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Technical Report #3

Solid-State Lighting on a Shoestring Budget: The Economics of Off-Grid Lighting for Small Businesses in Kenya

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The Lumina Project includes an Off-Grid Lighting Technology Assessment activity to provide manufacturers, re-sellers, program managers, and policymakers with information to help ensure the delivery of products that maximize consumer acceptance and the market success of off-grid lighting solutions for the developing world. Periodic *Research Notes* present new results in a timely fashion between the issuance of more formal and lengthy reports. Our results should not be construed as product endorsements by the authors. For a full archive of *Research Notes* and *Technical Reports* see: http://light.lbl.gov/technology-assessment.html

Introduction

Solid-state lighting based on light emitting diode (LED) technology has the potential to provide superior lighting services to low income people in off-grid areas of developing countries, many of whom currently rely on fuel based lighting sources such as kerosene. If this potential is to be achieved in the near term, however, manufacturers must produce off-grid lighting products that are inexpensive, perform well, and meet the needs of potential end users. At present, relatively few products meet all three of these goals (e.g., see Mills and Jacobson, 2008).

In this article, we report results from a detailed study of lighting use by micro-enterprises in two small towns in Kenya's Rift Valley Province. The work included a survey about lighting use by 50 small businesses, careful measurements of kerosene lighting use patterns and associated costs for 23 of these businesses, and a subsequent field trial in which 14 of the 23 businesses purchased and used low cost LED lamps over a number of months. See Figure 1 for an image that shows a micro-enterprise that uses fuel based lighting during evening time business operations.

A central goal of the work is to increase awareness on the part of manufacturers, policy makers, and other interested groups about the lighting needs, economics, and preferences of micro-enterprises in places like Kenya, as this group has potential to act as early adopters of off-grid lighting products based on LED technology. The findings are also intended to inform manufacturers about key linkages between product design choices and the affordability of these products for small businesses in places like Kenya.

Five key findings from the work include the following:

1) Kerosene for lighting is a modest but important operating expense for many micro-enterprises that operate at night, with costs ranging from approximately $1 to $13 per month for the 23 businesses for which we made careful measurements.[1]

2) The micro-enterprises that we studied had a strong interest in rechargeable LED lamps for both business and home lighting applications. They were especially impressed by the quality of the light output from the LED lamps that we introduced to them. At the same time, owners of these businesses were *extremely* price sensitive, as they gain access to cash in very small quantities. The results of the study indicate that they could afford LED lights at retail prices below $15. A number of business owners expressed interest in the possibility of purchasing LED lamps on short term credit, and nine of the 14 who bought LED lamps during the study paid in installments.

3) The off-grid business owners expressed a preference for off-grid LED lighting products that were charged using AC grid electricity over products that included solar chargers due to the higher initial purchase price of the latter type of lamp. This was true despite the fact that, for most of the small businesses, charging a lamp with grid electricity involved paying $0.15 to $0.30 per charge at a business that provided battery charging services, while solar charging did not involve any ongoing costs. Some business owners indicated

[1] All price and cost information was originally collected in Kenyan Shillings (Ksh). The exchange rate at the time of the fieldwork (June and July, 2008) was approximately 67 Ksh per $US.

that they would be interested to add solar charging at a later date; this suggests that products that can be charged with the grid or solar power may be most appropriate, as long as the charging systems can be purchased independently.

4) With respect to lamps that can be charged with grid electricity, the businesses indicated a preference for lamps that had a relatively large battery, provided that this did not increase in the purchase price of the lamps substantially. This was true because the price to charge a battery in a shop is based on a flat rate that is relatively independent of the ampere-hour capacity of the battery.[2] A larger battery that provides more hours of lighting service between charging events can, therefore, reduce the operating cost of grid charged lamps considerably. It is also possible, of course, to increase the number of hours between charging events by reducing the power consumption of the light sources (LEDs). This can be a reasonable strategy, provided that the level of illumination remains acceptable for the task at hand.

5) Finally, we found that business owners were interested in LED lighting even if the operating costs of the lamps were slightly higher than the cost of operating a kerosene lamp. This appeared to be true so long as the LED lamps performed well and delivered superior lighting services relative to the kerosene lamps that they were using.

LED Technology for Off-Grid Lighting

LED lighting is viewed increasingly as a key technology for delivering affordable lighting to low income people in unelectrified areas of developing countries. The rapid decline in the price of LEDs, which has taken place in conjunction with rapid increases in performance, has made them a prime contender in the push to replace increasingly expensive fuel based lighting (Mills, 2005).

Over the past few years, businesses, non-profit organizations, and development agencies have responded by working to develop and promote LED technology. There are now dozens of manufacturers of LED based off-grid lighting products, and scores of development groups and private sector businesses are involved in supporting the deployment of LED lighting systems. The Lighting Africa 2008 Conference in Accra, Ghana included participation by representatives of over 200 businesses and non-profit organizations from at least 30 countries (Lighting Africa, 2008a).

While this activity is promising, the industry is still in its infancy. Most high performance products are, at present, too expensive to be affordable for the large majority of the estimated 1.6 billion people worldwide who lack direct access to electricity, and many of the low cost products that are available have serious performance problems (e.g., see Mills and Jacobson, 2008). Fortunately, there are some exceptions to this trend, but even the most promising off-grid lighting products that we have observed have room for improvement with respect to performance and affordability.

[2] There are thousands of shops in Kenya that charge a range of battery powered devices for a fee. In general, shops charge a flat rate on the order of \$0.15 to \$0.40 to charge devices such as mobile telephones, rechargeable flashlights, and others that have batteries with a capacity that ranges from about 0.5 to 10 ampere-hours. The LED lamps in our study fell into this category. The cost to charge automotive batteries (e.g., batteries that have a capacity of 30 – 200 ampere-hours) is somewhat higher, with costs typically ranging from \$0.60 - \$1.00 per charge.

