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Interim Report **IR-00-009**

Technology Progress Dynamics of Compact Fluorescent Lamps

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Preface

Lighting is only a small fraction of electricity demand by the residential and commercial sector. Nonetheless, energy-efficient lighting has attracted the attention of many energy analysts over the last 20 years. As an object of analysis, this small part of the energy system involves many features typical of cost-benefit analysis in other sectors of the energy and even the economic system at large. For example, energy-efficient lighting involves the trade-off between high initial and low running costs on the one hand and low initial and high running costs on the other. Also, risk of investment, market barriers, transaction costs, and discounting play a role, to name but the most important.

This paper, which is based on the author's work during IIASA's 1999 YSSP, looks at Compact Fluorescent Lamps (CFLs) from the point of view of technology assessment. In the focus of the author's analysis is the tool of learning curves. In addition, CFL promotion programs and their effects are reviewed.

Abstract

Compact fluorescent lamps (CFLs) have been expected as one of the energy saving technologies for their characteristics of lower electricity consumption and longer life cycle compared to incandescent lamps. Although the price of CFLs has declined significantly during the last 10 years, they are still 10 times as expensive as incandescent lamps. This report examines the technological development of CFLs by using a learning curve that relates cost to cumulative production and estimates the future cost reduction of CFLs. Promotion programs of CFLs those greatly influence on the market expansion are also surveyed and future prospects are discussed finally.

Acknowledgments

I am grateful to Leo Schrattenholzer for giving me valuable advice and his full support to complete this report.

About the Author

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Technology Progress Dynamics of Compact Fluorescent Lamps

Yumiko Iwafune

1 Introduction

1.1 Study Objectives

The purpose of this report was to analyze the technological development of compact fluorescent lamps (CFLs). The advantage of CFLs over conventional incandescent lamps is their reduced energy consumption. Although the price of CFLs has declined significantly during the last 10 years, they are still 10 times as expensive as incandescent lamps. It is therefore important to estimate future cost reductions of CFLs in order to predict the market and energy saving potential of CFLs. As a concept for studying the past performance of CFLs, learning curves have been chosen. Learning curves relate specific costs to cumulative production using a simple, two-parameter functional form.

Section 2 of this paper presents an overview of the technical features of CFLs and past technological progress and current trends of CFL development. Section 3 surveys the development of the global market not only to determine past cumulative CFL production for the to-be-derived learning curve, but also to give a market outlook. Section 4 examines past CFL price data, disaggregated by different CFL types and analyzes CFL price components. Past cumulative production and price developments are combined to estimate a learning curve of CFL prices in Section 5. Section 6 contains an outlook on likely future CFL technical and price developments. Section 7 surveys subsidy programs and Section 8 presents conclusions.

1.2 Learning Curves

Learning curves are used to describe technological progress resulting from experience. They postulate that technological progress depends in a regular way on experience gained with the production and the use of a technology. Here, technological progress is expressed as unit costs and experience as cumulative production. The postulated relation is expressed in mathematical form by the following formula.

$$Cost = A * CCap^{-b} \quad (1)$$

where: Cost ……Unit costs

A ……… Unit costs at a total cumulative (initial) capacity of 1

CCap … Total cumulative installed capacity

-b ……… Learning elasticity

With this definition, a doubling of total cumulative capacity goes along with a reduction of specific costs by a factor of 2^{-b}. This factor is also called *progress rate* (PR). The complementary rate (1-PR) is called the *learning rate* (LR). A learning rate of 20% therefore means that capital costs per unit of newly installed capacity of a given technology decreases by 20% for each doubling of total installed capacity.

2 Compact Fluorescent Lamps

2.1 Technical Description

Compact fluorescent lamps (CFLs) are miniaturized fluorescent tubes that can be installed into nearly any table lamp or lighting fixture. CFLs are defined differently by different institutions. For example, the Lighting Research Center (LRI) defines CFLs as fluorescent lamps that have a tube of diameter of 16 mm or less and circular CFLs[1]. In contrast, the Electric Power Research Institute (EPRI) defines CFLs as lamps intended to replace incandescent lamps and having overall lengths of eight inches (20 cm) or less[2].

Most CFLs sold today consume between 5 and 27 watts of electric input and have a brightness and color rendition that is comparable to incandescent lamps. Unlike more conventional fluorescent tubes, they can directly replace standard incandescent bulbs. CFL bulbs are available in various shapes, as shown in Figure 2-1, the main types being two, three, or four-finger (with the tubes sometimes folded), 2-D and circline (circular design).

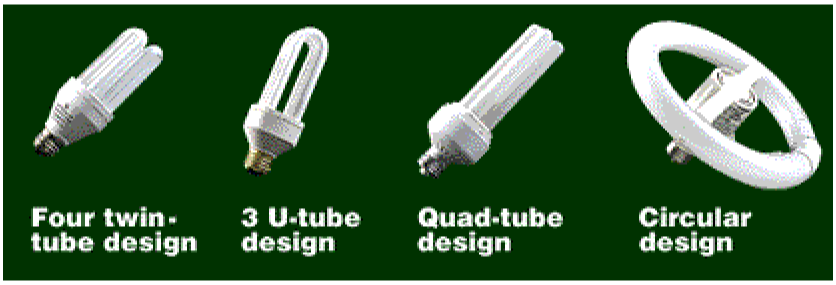


Figure 2-1: Examples of compact fluorescent lamps.

2.2 CFL Structure

CFLs consist of two parts, a gas-filled tube (bulb) and magnetic or electronic ballast (Figure 2-2). The ballast provides the initial voltage required for starting lamps and regulates lamp current during operation. The mercury vapor gas in the tube glows with ultraviolet light when electricity from the ballast flows through it. This in turn excites a white phosphor coating on the inside of the tube, which emits visible light throughout the surface of the tube.

Some CFLs are of the "modular" type, having light bulbs and ballasts that can be separated and replaced separately. Others are of the "integral" type, in which the ballast is permanently built into the bulb and is discarded with the bulb when the bulb burns out.

Another categorization of CFLs distinguishes between "dedicated" and "screwbase" types. Dedicated CFL products include fixtures and use ballasts that are hardwired to lamp holders within a luminaire like linear fluorescent lamp systems. They are often categorized as belonging to the modular type. Screwbase CFLs are designed to fit in a medium screwbase socket.

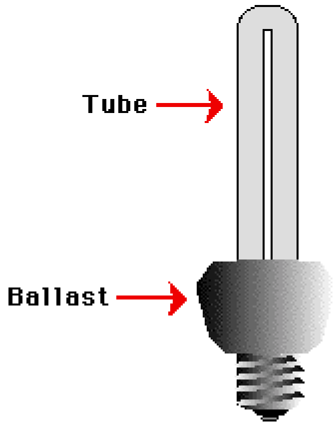


Figure 2-2: CFL structure.

2.3 Features

CFLs require less energy inputs than incandescent lamps. For example, a 27-watt CFL generates approximately 1800 lumens, compared to 1750 lumens from a 100 watt incandescent[3]. CFLs also have a significantly longer service life, 6000–15000 hours compared to 750–1000 hours for a standard incandescent[1]. These advantages must be compared with the following drawbacks.

1. CFLs are often bigger than the incandescent lamps they replace and may not fit the lamp or fixture conveniently or not at all.
2. The light is generally cooler and less yellow than incandescent lamps. This may be esthetically less pleasing than the light emitted by conventional incandescent lamps.
3. CFLs with magnetic ballasts flicker slightly when they start.
4. Ordinary dimmers cannot be used with CFLs.
5. Some types may have reduced light output when operated at cold temperatures.
6. Ballasts may emit an audible buzz.
7. CFLs may also produce Radio Frequency Interference (RFI).
8. CFLs cost approximately 10 times as much as incandescent lamps.

It should be noted, however, that CFL developers have addressed several of these drawbacks. For example, the color rendering of CFL light is being improved and some recent ballasts can dim CFLs[4].

2.4 Past Technology Progress

Early CFLs met with poor market acceptance because of the reasons mentioned above. However, the market acceptance is rapidly changing due to the new production trends described below.

2.4.1 The Shift to One-Piece Design

The modular type CFLs, in which the longer-lasting ballast can be reused by replacing just the tube, are more economical and resource efficient, but they have not been well accepted in homes. It has also proven difficult to use the more modern electronic ballasts in modular CFLs. As a result, the trend is toward one-piece, integral CFLs.

2.4.2 Efficiency Improvement of the Ballast

CFL efficiency varies widely with ballast type and ballast quality. Most early CFLs used magnetic ballasts, typically heavier and less efficient than electronic ones. Flicker, hum and long start-up times are also associated with magnetic ballasts. Electronic ballasts are now more common and overcome the above weakness of the magnetic ballasts. In addition, they typically are 75% lighter in weight and 50% smaller in volume as well as more efficient, and they produce better quality light.

2.4.3 Compact and Glass-enveloped CFLs

While early CFLs commonly had just a single U-shaped tube, the trend has been toward CFLs with two U-shaped tubes, and most manufacturers have now introduced triple tubes. Although they are still longer than most incandescent light bulbs, these are compact enough to fit into most fixtures.

Furthermore, major manufacturers, such as Philips, Osram, Panasonic, and Toshiba, have already started to produce CFLs enclosed within a glass envelope, giving it an appearance similar to that of a traditional incandescent bulb, and some CFLs are miniaturized into the almost same size as an incandescent lamp. For example, Toshiba has sold 11W CFLs, NEO BALL Z, that have a 60 mm diameter and are 123 mm high. For comparison, incandescent lamps measure 55 mm in diameter and 98 mm in height. These new lamps can be used with more than 90% of lamp fixtures (see the illustration in Figure 2-3). Although these bulbs have a lower specific light output and a shorter life (around 5000-6000 hours) than standard CFLs, they are expected to contribute to the expansion of market acceptance.

Figure 2-3: 11 W glass-enveloped CFL by Toshiba (corresponding to 40 W of an incandescent lamp).

2.4.4 *Improvement of Power Factor*

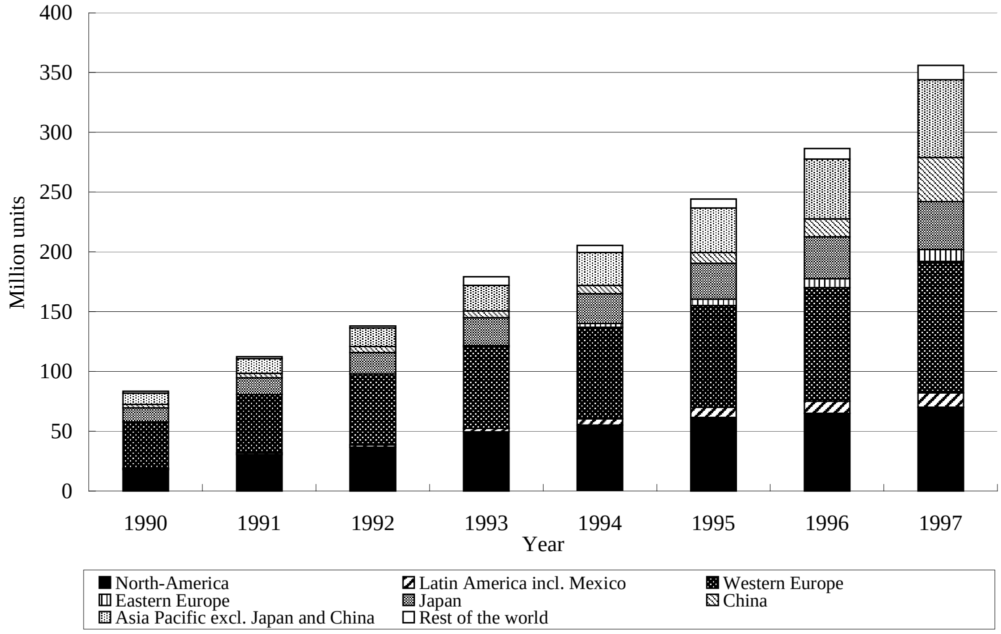
Power factor of a CFL is defined as the ratio of active (W) to apparent power (VA) and is a measure of the efficiency with which an electrical device converts input current and voltage into useful electric power. Power factor may not mean much to most end-users, but it makes a difference to utility companies who have been promoting CFLs through demand-side management (DSM) programs. Low-power-factor CFLs draw more power from the grid than is measured at the meter, so utility companies have pushed manufactures to produce high-power-factor products. Low-power-factor CFLs also can reduce the harmonic distortion, which is often caused by electronic ballasted CFLs.

3 The Development of the Global CFL Market

Having been introduced on a broad scale in the 1980s, CFLs soon became the icon of energy efficiency. CFL market growth was very strong in the early 1990s, fueled by utility demand-side management (DSM) programs. However, by the mid-90s there were signs of a slowdown in growth, especially for integral lamps in OECD markets. This coincided with cuts in DSM programs spending, following the utility deregulation trend. However, DSM programs in OECD countries never came to a complete end. In the UK, for instance, smart financial incentive programs have helped CFLs achieve a strong position in the market by 1995. Extensive quality testing and massive information campaigns have also helped the CFLs market continue its maturation. As a result, prices have dropped substantially in these markets. Where CFL markets are still weak, especially in developing countries, various financial incentive programs and information campaigns are helping to lay the foundation for self-sustaining CFL markets.

