Illumination and sustainable development
Part II: Implementing lighting efficiency programs

Gautam S. Dutt

Grupo Energía y Ambiente, Depto de Electrotecnia, Facultad de Ingeniería,
Universidad de Buenos Aires, Paseo Colón 850, (1063) Buenos Aires, Argentina

Evan Mills

Center for Building Science, Energy and Environment Division, Lawrence Berkeley Laboratory,
University of California, Berkeley, CA 94720, USA

In Part I of this article, we considered the technology and economics of alternative lighting systems, both electric and fuel based, demonstrating that there are ample and cost-effective opportunities for energy savings. In this second and final part, we consider some of the barriers that hinder the implementation of energy-efficient lighting. These barriers may be overcome by measures such as minimum efficiency standards, both voluntary and mandatory, assistance in building design, financial incentives, and subsidies. A number of programs in different countries have incorporated these measures successfully to promote energy-efficient lighting. We describe in some detail programs designed to promote the diffusion of compact fluorescent lamps.

Roughly a third of the world's population today does not have access to electric lighting. There are no practical alternatives among non-fuel lighting that are resource efficient and produce an adequate amount of light. We take a brief look at the options for making electricity available where it is currently not available for lighting: an alternative to extending the grid is decentralized generation, using diesel, producer gas, or biogas. Where biogas is being considered we show that it is far better to use it to generate electricity (for lighting) than to use it in gas mantle lamps. One electric lighting option is the use of rechargeable battery operated fluorescent lanterns that can be charged using a photovoltaic panel.

1. Introduction

In Part I of this article we showed that there are many technological alternatives for reducing the amount of energy required for lighting levels currently being provided by electric lighting systems. We also showed that very often energy efficient lighting options are less expensive overall than what is currently being used. This being the case, a question immediately arises: if they cost less, why are they not happening already? Various barriers hinder the diffusion of energy-efficient lighting. Many of these are common to energy-efficiency improvements in general, while some are specific to lighting. In Section 2, we discuss both types of barriers and how they may be overcome. In general, the presence of the barriers implies that specific programs must be implemented to promote the diffusion of energy-efficient lighting and in Section 3 we look at a few of these programs. In Section 4 we take a closer look at programs to disseminate compact fluorescent lamps.

Even today many people, especially in the rural areas of developing countries, do not have access to electric lighting, relying instead on kerosene and other lamps that produce little light for which users pay an inordinate amount since these lamps are inefficient. In Section 5 we consider the alternatives to make energy-efficient lighting, of adequate light output, available to the rural poor in developing countries.

2. Barriers to energy-efficient electric lighting

There are many barriers that impede energy efficiency improvements. Since these barriers, and how they may be overcome, have been extensively discussed (see, e.g., Reddy [1990a]) they will be described here only very briefly.

The major barriers can be grouped into five categories:

1. Lack of information

Users are often unaware of the existence of the cost-effective alternative.

2. Unavailability of the product

Some alternatives may not be available in a country or region.

3. Energy subsidies

Electricity is often subsidized (to some sectors) to levels below the average cost of supply, and virtually always below the long-run marginal cost [Kosmo, 1987]. While these are justified in terms of reducing the cost of electricity to, say, low-income users, the effect can be counterproductive. At low energy prices, combined with other barriers, the energy user invests little in energy efficiency and electric utilities have to invest far more, increasing society's overall costs for providing electricity.

4. Profit structure of energy suppliers

Electric company profits are often determined in terms of the amount of energy sold, so that it is in their interest to sell more rather than provide energy services at the least cost to society.

5. Split incentives

In some cases, the one who would have to invest in energy efficiency is not the one who would see the benefits in terms of reduced energy bills.

We will briefly describe what can be done about the barriers.

1. Potential users may be informed of the benefits of appropriate lighting alternatives through product labels, brochures, documentary TV programs, and other means. Lamps are generally labeled with the rated light output and power input. Energy consumption information could be included in the labels of other items such as ballasts and luminaires as well. A related barrier is the absence of (enough) trained persons to help users optimize their lighting systems. Such training can be provided through the professional engineering societies, trade organizations, and universities. The importance of energy-efficient lighting and efficient electricity use in general is such that much of the material should be included in undergraduate level electrical engineering curricula. Similarly, the implications of building design on daylight availability and its impact on the requirements for artificial lighting and energy use should be included in university architecture curricula.
2. Product unavailability is harder to solve, since there is a chicken-and-egg problem. Manufacturers are unlikely to introduce or promote an alternative product if a demand is not perceived to exist. Conversely, no demand can exist if a product is not available. However, many industrialized country manufacturers are interested in exploring licensing arrangements for their products in developing countries, sometimes with a commitment to purchase some of the production for sale in other countries. This makes a product locally available even though no demand for it existed previously. The manufacture of compact fluorescent lamps in Mexico is a case in point. Philips set up a plant there around 1989 with no local demand: indeed, at the prevailing electric tariffs, they were rarely cost effective to the consumer. Yet their availability prompted the electric utility to conduct technical and market studies, and by 1993 a significant project (ILUMEX) had been launched to promote them. More on this project later.
3. Energy subsidies produce the wrong economic signals, one of whose consequences is that many energy efficiency measures are not cost-effective from the energy user's perspective, though much less expensive and environmentally benign compared to supply expansion. In view of this, many countries have reduced or eliminated electricity subsidies. Where subsidies exist, and especially for low-income households, one possibility is to shift the subsidy towards the purchase of energy-efficient products, thus reducing electricity demand growth and overall costs to society.
   Many users do not pay for electricity. Individual users of commercial and public buildings do not pay for electricity that is consumed in their premises. This leads to wasteful practices and one way of dealing with it is through improved controls (occupancy and light level sensors to operate lamps). We have described these options in Part I. In some cases, especially for government buildings, even the institution(s) occupying the building may not be directly responsible for the energy bill. Thus, there is no incentive to invest in energy efficiency, since any savings do not benefit the institution. Indeed, even when energy costs are a large part of operating expenses, it may be a disincentive. Some agencies operating government-subsidized (''public'') housing in the US are reluctant to reduce their energy bills, since their ''prestige'' is measured by how much they spend. In these situations it is important to create a significant financial or prestige incentive, e.g., the institution can use a part of the savings for other expenses, instead of seeing it reflected as a reduced budget.
   Even when the price signals are right, i.e., there are no subsidies, many users are unwilling to pay the higher first cost of an energy-efficient alternative. As one of the most extreme examples, a compact fluorescent lamp (CFL) costs many times more than an incandescent one (INC), placing a psychological as well as a capital-cost barrier to its purchase. Many programs have been developed to promote the use of CFLs, and are discussed in Section 4.
4. Electric companies are often best informed on the energy demand of their customers and are in the best position to help them use energy more efficiently. Yet, if their profits depend on increasing sales, they stand to lose if their customers conserve energy, even though overall costs to society are reduced. In the USA, electric utilities are increasingly provided economic incentives that favor conservation so that their profits increase if their clients use energy more efficiently. Specifically, these incentives permit utilities to invest in energy efficiency on the customer's side of the electric meter, an activity known as demand side management (DSM).
5. Split incentives. Architects, designers, and builders of commercial and public buildings are not responsible for their clients' electric bills. Thus, they have no economic incentives to incorporate design features that would improve the availability of daylight, or install lighting fixtures, control systems, etc. that would increase the efficiency of electric lighting. An analogous case exists for rented buildings: tenants who generally pay for electricity may be unwilling to make capital improvements in a building they do not own. Energy-efficient building design and construction may be promoted through design incentives and building energy consumption standards, discussed in the following section.

