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ADVANCED LIGHTING AND WINDOW TECHNOLOGIES FOR REDUCING ELECTRICITY CONSUMPTION AND PEAK DEMAND: OVERSEAS MANUFACTURING AND MARKETING OPPORTUNITIES

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ABSTRACT

In the face of sharply escalating electric demands, developing countries face severe shortages of capital to invest in the necessary increases in generating capacity. Meanwhile, a substantial and cheaper untapped resource to meet the increasing demand already exists in terms of the large improvements possible in efficiencies of existing and future end uses of electricity in these countries. This paper illustrates with analyses two of the promising efficient end use technologies for developing countries: compact fluorescent lamps (CFLs) to replace incandescent lamps, and advanced windows for air conditioned buildings. The cost of conserving a kWh of electricity with a CFL is shown to be about US$ 0.02, 5 to 6 times less than the typical marginal cost of generating new electricity. For evening-peaking utilities, the use of CFLs to reduce peak demand is shown to avoid increases in installed peaking capacity at a cost of US$ 140/kW, about six times less than the cost of new peaking capacity. A CFL factory is shown to save as much electricity as the output of a power plant with 3,700 MW of installed capacity. Advanced windows for air conditioned commercial buildings (in Bangkok, for example), have an even more attractive economics. The cost savings from reductions in the air conditioning equipment capacity, as a result of advanced window installation, exceed the incremental cost of the advanced windows. This leads to a negative cost of conserved electricity of about US$ -0.001/kWh, and a negative cost for conserving peak demand for an afternoon-peaking urban utility. An advanced windows factory saves electricity equal to the output of power plant with 1000 MW of installed capacity. The analyses are followed with description of a strategy, being planned for implementation in Bombay, to overcome the consumer resistance to high first-cost efficient appliances, by guaranteeing their performance and leasing them to the consumers through the utility.

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1. INTRODUCTION

Many developing nations face widening gaps between electric supply and demand even though, as in India, significant fractions of their populations have yet to receive basic electric services. In India, demand for power already outstrips available supply despite the fact that 70% of residences remain unelectrified. Meeting projected increases in demand with new (often coal-fired) generating capacity would involve untenable capital drains, foreign exchange demands, and environmental degradation in these countries.

In contrast, low-cost energy-efficient end uses are particularly attractive options that can reduce demand, while maintaining and even increasing energy services in developing nations where living standards are already low. Cumulative inefficiencies in the current stock of single-glazed windows and incandescent light bulbs in the developing countries constitute significant electric resources (we emphasize the impact of windows on air-conditioning demand), that can be "tapped" inexpensively and used to augment electric supply. As long as a utility's cost to conserve a kWh during the time of power shortages is less than the cost of generating a kWh, the utility system should consider investing to conserve rather than generate electricity for meeting the demand.*

Tapping "efficiency resources" is inhibited by several market barriers including the ubiquitous practice throughout the developing world of subsidizing electricity. Analysis shows that transferring subsidies from electricity to compact fluorescent lamps (CFLs) is a remunerative proposition for the utility and its customers in almost every case [Gadgil and Jannuzzi, 1990]. We compare the economics of producing electricity and conserving electricity through cost/benefit analyses of power plants and manufacturing plants for energy-efficient CFLs and windows.

We are aware that this is not an option for some utilities, and would be possible only with a change in the utility regulatory mechanisms. But considering the societal good that this option offers, it is a sorely needed change.

As we show, constructing manufacturing plants for CFLs and advanced windows is more than a hundred times cheaper than building power plants per unit of electricity produced or conserved. Freeing capital from the power sector for use elsewhere in developing economies can help stimulate economic growth, increase the delivery of energy services, improve national security, and reduce the atmospheric pollution associated with energy production.

Today, India's utilities (almost all of which have evening peak demand) subsidize residential electricity (for lighting and other services) while many industries are unable to obtain enough power to meet their needs. Electricity for lighting now represents approximately 34% of Indian peak power and roughly 17% of the electrical energy consumed in the country. Incandescent lighting is estimated to constitute at least 17% of the peak demand, and roughly 10% of the national electricity consumption (135 TWh in 1984-85). Incandescent lighting consumption and its contribution to peak electric demand can be expected to grow rapidly because only about 30% of India's 130 million households are currently electrified. In addition, the average electrified household now consumes only 500 kWh annually. As more homes become electrified the negative impact of incandescent lighting will increase, aggravating already serious shortages in peak power.