Some of the innovations that are required to deliver appropriate and affordable products are related to technical advances in components (e.g., better LEDs and batteries) and some are related to manufacturing process improvements that lead to lower production costs. At the same time, there are also substantial opportunities to reduce costs and improve performance through product design.

Appropriate design, in turn, depends strongly on knowledge about end user preferences and needs, as well as insights about linkages between product design and affordability. Here, context specific information about lighting use and the economic circumstances of specific groups of potential end-users is especially important. The research findings presented in this article represent an effort to fill important knowledge gaps for one key group of potential early adopters of LED lighting technology – micro-enterprises that operate at night using fuel based lighting.

Case Studies from Kenya

In Kenya alone, there are hundreds of thousands of small, unelectrified businesses that operate into the evening or in the early morning hours, and proportionately similar numbers exist in most other countries in sub-Saharan Africa. Although the level of illumination delivered by fuel based lamps is very low, lighting often represents a major operating expense for these businesses. Given their business incomes, the high cost of fuel based lighting, and the benefits of improved lighting services, these small businesses appear to be well positioned to act as early adopters of LED lighting (e.g., see Mills and Jacobson, 2007).

To learn more about the economics and use patterns of lighting by these small businesses, we conducted fieldwork in two small towns in the Naivasha District of Kenya's Rift Valley Province. One of the towns, Maai Mahiu, is located at a crossroads of routes connecting Nairobi, Naivasha, and Narok. Much of the income for residents in the town is linked to businesses that provide services to people and freight carriers traveling these routes. Karagita, in contrast, is populated primarily by people who work in the flower farms that line the eastern shores of Lake Naivasha. These large, factory style farms specialize in exports of cut flowers to European markets. According to residents, both towns have populations on the order of 6,000 to 8,000 people. Our research in the towns focused on the use of lighting by small, unelectrified businesses that operated in the evening. As is common throughout Kenya, each town had dozens of such businesses situated alongside other, often larger and more established, businesses that did have electrical service. See Figure 2 for images of sections of the two markets where we conducted the field research.

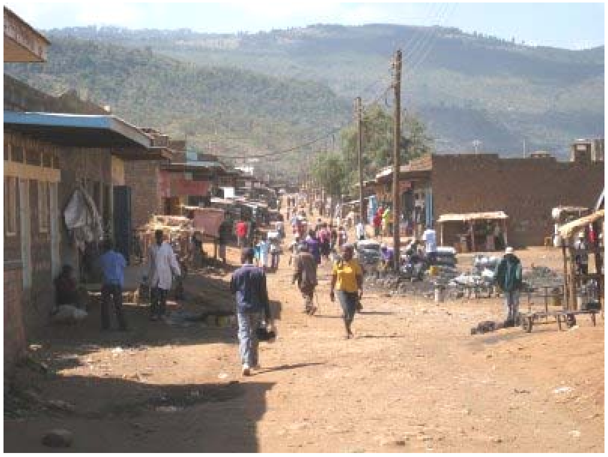


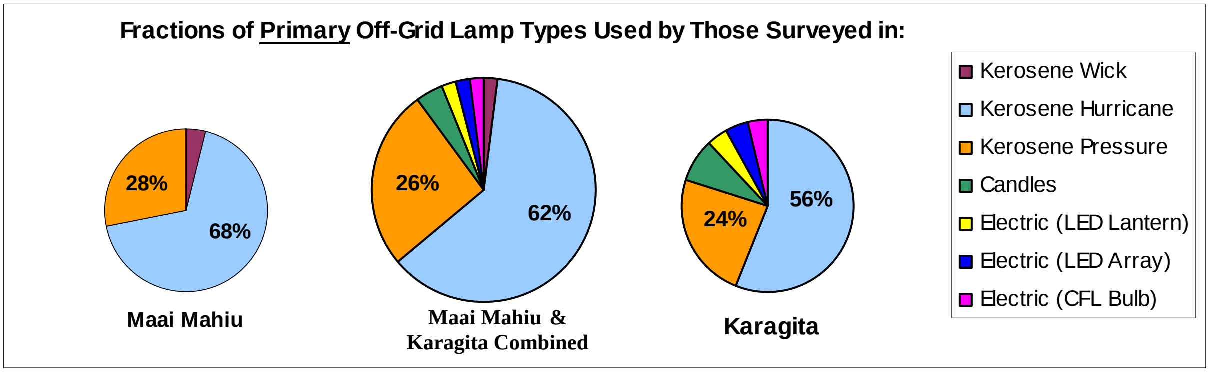
Figure 2. Sections of the markets in Maai Mahiu (left) and Karagita (right) on a sunny afternoon and just before dark, respectively. The electrical distribution lines provide power to some, but not all, of the businesses shown in the images.

Market Vendors and Off-Grid Lighting

Vendors in the markets we studied sell a variety of merchandise, including produce, housewares, clothing, stationary supplies, meats and electronics. As noted above, some of the larger and more established businesses were located in buildings made of brick or stone, and a number of these had an electrical connection. These businesses were located alongside others, including smaller shops and kiosks, that did not have a grid connection. In the sections of the markets where we made careful observations, more than half of the businesses did not have a connection to the electrical grid.

While not all of the off-grid businesses operated into the evening, many that did used kerosene lamps or candles to light their shops and to illuminate their wares. Our surveys of 50 small businesses in the two towns confirm that they use a diverse set of lighting technologies (see Figure 3). Hurricane-style kerosene lanterns were the dominant technology, followed by pressure-style kerosene lanterns. A variety of other technologies, including wick lamps, battery powered flashlights (i.e., electric torches), and rechargeable LED-based lamps, make up the balance of the products identified in our sample.[3] See Figure 4 for images of typical lighting technologies used by the small businesses observed in the study.

