full brightness. These fixtures are substantially more expensive than CFL designs, but show some promise for the future.

5.1.4 Higher Output CFLs

One reason for the extraordinary success of the halogen torchiere has been its intensely bright light output, which can replicate the feeling of day-light. The current crop of high lumen CFLs can approximate that light output, but a halogen light bulb is a compact point source while fluorescent tube emits a naturally more difuse glow. Therefore, people often perceive CFLs to be dimmer than halogen or incandescent sources, even if laboratory measurements confirm identical total lumen output.

Recently introduced higher wattage CFLs products should help to address this problem. GFL is working on ENERGY STAR compliant torchiere designs with compact fluorescent light sources rated at 75 and even 90 watts. The first commercially available ENERGY STAR torchiere utilized two high output 36 watt F lamps from Osram Sylvania, which provided very high light output, but at a cost that was ultimately less competitive than single lamp designs. Likewise, General Electric is moving to utilize its 55 watt 2D lamp in a series of hard-wired fixture applications. These configurations will allow compact fluorescent fixtures to exceed the brightness of incandescent fixtures that use multiple 75 or 100 watt incandescent bulbs. Here, the CFL fixture will offer something that incandescents cannot match: the convenience and visual symmetry of a single long life light source.

Three downsides are possible with these developments, however. First, from a utility perspective, some of these extremely high output CFLs will save a lower % of electricity than their predecessors, since consumers will use them to increase lighting levels. Second, these products can get substantially hotter than smaller

CFLs, and thus require more intelligent thermal management to perform as designed. Third, the products may require dimming capabilities to allow customers to achieve the desired light output level at different times of the day. This further raises cost, and may discourage or slow adoption

5.1.5 Higher Output Linear Fluorescents

The next step after the evolution from the T12 to the T8 linear fluorescent is the T5. These tubes are thinner and brighter than T8s and promise higher efficiencies and new applications. T5 lamps are only just being introduced in commercial applications Europe and are not yet common in the U.S. They require different luminaire configurations than T12 and T8 tubes because the brightness of the tube is so intense that uncomfortable levels of glare can result if it is used directly.

5.2 The Wild Frontier

In the more distant future, homes may be lit by exotic lamps that are only just emerging from laboratories. The following is a sampling of some interesting new technologies.

5.2.1 LEDs

Light emitting diodes (LEDs) have recently found applications in traffic signals, exit signs, and a host of smaller niche applications. By using a semiconductor-based process for creating light, LEDs offer high efficiency (50 to 100 lumens per watt over the long term). An LED can produce light of only a single frequency or color and there are now LEDs that can produce red, green, amber and blue light. This makes LEDs particularly useful in situations where colored light is produced by filtering a white light source, thereby wasting much of the light.

LEDs have long lives, can be easily dimmed, are very rugged, have good low temperature performance, are highly compact and produce focused lighting output. Their mean time between failures is dramatically higher than other light sources - about 1.5 million operating hours at temperatures of 160 degrees F and more than 10 million hours at temperatures of – 40 degrees F. The efficiency and light output of LEDs also continue to improve with new research.[71]

Although LEDs are already being used widely in homes for indicator lights, they have not been used for general illumination because they only emit light of a single color.[72] Recent innovations in creating white light LEDs include devices that combine red, blue and green LEDS in a single package to approximate white. Another promising development is the use of a high-output blue LEDs in combination with white phosphors to create a fluorescent LED. Preliminary testing indicates a CRI of 85 is achievable at a color temperature of about 4700 K through a combination of the blue light emitted directly and the white light emitted from the phosphors. Real Goods Trading Company and other specialty retailers have begun offering white light LED products, but prices remain quite high – up to a $100 for single light bulb (comprised of dozens of LEDs inside of a globe). It remains to be seen whether white LEDs will ever reach high enough efficacies at low enough prices to be able to start competing with fluorescent and compact fluorescent lighting for general illumination in homes.

5.2.2 Halogen infrared-reflective coating (HIR) and ceramic filament designs

Because the incandescent lamp's filament output is a function of its temperature, efforts to improve incandescent efficiency have focused on the filament as one way to increase its light output. Halogen infrared reflecting lamps incorporate an extremely thin layer of spectrally selective optical coating on the outside of the quartz capsule. The coating reflects heat (infrared radiation) back onto the filament, while allowing the visible light to pass though, thus achieving higher light output for a given level of power input than traditional halogens. Generally, larger HIR lamps exhibit higher efficiency than smaller lamps. One issue with increasing the lamp filament temperature is the decreased lumen maintenance, as well as other performance issues. One approach to addressing the resulting effects from increased filament temperature is to use more heat-resistant filament designs, such as the incorporation of ceramics into the filament materials.

