LIGHT EMITTING DIODES FOR PHOTOVOLTAIC OFF-GRID HOMES

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BACKGROUND

At the start of the 21st century, there are more people without electricity than at the end of the 19th century, as there are more than 2.1 billion people today without electrical service throughout the developing world (The World Bank, 2005). According to the World Bank, 24 percent of the world's urban population and 67 percent of the rural population are without electricity. Additionally, in the term of four decades the population of developing countries is expected to grow up by three billion, consequently the problem of energy consumption will compound and fuel prices will continue to rise. Almost all of these non-electrified homes still commonly use liquid fuel-based lanterns (e.g., kerosene) to meet their lighting needs.

Fuel-based lighting presents significant health and environmental hazards over electrical lighting. There are thousands of household fires per year caused to fuel based lighting claiming thousands of lives. Particulates from the fuel lanterns coat walls and lungs with carcinogenic residues. Lawrence Berkeley National Laboratories, LBNL (2005) estimates that fuel-based lighting results in 190 million metric tons of carbon dioxide emissions to the atmosphere each year, which means greater emissions than the total of Australia or the United Kingdom combined. Although one in three people obtain light with kerosene and other fuels, representing about 50 percent of global household lighting costs, they receive only 0.2 percent of the resulting lighting energy services (i.e., lumens).

Kerosene lanterns and the like are extremely inefficient, typically only offering one fourth of the lumens of electric lights, and are difficult to work or read by. Women and girls are typically responsible for obtaining kerosene for household lights in rural regions, which often involves walking long distances. Kerosene pricing and subsidies are often the source of political and social unrest, hoarding, and scarcity.

LBNL also estimates that global household-sector use of fuel-based lighting annually consumes about 77 billion liters of kerosene. This equates to 1.3 million barrels of oil per day. The cost of this energy is ~ US$38 billion/year or approximately US$77 per household each year. This is not insignificant, especially when compared with the US$230 billion spent each year to electrify the homes of the grid-connected world.

PV LEDs represent a new era of quality and inexpensive lighting for rural people around the globe. PV modules are the best option to power WLEDs lamps in rural areas. The potential multi-billion dollar market for this technology around the globe should help drive development given the great number of rural people who live off-grid.

INTRODUCTION

There are basically two distinct parts to the home lighting challenge; the light source and the energy source. Photovoltaics (PV) coupled with light emitting diodes (LEDs) offer a practical, more economic, and better energy and lighting alternative to fuel-based illumination in the developing world. Indeed providing reliable LED lights to the world's undeveloped areas may represent one of the most significant contributions of the growing global LED lighting revolution.

The current dominant application for PV in developing countries is the solar home system, with over 3 million systems installed. This involves the installation of PV systems from 40-100 peak watts (Wp), costing about US$500-900 each, in individual homes, mainly in rural areas. Emerging high efficiency white LED (WLED) technologies can significantly improve the quality, safety, and quantity of illumination, while reducing overall costs and environmental emissions. A 1-watt LED cluster can be run on about a square foot of PV cells. PV and LED technology offers developing countries the opportunity to leapfrog from 19th to 21st century lighting technology. Thus, overall PV system size and costs can be significantly reduced with LEDs. With the advent of WLEDs it is no longer necessary to think in terms of Kilowatts for developing country village lighting as it becomes feasible to light up an entire village with only a few hundred Watts, easily and cost-competitively supplied by PV power sources. In the future, it may be possible to run a PV LED lighting system with little or no batteries (e.g., ultra-capacitors), further reducing costs below those of kerosene lighting.

LEDs lighting

The LED is an electronic diode similar to other semiconductor diodes. What makes an LED unique is that its semiconductor junction is designed to convert current flow into visible light. LEDs have been used as discrete colored lights for years, and advances in the last few years have made blue and white light available from LEDs. The intensity of the LEDs light output is also increasing rapidly. Modern LEDs can have over a hundred times more light output than those available a decade ago.