[3] It is interesting and important to note that the distribution of lighting technologies used by small businesses in these two towns differs from the distribution observed by two of the authors in 2007 in markets in Kisumu and Yala (Nyanza Province, Kenya). In those markets, kerosene wick lamps were the most common technology used by off-grid businesses that operated in the evening hours (Mills and Jacobson, 2007). The difference in lighting technology use between the markets in the two regions is likely driven primarily by economic factors, although weather patterns may also play a role. The region in the Rift Valley around Naivasha is somewhat wealthier than most areas in Nyanza Province, although both are characterized by high levels of poverty. The somewhat higher income levels in the Naivasha area may provide vendors with an opportunity to invest in the more expensive hurricane and pressure-style lamps, which can typically be purchased for approximately \$7 and \$22, respectively, while many of their lower income counterparts in Nyanza Province are forced to make-do with inexpensive wick lamps, which generally can be bought for \$0.20 - \$0.30. Weather patterns may also play a role, though, as the area around Naivasha is characterized by high winds. As a result, wick lamps are impractical in this region for semi-outdoor applications



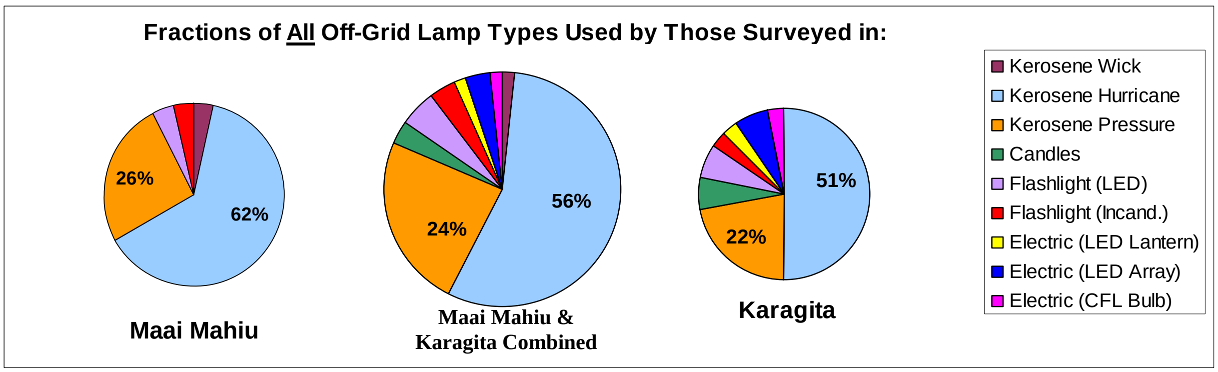


Figure 3. Distribution of Lighting Technologies Used by 50 Off-Grid Businesses in Maai Mahiu and Karagita. The upper charts provide information about the primary light used by each business, while the lower charts include all lights used by the businesses (n = 50 businesses, evenly divided between Maai Mahiu and Karagita).

Figure 4. Kerosene lamps used by small businesses in Maai Mahiu and Karagita, Kenya: hurricane-style, pressure-style, and wick lamp (from left to right)

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such as selling from a kiosk or vegetable stand. In any case, geographical variations in lighting technology use highlights the need for attention to place-based analyses of the uses and economics of off-grid lighting technology.

During our field work, we observed that many of the shops that used kerosene lighting purchased their fuel in small quantities from local vendors on a daily basis. Each town had a shop that sold kerosene from a metered pump; these shops appeared to dominate kerosene sales in the town. See Figure 5 for images of a typical kerosene vending business. The towns also had other kerosene sellers ranging from petrol stations to street vendors who sold kerosene in small soda bottles. See Table 1 for kerosene prices for July, 2008. Many of the vendors noted that kerosene prices had increased dramatically in recent years. Kerosene price data from the Kobil station in Maai Mahiu and the Total station in Naivasha Town, near Karagita, from January 2004 to October, 2008 confirm this observation (Figure 6).

Figure 5. Kerosene vending shop (left) and vendors filling a container for a customer (right)

Table 1. Kerosene Prices for Vendors in Maai Mahiu and Karagita, Kenya
(prices from July, 2008; $1US = 67 Kenyan Shillings, Ksh)

Kerosene Source	Kerosene Price (Ksh/liter)
Maai Mahiu Kerosene Shop (pump)	79
Maai Mahiu Kobil Petrol Station	81
Karagita Kerosene Shop (pump)	114
Karagita OiLibya Petrol Station	82
Karagita Street Vendors (sold in soda bottles)	88