Efforts by European and U.S. procurement agencies to encourage the mass production of affordable HIR replacements for the traditional incandescent bulb have not been successful. The reasons for this are discussed in Volume 1, section 2.4.2.

5.2.3 Remote-source lighting

The most efficient light sources are often very bright and very expensive. Rather than putting a light source where light is needed, remote source lighting generates light centrally and then distributes it using "light tubes" or fiber optic cables. The concept of remote source lighting originates from work done to distribute daylighting, and concentrated sunlight can be used as the central light source. Light tubes are now used in a number of commercial buildings to distribute light to interior spaces.

Steady innovation in light distribution technologies, as well as improved light sources, have maintained interest in this concept. A system employing the high efficiency, high output sulfur lamp has been tested and applied in limited demonstrations. Remote source lighting could find residential application if technology continues to advance and costs come down considerably. One day, homes may be plumbed for water and sewer, wired for electricity and telecommunications, and installed with optical guides for light.

5.2.4 Electro-luminescent (EL) panels

Electro-luminescent panels, as their name implies, are flat panels whose surface emits visible light when an electric current is applied. EL panels are solid-state illumination devices consisting of a dielectric sheet of material coated with phosphors sandwiched between two electrode plates, at least one of which is transparent. When an AC current is applied to the dielectric sheet, the phosphor layer glows. The color of light emitted by EL panels is determined by the phosphor's chemical composition. Available colors currently include amber, blue, green, white, or yellow, with green EL panels having the highest luminance.

EL panels are extremely efficient at converting energy to light. However, current technology has limited light output levels. EL panels also suffer from high lumen depreciation over their lifetime, which is about 8 years. Because of the low maximum lumen output and uniform luminance characteristics, these panels are ideal for a number of niche applications.

To date, uses for EL panels have been quite specific, with the most common commercial applications being portable computer display screens, control panels, and exit signs. One potential residential application for EL is night lights. Currently available products can provide sufficient nightlight levels at power levels more than 99% below typical incandescent nightlights (0.03 W vs. 5 to 15 W typical). These products have been sold under the Limelite brand for at least two years and were recently licensed by General Electric for sale under its own name.

6 Notes Volume 2

1 Lighting history drawn from Valerie-Anne Giscard d'Estaing, *The World Almanac Book of Inventions*, 1985, pp. 169-171.

2 Wiebe E. Bijker, "The Majesty of Daylight: The Social Construction of Fluorescent Lighting," in *Of Bicycles, Bakelites and Bulbs: Towards a Theory of Sociotechnical Change*, MIT Press, 1995, pp. 227-260.

3 One early example is described in "A Speculative Home with 7.4 kw of built-in lighting," *Illuminating Engineering*, March 1967, pp. 133-135. Note that the high connected load of 7,400 watts is billed as a desirable feature of the home.

4 For more information, see National L ighting Product Information Program, *Screwbase Compact Fluorescent Lamp Products*, Specifier Reports Volume 7, Number 1, June 1999, pp. 10, 14.

5 *Lighting Lighting Atlas*, E SOURCE, 1997, pp. 12-13, estimating candles at 0.15 lumens/watt and 7.5 hours of life. This is compared to HID and LED light sources with a maximum of about 100 lumens per watt and about 50,000 hours of life.

6 Southern California Edison offered low-income residential lighting programs as early as 1985 or 1986, and residential rebate programs were offered during the same period by Boston Edison. Boston Edison and EFI introduced a residential lighting products catalog in 1987-1988 which generated orders for 40,000 CFLs.

7 The IKEA chain regularly retails CFLs for under $6.00 each.

8 Personal communication, Steve Goldmacher, Director of Public Affairs, Philips Lighting, 10/26/99.

9 Analysis by Chris Calwell and Linda Latham of AC Nielsen and Triad POS data.

10 Rated efficiency ranges from 15 to 17.5 lumens per watt – nearly identical to traditional incandescent bulbs at similar wattages.

11 Nils Borg, "First true look-alike," *International Association for Energy-Efficient Lighting Newsletter*, 1/99, Issue #22, Vol. 8, p. 16.

12 See Chris Calwell, Chris Granda, Charlie Stephens, and My Ton, *Energy Efficient Residential Luminaires: Technologies and Strategies for Market Transformation*, May 13, 1996, for more detail on this issue.

13 Opinion Dynamics Corporation, *Baseline Study of the Northeastern Residential Lighting Market*, June 3, 1998, pp.1, 29; and Decision Sciences Research Associates, *Residential Lighting Market Transformation Study*, conducted for Southern California Edison, September 1998, p. 4-11.

14 Personal communication, Steve Goldmacher, Director of Public Affairs, Philips Lighting, 10/26/99.

15 Personal communication, John Zugel, General Electric Lighting, April 1999. NEMA membership obtained from NEMA website: www.nema.org.