The LED is a low voltage direct current (dc) device. While different colored LEDs have different junction voltage drops, they fall into the 1.8 to 3.1 V dc range. When it comes to using LEDs efficiently, they are best employed using low voltage dc as a power source. The LED is the longest lived light making device ever invented and some can last over 500,000 hours before failure. With use every night, all night, this means that an LED could last for decades. Physically the LED is very rugged and can withstand moisture, vibration, and shocks which can destroy more conventional lamps. The LED lamps also produce no radio frequency interference, unlike many compact fluorescents.

The application of LEDs in rural off-grid installations requires high lumen maintenance and color stability (both correlated color temperature (CCT) and color rendering index (CRI)). A high quality WLED should have lifetimes of at least 50,000 hours (>5 years), a CRI of >70, and a CCT between 2500 and 6500 Kelvin. The CRI is a measure of the light sources ability to accurately render colors, and the CCT is referenced to the spectrum of a blackbody source at a given temperature. A CRI above 70 is considered a good quality white light and adequate for normal everyday living. A CCT of 2500 is representative of a warm white (similar to an incandescent bulb), and a CCT of 6500 reproduces the daylight spectrum, or cooler white. A CCT greater than 7500 tends to have a bluish appearance and is not considered appropriate for indoor environments.

In 1997 Nichia Chemical Corporation of Japan developed the world's first White Light Emitting Diode (WLED). Today a number of other companies have joined Nichia in producing WLED's such as Hewlett Packard-Phillips, Panasonic, Sumitoma, Toyoda Gosei (Toyota), GE-Osram, and Fujitsu.

WLEDs come in a variety of packaging alternatives and configurations in square, rectangular, triangular, and circular forms. They vary from standard 5mm T 1 lamps with 1 lumen output, high power packages with 10's of lumen output, to integrated fixtures with 100 lumen outputs. A typical incandescent bulb has roughly 1,000 lumen output. In general, these devices can be obtained from many US and Asian suppliers. Unfortunately, the quality of LED solutions varies greatly with suppliers. The capital cost for WLED's should continue to drop dramatically over the next few years, principally through competition and increased output achieved by economies of scale. Likewise, WLED output power per dollar will increase.

Most of the WLEDs available on the market today typically consume between 0.5 watts and 7 watts. Light output varies from about 1.6 foot-candles to 5.6 foot-candles on the LEDs. WLED flashlights have at least seven times the battery life of similar incandescent bulb flashlights.

There are challenges as well to designing LED lighting systems. In order to optimize the size of a PV module, the battery energy should be stored and used as efficiently as possible, for example, when using a 12 Volt battery to power a 3 Volt LED. The current flow must also be regulated for a LED, with a high degree of reliability since the effective LED operating currents are on the order of 20 - 350 mA. Driver Circuit (LDC) chips must be designed at minimum cost. Chips have been built which can power up to three LEDs in series, however, designs are still evolving and costs should continue to drop dramatically as designs become standardized.

Unfortunately, as with PV systems, many of the superior characteristics of LEDs are not appropriately evaluated in traditional economic analysis. A mix of measures should be considered. Comparisons of LEDs to compact fluorescent lamps are made usually on the basis of lumens per watt and the cost of the light source. Additional metrics that should be used for PV LEDs in a developing world context should include general usefulness, system life, efficiency, power requirements, total energy consumption, hardware costs, and overall life cycle costs.

IMPLEMENTATION OF LEDS POWERED WITH PV SYSTEMS

PV has become an economical alternative to conventional fuels in developing countries for off-grid applications, such as lighting. Already there are over three million PV systems installed in developing countries that are economically competitive with little or no subsidy. In order to increase the impact of PV power in undeveloped regions, there must be improvements not only in decreasing technology costs, but also in the policy environment of implementing countries. In addition, the access to investment capital for PV must be improved. For industry to earn profits in PV and LEDs there must be profitable opportunities available.