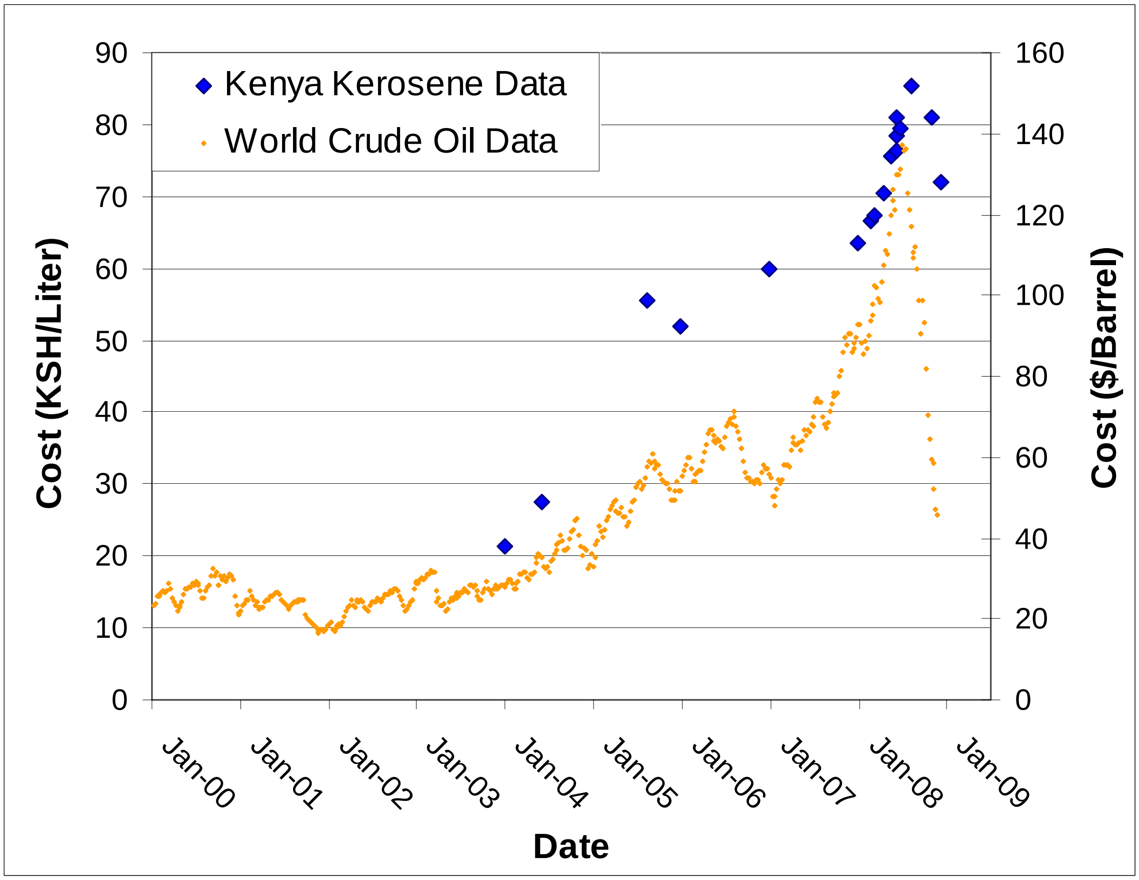

Figure 6. Kerosene Prices (Ksh per liter) at the Kobil petrol station in Maai Mahiu and Total petrol station in Naivasha Town, near Karagita, from January 2004 to November 2008. Representative world crude oil prices ($US/barrel) are included for comparison purposes.

In addition to kerosene for lighting, many small off-grid businesses utilized battery powered devices such as flashlights (i.e., electric torches) and mobile telephones with integrated LEDs. Many flashlights use dry cell batteries, but rechargeable flashlights have become increasingly common in Kenya since their introduction two to three years ago. Most rechargeable flashlights use low cost LED lighting sources and small sealed lead acid (SLA) batteries. Many brands are available at prices ranging from 150 to 300 Ksh ($2.20 - $4.50) in local shops. These products, while inexpensive, have a mixed record with respect to quality. Results of laboratory tests conducted by our research team indicate that some brands perform reasonably well, while others perform poorly (e.g., see Mills and Jacobson, 2008). See Figure 7 for typical rechargeable flashlights on sale by a street vendor in Naivasha Town and Karagita.

Figure 7. LED flashlights shown in a shop in Naivasha Town market (left), an LED torch with integrated LED array purchased in Karagita market (middle), and an LED lantern-style lamp with an integrated radio feature purchased in Karagita market (right)

Shops that offer battery charging services for a fee are common in Kenyan towns, and Maai Mahiu and Karagita were no exception. These shops appeared to be the most commonly used charging source for flashlights and mobile phones among those that did not have a grid connection in their home or business. Interestingly, the cost to charge devices in shops tends to be based on a flat rate that is relatively independent of the size of the battery. Shops charge a flat rate in part because it is simple and in part because the cost of the electricity to charge the batteries is a tiny fraction of the overall cost to provide the service. According to charging shop owners, rent, amortization of the cost of purchasing charging equipment, and labor make up the bulk of the cost for delivering the charging services. Table 2 provides a summary of the cost to charge small devices such as flashlights and mobile telephones in Maai Mahiu and Karagita. Note that the price was different in the two towns.

Table 2. Cost to Recharge Flashlights and Mobile Telephones in Shops in Maai Mahiu and Karagita (prices from July, 2008; $1US = 67 Ksh).

Charge Source	Cost per LED Lamp Charge (Ksh/charge)
Maai Mahiu Charge Shops	20
Karagita Charge Shops	10
Cost of Electricity to Charge a 1200 mAh Battery	0.04

Field Methods[4]

Our research to evaluate the economics and use patterns of off-grid lighting involved three main elements. First, we used a short survey to collect information about lighting practices and costs for businesses in the markets where we worked. We interviewed 25 businesses in each of the two markets, for a total of 50 survey interviews. In each case, we selected a geographic section of the market with high business density and interviewed nearly all of the off-grid businesses that operated at night in that area.

Second, after obtaining consent, we made careful measurements of kerosene use and costs for 23 of these businesses, including 12 businesses in Maai Mahiu and 11 in Karagita. The kerosene measurements for each business were made over a period of five to seven evenings. On the evenings that we collected data, we would measure the weight of each lamp two to three times over a period of several hours. We used these measurements to estimate the rate of kerosene consumption for each of the lamps. In addition, we asked each participating business to note the time that they turned their lamps on and off on a given night and the amount they had spent on kerosene fuel. We also crossed checked the accuracy of the reported kerosene lamp on/off times using spot observations and follow up questions. We used the combination of the burn rate data, the times that the lamps were turned on and off, and the information about kerosene prices to estimate use rates and costs for each evening of data collection.