16 Nils Borg, "Global CFL Boom," *International Association for Energy-Efficient Lighting Newsletter*, Issue 19, Volume 6, 1997. Nils Borg preliminarily revised his 1997 total estimate down to 45 million units and made a 1998 estimate of 50 million units in a personal communication to Chris Granda on May 4, 1999. These changes are not reflected in Table 2.

17 Personal communication, John Zugel, GE Lighting, April 1999.

18 Freedonia Group, *Lighting Fixtures and Lamps: Private Companies Report*, #1057, December 1998, (Section 04, Record 0005); and *Lamps to 2001*, #960, 12/1997, (Section 09, Record 0027), and (Section 08, Record 0002).

19 Personal communication, Mark Ledbetter, Pacific Northwest National Laboratory, April 1999.

20 Kate Griffin, "Getting consumers to see the light," *National Home Center News*, July 5, 1999, p. 21.

21 Sales of 600,000 to 700,000 units per year identified by utilities represented at the meeting and summarized in *Residential Lighting Market Transformation Programs – 1999 Summary*, CEE, June 1999. Our higher estimate recognizes that other utilities not involved in CEE offer incentives as well, though their numbers are likely to be small.

22 For a text of the relevant specifications, see www.energystar.gov.

23 Ira Krepchin, *A Brightening View of CFL Dimming*, E SOURCE, ER-98-3, July 1998.

24 Jane Peters et. al., "Market Effects Summary Study" (draft final report) October 15, 1998, pp v2-20

[25] Personal communication, Marvin Ellison, General Electric Lighting, November 1997.

[26] Fredrik Lundberg, "IKEA gives away 25 MW," *International Association for Energy-Efficient Lighting Newsletter*, issue # 19, vol. 6, 1997, pp. 9-10.

[27] Decision Sciences Research Associates, *Residential Lighting Market Transformation Study*, conducted for Southern California Edison, September 1998, p. 4-19.

[28] See Peter Boyce, "Is Full-Spectrum Lighting Special?" *IRC Internal Report Number 659*, pp. 30-36.

[29] Fredrik Lundberg, "Electronic Ballasts: Relief for the Senses", *IAEEL Newsletter*, issue no. 13, volume 5, 1996

[30] Portland Energy Conservation Inc. and Ecos Consulting, *The Northwest Energy Efficiency Alliance LightWise Initiative: Program Progress Report*, July 31, 1998. pp 18

[31] Portland Energy Conservation Inc., Ecos Consulting, *The Northwest Energy Efficiency Alliance LightWise Initiative: Program Progress Report*, July 31, 1998, pp. 13, 17-18.

[32] Debbie Howell, "Diversity Sidelines Soft White," *Discount Store News*, April 5, 1999, p. 31. and *The Northwest Energy Efficiency Alliance LightWise Initiative: Program Progress Report* pp17.

[33] Review comments, Yon Sung, MaxLite, November 16, 1999.

[34] National Lighting Product Information Program, *Screwbase Compact Fluorescent Lamp Products, Specifier Report* Volume 7 number 1, June 1999, pp 12, 43. NLPIP selected a total of 11 different CFLs representing six major manufacturers (General Electric, Lights of America, MaxLite, Osram Sylvania, Panasonic, and Philips). For each CFL, they tested four to eight individual samples in each of six different test cycles. These ranged from 5 minutes on/20 seconds off all the way up to 3 hours on/20 minutes off (the industry standard for determining lifetime). Some of the CFLs tested by NLPIP had not yet failed when the report was published. Thus, some of the longest-lived products plotted in Figure 14 have true lifetimes exceeding what is shown.

[35] *Lighting Technology Atlas*, E SOURCE, 1997, p. 2.2.3. The converse of Kruithof's findings is also relevant: fluorescent lamps that operate at cool color temperatures will generally appear brighter than fluorescents operating at warm color temperatures. This may partially explain why linear fluorescent fixtures and many compact fluorescent fixtures are demonstrated in retail stores with cool white lamps.

[36] Decision Sciences Research Associates, *Residential Lighting Market Transformation Study*, conducted for Southern California Edison, September 1998.

[37] Granda, Christopher, *A Statistically Based Impact Evaluation of a Direct Install Compact Fluorescent Distribution Program, Proceedings*, 1992 ACEEE Summer Study.

[38] PECI, Ecos Consulting, 1998.

[39] Specifications often draw a fine distinction between luminaires, which technically include light sources, and fixtures, which technically do not. This paper will use the more common term, fixtures, to refer to the combination of light source and housing.

[40] *Lighting Market Sourcebook*, p. 12.

[41] *Lighting Market Sourcebook*, p. 19.