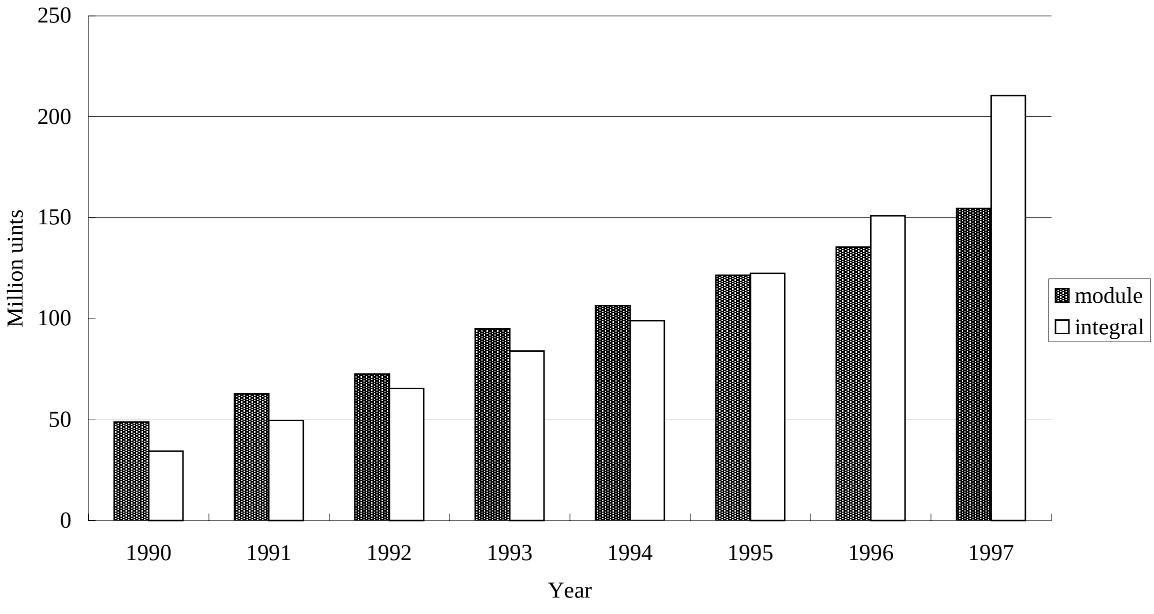
In 1997 about 200 million integral and 150 million modular CFLs were sold globally[5] (Figure 3-1). The energy savings achieved with these lamps are difficult to estimate because factors such as utilization, lamp life, the type and wattage of replaced lamps etc., are unknown. However, there are some indications that CFLs do affect sales of incandescent lamps in some markets. While about 10 billion incandescent lamps were sold in 1997 and sales are growing 3-5% per year in the world, their sales in Europe and North America have decreased by a few percent per annum over the last few years. Looking at two different CFL types separately, we can see from Figure 3-2 that the integral type has become more popular than the modular type only in 1995.

At the time of this writing, these data obtained from Borg [5] is the only worldwide data on CFL sales.



Source: International Association for Energy-Efficient Lighting (IAEEL) News Letter, 1997

Figure 3-1: World sales of CFLs, total.



Source: International Association for Energy-Efficient Lighting (IAEEL) News Letter, 1997

Figure 3-2: World sales of modular and integral CFLs.

3.1 OECD Countries

According to Borg [5], in Western Europe, total CFL sales grew by a little more than 10% annually in 1994–1996. In 1997, sales accelerated to 16%, and 110 million lamps were sold. Many programs have been carried out to encourage customers to use CFLs instead of incandescent lamps during the past few years. As a consequence, 30% of the 150 million households in the EU own CFLs now (Table 3-1). The owning rates are high in the Netherlands, Germany, and Denmark. The estimated number of CFLs owned in Europe's households is estimated at 138 million units.

Table 3-1: Domestic lighting in Europe: summary of individual country profiles. Source: The DElight project final report[6].

Country	Households (millions) 1994	Households with CFLs (%) 1997	CFLs owned (/hh) 1997	CFLs owned (/owing hh) 1997	Incandescent price (ecu) 1997	CFL price (ecu) 1997	CFLs Country owning* (millons)
Austria	3.1	-	-	-	0.9	15	-
Belgium	4.0	29.0%	0.9	3.7	0.9	18	3.6
Bulgaria	3.0	1.4%	0.02	1.3	1.0	14	0.06
Czech Rep.	-	-	-	-	0.3	11	-
Denmark	2.4	46.0%	2.0	4.4	1.0	16	4.8
Finland	2.2	-	1.0	-	0.5	20	2.2
France	22.8	-	0.5	-	1.2	17	11.4
Germany	36.3	51.0%	2.1	4.3	1.0	10	76.2
Greece	4.0	11.5%	0.1	1.0	1.0	13	0.4
Hungary	-	20.0%	-	-	-	-	-
Ireland	1.3	22.0%	0.9	4.0	0.6	15	1.2
Italy	24.4	55.0%	1.1	2.0	0.7	14	26.8
Lithuania	-	-	-	-	0.3	15	-
Luxembourg	0.2	-	-	-	-	-	-
Netherlands	6.4	62.0%	2.7	4.5	0.7	11	17.3
Poland	12.9	19.6%	0.3	1.6	0.3	9	3.9
Portugal	3.2	-	-	-	0.5	13	-
Romania	7.8	0.5%	0.006	1.1	0.3	13	0.05
Spain	12.0	11.5%	0.2	1.7	0.6	13	2.4
Sweden	4.1	10.0%	0.4	4.0	0.6	13	1.6
UK	24.3	23.0%	0.7	3.0	0.8	15	17.0
EU Total	150						138
EU Average		32%	0.9	2.8	0.8	15	

*: Number of households multiplied the by the number of CFL per household.

North America (excluding Mexico) has a weaker CFL market. There, sales grew by approximately 10% in 1994-1995, but then slowed down to an annual 6–8% in 1996-1997. In the United States, however, recently, new, energy-efficient sub-CFLs are being offered (see subsection 7.1.3).

In Japan, total CFL sales reached about 40 million units in 1997. Growth rates have decreased slightly over the past several years, from about 20% per annum in 1994 to about 15% in 1997.

3.2 Non-OECD Countries

Outside the OECD, CFLs sales are increasing very quickly, especially in developing countries. As in OECD countries, both growth rates and absolute sales are higher for integrated lamps than for modular ones. In Eastern Europe, Asia Pacific (excluding China) and the rest of the world, total growth was over 30% in 1996–1997.

Estimated Chinese total sales had already reached 100 million units in 1997, with integral lamps making up about 90% of the production, and grew by some 250% in 1996–1997.

In Latin America, growth has been slower than in other developing countries, and it seems that large-scale CFL programs need somewhat more time to produce a result.

4 Prices

4.1 CFL Prices

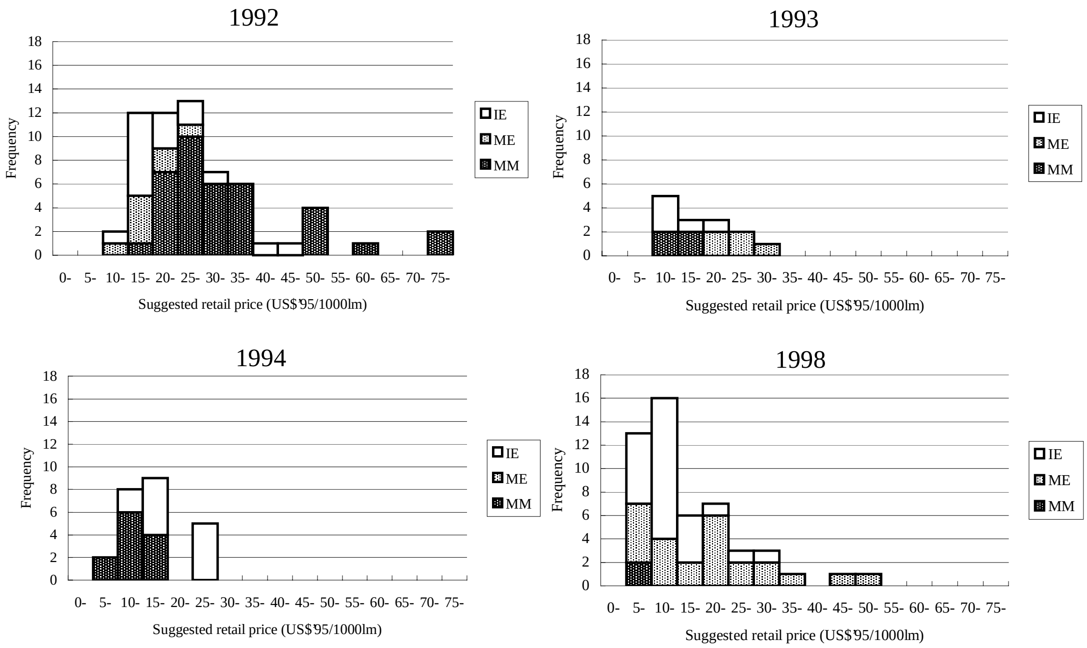
4.1.1 Distribution of Available Price Data

"Costs" mean the expense required for the production of manufacturers and "prices" mean the amount of money consumers pay. In the spirit of the concept of technological learning, CFL costs should be used in this analysis. However, the lack of cost data requires the analyst to use price data instead as a second best. Doing this, care has been taken to take proper account of subsidies. Moreover, since subsidies are an interesting and important topic in the study of technological progress, in this paper, a separate section is devoted to subsidies and other promotional activities. In this context, it should also be noted that the price data reported here are manufacturer's suggested retail prices, which means that they are higher than actual market prices.

CFL prices have declined during the past years. The following analysis distinguishes between CFLs with different ballast types and with different structure (modular or integral).

As already mentioned, present trends are away from magnetic ballasts to electronic ballasts, and from modular to integral types, and the prices are different for each type. I have estimated the average price of CFLs for each type based on the data reported by the Lighting Research Center (LRC). Since 1993, the LRC has surveyed and tested the performance of screwbase CFLs sold in the United States[1,7]. Although their data include major manufacturers, data are available only for some selected years. Moreover, so few integral CFLs with magnetic ballast were produced that they were excluded from the subject of estimation. All price data have been converted to US dollars (1995 prices).

The distribution of CFL price data is shown in Figure 4-1. In 1992 and 1998, many more data points were available than for the years 1993 and 1994. For 1992, data on modular CFLs with magnetic ballast can be divided into two types, one without reflector and another with reflector. Obviously, the latter is more expensive, typically costing over 50$/1000lm. In integral CFLs with electronic ballast, there are two price clusters in the 1994 data. The two clusters correspond to two different envelope types, where the cheaper type is without glass envelope (3-U tube or four twin tube design, for example) and the other is the type with a glass envelope. In 1998, modular CFLs with electronic ballast cover a wide price range. Prices above 30$/1000lm are by Mitor only, whose products have higher performance than conventional ones. They can operate at temperatures below –40˚C, and they are vapor proof.



MM: Modular CFL with magnetic ballast

ME: Modular CFL with electronic ballast

Source: National Lighting Product Information Program, Specifier Reports[1, 7]

Figure 4-1: CFL prices, 1992, 1993, 1994, and 1998.

4.1.2 Prices of Modular CFLs with magnetic ballast

Modular CFLs with magnetic ballast represent an old type that has some disadvantages in comparison with CFLs with electronic ballast. They are heavier, bigger, more noisy, have a longer starting time and are inefficient, among others. However, magnetic ballasts are cheaper than electronic ones, and they still have a large market for applications where there is little restriction on ballast size. As we can see from Figure 4-2, the average price of this type declined by 75% between 1992 and 1998. For 1993 and 1998, only one manufacturer's price data were available. It is therefore possible that the data of this year are biased.

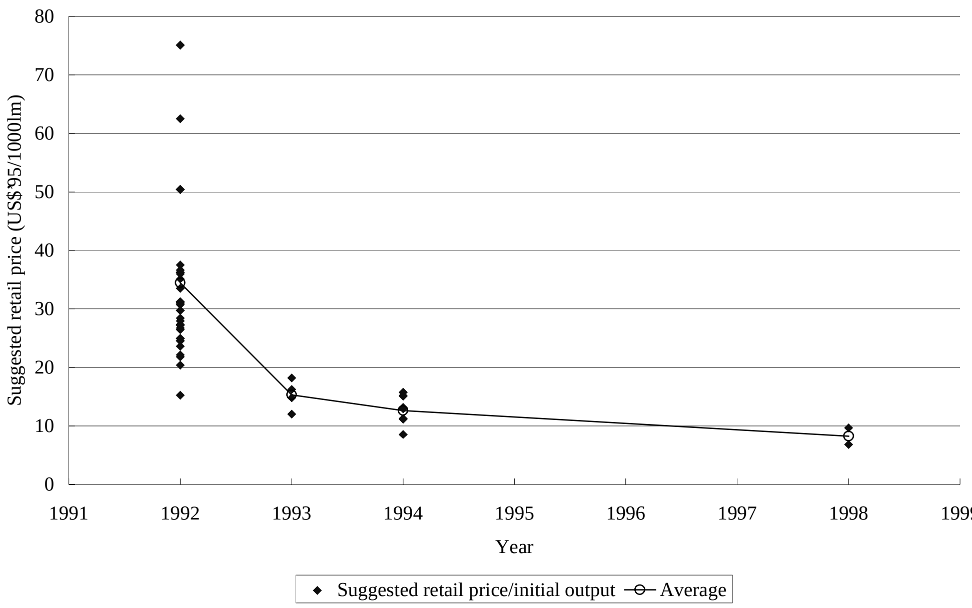


Figure 4-2: Price of modular CFL with magnetic ballast.