3. Programs to promote energy-efficient electric lighting

The barriers to improved energy efficiency are often overcome in the form of a program. The purpose of the program is to increase the level of adoption of energy-efficient lighting. While the ultimate goal is to reach the full cost-effective energy savings potential, programs differ in their costs and in their effectiveness in terms of energy savings achieved. Experience in various countries suggests certain programs to be particularly suitable to promote energy-efficient lighting: *voluntary standards (norms or agreements), mandatory standards, design assistance, financing, and subsidies.* We will discuss these in some detail.

3.1. Standards and voluntary agreements

Establishing minimum efficiency standards is a way of promoting significant energy savings at relatively low program cost. They have been successfully implemented in many countries to drastically reduce the energy consumption of household electrical appliances. An alternative to mandatory standards, and less confrontational between manufacturer and standard-setter, are voluntary standards. These might be in the form of norms, e.g., a manufacturer would be able to label its equipment as energy-efficient, according to some national or regional standard. A difficulty is that, if consumers are unwilling to pay more for an energy-efficient alternative, the efforts of an isolated manufacturer to promote an improved product may not be successful. Philips of Brazil promoted energy-saving incandescent lamps (that consume about 10% less while maintaining light output), only to find that they were losing market share of all lamps sold [Geller, 1991]. They were forced to withdraw their campaign to promote the energy-saving lamps. Thus, at a minimum, the standard should be a *voluntary agreement* to which *all* manufacturers agree to adhere. A higher level of energy efficiency should be in the interest of manufacturers, because it increases the value of their market, provided (a) they have the resources and time to switch over their production facilities, and (b) all manufacturers are subject to the same standards. Larger energy savings are possible through mandatory standards. A recent Lawrence Berkeley Laboratory study found that lighting standards in US commercial buildings could reduce power demand by as much as 60 GW (just below the total installed capacity of India).

Before describing lighting technologies where standards (voluntary or otherwise) are likely to be most effective, let us consider where they are inappropriate. The cost-effectiveness of lighting efficiency improvement depends on the hours of use, which varies greatly. Many incandescent lamps are used only a few minutes a day (e.g., in a bathroom), while elsewhere (e.g., interior hallways and lobbies) they may be on 24 hours a day. Clearly it makes no economic sense to set standards to oblige people to install compact fluorescent lamps in their broom closets. Standards are most suited to high-use lighting systems. Practically by definition, these include fluorescent and HID lamps and associated equipment. The typical fluorescent tube lamp in an office building or store is likely to be operating long hours. Similarly, street lamps are on many hours, and indeed there is little variation in the hours of use.

Brazilian accords (agreements) for energy-efficient lighting. Brazil illustrates the type of accords that can be used to promote energy-efficient lighting. In 1990, the Brazilian Lighting Industry Association (ABILUX), the principal Brazilian national electric company (ELETROBRAS) and the National Program on Electricity Conservation (PROCEL) reached the following agreement [Eletrobras, 1990a]:

> From 1991, manufacturers agree to produce and commercialize at least 50% of the total production of incandescent lamps as energy-saving models. By 1992, this fraction shall increase to 100%.
>
> This goal will not be applicable to special types of incandescent lamps with low sales volume.
>
> Manufacturers commit themselves to increase the production and sales of compact fluorescent lamps at the rate of 25% per year over a five-year period (1991-95).
>
> Manufacturers commit themselves to increase the production and sales of efficient fluorescent tube lamps (T8, 25-mm tube diameter), reaching a market penetration of at least 5% for the most popular models (20 and 40 W). This percentage should increase to 10% in 1993, and 20% or more from 1995 on.

The Brazilian agreement also includes an increase in the use of high pressure sodium lamps for street lighting. As of 1988, only 1% of street lamps in the service area of the Sao Paulo Electric Company were of this type, the remaining 99% being mercury vapor lamps, with efficacies typically half as much.

Fluorescent lamp ballast standards in the USA. The USA has implemented national energy efficiency standards (mandatory) for ballasts for fluorescent lamps. This is another good example of the use of standards to promote energy-efficient lighting. Since the ballast affects lamp energy input and light output, the standards are expressed in terms of a minimum ‘‘ballast efficacy factor’’ which we will not describe here. Recall that the power input to a typical two-lamp fixture with 40 W lamps and a common (US) electromagnetic ballast is 96 W, while the same with an energy-efficient one is 85 W, dropping to 78 W with an electronic ballast (see Table 3 of Part I). The standards prohibit the sale of the first type of ballast. By the year 2010, cumulative electricity savings from the standards were expected to reach 36.6 TWh, with avoided investment in new power plant construction of $9.7 billion [Geller and Miller, 1988, pp.7-8].