Figure 7. Team members Francis Ngugi and Kristen Radecsky making field measurements of the mass of kerosene lamps

Third, we offered to sell rechargeable LED lamps to each of the businesses that participated in the kerosene use measurement segment of the research. The LED lamps were custom assembled from commercially available components. Each lamp consisted of a gooseneck lamp head that had 12 LED light sources (5 mm size), a lamp body that contained a 1200 mAh nickel metal hydride (NiMH) battery pack and electronic circuitry to control battery charging and power deliver to the LED lamp, a six foot extension cable that allowed users to mount the lamp head away from the lamp body, and an AC charger. A one Watt solar module was available as a second, optional charging source.[5] See Figure 8 for an image of an assembled lamp. In addition,

[4] The field methods employed in this research effort were reviewed and approved by Humboldt State University's Committee for the Protection of Human Subjects in May, 2008.

[5] The gooseneck lamp head, electronic circuitry, AC charger, and solar module were purchased from Barefoot Power (http://www.barefootpower.com/). Other components, such as the lamp body housing, were purchase from various U.S. based suppliers. The NiMH batteries were purchased in Kenya.

the lamp bodies were fitted with a custom data logger designed to collect information about the use of the lamp.[6]

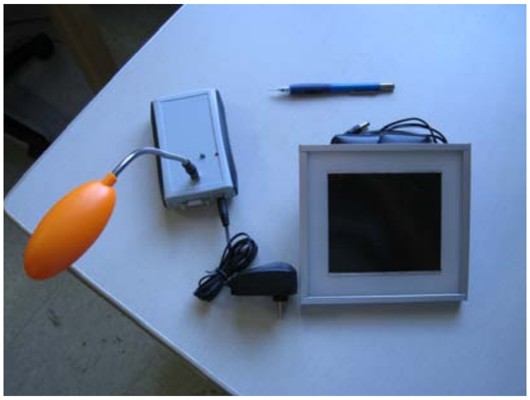

Figure 8. Image of the LED-based lighting kit offered to businesses during the study. The one Watt solar module was available as an optional charging source. The pen included is for scale. A close up of the lamp head and six foot long extension cable for the lamp are shown on the right.

The lamps were offered for sale to customers for a price of 700 Ksh ($10.45) without the solar module, or 1,500 Ksh ($22.40) with the module. These values were based on the expected retail price for similar products that are commercially available on a wholesale basis (although they are not yet widely available in Kenya). Those who chose to purchase the lamps agreed that they would not re-sell them and to allow our team to download and use data from the lamps on a regular basis during the initial six months of the study. In exchange, we provided a full service warranty on the lamps during the initial six months. Once this period has passed, which occurs in January of 2009, our team will remove the data loggers from the lamps. At that point, the users will have an option of receiving a full refund on the lamps, or they can choose to keep them for no additional charge. We plan to conduct exit interviews with each of the lamp users in January of 2009 in order to collect information about their experiences with the lamps. We will report findings from this aspect of the work in a forthcoming publication.

Finally, in addition to these three primary activities, we also collected price information in each of the markets for a variety of items of interest for our research. These included the purchase prices for kerosene lamps, flashlights, LED lamps, and others. We also collected information about the price of replacement parts (e.g., wicks and mantles for kerosene lamps, dry cell batteries, replacement rechargeable batteries) and kerosene fuel.

We used information about kerosene and LED lamp use patterns together with price information to estimate the cost to operate each type of lamp over a two year period. We report the results of this analysis in the next section of the report.

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[6] The custom data loggers were designed and built by Kyle Palmer and Scott Rommel of the Schatz Energy Research Center at Humboldt State University. The loggers record battery voltage and current into and out of the battery every two minutes. The resulting data provide information about when the lamps are in use, as well as when they are being charged.

Results and Discussion

Many of the businesses in the study indicated that kerosene fuel represented a modest but important operating expense. Although we were not able to collect information about business revenues, the mean monthly cost of $4.00 likely represents approximately 2-6% of net income for many of these businesses.

On a typical evening, shops would light their lamps at nightfall, which occurred at about 7:00 pm.[7] They would keep them lit until closing time, which generally occurred between 8:00 and 9:30 pm, although a few shops stayed open until later in the evening. As is suggested by the data in Table 3, businesses in Maai Mahiu tended to stay open later than their counterparts in Karagita. Residents of Karagita indicated the early closing time was due in part to security concerns specific to their town. Many of the businesses also reported using the lamps in their homes in the evening after closing, and some also used them again in the early morning hours.

These use pattern data (Table 3), when combined with information about burn rates for each lamp (Table 4) and kerosene prices (Table 1), allowed for an estimate of the daily cost of lighting for each business (rightmost column in Table 4).[8] While the median daily daily cost of 4.0 Ksh for hurricane lantern users appears modest, it is not an insignificant amount for businesses that may have net profits that are on the order of 50-200 Ksh per day. The daily costs for those who use pressure lamps (24.4 Ksh/day) are far higher. Businesses that use this technology tend to be somewhat larger and more profitable.

Table 3. Business Use of Kerosene Lighting in Maai Mahiu and Karagita

Town	Median Measured Use (hrs/night)*	St. Dev.	Median Reported Use (hrs/night)**	St. Dev.	Median Fuel Cost (Ksh/night)	St. Dev.
Maai Mahiu	2.1	0.97	2.5	1	4.0	10.9
Karagita	1.3	0.22	1.8	0.64	4.4	2.5

*Hours of use observed over at least five days for each business (n = 12, Maai Mahiu; n = 11, Karagita)
** Hours of use reported by each business in the short survey (n = 25, Maai Mahiu, n = 25, Karagita)

We used kerosene use pattern and expenditure results along with information about additional costs such as wick and mantle replacements and the retail prices of the various lamps to estimate the cost of ownership for each lamp type over a two year period. We also used complementary information about the purchase price and performance of the battery powered LED lamps introduced to the businesses and the cost to charge these lamps in local shops to make parallel estimates of the cost of ownership for LED lamps. See Table 5 for a summary of cost data used in the analysis. The results of this two year cost of ownership analysis are presented in Figure 9.