4.1.3 Prices of Modular CFLs with Electronic Ballast

Recently modular CFLs have become less popular than integral CFLs as shown in Figure 3-2 above. However, circular CFLs of modular type have a large market, particularly in Asian countries. From Figure 4-3, we can see prices of this type have not visibly declined in past years. Prices seem to have even increased between 1992 and 1993. A possible reason for this is that the 1993 data are for two manufacturers only, and low efficiencies of the products offered by one of the two make average efficacy worse. As already mentioned in Subsection 4.1.1, the expensive but high performance CFLs makes average 1998 prices high.

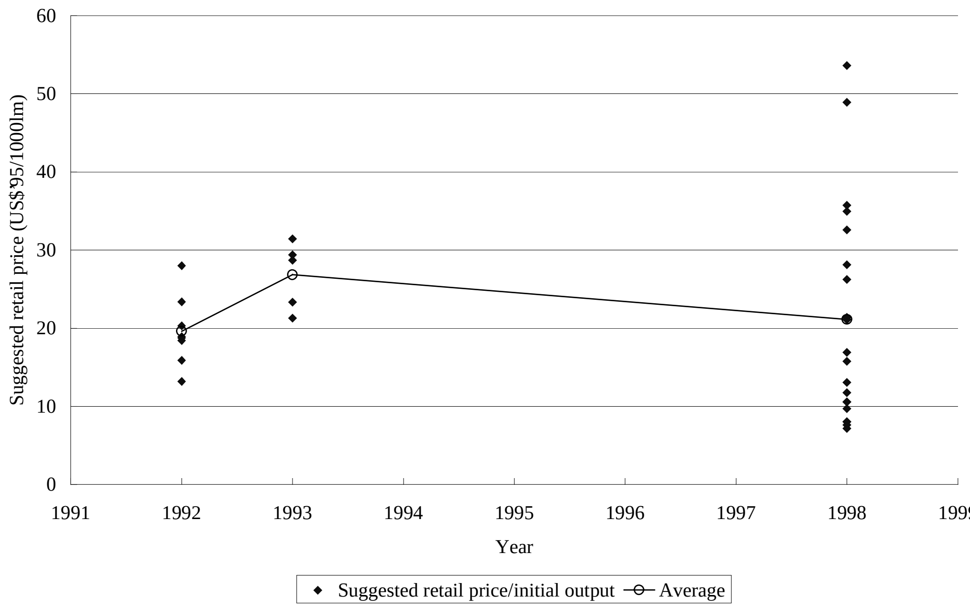


Figure 4-3: Prices of modular CFLs with electronic ballast.

4.1.4 Prices of Integral CFLs with Electronic Ballast

Owing to the popularity of integral CFLs with electronic ballast, the number of available data for this type is the largest. Its average specific price declined by 40% between 1992 and 1998 as shown in Figure 4-4. In addition, Figure 4-5 distinguishes between two subtypes; one without and one with glass envelope. The CFLs with glass envelope are less efficient. Their specific price is therefore higher than the price of CFLs without an envelope. However, major manufacturers have expressed their intention to make more acceptable CFLs by increasing their similarity to incandescent lamps. They have therefore increased the production of CFLs with glass envelope, so that their price is expected to go further down.

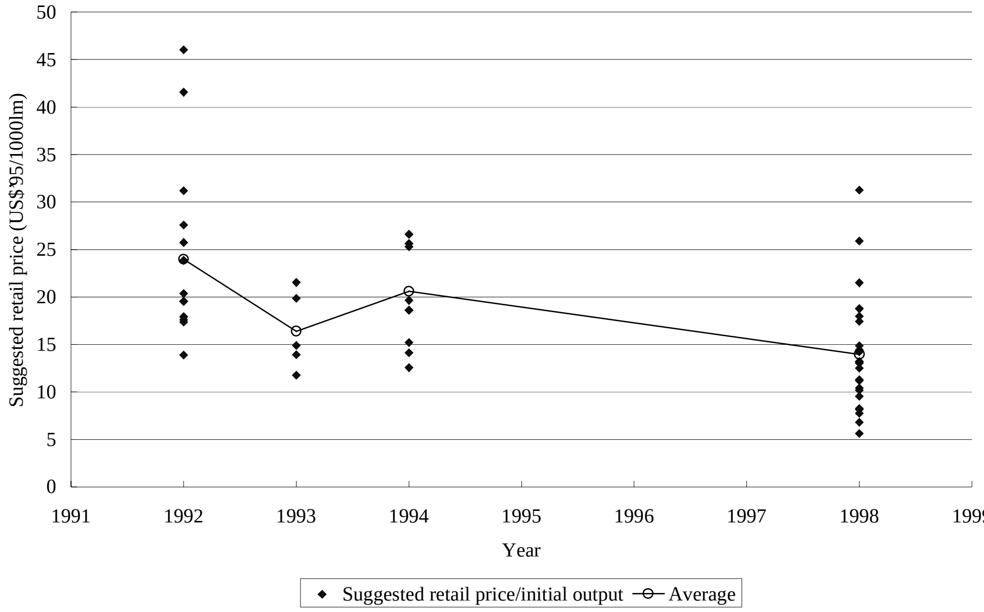


Figure 4-4: Prices of integral CFLs with electronic ballast.

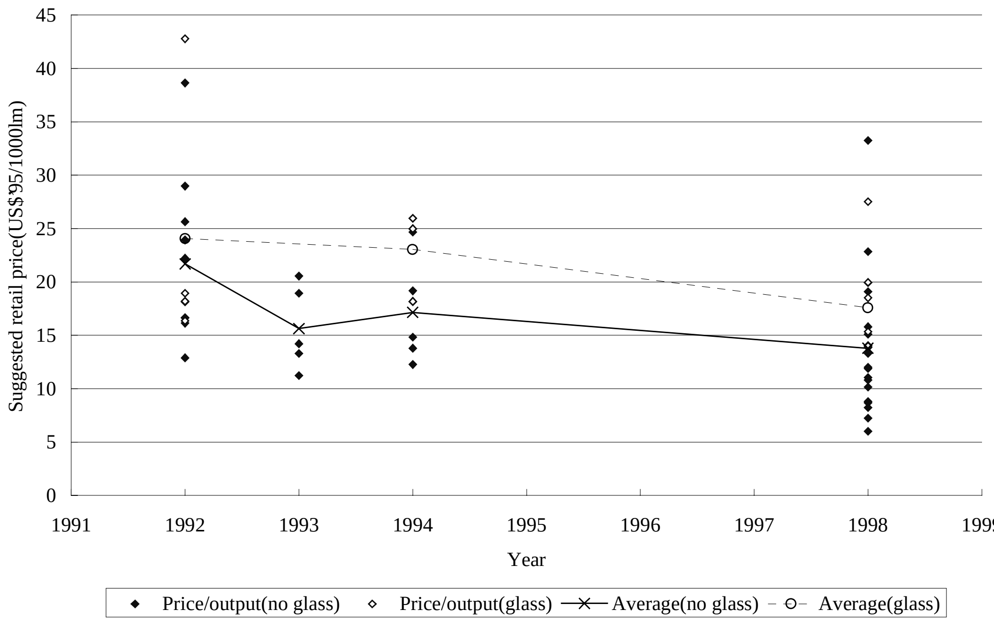


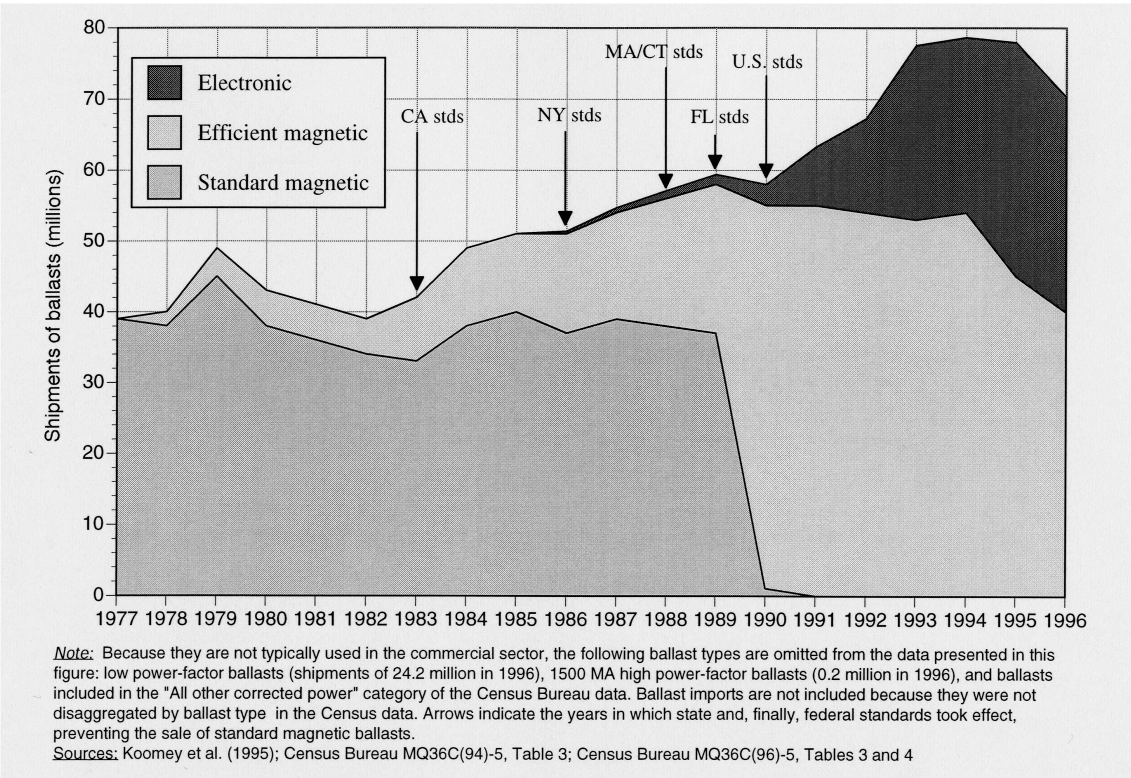
Figure 4-5: Prices of two kinds (without and with glass envelope) of integral CFLs with electronic ballast.

4.2 Ballast Prices

As shown in Section 4.1, the ballast type affects CFLs price significantly. It is therefore important for the estimation of CFL prices to separately consider the ballast prices. However, there are only few available data for particularly ballast of CFLs. In this section, the ballast price of all types of fluorescent lamps (compact and others) is analyzed. The analysis is based on US data. Although almost all of the general ballasts are for linear fluorescent tubes, and therefore of a completely different size than CFLs ballasts, we assume that the trend in general ballast price decline will be similar to the trend for CFL ballasts because their structure could be regarded almost the same.

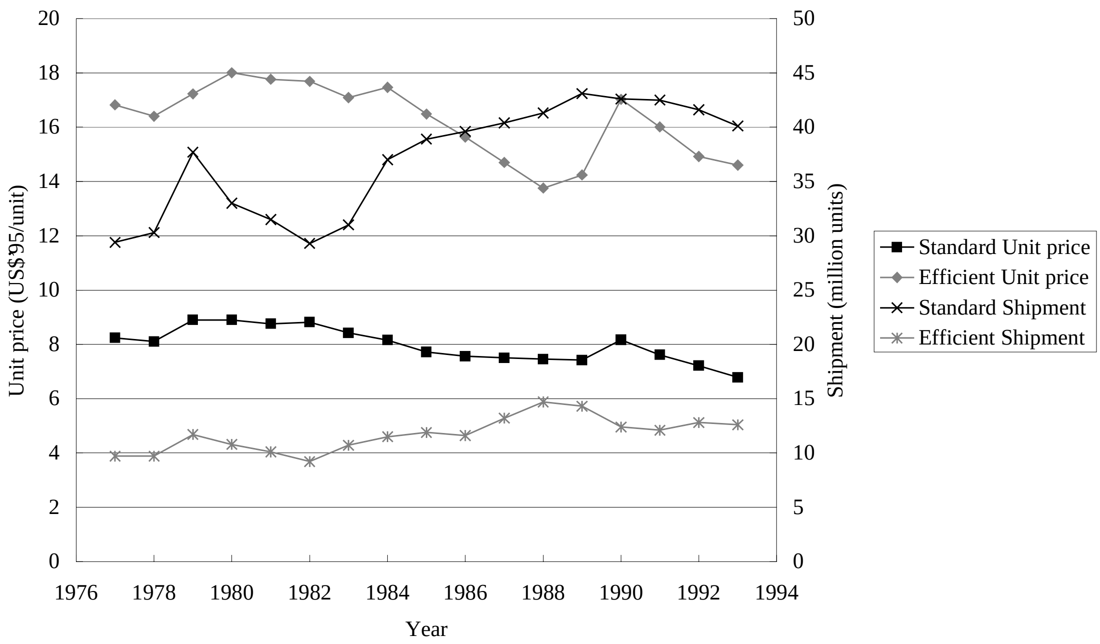
Figure 4-6 indicates US shipments of fluorescent ballasts from 1977 through 1996 as well as the years in which the various state standards and the federal standard took effect[8]. California adopted an energy-efficiency standard for fluorescent lamp ballasts in 1982. Over the following five years, four more US states followed and in 1990 a federal standard became effective. By 1991, all magnetic ballasts sold met the new standard. Electronic ballasts appeared in 1986 and their shipment increased rapidly after 1990.