Proposed lamp efficiency standards, Massachusetts. Individual states in the US have proposed efficiency standards for fluorescent and incandescent lamps, according to lumens/W, with specialty lamps excluded. For instance, the Massachusetts standards specify a minimum efficacy of 83 lum/W for a standard 40 W (power 35 W) fluorescent tube lamp. The standards are somewhat lower for reduced-wattage lamps since their use already reduces energy input. Thus a fluorescent lamp in a 40 W size that consumes less than 35 W need have an efficacy of only 80 lum/W.

Performance standards. Besides equipment standards, another type of standard is based on performance. Performance standards set upper limits on lighting energy consumption, expressed, say, as kWh per m^2 per year, and are best suited to overcome the split incentives barrier: builder/owner or landlord/tenant. In the US, performance standards have been set up in the state of California and elsewhere. Since lighting requirements vary according to use, standards are best specified according to building categories, e.g., multistory office buildings, hotels, etc.

Green Lights program. This is a voluntary program, sponsored by the US Environmental Protection Agency (EPA) ‘‘to encourage major US corporations to install energy-efficient lighting designs and technologies wherever they are profitable, and maintain or improve lighting quality’’ [Lawson and Kwartin, 1991]. Since lighting energy savings reduce electricity demand and associated air pollution emissions, the underlying principle of the Green Lights program is that environmental protection is profitable. When joining the program, the company signs a memorandum of understanding with EPA to perform an energy audit of its lighting systems, install all cost-effective, energy-efficiency measures within a five-year period, and document the results. EPA, in turn, publicly recognizes successful Green Lights companies, and ensures that the resulting achievements in environmental protection are widely disseminated. It is the first time that an agency such as EPA has acted to reduce pollution at the source, instead of as a clean-up measure after the fact.

A Green Lights program has recently been initiated in Brazil, and similar programs could be developed elsewhere.

Considerations for setting standards in developing countries. In developing countries, existing lamps and ballasts are often less efficient so that savings potentials are higher, in principle. Nevertheless, operating conditions (e.g., temperature, voltage fluctuations) and other factors may be affecting performance, and need to be taken into account. Lamp life is an important consideration, since it is apparently much less, and since it affects cost effectiveness. Energy-efficient lamps should not be shorter lived than conventional lamps. Indeed, life prolongation could be incorporated into any standards to improve efficacy. Another problem is technological infrastructure. In India, for instance, ballasts and lamp components are often made by small industries. Setting forth standards that require high technology would discriminate against these manufacturers. Since smaller industries tend to generate more employment than larger ones, a standards program could be counterproductive in terms of meeting developmental objectives. Thus, any such standards need to be accompanied by training so that manufacturers can upgrade their processes *and* by ensuring that capital is available for the necessary investments. In India, financing could be similar to what is provided by the Indian Renewable Energy Development Agency (IREDA) to promote infrastructure development in the manufacture of renewable energy equipment.

3.2. Design assistance

This is one way to promote energy-efficiency considerations at the time of building construction. Design assistance is given by some US electric utilities to promote energy-efficient lighting and other measures to help reduce customers’ electricity demand and the utility’s need to invest in power plants in the future [NEES, 1991]. This is a kind of subsidy to promote energy efficiency. There are many others, as discussed below.

3.3. Financing and subsidies

Financing is a key to overcoming barriers to energy efficiency improvement. One specific case we mentioned above is for equipment manufacturers to produce energy-efficient equipment. More often, energy efficiency improvements can be financed at the end-user level. For commercial and industrial buildings, lighting energy efficiency measures are varied, and financing can be made available according to energy audit specifications, through energy conservation loan funds, which may be part of national or regional development banks, or private banks. The World Bank and other multilateral development banks have authorized loans for energy conservation investments in various countries. Some of these loans could be used for lighting efficiency improvement.

As we have mentioned earlier, given appropriate incentives, electric utilities could finance lighting energy conservation through demand side management programs. There are several advantages: since the utilities have billing and other information on their customers, they can target energy conservation campaigns to specific groups of customers, e.g., promote energy-efficient fluorescent lighting systems for commercial buildings, compact fluorescent lamps for residential and small businesses, etc. They may also target clients with higher than average bills, unusually low power factor, or demand coincident with utility peaks, etc. to reduce program costs and increase effectiveness.

Since successful conservation reduces the utility’s cash flow, it is imperative that incentive structures are first implemented that make it profitable for utilities to implement effective DSM programs. For an excellent introduction, see Kahn [1988]. In the USA, appropriate incentives have been developed and modified over the 15-year history of DSM programs there [Nadel et al., Eds., 1992]. Much of this experience can be transferred to developing countries. One important element in any DSM program is careful monitoring so that electricity saved is measured with as much precision as electricity generated [Dutt and Fels, 1989].

Subsidies are sometimes included in programs to increase the implementation of energy efficiency measures and energy savings. Experience in subsidies (through tax rebates) to promote energy conservation and solar energy in the US suggests that these may be more expensive per unit of (non-renewable) energy saved. One way to determine whether a subsidy is useful, and at what level, is to consider the cost-effectiveness from the societal perspective. The subsidy is an internal transfer of resources, from a utility or other source to the energy end-user. As a result, more conservation measures are implemented, energy savings are increased, and electricity supply expansion decreased. The energy analyst developing a least-cost energy strategy needs to see if the net effect of all these changes is beneficial to society.