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[7] Maai Mahiu and Karagita are located just south of the equator, so the length of the day is relatively constant throughout the year.
[8] Note that expenses associated with home use of the kerosene lamps are not included in these calculations.

Table 4. Fuel Consumption Rates and Costs for Fuel Based Lighting Technologies Used by Businesses in Maai Mahiu and Karagita

Kerosene Lamp Type	Median Fuel Consumption Rate (g/hr)	Sample Size	Median Measured Use (hrs/night)	Median Fuel Cost (Ksh/night)
Hurricane Lamp (Large)	20.5	14	1.6	4.0
Hurricane Lamp (Small)	14.4	2	1.7	2.5
Pressure Lamp	70.2	7	2.2	24.4
Wick Lamp[9]	15.3	10	2.5	3.2

Table 5. Information about the Cost to Buy and Operate Off-Grid Lighting Sources in Maai Mahiu and Karagita, Kenya

Lamp Type	Retail Price (Ksh)	Hourly Operating Cost (Ksh)[10]	Wick/Mantel Replacements per Year	Wick/Mantel/ Candle Cost (Ksh/unit)
Hurricane Lamp (Large)	459	2.2	4	10
Hurricane Lamp (Small)	235	1.6	4	10
Pressure Lamp	1,495	8.2	8	10
Kerosene Wick Lamp	10	1.7	4	1
Candle	4.38[11]	1.6	--	4.38
LED Lamp (AC charging)	700	2.2	--	--
LED w/Solar Charging	1,500	0	--	--

The results indicate that the two year ownership cost is considerably higher for pressure lamps than for any of the other options due to their high fuel consumption. In cases where users charge at a shop, the two-year ownership cost for the LED lamps that we introduced is similar to the cost of operating a standard sized (i.e., large) hurricane lantern. In Karagita, where the charging cost is 10 Ksh, the estimated ownership cost for the LED lamp is about 2,200 Ksh over two years. This is almost 40% lower than the cost to use a large hurricane lamp (approximately 3,500 Ksh over two years). The cost to use the LED lamp is somewhat higher in Maai Mahiu (3,700 Ksh) due to the higher 20 Ksh cost for charging. LED lamp users that have grid access (e.g., off-grid businesses where the owner has electricity at home) are able to avoid the cost of charging shops, which yields a far lower operating cost for LED lamps (710) Ksh over the two year period. We estimate that those who purchase the solar module would pay as little as 1,500 Ksh over two years.

[9] The fuel consumption rate measurements for the wick lamp are from data collected by authors E. Mills and A. Jacobson in 2007. The measurements were made at off-grid businesses in Kisumu and Yala (Nyanza Province, Kenya). We use these data because, although they are commonly used in other parts of Kenya, only one vendor in Maai Mahiu and Karagita used a wick lamp. We therefore were unable to collect sufficient data for this lamp type in 2008.

[10] These values were calculated using a kerosene price of 89 Ksh per liter and an AC charging cost of 20 Ksh/charge.

[11] This is the per unit price for candles purchased in a pack of 8 in a shop in Maai Mahui in June of 2008.