If a country subsidizes fuels competing with PV and LEDs, which is a common practice in developing countries for kerosene, there is less likelihood that PV and LEDs will succeed. Often, it is politically difficult for developing country governments to remove subsidies. It may be easier in the near term for governments to provide one-time transitional subsidies to PV and LEDs as they phase out conventional fuel subsidies. Transitional subsidies may accelerate the spread of PV LEDs in the short term, but unless the entire PV supply chain is functioning and profitable, it will not produce an economically viable lighting alternative to fuel based lighting. Ultimately, developing country governments should provide an environment largely free of subsidies to create a climate supportive of PV LEDs growth.

One way this can be accomplished is by reducing import tariffs on PV modules and LEDs. This is a simple step that some national governments have taken to reduce the cost of PV systems (e.g., Mexico). It can be a difficult step for those governments that rely heavily on import tariffs for revenues. Developing country governments that want to promote PV should not only reduce import tariffs on PV modules and LEDS, but also offer incentives to encourage domestic PV or LED production (e.g., Philippines and SunPower). This can create a more sustainable revenue base long-term. Furthermore, PV technology can also help developing countries wean themselves from oil imports, which are generally high in developing countries, draining valuable hard currency.

Most PV projects in developing countries initially rely on imported PV modules. From the manufacturer's viewpoint, there is no reason to build a PV or LED manufacturing plant in a country until there is a significant regional market. Lowering import tariffs will keep imported module prices down and can catalyze the development of a domestic PV market, after which a manufacturer may well decide that local manufacturing makes economic sense.

Some governments, such as India, have provided tax incentives for PV or for renewable energy generally. Such incentives have encouraged the rapid proliferation of PV lighting systems (PVLS) in some places. But when the tax incentives are withdrawn, the industry suffers a severe decline, and the profits needed for systems servicing decline, harming both prospective sales and existing installations.

There are human capital constraints on PV in developing countries, including shortages of PV developers, installation, and maintenance personnel. PV LEDs offer the opportunity to greatly simplify PV installations and provide simple packaged systems to users (e.g., PV powered WLED flashlight). However, there will always be a need for PV installers as users often want other services (e.g, radio or television). Likewise, the power requirements for some of these services may drop significantly in the future as technology develops, such as with non-CRT TVs using flat plate screens. While the TV may be more expensive, it can offset higher PV module costs to power a more inefficient CRT.

There is a tremendous need in the less developed countries for more technical assistance in the area of management and PV development support. There have been plenty of PV development programs that failed in countries like India and Kenya, in part because the front-end consumer education and after-sales support was inadequate. Trained technicians are an indispensable part of a successful PV business, and technical assistance can reduce the risks of failure.

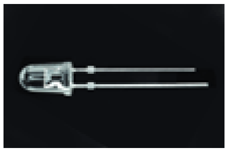
National governments, multilateral institutions, PV project developers, international research centers, and nonprofit organizations all have important roles to play in expanding PV markets in less developed countries. Each group should assist in promoting a fair policy environment, developing human capital (dealers, developers, and technicians), providing adequate investment capital, and furthering PV and LED technology development.

Additional research, development, and pilots will be required to make PV LEDs a global phenomena. Undoubtedly, LEDs represent an upcoming revolution in lighting and will allow the one-third of people who essentially live in the Middle Ages to obtain electric lights sufficient for reading and other activities. Two years ago LEDs were about half as efficient as fluorescent lights on lumens a per Watt basis. In 2005, LEDs in the laboratory became as efficient as fluorescent lights. Projections are that by the end of the decade LEDs will eventually be twice as efficient as today’s fluorescent lamps. Future PV LED development will require partnerships between industry, laboratories, universities, NGOs, and policymakers to be successful.