4. Programs to disseminate compact fluorescent lamps

In many cases, where an incandescent lamp (INC) is used several hours a day, a replacement compact fluorescent lamp (CFL) would have a lower annualized life-cycle cost, i.e., the annual cost of owning and operating a CFL is less than that of an INC. (See Figure 1.) Yet many people are deterred from purchasing CFLs by their higher first cost. Thus, considerable savings are forgone. Moreover, in many developing countries the electric power peak occurs in the early evening hours, coincident with residential and some commercial use of incandescent lamps. Many programs have been developed to promote the diffusion of compact fluorescent lamps. An energy conservation company may finance the purchase of the lamp, to be repaid in monthly installments over a year or two. The repayment may be through the user's electric bill, which may be convenient when the energy conservation company is also the electric utility. Alternatively, the utility makes a bulk purchase of the CFL and offers it to its users at a lower cost than normal retail prices. It may be administratively simpler to offer rebates for customers to purchase the lamp at a reduced price from conventional retail outlets. A more contemporary strategy is to give lump-sum rebates to manufacturers. This has the magical effect of creating very low retail prices, since the mark-ups in the manufacturer-distributor-wholesaler-retailer chain are reduced. A $5 rebate to the manufacturer can yield a retail CFL price of $5 to $10, whereas a $5 rebate at the point of retail may yield a price of $15 to $20. Based on the success at Southern California Edison (an electric utility), this method is about to be incorporated into the first national CFL program in the USA.

Below we review programs to disseminate CFLs in Europe, two proposals to promote CFLs in India, Mexico's Ilumex project, and successful CFL diffusion in the French Caribbean.

4.1. CFLs in Europe

Between 1987 and 1991, over 50 programs to promote CFLs in the residential sector were offered by utilities in 11 European countries: Austria, Denmark, Finland, Germany, Ireland, the Netherlands, Sweden, Switzerland, and the UK [Mills, 1993; most of the data in this section is taken from this source]. An evaluation of 40 of these programs (available to 5.9 million households in seven countries) included data on program characteristics, penetration rates, total program costs, and cost-effectiveness. Because of utility subsidies, lamp cost to consumers varied from zero to 20 dollars, with an average of $11. A successful program would increase energy savings at least cost, including costs borne by both users and the electric company. For the 30 programs where data were available, the cost of conserved energy (CCE) from a societal perspective varied from 0.9 to 4.6 cents/kWh, all lower than electricity prices paid by residential customers, and lower than the cost of generating electricity from new power plants. The average CCE was 2.1 US cents/kWh. In programs where lamps were given away free to participants, not only were penetration rates high, as might be expected, but CCE (societal perspective) was lowest as well, making these the most cost-effective programs. Despite utilities' program administration costs, the societal cost of saved energy turned out to be less than if consumers had bought the lamps individually. This is because high-volume purchases reduced lamp costs. Indeed, as a result of the programs, non-participants benefited as well, as retail prices fell overall. The programs also significantly induced non-participant purchase of CFLs: in four cases where estimates are available, non-participant sales ranged from 40,000 to 70,000 lamps, where the program sales varied from 7,000 to 70,000.

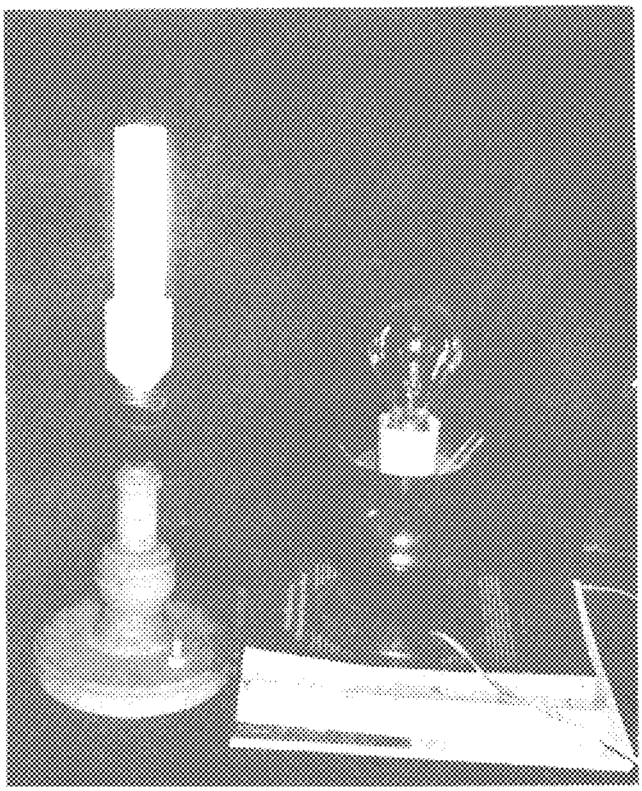

Fig 1. A 20-watt compact fluorescent lamp (CFL) with integral electronic ballast (left) produces the same amount of light as a 100-watt incandescent lamp whose size is shown at the right. The price and size of CFLs have shrunk in recent years.

More than lamp penetration, program effectiveness depends on energy savings realized. What are the hours of use, and how does this affect utility peak demand? Are the lamps being used where they are most cost-effective, i.e. in sockets where an incandescent was used many hours a day? Are CFLs accompanied by increase in light output and/or hours of use? What happens when the CFLs burn out? Will they be replaced by ordinary incandescent lamps? Some of these questions can be answered from data collected during and after program implementation. In four programs with data available as many as 34% of the participants reported using their CFLs more hours than the incandescents they replace. Only for Finland did the survey attempt to quantify the increase, and the effect is a reduction in savings of 4% compared to the normal assumption that use of the replacement lamp is the same. In Sweden and Denmark, average lamp use varied from 7 hours/day in the winter to 3 h/day in the summer. (Clearly, in tropical countries there will be little seasonal variation in lamp use.) One detailed survey of 1,200 Danish households found that 80% of CFLs were in use during utility peak load [Nielsen, 1993]. Strong peak coincidence would also be expected in developing countries, where utility peak demand occurs in the early evening hours.

It is clear that lamp give-aways, however attractive, cannot be extended indefinitely. One question asked of program participants in Denmark, the Netherlands, and Sweden was the price they were willing to pay for a CFL. Surprisingly, the results (compiled as the % of consumers who were willing to purchase a lamp at a given price) were identical for the three cases [Mills, 1993, Fig. 6]. Non-participants in the Swedish program were much less willing to purchase CFLs.