The newly industrializing (and rapidly urbanizing) countries have experienced rapidly increasing electricity consumption in buildings. For example, commercial buildings in the ASEAN (comprising Indonesia, Malaysia, Philippines, Singapore, and Thailand), already consume more than 30% of the total electricity generated in that region; the electricity costs of operating these buildings was more than US $ 2 billion annually in 1988 [Levine, 1988]. In Thailand, 27% of the electrical energy is used in commercial buildings, and another 7% is estimated to be used for building services in industrial buildings, making a total of 34% [Levine, op. cit]. The electricity consumption in the commercial buildings in the region is growing so rapidly that it is estimated to account for 40% of new electricity demand in the near future [Levine and Deringer, 1987]. A large fraction of this use is for air conditioning (e.g. for prototypical hospital and office buildings in Bangkok, air conditioning accounts for about 50% of the electricity use [Chitrarattananon et al, 1989]). Already, utilities in large hot-climate cities such as New Delhi have begun to experience summer peak demands on hot afternoons that correlate well with outside air temperature [Ramesh et al, 1988].

Because Indian power system is already unable to meet peak demand, Indian utilities now resort to power cuts, brown-outs, frequency drops, forced shutdowns of industrial units during peak load periods, and rotational schedules for industrial downtime. Industry often chooses to invest in its own generation stations as insurance against the unreliability of the Indian power system despite the fact that power from back-up generators costs Rs. 3.50 or $ 0.20 per kWh, more than twice the market rate. These stations remain idle most of the time, representing a highly unproductive use of capital. When they do operate, industrial generators run on state-subsidized diesel and achieve low conversion efficiencies.

This paper discusses the economics of manufacturing and using CFLs in India, and manufacturing and using low-E, argon filled, spectrally selective windows in hot tropical climates. Conserving electricity with these two technologies is shown to be so much cheaper than new generation, that the addition of administrative and programmatic costs (not estimated here) for their market promotion would make negligible difference in their economic attractiveness. The description of the Bombay Efficient-Lighting Large-Scale Experiment (BELLE) highlights an innovative financing scheme for strengthening the market for CFLs within a dispersed, low-income, risk-averse population. Its success may promote the indigenous production of CFLs in India. BELLE is a prototypical demand-management program suited for replication in other developing countries and Eastern Europe.

2. COMPACT FLUORESCENT LAMPS

The first two sections below present a brief summary of analysis of savings in electrical energy and peak demand in India resulting from the installation of compact fluorescent lamps. The detailed analysis appears in [Gadgil and Jannuzzi, op. cit.] The third section presents analysis of CFL production plants compared to electricity production plants.

2.1. Technology Characteristics

All fluorescent lamps operate by discharging an electric arc through a mercury plasma enclosed in a glass tube. The ultraviolet (UV) photons emitted by the de-excitation of mercury atoms are converted to visible light by a phosphor coating on the inside of the glass tube.

In the last decade, new rare-earth phosphors have been developed to provide a warm light that is close in quality to the light of an incandescent. The new phosphors improve the color-rendering ability of fluorescents with no decrease in efficiency. They also allow the diameter of the glass tube to be reduced to approximately one centimeter, with little lumen depreciation (the decreasing ability of the phosphor to convert UV to visible light at high intensities). The result is compact fluorescent lamps (CFLs) that are nearly the same size as standard incandescents and fit into the same sockets.

CFLs utilize either standard core-coil ballasts or advanced electronic ballasts. In some models the ballasts are detachable from the glass tubes. Electronic ballasts are somewhat more expensive but less bulky than core-coil ballasts, and enable the CFL to start-up instantly, producing light with no flicker.

CFLs last 10 to 20 times longer than incandescent light bulbs and provide the same high- quality light with less than one-quarter the electricity. Currently, the retail prices for these lamps range from $ 10.00 - $ 14.00 in the U.S. Approximately 10 million units were sold in the U.S. in 1988, and sales of CFLs have doubled annually in recent years.

A modern 16 watt, 900 lumen CFL consumes 13 W in the glass tube and 3 W in the ballast. One 16 watt CFL replaces a 60 watt incandescent bulb, and conserves 44 watts at the meter. When transmission and distribution (T&D) losses (8% in the US) are factored in, the replacement achieves a savings of 47.8 watts at the busbar of a U.S. power plant. Incandescents designed for the vagaries of developing countries' power systems are more robust, and have lower luminous efficacy. Thus in India a 16 watt CFL replaces a 75 watt incandescent. In their analysis, Gadgil and Jannuzzi [1990, op. cit.] assume that the 16 watt CFL will replace an average Indian incandescent (weighted average wattage 65.5 watts), and the consumers will obtain a little more light with the CFLs than they did with the incandescents. Ignoring the value of the additional lighting, the savings at the meter from this replacement are 49.5 watts. When India's high T&D losses of 20% are taken into consideration, busbar savings increase to 62 watts. Since CFLs replace only the most heavily- used incandescent bulbs, they have a peak period coincidence rate that is significantly higher than the average incandescent. Consequently, replacing a heavily-used incandescent in India with a CFL conserves 42 peak-coincident watts at the power station.

In summary, assuming conservatively that a 16 W CFL always has a lifetime of 10,000 hours,* over its lifetime it will save 478 kWh and 440 kWh respectively at a U.S. busbar and meter, and 619 kWh and 495 kWh at an Indian busbar and meter.