DIFFERENT TYPES PF WLEDs IN THE MARKET

Custom Solutions Based on Integrated 5mm Packages:

A large number of vendors can supply integrated task lighting solutions based on 5mm LED packages. A typical example is shown in Figure 1 below. A suggested requirement for this solution would be to require the 5mm LEDs to be supplied by Nichia Chemical Corporation of Japan. Nichia is the leading supplier of high quality, high lumen maintenance WLEDs in the world. Other high quality LED vendors of 5mm packages include Toyoda Gosei and Osram Sylvania.



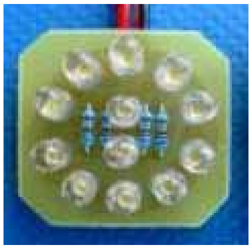


Figure 1. Nichia Chemical Corporation (Japan) 5 mm LEDs.

Custom Solutions Based on Single High-Power Packages

There are only a small number of vendors of reliable high power WLED packages in the world. The top tier supplies in this area would be Lumileds Lighting in San Jose, California, and Norlux Corporation in Carrollstream, Illinois. Some of their products and specifications are listed below.

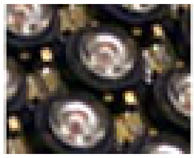


Figure 2. Lumiled Luxeon LEDs products

Table 1. Specifications of three LED lighting products

Norlux "Hex" Products

The Norlux white Hex is a LED with high flux density, which achieves a CCT range of 3500K - 4500K and optimized efficacy. This device uses a metal core substrate for having high thermal conductivity as well as a chip on board technology. The design significantly increases light extraction and does not suffers degradation in hard environments.

Currently in the Southwest Region Experimental Station at NMSU, four Norlux white Hex are under test. Two units are constantly on while tow others are blinking every second, so the degradation for each of the devices will be compared by Sandia labs taking into account the different operational conditions.

Figure 3. PV powered Norlux white Hex under test at SWRES.

Broad Area Lighting Vendors

There are very few high quality vendors who can supply broad area "fluorescent-like" LED solutions. Below (Figure 4) is a product from Norlux Corporation that is representative of a state-of-the-art implementation. The module has optical feedback and covers CCT from 2500K to 6500K right on the Plankian locus. The module is 6" is long, 1.5" tall and 3/4" wide and at 100% brightness at 4500K produces > 60 lumens. This design integrates packaging, optic, thermal, control, optical feedback, and drive. It may be too feature-rich for developing nations, but can be scaled back to a simpler light source. These building block units can be integrated with a variety of fixtures and control circuitry.

Figure 4. Two Norlux LED broad area lighting products.

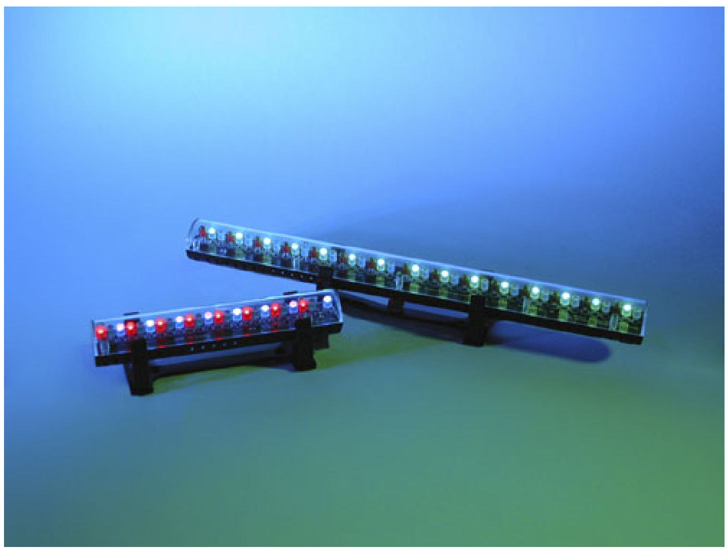


Figure 5. Color Kinetics broad area lighting products.