Figure 4-7 and Figure 4-8 show US shipments and unit prices data for each type of ballast[9]. Prices per unit were derived from the value of sales, divided by shipments and converted to 1995US$. For magnetic ballasts, prices per unit decline steadily during the 1980s. Between 1989 and 1990, however, there is a jump in the price of both types of magnetic ballasts. This upward price change seems to be caused by the federal standard, and prices resume their downward trend again after 1990. Electronic ballast prices decline throughout (with the one exception 1988 and 1989), reflecting the rapid increase in the shipment.



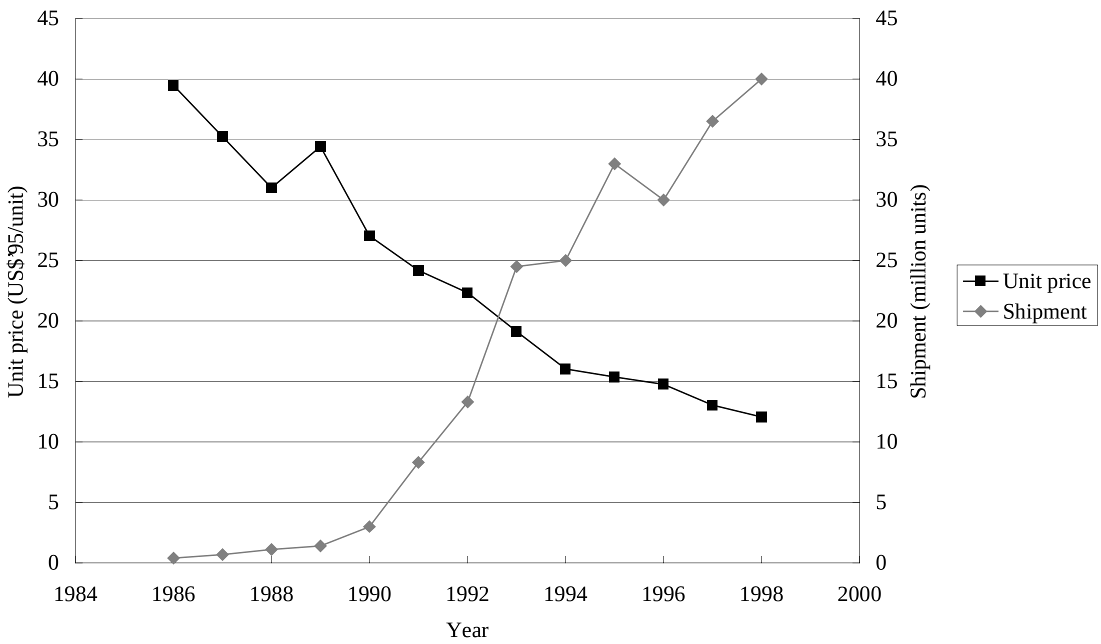
Source: Lighting Market Sourcebook for the U.S.[8]

Figure 4-6: US shipments of ballasts for the US commercial sector.



Source: Magnetic Fluorescent Ballasts:Market Data , market Imperfections, and Policy Success, 1995

Figure 4-7: US shipments and unit prices of magnetic ballasts.



Source: Magnetic Fluorescent Ballasts:Market Data , market Imperfections, and Policy Success, 1995

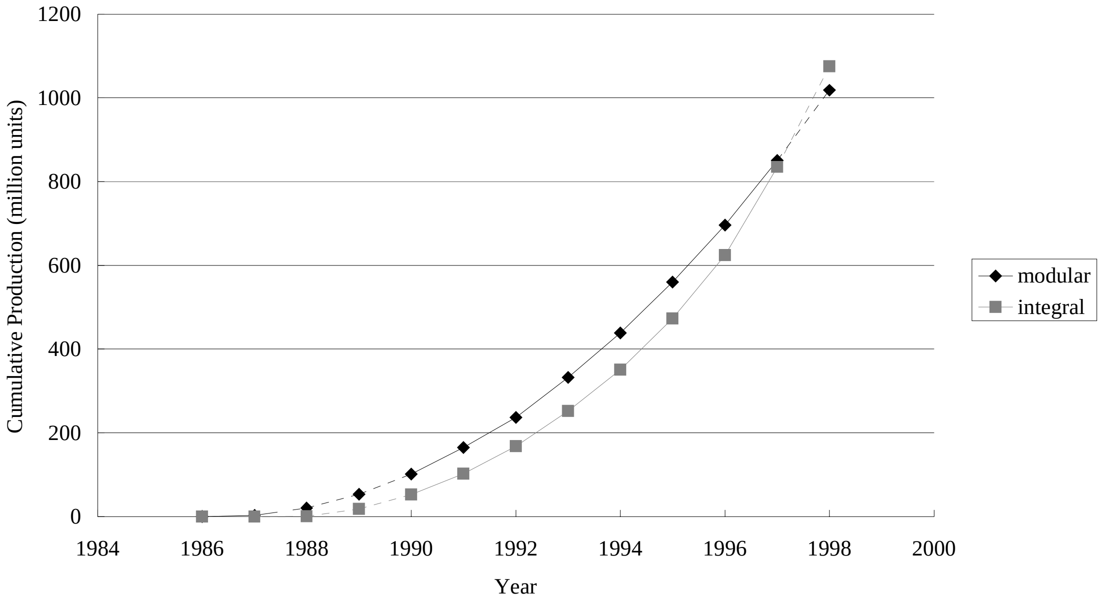
Figure 4-8: US shipments and unit prices of electronic ballasts.

5 Learning Curves

5.1 CFL Learning Curves

From the world sales data shown in Section 3, cumulative productions of modular and integral CFLs have been calculated (see Figure 5-1). Since the distribution of price data is so wide, three learning curves have been estimated from one cumulative production data series and three price data series. The three price data series correspond to average prices, high prices (defined by adding one standard deviation to the average), and low prices (defined by subtracting one standard deviation from the average). The resulting learning curves are shown in Figure 5-2. These curves include all data, i.e., they do not reflect the different technical characteristics discussed in Section 4. The data variability is therefore rather high in 1992 and 1998. As a consequence, the higher two of the three learning curves have rather low correlation coefficients (R^2 values). In a second estimate, the price data that have been identified as incomparable in Section 4 (modular CFLs in 1992 with magnetic ballasts and reflectors and, for 1998, modular CFLs with electronic ballasts and better performance in low temperatures), were eliminated from the sample. The learning curve estimated on the basis of the new sample is shown in Figure 5-3. The new curve has much better statistical properties (the standard deviation is lower and the correlation coefficient is much higher), and generally looks much more plausible. The estimated learning rate for average price is 21.6%.

Learning curves for each type of CFL have also been estimated separately as shown in Figure 5-4. These curves are again estimated from the data set from which incomparable data had been eliminated. As an approximation, all integral CFLs were assumed to have electronic ballasts, while the production ratio of magnetic and electronic ballasts in modular CFLs is unknown. For lack of better information, it was therefore assumed for this estimation that half of modular CFLs have magnetic ballasts and all integral CFLs have electronic ballasts. The estimated learning rates are 40.8% for modular CFLs with magnetic ballasts, 15.9% for modular CFLs with electronic ballasts and 20.1% for integral CFLs with electronic ballasts. The learning rate of magnetic ballasted CFL is very high compared to electronic ballasted CFL. This may be caused by the rapid price reduction in magnetic ballast as mentioned below (subsection 5.2). This kind of price reduction can be observed for each manufacturer.



Note: broken line's data are own estimation
Source: International Association for Energy-Efficient Lighting (IAEEL) News Letter, 1997

Figure 5-1: Cumulative production of CFLs in the world.

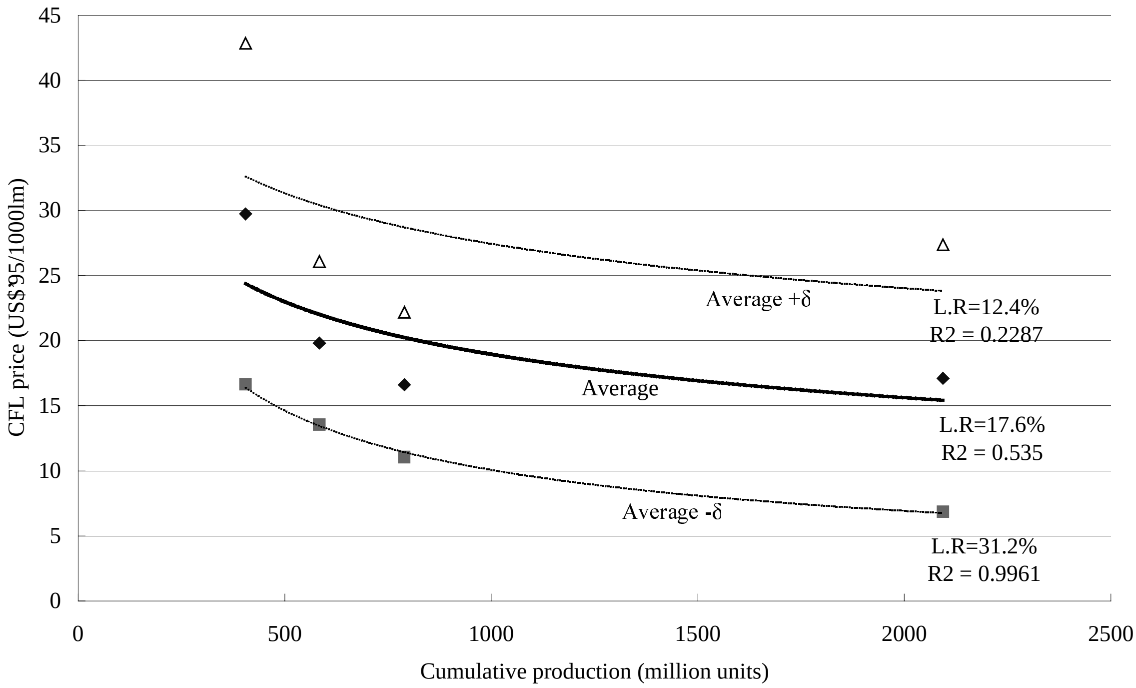


Figure 5-2: CFL learning curve (including all data).

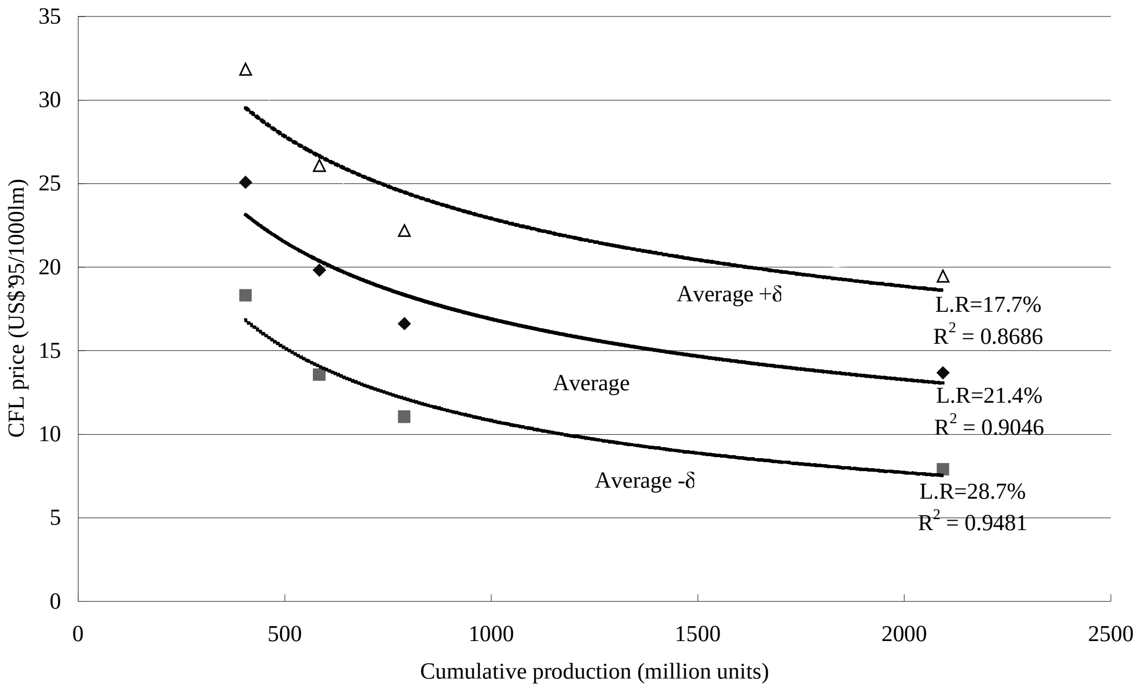


Figure 5-3: CFL learning curve (after eliminating incomparable data).