2.2. Energy Economics of a Single CFL

We deal with this in two parts, treating separately the cost of conserved electricity (CCE), and the cost of avoided peak installed capacity (CAPIC).

Cost of Conserved Electricity

The cost of conserving a kWh by replacing a series of incandescents with a long-lasting CFLs can be compared to the cost of energy. Calculating an energy-efficient technology's "cost of conserved energy" (CCE) is straightforward. The CCE is the annualized net cost of investing in the technology divided by the annual energy savings it achieves:

CCE = ((investment) (capital recovery rate) + (net annual increase in operation and maintenance costs minus avoided annual cost of incandescents)) / (annual energy saved in kWh).

From the consumer's perspective the annual benefit derived from a CFL is the difference between the annual savings from avoided energy consumption (and avoided purchases of incandescent light bulbs) and the annualized cost of the CFL. From the utility's perspective the net benefits of energy-efficient technologies are calculated by comparing avoided generation expenditures and avoided electricity subsidies with lost revenues from reduced electricity sales and subsidies (if any) of the energy-efficient technologies. Using conservative assumptions, calculations show that the CCE of a 16 W CFL (US$ 0.02/kWh) is one-sixth the long range marginal cost (LRMC) of electricity (approximately US$ 0.12/kWh).

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* A CFL operated on a standard test cycle (3 hours on, 1/2 hour off) lasts for 10,000 hours (up to 24,000 hours, if left "on" continuously).

In most developing countries the benefits to utilities of installing CFLs are large enough that subsidizing the technology heavily is a remunerative proposition in almost every case. For most Indian utilities a 50% subsidy of CFLs (to ensure their market success) would yield returns of approximately 250% (on an annualized basis). A scenario for the introduction of CFLs by a small transfer of subsidy from residential electricity to residential CFLs has been illustrated in [Gadgil and Jannuzzi, op. cit.]. They show that in 10 years, at 20% saturation, CFLs would save the Indian utilities rupees equivalent to U.S. $ 1 million per day.

Savings in Power System Expansion: Cost of Avoided Peak Installed Capacity

Major policy decisions related to power system expansion in the developing countries are often based on the availability of capital resources for initial investments. The cost of avoided peak installed capacity (CAPIC) can be used to inform such decisions. CAPIC refers to the net present value of an energy-efficient technology (to be operated for the duration of the life of a power plant) that renders the installation a kW of generating capacity unnecessary.

In India, the avoided peak demand at the busbar (42.38 watts) divided by power plant availability at peak hours (0.573) equals avoided installed capacity.* The investment cost of new installed capacity (that lasts 30 years for a typical Indian utility) is about US$ 867/kW. In comparison, from a societal perspective, one CFL operated for that period in India costs (in net present value) US$ 10.13 and avoids 74 watts of installed capacity. Hence the CAPIC, the ratio of the two, is US$ 137/kW, six times less than the cost of new installed capacity.

2.3. Energy Economics of a CFL Manufacturing Plant

In this section, we deal with comparing a CFL production plant with electricity generation plant. In this comparison, we do not ignore the "free" additional light that the consumers may obtain with the CFLs; instead, we assume that the 16 watt CFL will replace a 75 watt incandescent lamp in India, and provide the same amount of illumination (900 lumens).

A modern automated CFL plant costs about $ 7.5 million: $ 5 million for the machinery and $ 2.5 million for the buildings and land. It produces 3 to 7 million CFLs annually, depending on the number of shifts it operates. Since power plants operate 4 shifts, we assume that the CFL plant does also. We assume, conservatively, that the CFL plant can produces 6 million lamps annually. In the calculations below, we credit the production year with all the energy saved by these lamps over their lifetime. Socket life (as opposed to burning life) of the CFL may vary from 1.1 years to 10 years depending on duty cycle of use.

First we compare the CFL plant to a power plant in the US. The savings in electricity sales in the US, contributed by the annual output of a CFL plant, is 2.67 TWh/year**, equivalent to the sales of a 693 MW intermediate or baseload

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* 0.573 is the estimate of plant availability factor used in the long term forecasts by Central Electricity Authority of the Government of India.

power plant in the US.[+] A power plant of that size costs \$ 1 billion (\$ 1500 /kW) or 139 times more than the \$ 7.5 million CFL plant.

Now we undertake a comparison of investments in CFL plants to that in peaking capacity in India. As mentioned earlier, due to the poor quality of power, the incandescents used in the developing countries are more robust in design, and give less light: 12 lumens/watt compared to 15 or 17 lumens/watt in the U.S. So, a 16 watt CFL producing 900 lumens, replaces a 75 watt incandescent: 900/12 = 75 watts. This saves 75 - 16 = 59 watts at the meter, or 59/ (1 - 0.2) = 74 watts at the busbar. Assuming lamp use of 4 hours/day (i.e. 1460 hours annually) in a residential setting and a guaranteed burning life of 10,000 hours, the socket life of the CFL is 6.85 years.

