ID RL6 058

Alternatives to Fuel-Based Lighting in Rural China

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Keywords

China, LED, rural lighting, solar power, Tibet, fuel lamps, kerosene, diesel, CFL, flashlight

Abstract

Despite high rates of electrification in China, 25 to 30 million people remain without access to electricity. This population, as well as those with only intermittent access, must rely on alternate sources of power for their lighting needs. This paper presents a comparison of available off-grid and grid-based lighting options in terms of performance and economics, which is then contextualized using a case study of semi-nomadic populations in rural Tibet. Fuel-based lighting is shown to be significantly more costly than solar-powered compact fluorescent lamps (CFLs) and solar-powered light-emitting diode (LED) alternatives per unit of lighting services delivered. We calculate that a hurricane-style kerosene lamp costs approximately $0.40 per thousand lumen hours (klmh) or $2.89 per thousand lux hours (klxh), while a solar-CFL lantern costs $0.17/klmh and $1.20/klxh and a solar-LED device costs $0.15/klmh and $0.03/klxh. Furthermore, as LED efficiencies continue to improve, solar-LED products will become even more economical.

Three focus groups and 15 household interviews were held among off-grid populations in rural Tibet to gauge response to LED technologies. LEDs were universally ranked below CFL alternatives, primarily due to the directional nature of the LED devices exhibited, but were still ranked above all non-electric sources of light. Diffusing optics may thus need to be incorporated into solar-LED lighting systems before they are rated as more attractive for general illumination than solar-CFL systems. Accordingly, those surveyed placed a high value on the use of LED bulbs for flashlight applications. Finally, we note that despite the potential benefits of LEDs, market forces are not likely to spur innovation in solar-LED lighting options for the unelectrified populations of Tibet, as the design of these systems is dominated by the governmental bodies subsidizing their distribution. Unless this structure changes, the future development of LED-lighting technologies will depend on top-down investment from the central and local governments.

Background

China's recent electrification campaigns have been highly successful, with 97% of all townships, villages, and rural households in China receiving electric power in 1999 (State Statistical Bureau

2000).[1] Yet 25 to 30 million people in rural China remain without electricity today, and a much larger population has only intermittent access (Wang 2004). Those without access to electricity must resort to alternative sources for lighting, both in their homes and in non-residential settings. In addition, China's booming economic growth and the resultant energy demand has outpaced the country's generation capacity, leaving other segments of the population with only intermittent access to electricity. According to the U.S. Department of Energy, China's electricity shortfall will exceed 20,000 megawatts this year alone (Chellam 2004). Thus, there is a need to explore off-grid technologies for lighting in China. Although China is a critical player in the global lighting market, not only with respect to its energy consumption for electric lighting (estimated at 120 billion kilowatt-hours per year in 1991 by Fu Min, Mills, and Zhang 1997), but also as a major manufacturer and exporter of conventional modern lighting technologies, there is a lack of literature on its role in the development and consumption of off-grid lighting technologies. In this paper, we explore the technological, sociological, environmental, and market-based drivers for renewable, energy-efficient lighting in rural China. Specifically, we examine white light-emitting diodes (LEDs) powered by small solar panels, and the major hurdles that must be overcome for widespread dissemination of this technology. A cost-benefit comparison of alternative lighting technologies is presented, and then contextualized via a case study with semi-nomadic populations in rural Tibet.

Data presented in this report were drawn from a review of relevant literature as well as personal interviews, qualitative household surveys, and focus groups conducted by the authors between January and December of 2004. In-country personal interviews were carried out in Beijing in July and August 2004, utilizing governmental sources that included representatives from the Ministry of Science and Technology, the National Advanced Materials Productivity Promotion Center, and the Beijing Science and Technology Commission. Other notable in-country sources were the German Technical Cooperation (GTZ), the China Renewable Energy Industries Association (CREIA) and IT Power Consultants, as well as one of China's nominated equipment providers for its Township Electrification Project, the Beijing Jike Energy New Technology Development Company. Field research in Tibet was carried out in August 2004. Qualitative surveys and focus groups were conducted in five unelectrified villages in the Lhasa area of Tibet and one village in the Shannan area.[2]