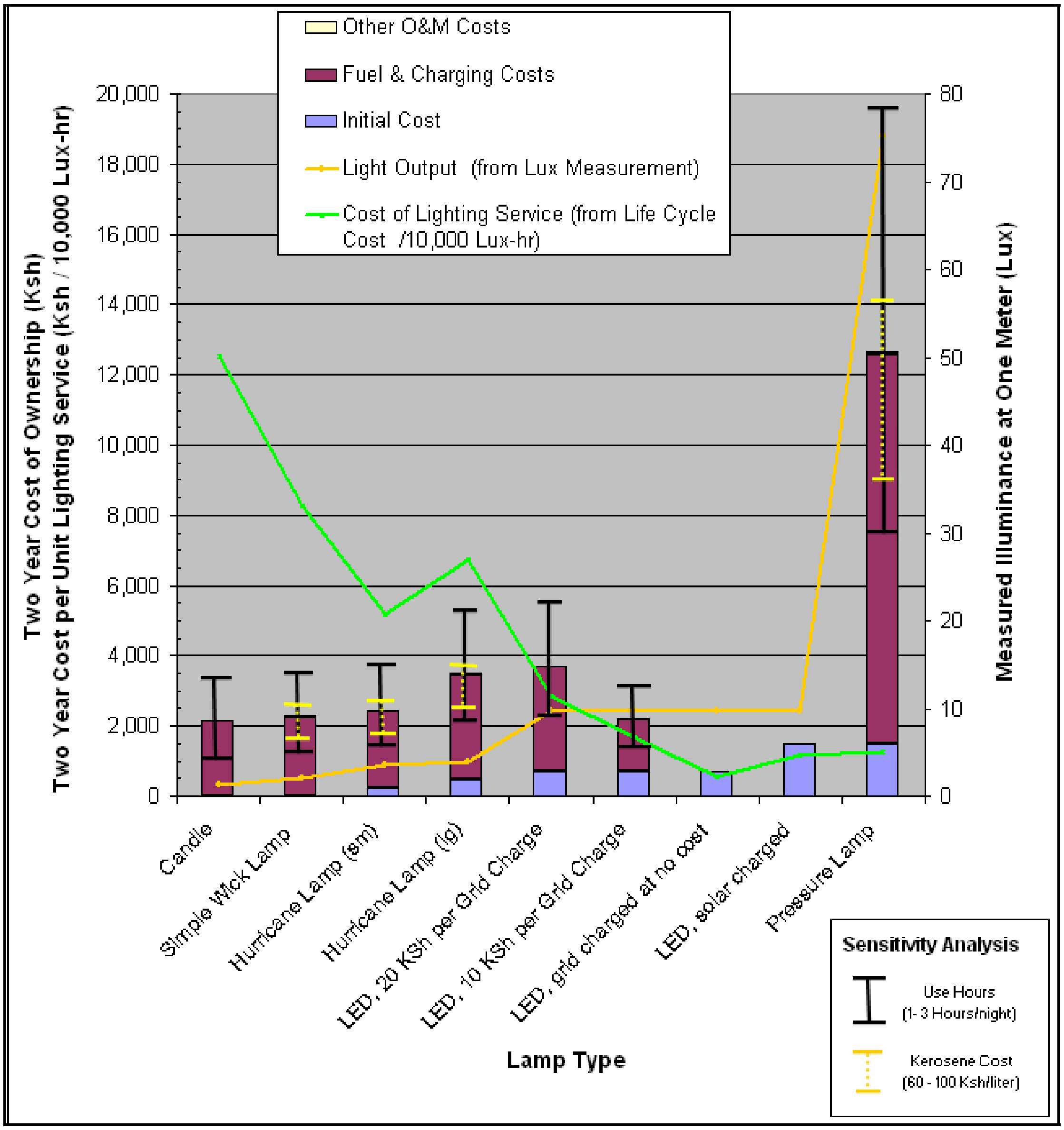

Figure 9. Estimated Two-Year Cost of Ownership for Lighting Technologies Used by Off-Grid Businesses in Maai Mahiu and Karagita, Kenya.[12]

The two year cost of ownership for a grid charged LED lamp is driven largely by a combination of the charging fee and the number of hours of light delivered by a full battery charge. While product designers generally have relatively little control over the charging fee, they can improve affordability by increasing the capacity of the battery. This is true because the cost to charge a lamp is relatively independent of the size of the battery. As noted above, shops in towns like Maai Mahiu and Karagita typically set a fixed rate to charge batteries in a given size range (e.g. < 10 Ahr). This approach makes sense, as the cost of electricity is a tiny fraction of the overall cost to charge the device (e.g., see Table 2). The result is that increasing the size of the battery (e.g., from 1,200 mAh to 2,000 mAh) can decrease the cost of ownership considerably by

[12] The estimated costs in Figure 9 are based on an assumption that businesses use each lamp type for 1.85 hours per day and a kerosene fuel cost of 89 Ksh/liter.

allowing more time between charging events. If this increase in capacity is achieved without raising the purchase price substantially, the overall affordability of the lamps can be improved. As noted previously, it is also possible to increase the number of hours between charging events by decreasing the power consumption of the light sources (LEDs).

As shown in Figure 9, we conducted a sensitivity analysis for the cost of ownership by varying two key parameters. The lower and upper black sensitivity analysis markers indicate cost of ownership values for each lighting source for lighting use rates of one and three hours per night, respectively. These numbers confirm that – with two exceptions – the cost of ownership is strongly influenced by the use rate for each light type. The first exception is the solar charged LED lamp. The cost to use this lamp does not vary with use rates because solar charging is free, but it is important to recognize that use is limited by the size of the solar module and the availability of the solar resource. The solar charged version of the LED lamp in our study could be used for just over two hours per day on average given the local solar resource, although there are cloudy periods in the year when the availability would be considerably lower.[13] The second exception is the grid charged LED lamp in circumstances where people are able to charge without paying a fee. Here, there are very minor variations in cost with changes in use, but the differences are negligible due to the very low cost of electricity per charge.

The second sensitivity analysis provides information about variations in cost of ownership due to changing kerosene prices. The yellow sensitivity analysis markers (dashed lines) show variations in the two year cost for average kerosene prices ranging from 60 Ksh/liter to 100 Ksh/liter. The baseline values were calculated using 89 Ksh/liter (the price in early July, 2008), but prices have declined since then in response to the sharp drop in world oil prices. These sensitivity analysis results confirm that the cost of ownership of the kerosene lamps is strongly influenced by kerosene prices. It will be interesting to note if demand for LED lighting products shifts with variations in the cost of fuel based lighting. We will explore this issue in subsequent research.

In addition to the two year cost of ownership, we also estimated the cost to operate each lamp per unit of lighting service delivered. Here, we used the illuminance on a surface at a distance of one meter from the lamp as the measure of lighting service. The results, reported in Kenyan Shillings per 10,000 Lux-hours, are presented in Figure 9 along with the two year cost of ownership values.

The cost of lighting service analysis confirms that the LED lamps provide lower cost lighting services than candles, kerosene wick lamps, or kerosene hurricane lamps, regardless of which charging method (solar or grid) is used (see Mills, 2005 for an earlier analysis). The results also indicate that kerosene pressure lamps provide lighting services at a cost rate that is lower than LED lamps that are charged at a shop for a fee and comparable to the rate for the solar charging option. This is true because of the very high burn efficiency of the pressure lamps. A summary of these results is provided in Table 6.

[13] Solar charging could, of course, be supplemented with grid charging for this product during cloudy periods. This would increase the price of operating the lamp modestly, but it would also improve its ability to reliably deliver lighting services.