PILOT LED LIGHTING APPLICATIONS IN THE DEVELOPING WORLD

WLED lamps represent a new low-cost entry point for rural lighting and already several important pilot projects have been implemented in Nepal, India, Honduras, Nicaragua, and Mexico. When designing a lighting system for rural villagers in the developing world it is important to keep costs down as villagers generally have very little income, often only a few hundred dollars per year. Any intended lighting system must be simple, reliable, and economic. Likewise, it is not necessary to light up a rural home to modern levels of illumination, but only light up those areas of the home used at night. Rural homes in the developing world tend to be rather small, thus 2 or 3 lights is more than sufficient.

Asia

In Asia, the Light Up The World Foundation (LUTW) is quite active in Nepal, India, and Sri Lanka. LUTW was founded in 1997 and often use PV in their projects. They are a world leader in utilizing solid state lighting technologies to enhance the quality of life of the poor in the developing world. LUTW uses donor and local social entrepreneurial means to bring safe, healthy, reliable, environmentally friendly and affordable home lighting to the one third of humanity that lives virtually in darkness. LUTW is active in over a dozen countries is committed to raising the quality of solid state lighting used in the developing world home with every improvement in the technology. LUTW partners with LumiLeds, which sells 1 Watt LEDs used in their reference designs. LUTW plans to work in 1,500 villages in India over the next several years.

The first significant LED lighting project was implemented in Nepal during 2000, led by the University of Calgary under the auspices of Light Up The World - Nepal Light Project. This was the world's first permanent installation of large-scale rural lighting using WLED lamps, with some villages using hand generator cranks and others PV. The vast majority of rural homes in Nepal are lit by kerosene wick lamps or resin soaked twigs, all of which are a fire hazard and a health problem due to the smoke produced. The LED lamps consist of a cluster of WLEDs mounted on a printed circuit board with simple electronics. While the light emitted does not project as well as a 15W incandescent bulb, it is more than sufficient for getting around, cooking, and reading, all of which are the primary activities of rural people during the early morning and evening hours.

The Nepalese pilot project was initially supported with LED donations from Nichia Chemical Corporation. The Nepal project found that a rural house can be lighted to an acceptable level with either 6 or 9 WLED lamps, with a power consumption of approximately 1 W. The chosen design is the concentric circular that allows either of these: 3, 6 or 9 WLED configuration using the same printed circuit board. Each lamp requires around 0.4W, since there are 6 WLEDs in the cluster. The diodes are rated at having a life of 100,000 hours, which is 45 years if used 6 hours a day.

In Nepal, WLED technology is emerging as an important component of rural electrification: no other technology can provide light for as many people for the same power input. A notable advantage to the adoption of WLED lighting for homes is environmental since the significantly increased battery life reduces waste including toxic heavy metals found in single use and rechargeable batteries, a serious problem in developing countries like Nepal where disposal facilities are primitive or non-existent.

Central America

In 2003, with seed funding from the World Bank and technical assistance from New Mexico State University (NMSU) and Sandia National Laboratories, the Consejo Hondureños de Ciencia y Tecnología (COHCIT) set up a first pilot PV powered telecenter in the community of Montaña Grande near the capital of Tegucigalpa that included the use of LEDs. As a result of this successful pilot installation, COHCIT and IDB installed 5 more telecenters with LEDs in 2004 with InterAmerican Development Bank funds, with three additional installations installed in 2005. All of the Honduran solar-net telecenters use a combination of 20 W fluorescent lights, and Steca LED 0.7 W lights.

Figure 6. Steca 0.7 W LED light used in the Honduras PV telecenters.

Another PV LED project in Latin America is with the Nicaraguan Renewable Energy for Remote Zones Project (PERZA), whose objective is to support the sustainable provision of electricity services and associated social and economic benefits in selected rural sites in Nicaragua. About 89% of the Nicaraguan population in the rural areas is still without access to electricity. To address this problem, the Comisión Nacional de Energía (CNE) is working with the World Bank in the design and implementation of a national rural electrification strategy, which covers both grid extension and off-grid solutions, including PV.