If a factory produces CFLs only for residences, production for the first 6.85 years goes to increase the number of lamps in the sockets. Afterwards, each year's production just replaces the lamps that have burned out after 10,000 hours of use. So, in the steady state there are:

(6 million CFLs/year) (6.85 years) = 41.1 million lamps in use.

Assuming conservatively only 70% peak-coincidence, these will save a peak demand of:

(41.1 million CFLs) (74 W/CFL) (0.7) = 2,129 MW at the busbar.

To produce this amount of peak power, the installed capacity needed in India is (2129/ 0.573 =) 3,715 MW.

If the capacity were to consist of coal-fired thermal power stations (common to India), an investment of \$ 5.6 billion would be required (\$ 1500/kW) of which 40% (or \$ 2.2 billion) would be in foreign exchange. If the peaking capacity is obtained from cheaper (but more expensive to operate) gas turbines, the total investment would still be \$ 2.8 billion, with at least \$ 1.1 billion in foreign exchange. In comparison, investment in a CFL plant is more than 350 times cheaper. One CFL plant requires an investment of \$ 5 million in foreign exchange and a total investment of \$ 7.5 million.

3. ADVANCED WINDOWS

In the three sections that follow, we illustrate by an analysis similar to the above, that the new technology of spectrally selective, low-emissivity, argon gas filled, sealed, double glazed window units can make a substantial contribution towards conserving electrical energy in the developing countries, and also reducing peak

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[**] (6 million CFL/yr) X (440 kWh/CFL) = 2.67 TWh/year.

[+] Assuming a 47.3% capacity factor for the US plant. Actually, the capacity factor for U.S. baseload plants is 65%, for intermediate plants it is 40%, and for peaking plants, it is 10%. The weighted average capacity factor for all U.S. capacity (of 661.58 GW) is 45%. Since the U.S. peaking capacity is 40.3 GW, we derive a weighted average capacity factor for baseload and intermediate capacity of 47.3%, [Energy Information Administration, 1989] and [North American Electric Reliability Council, 1989]. The calculation assumes 8% losses in transmission and distribution, for the US plant, based on [Energy Information Administration, 1988].

demand in the newly industrializing countries. For sake of brevity we shall refer to these windows simply as "low-E windows" in the following text, although we have in mind double glazed, argon filled sealed windows that have low-emissivity coatings to reduce heat transfer, and also have spectrally selective coatings to filter out the infrared component of sunlight.

3.1. Technology Characteristics

During the last decade advances in sealants used in double glazed windows, low-emissivity ("low-E") coatings, and low-conductivity gas-filling technologies have significantly improved the thermal and optical performance of windows, reducing or even reversing their adverse impact on building energy consumption and peak demand. Various combinations of these components can provide solutions tailor-made for the cooling and heating requirements specific to hot and cold climates [Labs, 1990].

Heat transfer through windows occurs in two primary ways:

1) Losses or gains by conduction, convection, and infrared radiation are driven by an indoor to outdoor temperature difference and are quantified by a U-value, given in W/sq.m.-C.

2) Solar gains through glazings are quantified by a Shading Coefficient (SC). The SC of a glazing system is the solar heat gain through that glazing divided by the solar heat gain through clear 3mm glass.

In cold climates where heating rather than air-conditioning dominates, conductive energy flows through the windows of residential and commercial building are the biggest problem. Windows that maximize solar heat gain and minimize conductive losses are the solution. Such windows would utilize two components: 1) conventional low-E coatings with high transmittal rates of visible and solar infrared radiation; [*]and 2) an insulated glass unit filled with a low-conductivity Argon gas-filling.

However in this paper we focus on warm climates where air-conditioning dominates. In such climates, a highly insulating window that appears clear, but that actually eliminates the solar infrared heat gains of conventional clear or frosted glass is the solution. Such a window utilizes a modified, spectrally selective low-E coating with high visible transmittance but low transmittance in the solar infrared. The result is an overall SC of approximately half that of monolithic glass of the same color. The insulated glass unit also uses argon gas-filling. The window's U-value of approximately 1.5 W/sq.m.-C is substantially less than the U value of approximately 6 W/sq.m.-C for conventional single glazings.

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[*] This window achieves a U-value of approximately 1.5 watts/sq.m.-C, an improvement of 4.5 W/sq.m.-C over the approximately 6 W/sq.m.-C U-value of conventional single glazing.

3.2. Cost of Conserving Electricity with Low-E Windows in Developing Countries

In most developing countries with relatively low levels of industrialization and urbanization, the peak electric demand occurs in the evening, primarily driven by residential lighting. But as these countries industrialize and urbanize, (as is already the case in the so-called Newly Industrialized Countries), the peak electricity demand shifts from evening to afternoon hours (driven by air-conditioning loads in commercial buildings and by industrial demand).