Many factors affected program participation. Most significantly, there is little correlation between penetration rate and cost of lamp to household. The importance of effective marketing strategies is borne out by another observation: in programs in Denmark and the Netherlands, where consumers were given the option to pay cash for the lamps or to pay gradually via their electric bills, about 75% preferred the latter method.

As CFL sales and production volumes increase, the price reduction appears to be spreading even to countries with no programs to promote them. In Argentina, where Dutch and German CFLs retailed for $40 in professional lighting stores in mid-1993, the prices have now fallen to around $25, with the lamps becoming available in larger supermarkets. (These prices include a 32% import duty and an 18% value added tax.)

4.2. Bombay Efficient Lighting Large-Scale Experiment (BELLE)[1]

The BELLE experiment was designed in 1990 to demonstrate the technical and economic feasibility of compact fluorescent lamps (CFLs) in India and to develop and demonstrate institutional partnerships and financial arrangements to create a market for CFLs in Indian households. BELLE was to be a partnership of several groups – Philips India (Peico Electronics and Electricals Ltd.), Bombay Electric Supply and Transport (BEST), Indira Gandhi Institute of Development Research (IGIDR), and the Programme for Acceleration of Commercial Energy Research (PACER). Philips is one of the manufacturers of CFLs and has other lamp manufacturing plants in India. BEST is a utility that purchases power generated by Tata Electric Company and distributes it to 700,000 Bombay homes. IGIDR is an institute dedicated to investigating the economic and social aspects of development issues, with experts in power systems, consumer surveys, and policy analysis. PACER is a US government-supported program for financing innovative energy technologies in India.

Beyond an initial planning phase, BELLE may be divided into two stages – a pilot experiment and a full-scale experiment. In the first stage, 1,000 CFLs were to be installed and tested over six months. In the full-scale experiment, 35,000 CFLs would be installed (in about 25,000 households) and monitored over four years. The second stage would also test a utility leasing program. Lamps would be purchased abroad with a hard currency grant or loan from PACER or another agency. The wholesale price of each CFL can be as high as $11 (including freight, insurance, warehousing, and handling charges, but excluding customs duty). A request would be made to the government that the import duty be the same as for imported components of large power projects (about 30%). This would permit a fair economic comparison with energy supply options, an important element of least-cost planning. The lamps would be installed in households in good financial standing with BEST, who would bill its customers about $0.25 per month per CFL. These lease payments, spread over four years, would repay the interest-free first cost of the CFLs. The customer would realize savings of $0.33 to $0.39 per month from reduced electricity bills and another $0.05 per month in avoided incandescent light bulb purchases. BEST, Philips and PACER would share the overhead costs for planning, administering and monitoring the project, estimated to be about $0.11 per CFL per month, including multiple market surveys and technical research that would not be needed beyond the experiment. Monthly revenue for BEST of $0.03 to $0.11 per CFL would result from avoided subsidies to the residential sector. This revenue would help offset overhead costs. Insofar as the CFLs reduce the rate of growth of electric demand, each CFL saves India more than $55.6 over its lifetime in avoided investments in peak generating capacity. This represents societal savings from avoided investments in power plants of $0.89 per month per CFL, in addition to avoided impacts on the environment.

Since BELLE was to be the first utility-sponsored demand management program in India, its financial, technical, and managerial structure would be carefully documented. If successful, BELLE would demonstrate that innovative institutional partnerships could overcome the ‘‘real-world’’ constraints that presently limit the attractiveness of CFLs to those participating in the project. The experiment would lead to the indigenous manufacture of CFLs in India, and the process could be replicated as a full-fledged program in Bombay and elsewhere.

Despite its attractiveness, BELLE was eventually not initiated due to a number of institutional problems [Gadgil and Sastry, 1992]. Nevertheless, the design is worth emulating, and a larger-scale version is being implemented in Mexico, as discussed below.

4.3. CFLs in Karnataka

Another proposal to introduce CFLs in India on a large scale, developed by Reddy et al. [1990] was based on the following argument.

A plant to manufacture 1.8 million CFLs a year cost around $7.5 million in 1991 [Gadgil et al., 1991]. The production from such a power plant would lead to enough electricity savings to offset 3,715 MW in power plant installed capacity, under typical Indian conditions, representing an investment savings of \$2.8 billion (gas turbine peaking plant) to \$5.6 billion (coal-fired plant). Thus, investment in a CFL plant is more than 350 times cheaper. (Operating costs are significant, however, and a proper economic comparison clearly includes all costs.)

There are few CFL plants in developing countries, which increases lamp cost, and reduces the opportunity of capital savings and environmental benefits by offseting power plant construction. One way of increasing the availability of CFLs in developing countries, and to reduce their cost to the public on a long-term basis, would be for electric utilities to invest in these plants. By subsidizing the construction of the plant, they can reduce lamp costs indefinitely. (Compare this with the recent strategy in the US of giving rebates to manufacturers, another way of greatly reducing costs.)

The proposal of Reddy et al. [1990] involves *utility financing of a CFL plant,* for the state of Karnataka, India. Electricity is generated in Karnataka by the Karnataka Power Corporation (KPC) and distributed by the Karnataka Electricity Board (KEB). The purpose of the program is to ensure that KPC, KEB, and the consumers benefit financially through the introduction of CFLs. Besides the utilities, the program also includes the participation of a financial institution, a potential CFL manufacturer, and an independent technical organization (for program monitoring and evaluation).

In essence, KPC would invest in two CFL plants, one initially and another during the fourth year. KEB would purchase thc CFL at a special wholesale price (around \$11), and install 2 to 4 lamps per household, free of charge. Households pay for a part of the cost of the lamp, by monthly payments through the electric bill. The remainder of the costs is shared between KPC and KEB. The technical institution monitors and evaluates the program for effectiveness, provides feedback, and suggests mid-course corrections, if needed. Benefits are shared by KPC, KEB, and residential customers. If conservation helps delay or reduce power plant construction, KPC benefits in these avoided costs. On the other hand, if supply is unable to meet demand, residential savings through CFLs are available to commercial and industrial customers who were having their demand curtailed because of shortages (common in India). Since the latter consumers pay significantly more (per kWh) for electricity than households, KEB benefits by being able to resell the savings at a higher tariff. Societal benefits from two CFL plants, each producing 1.8 million CFLs per year, and costing \$15 million overall initially, turn out to be several hundreds of millions of dollars. Program costs must be divided among KPC, KEB, and residential consumers in such a way that overall program benefits (i.e. societal benefits) are shared equally among the three groups.