Table 6. Cost of Lighting Services for Off-Grid Lighting Options in Maai Mahiu and Karagita, Kenya

Type of Light		Cost / lux-hr (Ksh)	Illuminance at 1 meter (Lux)
Kerosene Hurricane Lamp (Large)		0.67	3.8
Kerosene Hurricane Lamp (Small)		0.52	3.5
Kerosene Pressure Lamp		0.12	75.2
Kerosene Wick Lamp		0.83	2.0
Candle		1.25	1.3
LED Lamp Option	**Charge Cost (Ksh)**	**Cost / lux-hr (Ksh)**	**Illuminance at 1 meter (Lux)**
AC Charging (Maai Mahiu Shop)	20	0.28	9.7
AC Charging (Karagita Shop)	10	0.17	9.7
AC Charging (no charging fee)	0.04	0.05	9.7
Solar Charging	0	0.11	9.7

As we discuss below, the results of this cost of lighting services analysis may explain some of the purchasing patterns that we observed when selling the LED-based off-grid lighting products used in the study. Namely, end users considered the level of lighting service as well as the cost of the product when making purchasing decisions. In total, 14 businesses chose to purchase/lease the LED lamps, including 10 of 12 businesses in Maai Mahiu and four of 11 businesses in Karagita.[14]

All 14 of the businesses that chose to purchase LED lamps selected the grid charging option. None of the businesses decided to buy the optional solar module when the initial transactions were made in June and July of 2008, although some indicated an interest to purchase the module at a later date.[15] In conversations with business owners, the higher purchase price for the solar option (1,500 Ksh) was the primary reason cited for choosing the grid-based charging lamp (700 Ksh). Additionally, nine vendors asked to purchase the lamps on credit; in these cases we agreed to allow buyers to pay 350 Ksh initially and the balance within 30 days. Overall, our experiences interacting with the businesses indicated that most would consider purchasing lamps at retail prices below $15 (i.e., approximately 1,000 Ksh), but relatively few would consider purchasing lamps at higher prices. These findings are consistent with market research results published by the Lighting Africa Project of the International Finance Corporation and the Energy and Water Department of the World Bank (Lighting Africa, 2008b).

Of those that did purchase an LED lamp, 10 owned hurricane lamps and 4 owned pressure lamps. These purchasers represented 63% and 57% of the hurricane and pressure lamp owning

[14] In other words, approximately 60% of the businesses that were given an opportunity to purchase a lamp chose to do so. The difference in purchasing patterns between the two towns may be related to income levels, as Maai Mahiu has a moderately stronger economy. The difference may also reflect relatively stronger relations of trust between our field team, which included a long term resident of Maai Mahiu, and businesses in that town than existed between our team and the businesses in Karagita.

[15] Although the solar modules remain available to the businesses through our team's agent in the field, none have chosen to purchase a solar module as of November, 2008. This remained true even after we reduced the purchase price for the modules from 800 Ksh to 500 Ksh in September ($11.94 and $7.46, respectively).

businesses in the study, respectively. While these results seem to suggest similar levels of interest in the LED lamps by hurricane and pressure lamp using businesses, other evidence suggests that those who owned pressure lamps were not interested to use the LED lamps as a substitute in their businesses. First, when given a chance to purchase LED lamps in June and July, a number of the pressure lamp owners correctly commented that the LED lamps were not bright enough to act as a substitute for their existing lamps. Second, recent field observations by our team appear to indicate that at least three of the four pressure lamp using businesses that purchased an LED lamp have not used the new lamps in their place of business on a regular basis. Instead, they appear to be using them at home. These observations suggest that pressure lamp owners were less interested in using LED lamps in their businesses than hurricane lamp owners were, despite the fact that pressure lamp owning businesses appeared to be wealthier than hurricane lamp owning businesses. One possible reason for this preference is related to the lower level of lighting service provided by the LED lamps relative to their pressure lamps.

Conversations with lamp owners at the time of sale support the idea that businesses considered initial costs, operating costs, and the level of lighting service when making their purchasing decisions. Prior to offering the lamps for sale, our team presented estimates of the two year cost of ownership for the various lighting options to each of the business owners. After considering this information, many of the pressure lamp owners declined to purchase the LED lamp – despite its lower operating cost – because they felt that it did not produce sufficient light to illuminate their businesses. Likewise, a number of hurricane lamp owners in Maai Mahiu chose to purchase the LED lamps despite the fact that the cost of ownership was somewhat higher than their kerosene lamps because they were impressed by the level of lighting service that the LED lamps provided.

Conclusions

Solid-state lighting using LED technology is a promising substitute for fuel-based lighting, but there is a need for a greater number of affordable, high performance off-grid LED lighting products that meet the needs of end users if this promise is to be realized. This report is intended to present findings about the economics of lighting technology for one group of potential early adopters – small, off-grid businesses that operate at night. The goal is to provide manufacturers with information that they can use to improve the affordability and performance of their products.

Most of the off-grid businesses in Kenya that participated in the study had a strong interest in LED lighting as a substitute for kerosene lighting. At the same time, the businesses were very price sensitive; products that cost less than $15 appeared to be affordable, while those with higher retail prices were not.

It was especially notable that while 14 of the 23 businesses that were given an opportunity to purchase an LED lamp decided to do so, none of them elected to buy the optional solar charger due to its higher price. Instead, they chose to charge using power from the AC mains. This was true despite the fact that for most of the businesses charging with AC power involved a cost of $0.15 to $0.30 per charge at a grid-connected shop. In other words, the businesses chose an option that involved a lower initial purchase price and higher operating costs over an option that involved higher initial cost and near zero operating costs.

In many cases, in fact, businesses chose to purchase an LED lamp that involved a two year operating cost that was equal to or moderately higher than the cost of their existing kerosene lamp. Our observations and discussions with the business owners suggest that many chose to do so because the LED lamps provided a higher level of lighting service than their existing lamps.

Finally, while the businesses appeared to be most constrained by the initial cost of the lamps, they did express concern about operating costs. Here, we note that for lamps that are charged with AC mains at a charging shop, an increase in the number of hours of lighting between charging events results in lower lamp operating costs. Increased run time can be achieved either by reducing the power consumption of the light source (LEDs) or increasing the capacity of the battery. The most desirable and affordable products, therefore, strike a balance between the level of lighting service, the initial cost of the lamp, and the number of hours of lighting between charging events.

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