To illustrate the positive impact of energy-efficient windows on air-conditioning demand in hot climates, calculations for Bangkok, Thailand, are given below.[**] Since the benefits of low-E windows are weather-dependent, climate-specific calculations must be performed for any other sites, in order to quantify low-E windows' conservation potential, CCE (and CAPIC, if applicable) in each location. The building used as the illustrative example has single glazed windows of grey 8mm glass. But comparable savings would still result if the windows were of clear glass or glass of other tints.

There are two main applications in which low-E windows could contribute significant electricity savings in avoided air-conditioning demand. Large commercial buildings with central air-conditioning is the first application. The second application is smaller (two or three floor) commercial buildings which may have individual window units for air conditioning. For the sake of conservative calculations, we assume that both types of buildings have appropriate vernacular architecture emphasizing vertical and horizontal overhangs to reduce solar gains. We note that although tall commercial buildings featuring glass curtain walls (and no overhangs) are not treated in this paper; such buildings are nonetheless increasingly popular in the urban centers of developing countries. Low-E windows on such buildings would capture even larger electrical energy and demand savings than estimated here.

We first estimate savings with low-E windows for a centrally air conditioned office building. The characteristics of this reference office building are drawn from building simulations conducted for Thailand's preliminary building performance standards [Chitrarattanañon et al, 1989]. The 15 floor office building has 1 meter deep overhangs over all windows. The windows are single glazed with grey-colored glass, which has an SC of 0.63. The simulations show that the average value of solar radiation incident on a vertical surface is 165 watts.

The DOE 2.1C simulations also provide the following information regarding the relevant data for air conditioning load on the reference building.

1)	External SC (due to overhangs), depending on time of day and orientation:	0.57 - 1.0
2)	Shading coefficient of 8 mm grey glass:	0.63
3)	Thermal conductance of window glass:	5.81 Watts/sq.m.-C

[**] Bangkok has 3668 centigrade annual cooling degree days, calculated using a 30 year climate record, with a base temperature of 18.3 deg C. [Departments of the Air Force, the Army, and the Navy, 1978].

4) Cooling set-point: 25 deg C
5) Night set-back for cooling: 37 deg C.
6) COP of Centrifugal Chiller: 4.5
7) Average annual Window Conduction Heat Gain++: 11.1 W/sq.m.
8) Average annual Solar Transmission through Windows++: 24.5 W/sq.m.

++ These are annual (8760 hour) average values obtained from the annual operating hour (2574 hour) averages quoted in [Chitrarattananon et al. 1989].

The low-E window has a conductance (U value) of 1.5 W/sq.m.-C, and (with glass panes of the same total transmission in the visible wavelengths) has an SC of 0.31. Therefore, one square meter of low-E window will avoid a conduction gain of 72.4 kWh (thermal), and a transmission gain of 109.2 kWh (thermal), for a total avoided heat gain of 181.5 kWh (thermal).[*]

DOE 2.1 reports centrifugal chiller COP for the actual chiller only, without taking into account auxiliary losses (e.g. in pumps for the coolant circulated to the cooling towers). Discussions with experts familiar with DOE 2 simulations lead us to conclude that the effective COP for the entire chiller system is likely to be at most only 3.5, if the chiller COP is 4.5. The chiller system would therefore avoid using 51.9 kWh (181.5 / 3.5) of electricity to remove this heat, assuming conservatively that it operates at its full-load COP.[**] Assuming transmission and distribution losses of 15%, the electric utility would avoid generation of 61.1 kWh of electricity to meet this demand.

These annual savings are obtained at some annualized incremental cost of installing the one square meter of low-E window. Estimating that cost allows us to calculate the CCE. The capital recovery rate, assuming a 30 year life for the low-E window, and a 12% discount rate, is 0.1241. For windows manufactured in indigenously established factories, (or initially imported with customs duty exempted for establishing a market), we can assume costs similar to those in the US. Therefore, the annualized incremental cost of the low-E window is
(US$ 13.00 - 6.60) X (0.1241) = $ 0.795/sq.m.[+]

A square meter of low-E window could therefore avoid the generation of 61.1 kWh annually, at an annualized cost of US$ 0.80. Thus, the CCE for the low-E window is only US$ 0.013/kWh, two to three times less than even the short-run marginal cost of electricity production (typically US$ 0.03 to 0.04/kWh), and six to nine times less than the LRMC (typically US$ 0.08 to 0.12 / kWh).

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[*] Conduction: (11.1 W/sq.m.)X((5.8 - 1.5)/5.8)X(8760 hours) = 72.4 kWh (thermal)
Transmission: (24.5 W/sq.m.)X((0.63 - 0.31)/0.63)X(8760 hours) = 109.2 kWh (thermal).

[**] There will also be electricity savings in the air-handling system because less cooling air has to be moved around. But we ignore these in the present calculations.

[+] The dealer cost per square meter of the low-E window is US$ 13.00, compared to US$ 6.60 for the single glazed window. We assume that the costs of storage and handling for both the windows are the same, US$6/sq.m.; thus the final differential in the retail price will equal the difference in dealer cost. There is no incremental operations and maintenance cost for the low-E window over that of an ordinary single glazed one.