Reddy et al. [1991] do not quantify economic benefits to commercial and industrial customers, whose availability of electricity is increased, nor the benefits of reduced environmental impact from reduced power plant construction in the future. Both of these additional benefits are substantial. As far as we know the Karnataka proposal has not been implemented yet.

4.4. ILUMEX project (Mexico)

The project furthest along on the road towards the dissemination of compact fluorescent lamps on a large scale in a developing country is the Project for the Rational Use of Illumination in Mexico (ILUMEX)^2. As we have mentioned before, Mexico was one of the first developing countries to have a CFL plant. Electricity tariffs to the residential sector were heavily subsidized so that these lamps were generally not cost-effective even from the rational and informed user's perspective. Nevertheless, the Federal Electricity Commission (CFE), the national utility that generates electricity and distributes it over most of the country, conducted a number of small-scale projects to evaluate these lamps in residential and other sectors [Blanc and de Buen; 1992]. Almost three quarters of Mexico's electricity is generated using fossil fuels, most of the remainder being hydroelectric. Residential lighting is a strong contributor to peak demand for electricity which occurs during the early evening hours, and peaking power plants are virtually all fossil-fuel fired. Thus reduction in lighting energy demand would lead to considerable reductions in carbon dioxide emissions, which would contribute to ameliorating global warming. A fund designed to help developing countries invest in projects that benefit the global environment was established a few years earlier. This so-called Global Environment Facility (GEF) is administered jointly by the World Bank and the United Nations.

In 1991, the Mexican utility CFE approached the World Bank for GEF funding for a \$20 million project to disseminate 1.5 to 2 million CFLs. Since this was the first such GEF project, a careful feasibility study was conducted, where CFE's own efforts were complemented by the International Institute for Energy Conservation (Washington, DC) and Lawrence Berkeley Laboratory, with additional funding from the Government of Norway and the US Agency for International Development (USAID). A survey of 500 households in the targeted cities of Monterrey and Guadalajara was conducted to ''determine household lighting characteristics, market saturation/acceptance potential of CFLs, energy conservation potential, and purchasing preferences of consumers'' [CEE, 1992].

Not surprisingly, the survey found very little saturation of CFLs, but ''a strong consumer desire to purchase CFLs if they were more affordable, and *if better information were available about their performance and capability".* We add the emphasis here to show that, economic factors aside, lack of information is an important barrier: if the consumer is unsure of say the durability or light quality of the hitherto unknown product she/he will be reluctant to invest a sum considerably more than the cost of a common lamp. The survey identified a potential to replace 1.7 million lamps with CFLs in the two cities assuming the existing lamp was 40 W or more, and used at least four hours a day; if all lamps that are used at least two hours a day are considered the potential doubles to 3.5 million CFLs.

In earlier pilot studies, CFE tested a variety of marketing techniques to promote CFLs. Based on this experience, the initial effort will focus on direct sales at CFE offices. However, the project design allows for adjustments to improve penetration if necessary. Modifications include changes in lease terms, lamp price, use of mobile sales units, or even door-to-door sales to promote the lamps.

For bulk purchase, CFE expected to pay about US$10 per lamp, and would offer it at $6 each to residential customers who would be eligible to purchase up to six CFLs, either outright or to pay US$1.65 initially with the remainder added to the normal, bi-monthly electric bill. The economic analysis considered costs and benefits from individual, CFE, and societal perspectives.

In Mexico, residential electricity tariffs are higher per kWh for those who consume more. This tariff structure is intended to favor those who consume less, presumably lower income households. On the other hand, it provides a disincentive to investing in energy efficiency. In Mexico, the lowest residential tariff is heavily subsidized: 1.8 cents/kWh, several times below the marginal cost of electricity to CFE. Consumers in this category gain little or nothing if they have to pay full cost for a typical CFL used four hours a day. The net present value (NPV) is around $6.7 per CFL for the average consumer. The subsidized price was set by CFE to ensure that even low energy users (who pay a low electricity tariff) who finance their CFL over a two-year period, will see their bills reduced by an amount equal to the CFL repayment. The average customer will have a payback period of 1.5 years.

The utility gains through the installation of CFLs to the extent that this reduces its losses through subsidies. Since the subsidies are highest for the low tariff categories, the program targets CFLs especially to low-income households where it stands to gain the most[3]. For the highest tariff categories, CFE suffers a net loss from CFL purchases. The net benefits to CFE depends on the extent to which CFE can compensate for lost revenues from reduced higher-tariff sales. The NPV for the utility from ILUMEX is about $41 million if it fully recovers all costs (including lost revenue) in the price charged to customers. The NPV falls to about $33 million if it can recover only half of these costs. A potentially important non-economic benefit will be to the public image of CFE, tarnished in recent years, in part because of strong public opposition to its nuclear power program.

The societal benefits are considerable, since a CFL in all tariff categories helps offset power plant construction. If 1.5 million CFLs are installed and are used four hours a day, the expected NPV for society was estimated to be about $57.5 million. A sensitivity analysis, varying the key assumptions, shows that NPV increases further or falls slightly for the alternative scenarios.

From a global environmental perspective, the program reduces carbon emissions (as CO_2) by 150,000 tonnes over the life of the CFLs, at a *negative* cost of $0.28 per kg of carbon, since the investment is profitable in terms of energy savings alone. Cost-effective electricity efficiency measures always make environmental protection profitable.