NMSU and Sandia worked with CNE and the World Bank to develop a technical specification for the procurement of a turnkey photovoltaic centralized battery charging station (SBCS). The purpose of this specification is to standardize the equipment acquisition criteria and parts for the photovoltaic systems to be utilized in CNE PERZA programs. The reliability of any PV system depends on the overall design and the durability of each component. The specifications were designed to be a guide for the Vendor to help them meet the legal requirements for electrical installations according to the Nicaraguan National Electrical Code (Codigo de Instalaciones Eléctricas de Nicaragua, 1996). One of the innovative aspects of this specification is it is the first time that a multilateral lending institution, in this case the World Bank, specified the use of PV LEDs. The specification also included provisions for fluorescent lamps (CNE nor the World Bank were ready for a complete leap of faith to LEDs), thus only one LED is specified per household. The LED part of the specification under the lighting section is as follows (translated from the Spanish):

"The Vendor should also supply one Light Emitting Diode (LED) light per household. The application of LEDs in rural off-grid installations requires high lumen maintenance and color stability (both correlated color temperature (CCT) and color rendering index (CRI)). The CRI is a measure of the light sources ability to accurately render colors, and the CCT is referenced to the spectrum of a blackbody source at a given temperature. The Vendor shall supply a high quality WLED with an expected lifetime of at least 50,000 hours, a CRI of at least 70, and a CCT between 2500 and 6500 Kelvin. A high powered LED package is required with at least 60 lumens output."

Household installations of PV LEDs should begin in 2006 for the Nicaraguan program.

LIFE CYCLE COST ANALYSIS

The life cycle cost analysis compares LEDs lamps to Fluorescents lamps, both powered with PV modules, and to kerosene lamps to estimate competitiveness over the life of the system. Evaluation is conducted for 24 years (covering 4 periods of 6 years each for a typical battery life, depth of discharge (DOE) of ~ 15%). This analysis estimates that each one of the three systems meets the lighting necessities and provides service alike for the users in rural areas. This analysis was developed in Constant dollars of 2005, and the discount rate used was 3 percent[1].

The Federal Energy Management Program's publications Life-Cycle Costing Manual (NIST Handbook 135) and its supplement Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – April 2005 were used to determine present values of future costs. The factor used for getting the present value of kerosene annual costs was obtained from "Table Ba-5. FEMP UPV* Discount factors adjusted for fuel escalation, by end-use sector and fuel type". The value was considered for the United States average for distillate oil and 24 years. Thus, the value obtained and used in this analysis was 14.46.

The discount factors for bringing to present value the future cost of PV lighting systems were obtained from "Table A-1 SPV factor for finding the present value of future single costs (non fuel)". In Table 3 are displayed the values used for this analysis for those years when some money should be carried out.

To determine the cash flow of kerosene lighting two lamps were considered with a cost of $12.00 each. According to LUTW, each lamp's rate consumption is in the range of 0.04-0.6 liters per hour. Each lamp will work four day an hour during 365 days a year, so an average consumption of 0.05 liters/hour was assumed. It means that a single kerosene lamp working four hours a day consumes, each year:

$$0.05 \, liters/_{hour} \times 4 \, hours/_{day} = 0.20 \, liters/_{day}$$

$$0.20 \, liters/_{day} \times 365 \, days/_{year} = 73 \, liters/_{year}$$

[1] Discount rate used by Department of Energy related to energy conservation, renewable energy resources, and water conservation.