However that is not the full story. The savings captured by low-E windows increase markedly when we take credit for the decreased cost of a down-sized centrifugal chiller and auxiliary (made possible by a smaller peak cooling load). When calculations include savings in cooling equipment investments, the cost of conserving electricity with low-E windows is negative; the savings from down-sizing the chiller exceed the initial cost of the low-E window.[++]

In the example above, each square meter of low-E window saves, on average, 70.5 watts (thermal) of the cooling load during operating hours.
(181.53 kWh thermal) / (2574 hours of operation) = 70.5 Watts
Assuming conservatively, that the peak cooling load savings on the chiller will be no larger than this amount, the savings in chiller cost (from down-sizing) equals U.S. $ 6.87 per sq.m. of low-E window.[#]

We assume that the chiller and auxiliary have the same life as a low-E window, i.e. 30 years, and are annualized at the same discount rate, 12 percent. So the annualized savings from down-sizing the chiller and the auxiliary are $ 0.85 per sq. m. of low-E window. Taking credit for these savings makes the annualized cost of the low-E window negative, (because the annualized cost of the window itself is slightly smaller than this amount). The net annualized window cost (including credit for down-sized chiller and auxiliary) is US$ -0.058 / sq.m. Consequently, the cost of conserved electricity is also negative, approximately US$ -0.0009/kWh.

In many developing countries, it is uncommon for even multi-story buildings to have central air-conditioning; instead they are cooled by individual window units. If the reference building were cooled with window air-conditioners, the COP would be much lower. Window air-conditioners in most developing countries have relatively low efficiencies [Meyers et al, 1990]. Such units use about 1 kWh electrical energy to remove 2.19 kWh of thermal energy. Thus the savings in electricity demand and energy quoted above increase by 60% while the annualized cost of the low-E window remains the same. The CCE of low-E windows (excluding the savings from down-sizing the cooling equipment) decreases to US$ 0.008/kWh assuming: 1) an average energy efficiency ratio (EER)[**] of 7.5 for the existing stock of window air-conditioning units in developing countries, 2) a discount rate of 12% and 3) a life-span for the low-E window of 30 years.

The CAPIC may be calculated for avoided electricity demand related to air-conditioning for countries (or utilities) where afternoon air-conditioning, rather than evening residential lighting, drives peak demand.[$$] We illustrate the CAPIC calculation for a hypothetical utility with summer peak driven by air-

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[++] The electricity savings are thus not only a "free" lunch, but as Amory Lovins says, "it is a lunch one is paid to eat."

[#] The centrifugal chiller and auxiliary cost US$ 336 / Refrigeration Ton. (one refrigeration ton = 3.45 kW thermal), [Chitrarattananon, Rakwamsuk, Kaewkiew, 1989]. So savings from down-sizing = (70.5 W / 3.45 kW) * US$336 = US$ 6.87

[**] The energy efficiency of window air conditioners is commonly measured in units of Btu/h-Watt, called EER.

[$$] In contrast to CAPIC, the CCE of low-E windows is applicable to all utilities, regardless of the time of peak demand.

conditioning loads assuming that: 1) 75% of the low-E windows are installed in buildings with peak-coincident air-conditioning; 2) the peak cooling load savings from low-E windows are no larger than the the average annual value during operating hours; 3) the low-E windows are installed in buildings with a cooling plant efficiency (COP of 2.8) halfway between a centrifugal chiller system and a window air conditioning unit; 4) the plant availability factor for thermal power plants is 0.573; 5) and that transmission and distribution losses are 15%.

An investment in one square meter of low-E window, (with the same 30 year life as the power plant), saves a peak demand at the busbar of the power plant of 38.77 watts.[##] This savings is achieved with an investment which has a net present value (equal to the incremental difference between the single pane window and low-E window) of U.S. $ 6.40. Thus the CAPIC is $ 165 / kW, substantially lower than the $ 1500 / kW cost for new coal fired thermal power plants, (used e.g. in India), and the $ 600 / kW cost for power plants based on gas combustion turbines.

3.3. Comparing Superwindow Manufacturing Plants to Power Plants

We ignore the customs duty on the superwindow manufacturing machinery in these calculations, because customs duty is not a societal cost. In any case, most developing countries also import 40 to 80% of the capital investment in their power plants as machinery from abroad (thus one may argue that customs duty rate on both should be equal, and can be ignored in making the comparison). A low-E windows plant costs about $ 10 million; $ 8 million for the machinery and $ 2 million for the buildings and the land. Operated 3 shifts, it produces about 2 million square meters of low-E windows in a year. Each square meter of low-E window lasts for 30 years, and saves, annually 61.1 kWh of electricity generation for air-conditioning (assuming that it is installed in efficient, centrally air-conditioned commercial buildings in a climate like Bangkok's.) In buildings with window air-conditioning units, the savings will be 60% larger. We credit the production year with all the electricity saved by these 2 million sq.m. of low-E windows over their 30 year life. Thus the savings in electricity sales, contributed by the annual output of a low-E windows plant equals 11 TWh.[*] Assuming a 47.3 capacity factor (similar to the average for the US baseload and intermediate plants), but assuming 15% losses in transmission and distribution, this is equivalent to the sales from power plants with installed capacity of 1029 MW. These plants would require a capital investment of US$ 1.54 billion (at $ 1500/kW), or more than 150 times the investment in the low-E windows plant.