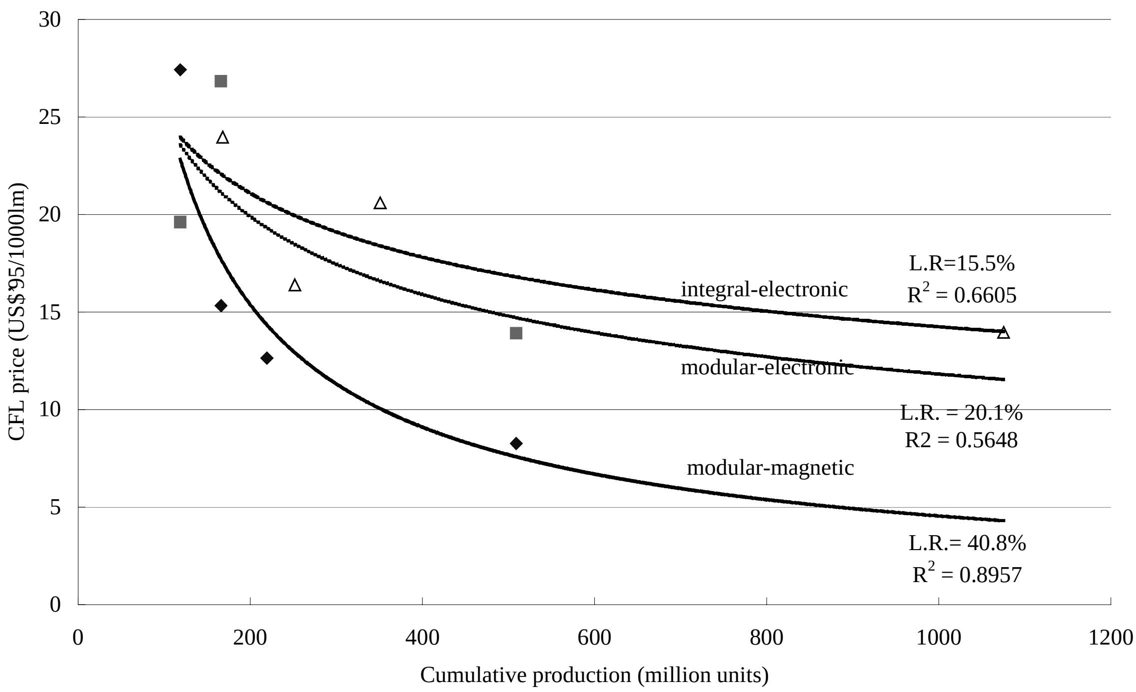


Figure 5-4: CFL learning curves by type.

5.2 Ballast Learning Curves

As already mentioned, CFLs have two components, a tube and a ballast. In the Lighting Research Center data of 1992[1], many price data are reported for each component of modular CFL. On average the price of magnetic ballasts is 48% of the whole CFL and even higher, 69%, for CFLs with magnetic ballasts. It is therefore useful to analyze technological learning separately for ballasts only.

Learning curves for magnetic and electronic ballasts have been estimated and are shown in Figures 5-5 and 5-6. For magnetic ballasts, only the data for efficient magnetic ballasts were used for the estimation of the learning curve because there were no shipments of the old magnetic ballasts after 1991. In Figure 5-5, we see two price declines of efficient magnetic ballasts, one during 1981–1988 and one between 1990 and 1993, that is, before and after the enforcement of federal standards in 1990. The two corresponding learning rates are 16.4% (1981–88) and 41.1% (1990–93), suggesting that technology progress after the law has accelerated. For electronic ballasts, the unit price declined reflecting the production growth and the learning rate is 12.5%.

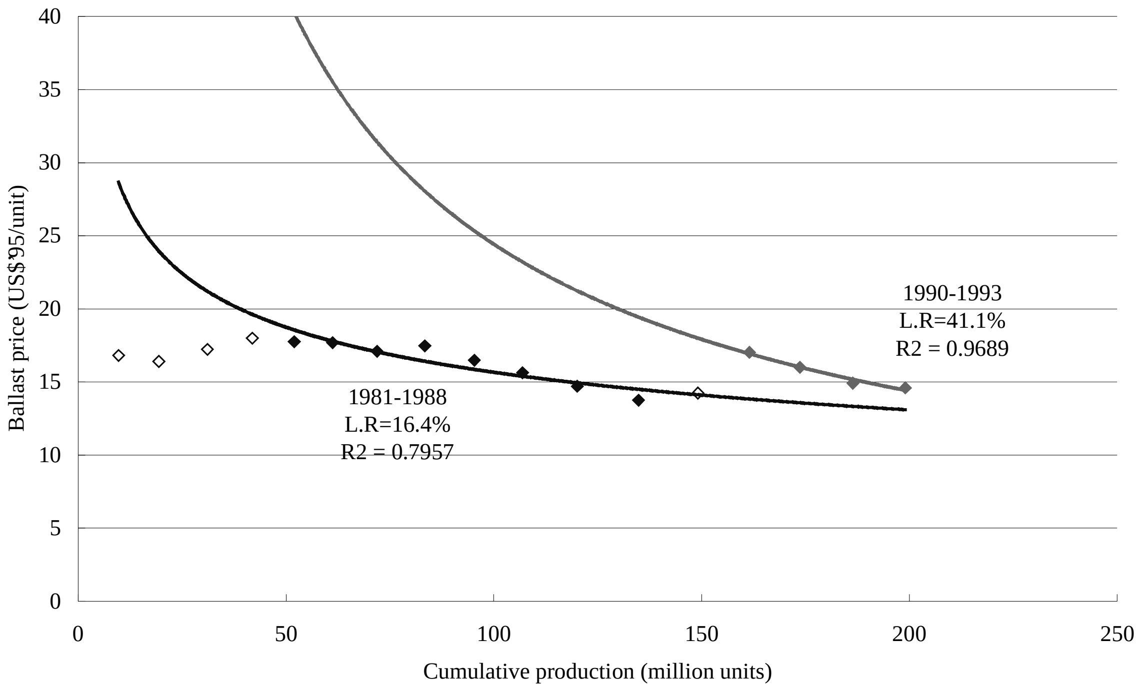


Figure 5-5: Learning curves for magnetic ballasts in the United States.

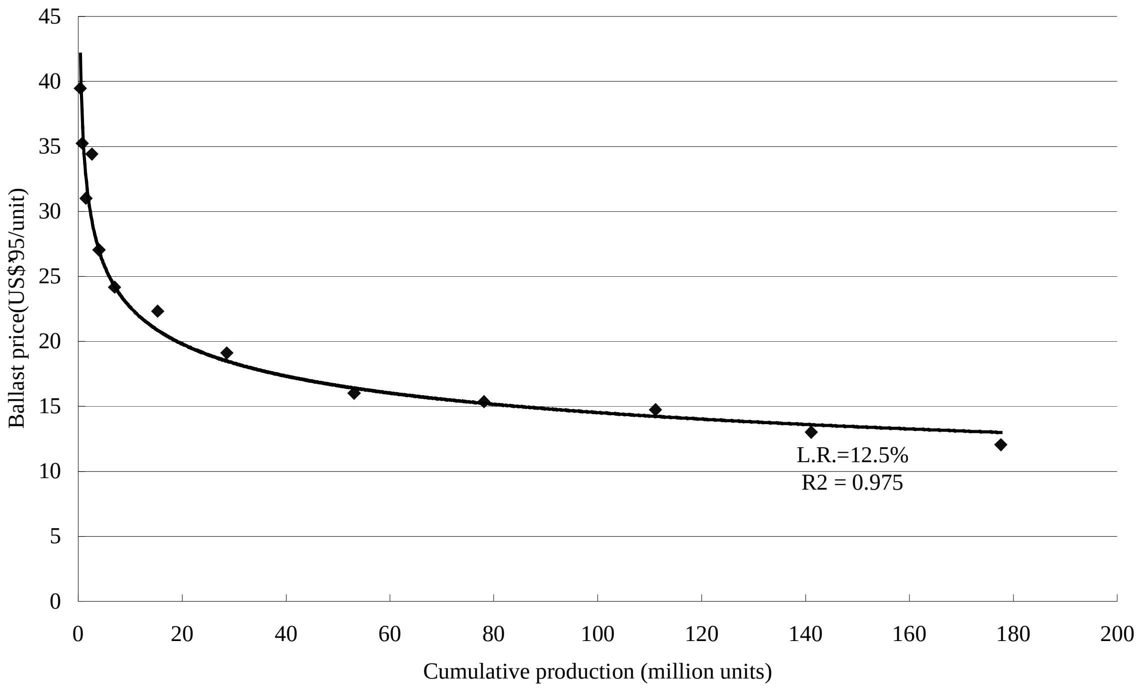


Figure 5-6: Learning curve of electronic ballast in the United States.

6 Future Prospects

6.1 Market Potential

As shown in Table 6-1, [6] used three categories to classify the suitability of the luminaires for integral-ballast CFLs in the residential sector, based on on-site surveys in 24 households in each of the three countries, Germany, Sweden, and the UK. 'Instant conversion possible' means that the surveyed luminaire was found suited for direct replacement with an integral-ballast CFL with acceptable appearance, light distribution and quality, 'future conversion' means that a CFL would fail to meet one of these criteria and therefore not be acceptable without a new fixture. 'Conversion unlikely' describes the category of luminaires with fluorescent strips or tungsten halogen bulbs, any dedicated fixtures, and fixtures on dimmer switches. Across the three countries, the surveyors found 32–42% of all luminaires suitable for CFLs, without any modification necessary. These potentials are conservative estimates. Given the current trend towards smaller CFLs and CFLs with an appearance similar to incandescent lamps, this potential can be expected to increase in future.

Table 6-1: Technical potential for CFLs.

	Germany	Sweden	UK
Successful conversion	34%	32%	42%
For future conversion	47%	43%	50%
Conversion not attempted	19%	25%	8%
Number of light fixtures per household	21	30	20
Number of luminaires per household categorized to successful conversion	7.1	9.6	8.4
Number of CFLs ownership per household in 1997 (Number of CFLs ownership per CFL-owning household)	2.15 (4.3)	1.0 (4.0)	0.7 (3.0)

Base: 24 households in each country – percentages of all fixtures (1997)

Source: The Delight project final report

Table 6-1 includes only the technical potential. The economic potential will have to reflect that it requires CFLs to be used at least for 2 hours per day to render them economic[10]. In the United States, about 30% of lamps are used more than 2 hours per day and they consume about 75% of all lighting energy use (Table 6-1). CFLs are used less than 1% in household lights in US and 4% in Europe now.

In 1997, 10 billion incandescent lamps and 365 million CFLs were sold in the world[5]. Since CFLs have a service life approximately 10 times as long as incandescent lamps, 1 billion CFLs could replace all incandescent lamps. Assuming now that CFLs will replace another 30% incandescent lamps, then the total market potential of CFLs is 665 million per year. With the assumptions that this potential is essentially reached in 2010 and that the 1997 modular/integral share remains constant, future market growth is roughly estimated as shown Figure 6-1. As an alternative projection, Figure 6-2 disaggregates the total market assuming a continuation of the historical trends, i.e., describing a phase-out of modular CFLs.

Chinese and Far East CFL production is a key issue for projections of future global market growth because production there is growing rapidly. For example, the number of CFL producers in China grew from 500 to 1000 between 1995 and 1997, and Chinese production in 1997 was estimated at 100 million, about 20–25% of global production. Since global production capacity seems to be far greater than demand, it is likely that the price of CFLs will continue to decrease. However, quality remains a crucial issue. Downward price pressures may lead to less quality and consumers will find it increasingly difficult to distinguish between low-quality and high-quality lamps. Therefore, the role of independent testing, labeling, and standards will become increasingly important.