Assuming the cost of kerosene in rural areas as 0.528 $/liter (2.00 $/gallon), then the total expenditure of kerosene per year for a kerosene lamp is:

$$73 liters/_{year} \times \$0.528/_{liter} = \$38.57/_{year}$$

Finally considering two lamps per household the total cost of lighting using kerosene in a rural household for one year is:

$$\$38.57 liters/_{year} \times 2 = \$77.14/_{year}$$

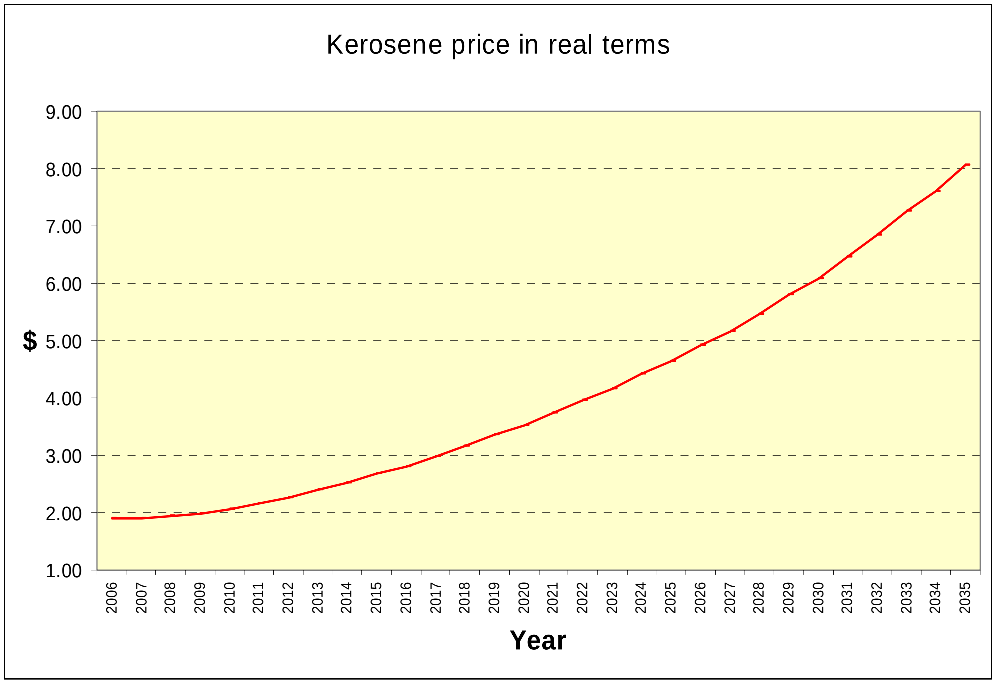


Figure 7. Kerosene price projection using the DOE's escalation factors.

Two options were considered for lighting powered with photovoltaic modules. The first was the use of 7W fluorescent lamps, and the second considered 0.7 W LEDs lamps. In the first case a system with two lamps was evaluated, but when LEDs lamps are used, and because of their lower output light, four of them were considered, so the quality of service for the end user is similar. In both cases a 6A charge controller was utilized.

The battery capacity considered was for a depth of discharge (DOD) of 15 percent. The PV modules considered were of 30 W and 5 W respectively (a PV LED system can more easily use a smaller PV system). Table 2 summarizes the components for each of the two systems considered.

Table 2. Components of the lighting PV powered systems

Component	Capacity	Price in the market
Fluorescent lamp	7 W	$25.00 x 2 = $50
Photovoltaic Module	30 W/12 V	$240.00
Charge Controller	6A	$48.00
Battery	38 AH	$65.00
	Fluorescent lamps system initial cost	**$403.00**
Component	Capacity	Price in the market
LED lamp	0.7 W	$27.00 x 4 = $108.00
Photovoltaic Module	5 W/12 V	$98.00
Charge Controller	6A	$48.00
Battery	10 AH	$24.80
	LEDs lamps system initial cost	**$278.80**

Lighting systems components lifespan

It was assumed that the life of the deep cycle battery will be 6 years. The average lifespan of the fluorescent lamp is about 6,000 hours, which is about five years of life. The lifespan of a quality LEDs ranges from 50 -100,000 hours, so if used 4 hours a day, a LED would not have to be replaced at all during a 24 year analysis period and could indeed function for several decades. Thus no LED replacements were considered for the 24 year life cycle cost (LCC) analysis period.