As of now (early 1994), final GEF clearance for the implementation of ILUMEX is imminent. The GEF loan will be added to a $500 million World Bank loan to CFE to reduce electricity transmission and distribution losses in Mexico. Since individual projects on efficiency improvement such as ILUMEX are small compared to typical magnitudes for World Bank and other loans, combining them with another loan is a practical mechanism for reducing bank overheads. In the future, when investments in energy efficiency are taken more seriously by borrowers and lenders, several conservation projects may be combined in a single loan of appropriate magnitude.

4.5. Programs in the French Caribbean

The world's most successful dissemination of CFLs occurred in 1992 in the French Caribbean island of Guadeloupe [Mills, 1992b]. Electricity is sold on the island at around 11 US cents/kWh, which is less than half the cost of supply. To reduce utility losses, the French Agency for Environmental Protection and Energy Management (Ademe) decided to promote CFLs by placing 100,000 lamps at retail outlets, offering rebate coupons to customers at a special price of around $16.5 per lamp (a third of the prevailing retail price). The rebate permitted customers to acquire as many as 10 CFLs, and to pay for them over six electric bills (18 months). During May 1992, about 12,000 households redeemed their coupons, buying 8 CFLs per household, so that the original stock of 100,000 lamps was sold out *in one and a half days.* After additional lamps were imported, the program had a participation rate of 358,000 lamps among 44,000 households, representing 37% of the eligible total. Encouraged by this success, Ademe offered a similar program in the neighboring island of Martinique. This time the offer was limited to two, four, or six lamps per household. Half of the 110,000 households responded to the offer, in virtually each case purchasing the maximum number of lamps (six). A total of 350,000 lamps were disseminated, including non-program sales. An evening peak load reduction of 7 MW was reported by the utility [Borg, 1992].

5. What to do when electric lighting is not available

Improving lighting levels and energy efficiency in areas where electricity is not available requires electrification, or the availability of improved fuel-based lighting systems. The benefits of rural electrification have been recognized for many years, and even the now industrialized countries promoted rural electrification through government-supported programs, recognizing that conventional market forces were unlikely to foster it. India and many developing countries have followed suit, and rural electrification has greatly advanced in the last decades. However, while many villages are now electrified, many households within electrified villages do not have electricity connections. Even many urban households do not have electric connections. Thus, according to a 1979 survey, though 70% of Indian rural households lived in electrified villages, 95% of all rural households relied on kerosene for lighting [NCAER, 1985, reported in Sinha and Kandpal, 1991]. According to the same report, 87% of *all* Indian households used kerosene for lighting. Although reliable figures are not available, one source places the number of people worldwide who depend on kerosene for lighting at 2.13 billion (about 35% of the total) [Efforsat and Farcot, 1994].

Surprisingly, given the number of people who still depend on kerosene and other fuels for lighting, very little is known about these devices. In Part I (Tables 1 and 2), we showed how two studies differed in their estimates of even the most basic parameters: light output and power input. Both agree, however, that among the common kerosene lamp types, more efficient lamp types increase both light output *and* fuel consumption. There are no compelling reasons for promoting the more efficient lamps. We need better information on these common lamp types, e.g., to what extent can light output and power input be varied, etc. Some effort has been made to develop improved lamps that reduce fuel consumption while increasing efficacy. One lamp developed in India is the Noorie, ‘‘a non-pressurized mantle lamp producing light through the heating of a non-burning glass cloth thermoluminescent mantle to temperatures exceeding 1000ºC’’ [Rajvanshi, 1987 quoted in Sinha and Kandpal, 1991]. Its characteristics place it between wick lamps and mantle lamps in terms of fuel consumption, light output, efficacy, and cost. It does not provide fuel savings with increased efficacy, and again there is no obvious reason to promote it.

Besides low light levels, kerosene used for lighting in India represents about a third of the total consumption of the fuel, which makes up a significant contribution to India’s petroleum imports [Reddy, 1981, and 1990b]. (Much of the remaining two-thirds is used for cooking, where it turns out to be an excellent choice [Dutt and Ravindranath, 1993].) Extrapolating India’s kerosene usage for lighting leads to a worldwide demand of 7.2 million tonnes of oil equivalent (MTOE) per year.

All known fuel-based lighting systems suffer from low light levels and low efficiency, and there do not seem to be any reasonable alternatives to electricity for lighting. If 16 W compact fluorescent lamps were used instead of kerosene wick lamps, there would be a 20-fold improvement in light level *and* an eight-fold reduction in petroleum consumption, if the electricity were generated using diesel generators.

Much greater petroleum savings would accrue if the electricity were generated using biogas or producer gas to substantially replace diesel in dual-fuel engine generators [Rajabapaiah et al., 1993, Mukunda, et al., 1993]. It should be pointed out that biogas can be used in mantle lamps similar to those used with kerosene, and indeed these lamps are promoted in India. A cubic meter of biogas produces 6,500 lumen-hours in such a lamp compared to 120,000 lumen-hours in a fluorescent lamp – an 18-fold improvement (taking into account energy losses in electricity generation). At present electricity can be generated with biogas at small scale using internal combustion (IC) engines, which are commercially available for the purpose. Using these devices, a minimum practical level of electricity generation might be, say, 5 kW for four hours a day. This ‘‘minimum’’ requires about 10 m^3/day of biogas, equivalent to the dung production of 25 cattle, 40 pigs, or the sewage of 300 people [Dutt, 1992]; this scale would be out of reach to the rural poor, except possibly in community-scale biogas plants. Though much smaller IC engines exist, e.g., for use in model airplanes, corresponding generators at power levels below 1kW appear not to be commercially available. Some external combustion engines (e.g., the Stirling engine) and fuel cells are practical at smaller scales, but are more expensive per kW than IC engines.

The anaerobic digestion of sewage from a six-person household (without any domestic animals) produces around 0.2 m^3 of biogas a day. Converted to electricity at an efficiency of only 20%, it would produce about 250 Wh per day, enough for almost *five* 13-watt (compact) fluorescent lamps *each* operated four hours a day. The biogas needs for cooking for the same household would require the sewage of perhaps 30 persons, or four pigs, or two to three cattle. Thus, if electricity generation from biogas can be made practical and economic at low power levels, biogas can be more extensively used to provide electric lighting, even when biomass resources are small. Higher capital costs for the digester and engine can be justified than when biogas is used for a fuel end-use, since the output is electric lighting, which will greatly reduce kerosene used for lighting while providing much higher levels of illumination.