[42] *Lighting Market Sourcebook*, p. 20.

[43] *Lighting Market Sourcebook*, p. 19; and Chris Calwell and Chris Granda, *Halogen Torchiere Market Transformation: A Look at Progress to Date and Future Strategies*, prepared for the Natural Resources Defense Council by Ecos Consulting, September 10, 1999.

[44] AC Nielsen POS Data for 52 Weeks Ending April 17, 1999.

[45] Assuming one night light per household and a savings potential of 3 watts per household yields 2.6 billion kwh/year of potential savings if the night lights operate around the clock, compared to national residential lighting demand of about 140 billion kwh/year.

[46] See Russell P. Leslie and Kathryn M. Conway, *The Lighting Pattern Book for Homes*, Lighting Research Center, 1993, pp. 143-188 for detailed examples.

[47] Russell Leslie and Kathryn Conway, *Lighting Pattern Book for Homes*, pp. 25, 35, 44, 46; Russell Leslie, *Builders Guide to Home Lighting*, 1994, pp. 9-10; Chris Calwell and Jennifer Brons, *California Kitchen Lighting Project Cost Effectiveness Discussion*, May 1998.

[48] Bruce Wall, *Draft Request for Proposals for a Market Transformation Initiative to Develop and Produce ENERGY STAR IC-rated, Airtight Recessed Can Lighting Fixtures*, NEEP, October 1, 1998.

[49] Pacific Consulting, *Northwest Energy Efficiency Alliance Energy Star Residential Lighting Fixtures Program, Market Progress Report #1*, November 1998.

[50] Heschong Mahone Group, *Residential Lighting Baseline*, Lighting Efficiency Technology Report, California Energy Commission Contract #400-95-012, October 21, 1996, p. II.

[51] Economic Industry Reports, *The U.S. Lighting Fixtures Industry: An Economic and Market Study*, 1998 Edition, p. 32.

[52] Attempts to obtain data for both portable and hard-wired fixtures in either units or dollars were confounded by the limitations of the available data.

[53] *The U.S. Lighting Fixtures Industry: An Economic and Market Study*, p. 34.

[54] HomeWorld Business, *Portable Lighting: Lighting Thrives in Home Specialty, D-I-Y Channels*, January 1999, p. 70.

[55] For additional discussion of the split incentive problem with builders and electrical contractors, see *Energy Efficient Residential Luminaires: Technologies and Strategies for Market Transformation*.

[56] Opinion Dynamics Corporation, p. 27.

[57] Sergio Zyman, *The End of Marketing As We Know It*, 1999.

[58] Personal communication, Kevin Cody, Midwest lighting buyer, Home Depot, September 1999.

[59] *The U.S. Lighting Fixtures Industry: An Economic and Market Study*, p. 33.

[60] *Energy Efficient Residential Luminaires: Technologies and Strategies for Market Transformation*, p. 4.

[61] Chris Calwell, Danielle Dowers, and Doug Johnson, *How Far Have We Come? Remaining Opportunities for Upgrading Fluorescent Lamps and Ballasts*, E SOURCE, SM-98-4, May 1998, p. 6.

[62] Chris Calwell, *Halogen Torchieres: Cold Facts and Hot Ceilings*, TU-96-10, E SOURCE, September 1996, p. 6.

[63] Summary statistics excerpted from on-line database of torchiere fires at www.lightsite.net.

[64] Chris Calwell and Chris Granda, *Halogen Torchiere Market Transformation: A Look at Progress to Date and Future Strategies*, prepared for the Natural Resources Defense Council by Ecos Consulting, September 10, 1999.

[65] Chris Calwell and Chris Granda, *Halogen Torchiere Market Transformation: A Look at Progress to Date and Future Strategies*, prepared for the Natural Resources Defense Council by Ecos Consulting, September 10, 1999.

[66] Chris Calwell, “Customers Turn Out for Torchiere Trade-In,” *Home Energy*, March/April 1999, pp. 32-35.

[67] Ecos Consulting and Portland Energy Conservation Inc., *Energy Star® Fixtures: A Bright Idea*, 1998 results summary from Northwest Alliance, California, and Wisconsin Electric lighting programs, 1999, p. 7.

[68] Ecos Consulting internal estimates, based on interviews with manufacturers and retailers and a survey of utility program results.

[69] Ira Krepchin, *A Brightening View of CFL Dimming*, ESOURCE, ER-98-3, July 1998, pp. 1-3.

[70] Ira Krepchn, pp. 8-9.

[71] Andrew Bierman, LEDS: From Indicators to Illumination?, *Lighting Futures*, vol. 3, no. 4 LRC 12/1998

[72] David Evans, *Status of LED Technology*, March 25, 1998.