Using the LLC methodology and applying the discount factors, the costs were brought to present value. The results obtained from the LLC are shown in Table 3.

Table 3. Results of the Life Cycle Cost analysis of three lighting options for rural areas in developing world

Year	Kerosene lamps	Fluorescent Compact lamps			LEDs lamps		
	Annual Cost	Base date cost	Discount Factor	Present value	Base date cost	Discount Factor	Present value
0	$24.00	$403.00		$403.00	$278.80		$278.80
1	$77.14						
2	$77.14						
3	$77.14						
4	$77.14						
5	$77.14	$50.00	0.863	$43.15			
6	$77.14						
7	$77.14	$65.00	0.813	$52.85	$25.00	0.813	$20.33
8	$77.14						
9	$77.14	$50.00	0.766	$38.30			
10	$77.14						
11	$77.14						
12	$77.14						
13	$77.14	$115.00	0.681	$78.32	$25.00	0.681	$17.03
14	$77.14						
15	$77.14						
16	$77.14						
17	$77.14	$50.00	0.605	$30.25			
18	$77.14						
19	$77.14	$65.00	0.570	$37.05	$25.00	0.570	$14.25
20	$77.14						
21	$77.14	$50.00	0.538	$26.90			
22	$77.14						
23	$77.14						
24	$77.14						
LCC	**$1,139.44**			**$709.81**			**$330.40**

Obviusly, paramenters and system configurations for this type of analysis can vary depending on assumption used. However, the basic results demonstrate that a PV LED lighting system represents a lower cost option for off-grid lighting systems, with a present value LCC of about $330, which is about half of the LLC for fluorescent lamps of over $700. A kerosene lighting source on a purely economical basis, excluding environmental externatilities including health and fire danger, were found to be the worst option with a 24 year LCC of over $1,100, or nearly three times the cost of LEDs while providing relatively poor quality lumens.

CONCLUSIONS

Global lighting energy use is significant, totaling approximately $230 billion per year.

The world's 2 billion users of fuel-based lighting collectively consume significant amounts of energy and emit large amounts of greenhouse gases, even compared to industrialized households with electric lighting. Unfortunately, fuel-based lighting has been largely ignored in the global energy discussions to date. Rural users pay the highest cost for energy of anyone in the world with fuel-based lighting and dry cell batteries typically exceeding over US$0.50/kWh. Fuel-based lighting expenditures rival those of affluent households who enjoy vastly higher levels of quality, safety, and services provided by electric light.

The potential for reducing global lighting energy use, associated costs, and emissions is substantial. As Kyoto accords are implemented and there is greater interest in decreasing CO_2 emissions, a shift to LEDs should provide substantial cost and emissions savings. Homes in the developing world can be lit to the same standards as those in industrialized countries, while reducing costs and emissions. For lighting, attaining a higher standard of living does not necessarily require increased energy use. The single-greatest way to reduce the greenhouse-gas emissions associated with lighting energy use is to replace kerosene lamps with PV LEDs in developing countries.

WLED lamps represent a new low-cost entry point for rural households in less developed countries. LED-based lighting systems for PV rural white lighting applications can help take the one-third of the world literally still living in the dark ages into the modern age. Emerging high efficiency WLED technologies can significantly improve the quality, safety, and quantity of illumination for both rural and urban homes, while reducing overall costs and environmental emissions.

PV modules are the best option to power WLEDs lamps in rural areas, since they can be installed at the site where the energy is needed and no further imports are required. Therefore, investment in infrastructure is not required. There are projects that are promoting WLEDs lamps technology powered with photovoltaic modules, which are reporting excellent technical results. However, the high initial cost, compared with fuel-based lighting, is a barrier to achieve them, so other evaluation methods must be used such as the life cycle cost metholody here, which found the PV LEDs are twice as cost effective as fluorescent lights, and three times more cost effective than traditional kerosene lighting technologies.

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