The Case for Solar-LED Lighting

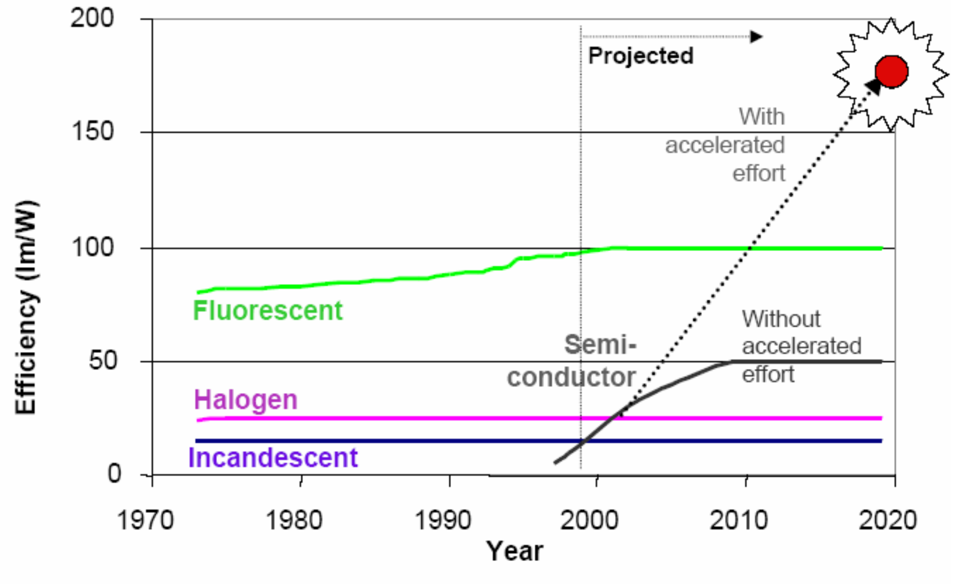

Figure 1: Comparison of achieved and projected bulb efficiencies of white LEDs, denoted by the "Semiconductor" line, with other white light sources (Drennen 2001). A strong increase is projected for LED efficiencies, while those of the other sources have saturated.

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[1] This number was observed to be remarkably well-accepted within both the public and private domains of the Chinese energy sector.

[2] The villages in the Lhasa area were the Shara, Badu and Ribu villages in Lhin Drup County and the Tong Kar and Drong Kar villages in Damshong County.

For over a decade, the state-of-the-art alternative to fuel-based lighting for the developing world has been solar photovoltaic panels powering relatively efficient compact fluorescent lamps (CFLs). The high wattages of these lamps necessitate costly lighting systems, the price of which are dominated by the solar panel and battery components, and scale with the power output needed. The retail costs of these systems to the end-user are often prohibitive; they may be on the order of the annual household income of the world's poorest households. As a result, the potential for these systems has remained highly dependent on subsidy. However, recent advances in solid-state lighting technologies may afford a dramatic shift in the design and economics of solar-powered lighting, by requiring significantly less power and thus smaller solar panels and storage batteries.

The efficiency (lumens of light emitted per watt of power input) of solid-state LED lamps has increased dramatically in recent years, with white sources entering the market in the mid-1990s. The prototypical 1960s-era red indicator LEDs produced only about 0.1 lumens per watt (lpw), while today's best white LEDs approach 50 lpw. Sub-watt white LEDs attaining 100 lpw are expected in 2005. In contrast, the first-generation "keychain" white LEDs with which most consumers are familiar produced only five lumens per watt.