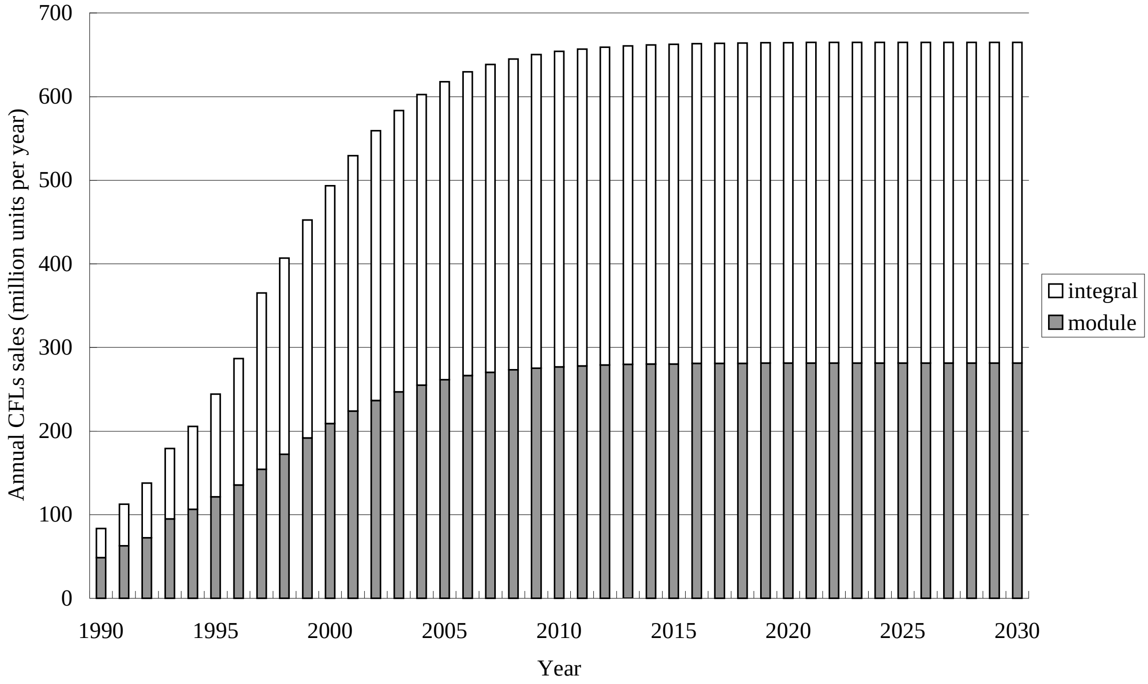


Figure 6-1: CFLs market prospect (retaining the 1997 modular/integral share).

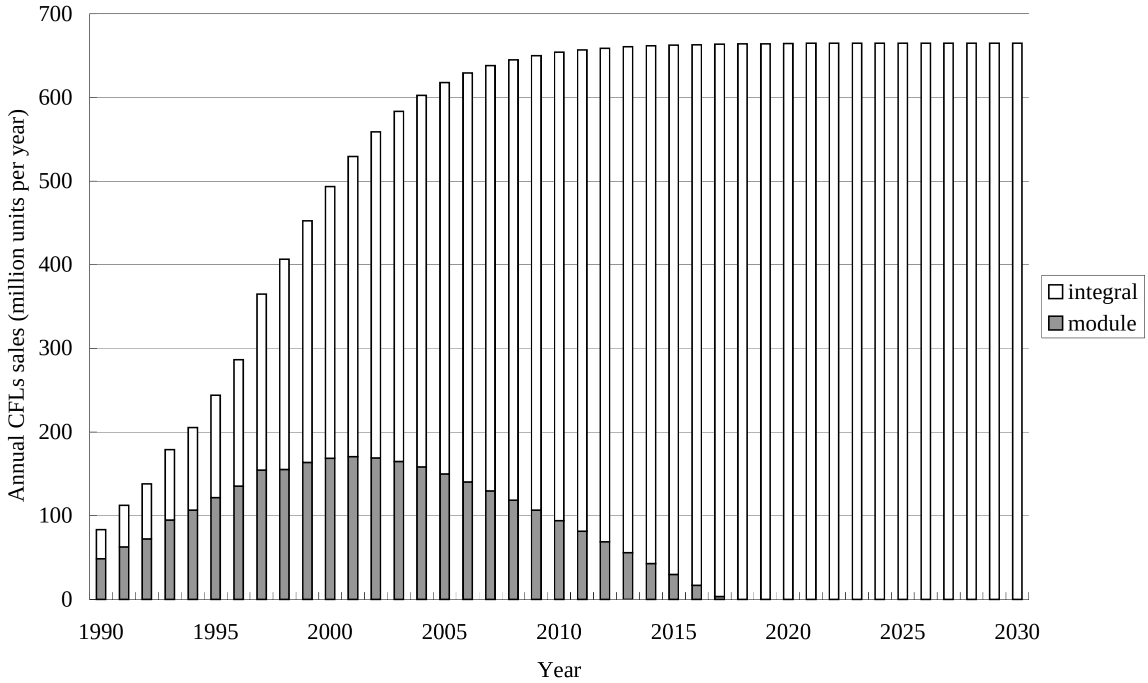


Figure 6-2: CFLs market prospect (modular/integral share according to historical trends)

Note: For the estimation of CFLs future market, a logistic (S-shaped) curve was used:

$$y = \frac{K}{1 + e^{-b(t-t_0)}}$$

K: upper asymptote

t_0: inflection point at K/2, where growth rates reach their maximum

b: diffusion rate (determining the steepness of the S-curve)

6.2 Technical Progress

As mentioned above, the technical potential of the CFL market is limited because of their size, color rendering, and limited dimming capabilities. Further, CFL service life is sensitive to factors such as operating position, operating temperature of the lamp within the fixture, frequency of switching, which all may limit the economic potential of CFLs.

The remainder of this subsection discusses some of these limiting factors in more detail.

6.2.1 Low-Temperature CFLs

Many fluorescent lamps are not suitable for outdoor applications. At low temperatures (below 4˚C), the ballast (in particular, magnetic ballasts) may not be able to start the lamp. Low-temperature CFLs with electronic ballast can operate properly down to -29˚C provided they are installed in an enclosed fixture. The light output is reduced at low temperatures, but if the lamp is in an enclosed fixture, the heat from the lamp will warm the fixture and the light output will rise gradually to its normal level. Such CFLs could be used for walkway or low-level security lighting, however they are not suitable for high outdoor lighting requirements such as parking lots. One type of security lighting combines CFL with a motion sensor. The price of a 26 W CFL for use in enclosed fixtures is 20 US$, offered for example, by GE and Osram.[11]

Figure 6-3: Low-temperature CFL.

6.2.2 Dimmable CFLs

Dimming is the reduction in the luminous flux of a lamp achieved by reducing electrical operating current. Dimming results in lower energy usage. It also increases occupant comfort because lighting levels can be adjusted to meet user requirements. However, producing CFLs that can operate safely in dimming sockets has proven difficult.[11]

Phillips developed a 23 W dimmable CFLs in 1997 that would dim to as little as 10% of its light output and would work with dimmers, photosensors, and timers, even with those marked ‘incandescent only’. At about $18 per bulb, the dimmable lamp’s price is comparable with that of non-dimmable CFLs.[4]

Figure 6-4: Philips dimmable CFL.

6.3 Price Reduction

Assuming the learning rates estimated in section 5-1, 5-2 and the market potential as shown Figures 6-1 and 6-2, price reductions of CFLs and ballast over time are estimated. Assuming further that the future share of integral CFLs remains the same as 1998, CFL prices per unit will decline to 7.7US$/1000lm (8.6US$/unit) in 2030. If the share of integral CFLs increases according to historical trends, specific CFL prices will decline even further, to 6.9US$/1000lm (7.9US$/unit) in 2030 (Figure 6-5). Ballast price will also decline as CFL’s trend (Figure 6-6). The values in parentheses are the price per unit, calculated by multiplying the price by an assumed CFL average output. In each case, CFLs market becomes big CFLs price declines between 1998 and 2030 by 45%, 50% respectively.

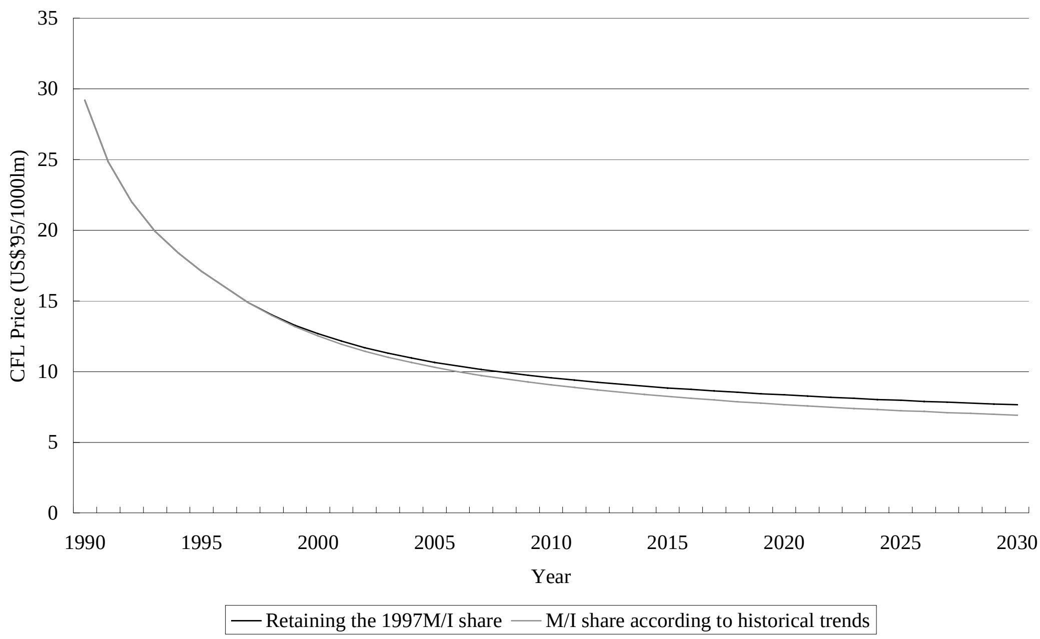


Figure 6-5: Projected whole CFLs price reduction.

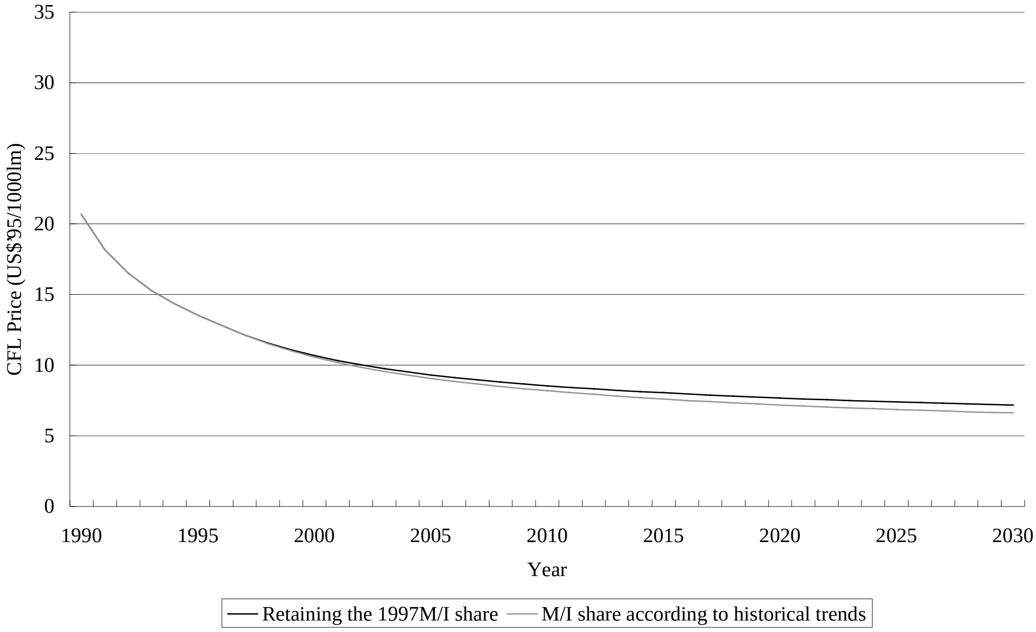
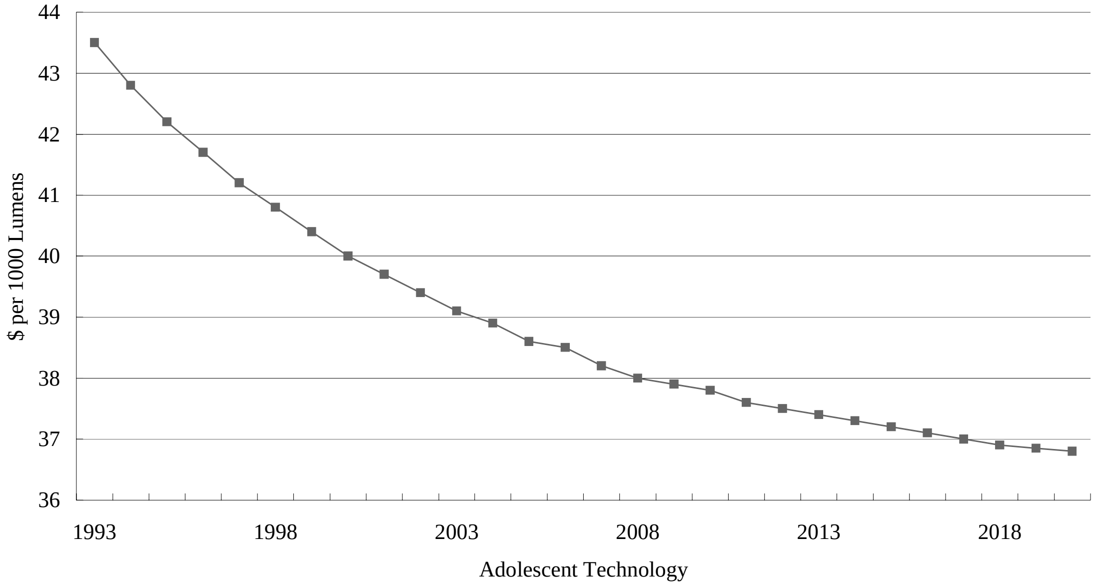


Figure 6-6: Projected ballast price reduction.