4. BARRIERS TO THE LARGE-SCALE IMPLEMENTATION OF ENERGY-EFFICIENT TECHNOLOGIES

Despite the potential economic and environmental benefits of implementing energy-efficient CFLs and windows worldwide, consumers may avoid adopting

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[##] ((70.53 watts [thermal]) (0.75)) / ((0.573) (0.85) (2.8)) = 38.77 watts.

[*] (2 million sq.m.) (61.06 kWh/yr-sq.m.) (30 years) = 3.66 TWh.

such technologies for any of the following reasons.

1 High discount rates for future savings: Energy-efficient technologies' annualized societal costs[+] may be much lower than those of inefficient counterparts, but their first costs are usually higher. Consumers with little access to capital are unwilling to invest in an initially costly technology which is profitable only in the long run.

2 Unsubsidized efficiency has to compete with subsidized energy: Residential consumers (especially in Eastern Europe and the developing world) benefit from subsidized electricity; their electricity bills do not reflect the full social costs of inefficient electric appliances. Where residential electricity is subsidized, consumers have little or no incentive to purchase and install relatively expensive, highly efficient appliances.[$]

3 Technological uncertainty: Energy-efficient technologies are often unfamiliar. Purchasing an expensive, locally unproven appliance represents a financial risk that many households refuse to accept.

4 No indigenous production: In too many countries, energy-efficient appliances must be imported and in several countries (e.g. India), such imports must bear a high customs duty. The resulting high prices can make such appliances uneconomical from any viewpoint within the energy sector. Even worse, the absence of a proven market for CFLs and Low-E windows strongly inhibits indigenous manufacturing.

Few manufacturers will invest in a factory without proof that a market will develop to absorb the plant's production. The following discussion of BELLE details an innovative financing method for developing a market for CFLs within a dispersed, low-income, risk-averse customer base in Bombay.

5. BOMBAY EFFICIENT-LIGHTING LARGE-SCALE EXPERIMENT (BELLE)

Negotiations on BELLE are currently underway among the Bombay Suburban Electric Supply Limited (BSES) utility, Philips India, Indira Gandhi Institute of Development Research (IGIDR), and the Program for Acceleration of Commercial Energy Research (PACER). Participation of additional lighting manufacturers is also being negotiated. The BELLE Project will demonstrate utility profits and benefits for residential and industrial customers that may lead to the construction of a CFL factory in Bombay. Replacing one household's incandescent bulbs with CFLs would allow three additional unlit households (suffering from power

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[+] A technology's annualized societal cost equals the sum of: 1) the annual amount of energy used by the technology multiplied by the unit societal cost of that energy; 2) its annualized purchase price; and 3) the technology's annual operations and maintenance costs.

[$] Poor customers (who receive cheap subsidized electricity in India) have no reason to purchase CFLs unless they are subsidized at about 50%. Consider the fact that imported CFLs cost on average Rs. 135, and in 1985, 66% of electrified households in India had incomes of less than Rs. 1000 per month; 92% had incomes of less than Rs. 2500 per month (in 1985 US $1 = Rs. 12). [Gadgil and Jannuzzi, op. cit.]

shortages), to receive lighting with CFLs, or would allow the additional electricity to be used elsewhere in the economy.

Since the long term goal of the project is to establish a market mechanism for large scale diffusion of energy efficient end use technologies that will be indigenously produced, the project is based on economic calculations and trade offs that do not take into account the present high customs duty on import of individual CFLs. The participating lighting manufacturers are committed to establishment of local CFL production facilities once the market can be demonstrated.

Operational Plan

BELLE will be conducted in three stages:

1 Planning has been underway since late 1989 and will include input from consumer panels in 1991. The planning process addresses three key areas:

The technical aspects of CFL performance under Indian power conditions.
The leasing scheme.
Methods for promoting the replication of the successful project.

2 Phase One -- The Pilot Experiment -- includes installation and testing of 1000 CFLs over 6 months. Preliminary findings will be used to develop technical specifications for the CFLs. Three or four models of CFLs will be tested in the 1,000 CFL Pilot Test. The CFLs will be installed in targeted Bombay households, and their technical performance and consumer acceptability will be monitored and assessed over a 6 month period. The results of this trial period will determine which CFL will be used for the full-scale experiment.

Preliminary advertising, educational, and promotional materials will also be developed and tested during this period. Feedback from presentations to consumer groups will guide the consortium members in designing BELLE's marketing approach.