Even in the absence of any form of rural electrification, electric lighting is still possible using photovoltaic solar cells. In recent years, the cost of electricity generated using solar cells has decreased substantially and further decreases are expected, as demand and production volumes continue to increase. If we combine this development with that in energy-efficient lighting, a new type of artefact emerges that could one day replace the kerosene lamp. Indeed, in recent years, light sources of this type are being mass produced. The basic device includes a small fluorescent tube (typically 23 cm long) operated by rechargeable batteries (nickel-cadmium or lead-acid), that can be recharged using a solar cell. Many of these devices are marketed to replace common flashlights, and especially for use in cars (where they can be recharged from the car battery) or as an emergency light source during power outages, to be recharged from a wall socket. (See Figure 2.)

Many of these rechargeable fluorescent lamps are made in China, and considering a retail price in Argentina varying from $30 to $100, suggests a production price of $10 to $35. Adding the photovoltaic panel would add significantly to the cost, though some models have a solar panel built into the side of the lamp, and retail for around $100. While these prices are out of the range of poor rural households, they are likely to become more affordable in the near future. Meanwhile, they may be practical where electric lighting is of high value, e.g., in rural clinics.

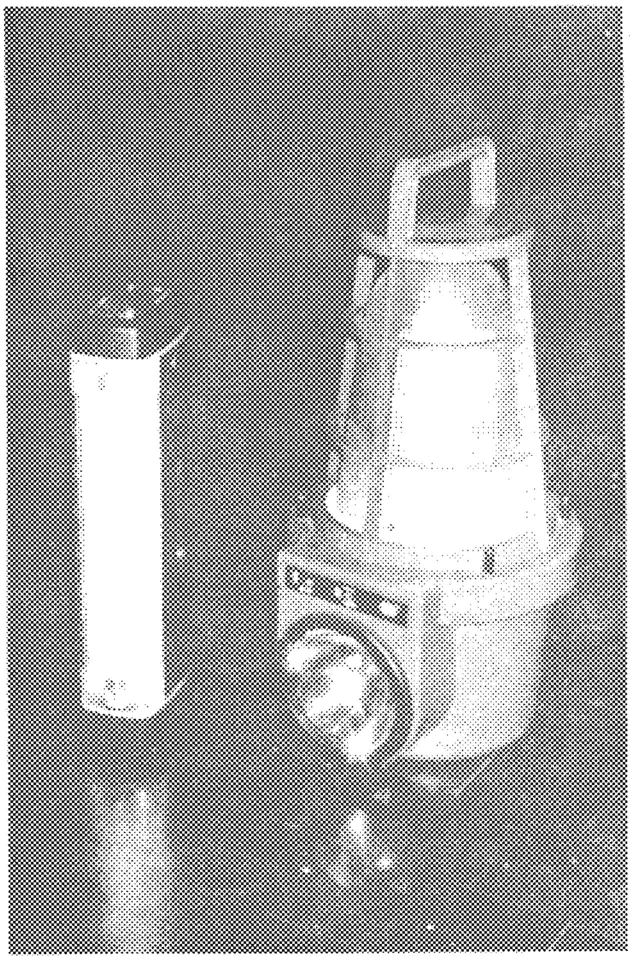

Fig 2. Rechargeable battery-powered fluorescent lamps. The unit at left uses nickel-cadmium batteries while the other uses lead-acid batteries. DC-powered lamps such as these recharged by solar photovoltaic panels could replace kerosene wick lamps. Both lamps shown are of Chinese manufacture. Interestingly, the traditional kerosene wick lamp was once invented in China, and is known everywhere today.

There also exist innovative ways of using them. In one French foreign assistance program (Lampes Francophonie), lamps are recharged at a central village photovoltaic recharging station, and hired out for the duration of the charge [Efforsat and Farcot, 1994]. Users bring the lamp back to exchange for a charged lamp, as if they were taking their kerosene lamp to be refilled. Regular users (upper income people) tend to own their lamps, while other villagers tend to hire the lamp for religious festivals and other special occasions when higher lighting levels are needed. In Senegal, one of the countries where this program is in place, solar lamps are more expensive to operate per day than kerosene, and comparable in expense to a gas mantle lamp. On a cost-of-light basis, however, the solar lamp is 4.5 times less expensive, since its light output is much higher.

6. Conclusions

In this review we have attempted to demonstrate that energy-efficient lighting can be a powerful instrument of development. For those without electricity, providing electric lighting with energy-efficient systems reduces costs, fossil fuel use, and associated emissions of greenhouse gases, while considerably increasing the light available. Where electricity is already used for lighting, a number of technological alternatives can significantly reduce electricity requirements to provide necessary levels of illumination. By reducing the future demand for electric power, considerable savings in the capital cost for power plant construction are possible, again accompanied by fossil fuel savings and corresponding reduction in local and global pollution emissions. Although lighting is generally a relatively small part of total electricity use, the potential for energy and peak power savings is a large part of present consumption, and the savings can be obtained much faster than most other measures to improve electricity end-use efficiency. Lighting efficiency improvement thus can be an important part of programs to provide electricity services at least cost, in developing and industrialized countries alike. ■

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Notes

1. The description of BELLE is taken largely from Gadgil [1990]. In some cases it is verbatim, but quotes have largely been avoided to reduce interruptions in reading.
2. The information in this section is obtained from Sathaye et al. [1993], de Buen and Masera [1993], and Mills [1992a]. Where they derived their information from other primary sources, these references are given in parentheses. All cost figures are in US dollars, and not Mexican pesos, which are represented by the same symbol ($).
3. There is an additional benefit to the utility for the customers. Smaller consumers are likely to have fewer lamps, which are more likely to be on at the same time as the utility's peak demand (the early evening). An average CFL in such a household would reduce peak demand more than one in a household with higher consumption and more lamps.

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