For reference, Figure 6-7 shows a forecast of future CFL costs by the U.S. Energy Information Administration (EIA)[12]. Not only are EIA's cost figures higher than those used in this report, the projected decreases are less steep. The difference of two estimations came from EIA's forecast includes CFL fixtures cost.



Source: U.S.Energyy Information Administration,Modeling Learning in National Energy Modeling System (MEMS).1999

Figure 6-7: CFL cost forecast by the US DOE-EIA.

7 Demand-Side Management

As briefly mentioned in Section 4, subsidy programs have stimulated CFLs markets and contributed to price declines in many countries. In this section, subsidy programs in selected countries are discussed in some detail. The purpose of this analysis is to do first steps in the analysis of the effects of subsidy programs and of the suitability of different programs depending on maturity level of the CFL market.

In recent years many programs that were designed to promote energy-efficient lighting have been conducted worldwide by government agencies and non-governmental organizations. Particularly, programs to promote CFLs for residential customers are popular. Several kinds of demand-side management (DSM) programs have contributed to maturing the CFLs market.

Three main strategies behind such programs have been identified.

(1) Raising consumer awareness and information

(2) Creating and strengthening effective distribution channels

(3) Improving product quality and building the necessary domestic and regional institutions for quality management, testing, and product standardization

In mature CFL markets, such as in the Scandinavian countries, direct-subsidy programs become less important in pursuing these strategies. Rather, quality is becoming a major issue. In less mature markets, such as in many non-OECD countries, properly designed subsidy programs can still be an important and cost-effective tool for expanding markets.

7.1 Western Europe and United States

7.1.1 UK

The Energy Saving Trust (EST), funded by government and utilities, conducted several lighting programs between 1994 and 1997, including subsidies through a manufacturer rebate mechanism and give-away programs. Rebate of about US$1.60 were offered by the EST to consumers in the form of a price reduction at the point of retail, matched by a similar amount subsidy by the lighting industries. The combined EST contribution and the manufacturer contribution translated into a significant reduction of US$8 from US$24 retail price in the earlier programs. Because of increased competition and lower prices, the retail price reduction in 1997 was about US$5 from a US$16 retail price and the 3 million CFLs were sold from 1994 to 1997. In the give-away program, 800,000 households received a 20W CFL to replace a 100W incandescent lamp and the program cost per lamp was an estimated US$11. The CFLs were part of a package of the Home Energy Efficiency Scheme (HEES) tailored to poor households. In UK, the rate of households that own at least one CFL increased from less than 10% to 23% during 1993-1997[13].

7.1.2 Denmark

Denmark has the second highest CFL ownership rate in the world (second only to the Netherlands) and the share of households with CFLs is 46% in 1997[6]. Between 1988 and 1994, Danish utility programs deployed about 1 million CFLs through a combination of give-aways, pay-on-the-bill sales, and sales through rebate coupons. In the later programs, subsidies were lower and finally phased out. Since 1994, Danish CFL programs have moved away from rebate programs towards an increasing focus on quality, testing and labeling. Danish utilities contracted with the Danish Illuminating Engineering Society to manage a test program by an independent accredited testing laboratory to test CFLs according to IEC standard testing protocol. Later, the so-called *ignition tests* also became part of tests are placed on a utility-supported quality CFL list, *the Sparepaere*[R] list and this list is been accepted as a quality standard outside Denmark as well European wide. An extensive but relatively low-cost CFL quality program has resulted in a very low market share of low-quality CFLs – only 5% compared to 30–40% in Germany. [13]

7.1.3 United States

In the United States, several suppliers began to offer new, energy-efficient sub-compact fluorescent lamps (sub-CFLs) that are significantly smaller than conventional CFLs. Several of these products have nearly the same length as incandescent light bulbs.

The lamps are available as a result of a new energy-efficiency technology procurement organized by the U.S. department of Energy's (DOE) Pacific Northwest National Laboratory (PNNL). PNNL has carried out this promotion program, which consists of two phases. Phase 1, which was awarded in early April 1998, required the furnishing of 5,000 to 15,000 small-dimensioned screw-base CFLs to test the commercial application of the existing small-dimensioned screw-base CFL technology in outdoor and common-area lighting applications in multifamily housing. Phase 1 involved three suppliers and the sales reached over 80,000 lamps. Phase 2 is an additional bigger purchase that will require furnishing and delivering more advanced small-dimensioned screw-base CFLs to a group of large-volume buyers. The goal for the Phase 2 purchase is at least 1 million individual CFLs. Phase 2 is planned to last through at least October 1999.

A unique feature of this program is that the qualified suppliers can propose new sub-CFL products for inclusion in the program. Sub-CFLs are offered at lower prices than conventional CFLs (Table 7-1).[14]

Table 7-1: SUB-CFL Products and Price Range from Suppliers.

Company, Model and Wattage	Lamp Life (hrs) and Power Factor	Length (in.)	Delivered Price Per Lamp			Range: 6 or 10 to >999	
			Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Duro-Test							
Durolite 15 15W	8000 Mid PF	5.00	$7.40-$8.65	$7.45-$8.75	$7.50-$8.80	$7.60-$8.95	$8.85-$10.95
Durolite 20 20W	8000 Mid PF	5.25	$7.95-$9.20	$8.00-$9.30	$8.05-$9.35	$8.15-$9.50	$9.40-$11.50
Lights of America							
2415C 15W	10000 Mid PF	4.6875	$8.36-$8.96	$8.36-$8.96	$8.36-$8.96	$8.36-$8.96	$8.36-$8.96
2420C 20W	10000 Mid PF	5.1875	$8.36-$8.96	$8.36-$8.96	$8.36-$8.96	$8.40-$8.96	$8.60-$9.61
Sunpark							
SP 15SL 15W	8000 Mid PF	5.20	$6.10-$7.74	$6.10-$7.66	$6.10-$7.64	$6.95-$7.79	$6.95-$7.79
SP 15S 15W	15-16 W High PF	5.20	$6.35-$7.99	$6.35-$7.91	$6.35-$7.89	$7.20-$8.04	$7.20-$8.04
SP 20SL 20W	8000 Mid PF	5.20	$6.31-$8.00	$6.31-$7.92	$6.31-$7.90	$7.16-$8.05	$7.16-$8.05
SP 20S 20W	8000 High PF	5.20	$6.56-$8.25	$6.56-$8.17	$6.56-$8.15	$7.41-$8.30	$7.41-$8.30
SP 23SL 23W	8000 Mid PF	5.60	$6.55-$8.28	$6.55-$8.20	$6.55-$8.18	$7.40-$8.33	$7.40-$8.33
SP 23 S 23W	8000 High PF	5.60	$6.80-$8.52	$6.80-$8.44	$6.80-$8.42	$7.65-$8.57	$7.65-$8.57

Source: http://www.pnl.gov/CFL/

7.2 Other Countries

7.2.1 Peru

Peru implemented a National Energy Saving Campaign with the aim to reduce electric demand by 100MW during peak hours from 1995 to 1996. Electricity consumption had grown quickly during the economic boom in 1993 and 1994 and been also affected by little rainfall in their hydropower plants in 1994. The campaign included only public information, education, demonstrations, and a CFL replacement program but no subsidies. The campaign was conducted for only four-month, and led to a high degree (75%) of consumer awareness about CFLs, and two-thirds of consumers surveyed after program intended to buy CFLs. 380,000 CFLs were sold in a short period of time and projected annual sales after the program increased to 250,000 from cumulative sales of 100,000 CFLs before the program. However, this campaign was quite expensive (several million dollars), and not as cost effective as other programs.

A small-scale pay-on-the-bill program was also conceived, in which consumers purchased CFLs through 24-month installment plans: consumers purchased lamps in shops with special coupons from their electricity suppliers, and the cost of the lamps was added to their electric bill in installments. The programs led to an additional 50,000 CFLs sold, but suffered from legal and institutional difficulties.[13]

7.2.2 Thailand

The national electric utility (EGAT) promotes the development and implementation of a number of different market intervention strategies for energy efficiency, including CFL and linear fluorescent lamps. EGAT was very keen in this project to avoid subsidy programs, instead has tried to rely on voluntary agreements, market mechanisms, and intensive publicity and public education campaigns since 1993. Voluntary agreements by manufacturers to produce more efficient lighting products were successful such that efficient ones could replace old linear fluorescent lamps. Under a CFL program, EGAT was purchasing in bulk a planned 1.5 million CFLs and selling them through a distribution network of '7-11' convenience stores and price reductions solely through bulk purchase appears to be working well. This approach has made CFLs more accessible to many more consumers, although this approach can also create market distortions at the distribution level by making one distributor more attractive to customers.

With bulk purchase, the retail prices of CFLs (estimated at US$9) are about 40% lower the normal retail price. In 1996-1997, the program sold 230,000 CFLs, but recent economic difficulties in Thailand are expected to increase the first-cost barrier.[13]

7.2.3 Brazil

A number of the large Brazilian utilities have conducted pilot CFL programs to research marketing approaches, consumer behavior, and T&D (transmission and distribution) system impact between 1993 and 1996.

In its first pilot program, an utility, CPFL (Sao Paolo Light and Energy Company), introduced three different rebate levels in three different cities, 30% (Americana), 60% (Marlia), and 70% (Franca). The programs were rather small: only 10,000 lamps in each city for each rebate level. A 30% rebate program generated sales of 5,700 lamps within the pilot period of a month, while 60% and 70% rebate levels sold the full quota of 10,000 lamps per city well before the pilot period had ended. And the most popular lamp was the cheapest lamp, a circular electromagnetic lamp, which sold for US$16 without rebates.

In a second program, another utility, CEMIG (Minas Gerais State Energy Company), tried a direct-install, give-away CFL program to improve regional frequent brownouts. Aiming at for low-income families, the utility gave away 89,000 9W-CFLs to 52,000 households that had energy consumption below 50kWh per month. CEMIG estimates a total cost per lamp, including installation, of US$8 in this program.[13] By these DSM programs, the CFLs sales increased to about 3 million in 1996, which is equal to 1% incandescent lamps sales.

New larger-scale programs are being planned by PROCEL (the National Electricity Conservation Program), and some utilities to promote the adoption of CFLs in particular regions. For example, one utility is planning to finance the installation of up to 180,000 CFLs, with consumers paying for the lamps through the monthly utility bill. Another utility is planning a bulk purchase of 135,000 CFLs and give-away program for low-income households. In both cases, the local distribution utility is interested in reducing peak demand in order to delay transmission and distribution system investment.[15]

7.2.4 Mexico

Since 1990, Mexico has promoted CFLs. Early programs were small-scale give-away programs with the purpose to establish CFL technology as an energy saving option and enhance customer acceptance.

From 1991, The National electric utility (CFE) started the rebate program, targeting 120,000 CFLs sales with the rebate of about US$3 per CFL (half the retail price of the least expensive 9W-CFL). Customer acceptance was examined in several programs, such as availability related to distribution channels, accessibility by using simple procedures that encourage participation and differentiated rebate levels. CFE succeeded to reach the target sales till 1995, and to collect much detailed information through computerized tracking of sales.

The Ilmex project during 1995-1998 followed these projects and it was the first large-scale residential project in a developing country. Its objective was to sell 1.7 million CFLs, primarily to small, highly subsidized (over 50% subsidy) residential customers. The utility purchased the CFLs in bulk under competitive procurement from manufacturers, receiving a significant discount over retail market prices. Purchased CFLs were sold directly to consumers through its offices or financed over 2 years together with bill payments. The Ilumex project was successful: sales reached 2.5 million units and the average participation rate was 16%. Consumers received very favorable retail prices of US$5–US$8 (compared with a market price of up to US$25 or more) due to a utility subsidy (estimated at about US$7-US$10 per lamp) and economies from bulk purchases by utility.