3 Phase Two -- The Full-Scale Experiment -- includes installation of 17,000 CFLs and monitoring for four years using a three-part survey. In the Full-Scale Experiment, 19,000 CFLs will be purchased and 17,000 will be installed in targeted households that have agreed to participate in BELLE. Three detailed surveys will be carried out during the four years of Phase Two to monitor consumer response to BELLE as well as the technical performance of the CFLs.

These data and findings from technical examinations of the CFLs will be presented in semi-annual reports to the BELLE consortium members. IGIDR staff will play the leading role in survey design, analysis, and project evaluation.

To facilitate replication, significant findings and recommendations will be carefully documented. This will enhance BELLE's usefulness as a model for other programs in India and abroad.

Finances

The twenty thousand CFLs will be purchased abroad with hard currency loan monies from a supporting agency such as PACER.# Phases One and Two will install a total of 18,000 CFLs. The additional 2,000 CFLs will be purchased to cover premature failures and breakage.

During Phase One, 1,000 CFLs will be installed in Bombay households and monitored for 6 months. This pilot experiment will not produce any revenue.

During Phase Two, 17,000 additional CFLs will be installed in approximately 10,000 Bombay residences chosen for their good financial standing with BSES. An innovative utility-leasing program (modeled after successful programs in the U.S.), will be used to reduce the CFL's purchase price from a large one-time payment to many payments over a long period. This is necessary because each CFL costs more than half the monthly income of an average Indian.

* BSES will collect monthly lease payments for CFLs from its residential customers of Rs. 6 - 7 per month. Over four years this fee will pay for the CFLs' first cost (excluding interest charges).
* The customer will realize savings of Rs. 8 - 9 per month from reduced electricity bills and savings of another Rs. 1 per month in avoided incandescent light bulb purchases.
* BSES, Philips, and PACER will share the overhead costs for planning, administering and monitoring the project in proportions that are yet to be finalized. These expenses are currently estimated at approximately Rs. 2 per CFL per month. Because of its ground-breaking nature, BELLE will incur some first-time costs (especially for multiple market surveys and technical research) that will not apply to future versions.
* Monthly revenue for BSES of Rs. 0.5 - 2 per CFL will result from avoided subsidies to the residential sector. This revenue will help to offset overhead costs.
* The electricity conserved by BELLE will be made available to households and industrial customers on the Western grid. Because of existing regulatory and equipment constraints, it will be difficult for the consortium to receive direct revenue from these sales. However, each CFL saves India more than Rs. 1,000 over its lifetime in avoided investments in peak generating capacity. This represents societal savings from avoided investments in power plants of Rs. 16 per month per CFL, in addition to avoided impacts on India's environment.

The loan amount will be immediately returned in local (soft) currency to PACER after the CFLs are landed in India, by refinancing the project locally. With the help of the funding agency, the consortium will request that the government charge a customs duty rate on CFLs for BELLE that is no higher than the rate charged for imported components of large power projects. This rate is currently about 30% compared to the more than 250% duty which would otherwise be charged for CFLs. Without such an adjustment in the customs duty, BELLE would be uneconomic.

Risk Management

The function of the Pilot Test (during which 5% of the CFLs are installed), is to provide technical and program-related input which can be used to redesign the Phase Two Full-Scale Experiment. Phase One will provide marketing, financial, and management information essential to making Phase Two a success.

BSES customers incur almost no risk by participating in BELLE: the CFLs are guaranteed against early failure by free replacements; and household participation in the program can be terminated at any time with no penalty.

Replicability of BELLE

The BELLE Project is the first utility-sponsored demand management program to be initiated in India. For this reason, careful consideration will be given to preparing materials that document BELLE's financial, technical, and managerial structure. If successful, BELLE will demonstrate that innovative institutional partnerships can overcome the "real-world" constraints that presently limit the attractiveness of CFLs to those participating in the project.

BELLE should provide BSES and other utilities with the information and experience necessary to establish their own innovative, profitable, large-scale, energy efficiency end use programs. Eventually, demand management programs throughout India may succeed in slowing the rate of supply expansion, allowing capital to be diverted to other sectors of the economy.

6. CONCLUSION

The severe power shortaged expected in the developing countries, and the accompanying shortage of capital for investments in new generation capacity require alternative solutions for reducing the widening gap between demand and supply through increased end use efficiency [Meyers et al, 1989].

We illustrate our case with two technologies: the compact fluorescent lamps, and insulating, spectrally selective, low emissivity windows. The technologies provide demand reduction in electrical energy and peak demand at costs (on per energy and power unit basis) that are many times lower than the cost of new energy and peak demand supply. The production factories for these technologies are shown to be more attractive investments than investment in new power plants by factors of several hundreds to more than a 1000.

However, the high first cost of these technologies can be a barrier to their wide scale introduction and dissemination in the developing world. Institutionally cooperative arrangements, such as BELLE, between the utility, manufacturers of such appliances and financial institutions can be socially beneficial and serve to overcome the severe barriers that these new technologies will otherwise face.

7. Acknowledgements

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