Currently, CFE is carrying out a nationwide residential CFL project, which will introduce 6 million CFLs by the year 2000.[16]

7.2.5 Jamaica

Since 1995, the Jamaica Public Service Co (JPSCo) utility conducted give-away programs for 100 homes (about 300 lamps) to test CFLs and to establish technical criteria regarding equipment performance, customer response, and installation problems. Subsequently, the utility has begun to sell a planned 100,000 CFLs to approximately 30,000 households at discounted prices. An estimated subsidy of US$6 per lamp, combined with bulk purchases by the utility led to an estimated retail price of about US$6 per lamp. The utility sold CFLs as a part of an overall energy savings package along with combinations of other equipment (low-flow showerheads, outdoor lighting controls). They also conducted a major public education and information campaign. [13]

7.2.6 Poland

Since 1995, the Polish efficient lighting project was designed to stimulate the national market for energy efficient lighting in Poland and accelerate the market by five years through four components:

(1) CFL subsidies were provided on a competitive and contractual basis through manufacturers to reduce whole sale prices to dealer and retail prices to consumers (also called "wholesale buy-down".)

(2) Municipal governments and local electric utilities conducted a pilot peak-load-shaving DSM program in three towns. Through special promotion program, discounted CFLs were sold to residents in specific districts where peak electric capacity was constrained.

(3) A wholesale buy-down was also conducted for CFL luminaires.

(4) A public education program with the participation of non-governmental organizations conducted.

This program was unique in the way subsidies were channeled through the private sector, and the intention was to use manufacturers' knowledge of marketplace to maximize CFLs sales per dollar of available subsidy. In this case, a large retail price reduction (about US$6) was possible with a smaller program subsidy (about US$2) because of manufacturer subsidy contributions and the multiplier effects of VAT tax and retail markups. During 1995-1997 in two separate promotions, consumers bought 1.2 million CFLs through the project in the half period within the first month of each promotion, with over 40 different models represented. After program retail prices of CFLs are lower by about 30%m and the number of households with CFLs increased from 11.5% to 19.6%. Five manufacturers participated in the subsidy programs including two dominant manufacturers, General Electric and Philips Lighting.[13]

7.3 Observations and Lesson Learned from Experiences

From the experiences in OECD and non-OECD countries including the countries described in section 8.2, knowledge about CFL promotion programs were gained as below:

(1) Where utilities provided subsidies, the retail price reduction has typically been 40-50%, although in the Mexico and Brazil cases there were reductions of up to 60% or 70%.

(2) In some cases the retail price reduction was partly attributed to large economies from bulk lamp purchases by a program, especially in very immature markets. For example, in Mexico, the retail price reduction of 17-20 was due to not only a subsidy of US$7–US$10 but also economies from bulk purchases of about US$10 per unit.

(3) The subsidy to manufacturers also yields economies from additional manufacturers' efforts shown in the Polish subsidy programs.

(4) Setting up the differentiated rebates is important because customers prefer to purchase cheaper CFLs that may be less efficient, for example circular CFLs in Mexico.

(5) Give-away programs are effective immediately where the utility is facing a shortage of electricity capacity.

(6) High initial costs in combination with uncertainty about CFL performance (mainly lifetime) reduce the confidence and willingness to invest in CFLs. Quality management programs such as in Denmark may help to overcome these.

(7) Daily operating hours per CFL tend to be fewer in households with high numbers of luminaires.

(8) Higher-wattage of CFLs is needed than suggested by nominal lumen specifications because lumen output is measured in perfect laboratory conditions. Due to high ambient temperatures, poor optical performance, unfavorable lamp orientation and other factors, a CFL will typically give less light than expected. Some European researchers have recommended that 13 W or 15 W CFLs be used instead of 11 W CFLs as a candidate for 60 W incandescent lamp's replacement. Higher-wattage CFLs might therefore be chosen worthy of subsidy increasing CFL reputation.

(9) European and US programs are increasingly supporting dedicated CFL luminaires to avoid 'snap-back' – the future replacement of program CFLs with incandescent lamps.

(10) The expansion and exploitation of distribution channels are important. It is sometimes said that CFLs are not preferable goods for retailers because CFLs long lifetime may cause the decrease in the opportunity of customers visiting the shop. IKEA, one of the world's largest furniture department store chains with outlets in 28 countries, has started to sell Chinese-made CFLs that meet Danish quality and performance standards for US$5 apiece. Other department stores are reportedly lowering their prices of quality CFLs to less than US$10 in response to IKEA's move.

Therefore conditions for promotion programs differ from country to country, so that the experience made in one country cannot be generalized readily. Mexico's successful residential CFL programs have progressed consistently from pilot-stage to large-scale, mature programs by the same implementing agencies, using previous experiences to refine the design of new projects. The evaluation has also progressed from only examining energy impacts to examining marketing accessibility and availability to ensure sales, and finally, examining the cost-effectiveness of the strategies, including environmental aspects. To increase the opportunity of promotion programs to learn-by-doing from each other, a common evaluation method must be established.

Table 7-2: CFL DSM program.

Country	Year	Type of Program	Type of implementing agency	Rebate (Lamp costs to customers) (US$)	Regular lamp price (US$)	Wattage (Ballast type)[*1]	Number of participants	program cost (thousand US$)	Total number of lamps sold in program	Comments
UK	1994-1997	Rebate to manufacturers	Utility/agency with government support (EST)	3.2	24	-	-	9,600[*2]	3 million	-Retail prices are reduced from 24$ to 11$(1994 to 1997) -Half subsidy by EST, the remain by the lighting industry)
		Give-away		-	-	20	800,000	-	-	-A part of a package of the Home Energy Efficiency Scheme tailors to poor households
Denmark	1988-94	-Rebate -Give-away -Pay on the bill sales	Utility	-	-	-	-	-	1 million	-Share of households with CFLs is 46% (1997) -Very low market share of low-quality CFLs 5% (1997)
	94-	Testing and labeling	Utility	-	-	-	-	-	-	
Peru	1995-1996	-Public information -Education -Demonstration -Pay-on-the-bill	The Ministry of Energy and Mines					Several thousands	430,000	-Cumulative sales of 100,000 CFLs before program increased to annual sales production of 250,000.
Thailand	1993-	Bulk procurement	Utility (EGAT)	(9)	12.6				230,000 (96-97)	-Sales through distribution networks of 7-11convenience store -About 40% lower than normal retail prices)
Brazil	1990	Give-away (Direct nstall)	Utility (CEMIG)	None	13	9 and 13 (M)	514	180	3,000	
	1995-96	Give-away	Utility (CEMIG)	None	-	9 (M)	52,000	1,100	89,000 (72,000)	
	1992	Give-away	Utility (CPFL)	None	16-22	22 and 32 (E)	369	22.2	380	
	1994	Rebate	Utility (CPFL)	4-24	13-34	15-32(E)	9,634	550	26,808	-Three different rebate levels in different cities (30%,60%,70%) -Mailing discounting coupons to the customer -CFL and circular
	1995	Monthly-payments	Utility (CPFL)	10-25	13-27	15-32(E)	-	-	-	CFL and circular
	1993	Manufacturers discount	CESP	11	-	9(M)	1,428	19.3	1,350	-CFL sales in Brazil 3 million -The Price without rebates is 16$ (1996)
Mexico	1990-91	Give-away	Utility (CFE)	-	-	9,18	336	-	1,722	-3 area -3-5 CFLs were installed per home
	1990-95	Rebate	Utility (CFE)	3	6	9	-	400	120,000	Circular type dominated
	1995-98	Rebate and bulk procurement	Utility (CFE)	7-10 (5-8)	25-	-	-	17,500-25,000[*2]	2.5 million	Participation rate 16%
	1998-2000	Rebate and bulk procurement	Utility (CFE)	-	-	-	-	-	2 million (by 98/12)	17 cities Target sales : 6.1 million
Jamaica	1995-	Give-away	Utility (JPSCo)	-	-	-	100	-	300	
		Rebate or Monthly-payments		6 (6)	-	-	30,000	600[*2]	100,000	Involving a substantial public education and information campaign
Poland	1995-97	Rebate to manufacturers	Internat'l consulting firm (utility affiliate)	2.14 (6$ decline)	12.14	-	-	2,600 (for subsidy program)	1.2 million	-Market size 0.6 million (1994) to 1.6 million (1996) -Households possessing CFLs increased from 11% ->19%

*1: M = Magnetic ballast, E = Electronic ballast

*2: Own estimation by multiplying "Rebate" by "Total number of lamps"

8 Conclusions

In this paper recent developments and medium-term future prospects of CFL technology were assessed using the learning-curve concept. In addition, to reflect the importance of CFL promotion, such programs were analyzed and presented here in an overview.

The following account results from this study:

(1) The situation of CFL technology was surveyed and the following observations were made.

- CFL technology has progressed rapidly and the application of electric ballasts has contributed to efficiency improvement, reducing size and weight.
- Manufacturers' efforts have been dedicated to increasing the acceptability of CFLs by increasing their similarity to incandescent lamps. They have stressed one-piece design, i.e., integral, further miniaturized, and CFLs enclosed in a glass envelope.

(2) To estimate CFL learning curves, the CFL market was examined. As a component of CFL, ballasts were examined separately.

- CFLs markets have grown year by year. Particularly, the growth of CFL sales in Non-OECD countries has been strong and total growth was over 30% in 1996–1997. As to OECD countries, the market growth in the US has become stagnant recently, whereas in Western Europe and Japan CFL sales are increasing steadily. As to CFL structure, the integral type has become more popular than the modular type after 1995.
- CFL prices came down with market growth. In the old type, modular CFLs with magnetic ballast, average prices declined by 75% between 1992 and 1998. In the most popular one, integral CFL with electric ballast, CFL price declined by 40% between 1992 and 1997. Prices have not visibly declined in modular CFLs with electronic ballast.
- The US ballast price of fluorescent lamps in general was analyzed to estimate CFL ballast prices. For magnetic ballasts, prices per unit a steady decline during the 1980s. 1989 to 1990, however, there is a jump in the price of both types of magnetic ballasts, costs resume their downward trend after 1990. This price change followed the introduction of a new federal standard. Electronic ballast prices declined, reflecting the rapid increase in shipments.

(3) From the sales and price data, CFL learning curves were derived. Summarizing past technological progress of CFL technology, a learning rate of 15.5% was found for the most popular type, i.e., integral electric ballasted CFLs. This estimate means that for each doubling of total production of this type of CFLs their price came down by more than 15%. In modular magnetic ballasted CFLs and modular electronic ballasted CFLs, the learning rates were estimated at 40.8% and 15.9% respectively. The learning curves of ballasts alone were also estimated. The resulting learning rates were 41.1% and 12.5% in magnetic and electronic ballast respectively.

(4) The prospects for further CFL price reductions were discussed under an assumed CFL market potential. This estimate is based on the assumption that 30–40% of all luminaires in a household are suitable for CFLs. Supposing CFL market potential is 30% of incandescent lamps sales, integral electronic ballasted CFLs price will decline between 1998 and 2030 by 45–50%.

It should be also noted that low-temperature dimmable CFLs could be expected to contribute to the further expansion of CFLs markets.

(5) Subsidy programs in selected countries were surveyed. In mature CFL markets, quality control has become a major issue, rather than rebate programs. In less mature CFL markets, such as in many non-OECD countries, properly designed subsidy programs can still be an important and cost-effective tool for market expansion. It is important for effective programs to learn-by-doing from each other and establish a common evaluation method.

The following issues of expanding CFL markets are important also in the future.

1) Establish the mechanism for CFL quality management, particularly in non-brand CFLs.

In the mature market, recent CFL price developments have shown two trends, one for big-name brand and non-brand CFLs. In this paper, brand CFLs are discussed mainly. Their market share is still larger than that of non-brand CFLs. However, non-brand CFLs are cheap (sold by less than 5$ per unit) and if their qualities are ensured, their market will be expanded more and more and the influence to the brand prices cannot to be ignored.

2) High subsidy level in immature markets.

What is significant to expand CFLs immature markets, the high rebate should be set up at the initial step in the subsidy program. It will promote customers' participation in the program and market expansion will contribute to reduce CFL price and subsidy will become needless finally. The bulk purchase or the subsidy to manufacturers was effective that yielded further retail price reduction, rather than direct subsidy program.

3) Diversification of dedicated CFL luminaires.

The diversification of dedicated CFL luminaires is very important not only to give a motivation to purchase CFLs but also to encourage their continuous use. The modular CFLs and longer-lasting ballast can be utilized for dedicated CFL luminaires and it will cause further price reduction and energy saving in CFL.

4) The expansion and exploitation of distribution channels;

The limitation of distribution channel makes CFLs more difficult to purchase than incandescent lamps. Such as a network in convenience stores should be utilize more and more.

To assess CFL technology, the following questions seem still open.

- Detailed examination in CFLs market potential

  Only rough estimation of CFL market potential was done in this paper, because of the limitation of available data. The sales and stock data of incandescent lamps or CFLs can lead to improved estimates.

- Surveys of the competition between CFLs and other lamps

  Besides incandescent lamps, CFL has many competitors, such as Tungsten-halogen lamps, electrode-less induction lamps, HID (High Intensity Discharge) lamps and so on. The competitors' technology progress may restrain CFLs diffusion.

- Estimation of CFL energy saving potential

The energy saving by replacing incandescent lamps is difficult to estimate. The usage time and frequency of lamps must differ depend on countries, areas, houses. In US and Western Europe, Several studies about residential lighting were done, and they will help to estimate the average CFLs energy saving potential.

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