Performance Analysis

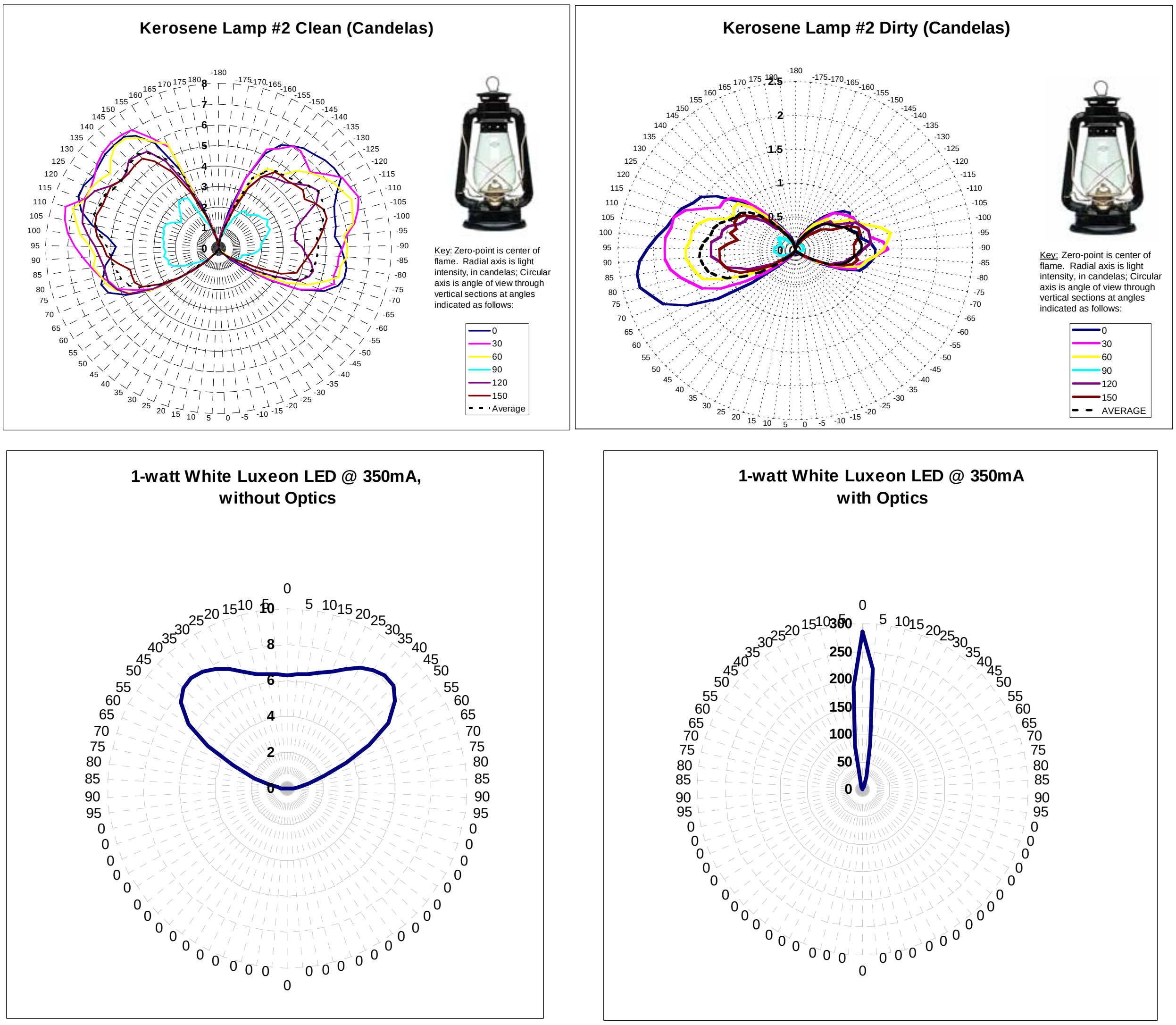

Figure 2: Candlepower diagrams for a hurricane-style kerosene lamp with a clean globe (top left) and a dirty globe following one hour of use (top right), and for a one-watt white Luxeon LED without optics (bottom left) and with optics (bottom right). One candela is equivalent to one lux at one meter.

Figure 2 summarizes performance data measured by Mills (2003) for a Chinese-made hurricane-style kerosene lantern with a 12 millimeter wick (both clean and dirty globe cases), and a one-watt white

Luxeon LED (approx 25 lpw), with and without focusing optics. The kerosene lantern is representative of the fuel-based lighting used in much of the world, although the poorest households have simpler lamps with an open wick and up to fivefold less light output.[3] It can be seen that these fuel-based lanterns do not provide adequate levels of lighting services, and the flux declines rapidly with time as the globe becomes soiled with soot. The light output of the kerosene lantern was 48 lumens with a clean globe, falling to only eight lumens as soot accumulated after a single burn cycle. For reference, a typical 60-watt incandescent lamp emits roughly 800 lumens of light. We observed that the unfocused white LED has a lighting intensity similar to that of the clean fuel lantern, but its intensity remained constant with time. Focusing the LED light output was easily accomplished by means of an inexpensive (i.e. less than $1) polycarbonate lens, and afforded a 40-fold enhancement in narrow light output. We note that LED light sources coupled with optical controls are becoming more efficient than even fluorescent sources (illustrated in Figure 3a). Still, further advancement in LED efficiencies and luminaire design is needed to address general illumination configurations.

LEDs offer other important attributes for developing country applications, including ruggedness and significantly longer service life than competing electric light sources. The rated lifetimes of LED lamps are approximately 50 times those of incandescent lamps and five times those of fluorescent lamps.

Economic Analysis

We prepared a comparative economic analysis, shown in Figures 3a and 3b, of “competing” on- and off-grid lighting alternatives, ranging from fuel-based lamps to traditional grid-connected incandescent lamps to portable solar lanterns using CFLs or LEDs. (Figure 3a also lists the carbon dioxide emissions from each of the alternatives.) Assuming that the initial costs are amortized over a three-year period and that lighting usage is four hours per day, the operating costs range from $0.01 per thousand lux-hours (klxh) or $0.002 per thousand lumen-hours (klmh) for a grid-connected CFL to $59 per klxh or $38 per klmh for flashlights, which are widely used as a supplement to off-grid lighting.

This analysis illustrates the economic motivation for development of LED-based systems. When evaluated in terms of total cost of ownership (fixed and variable), the LED systems emerge as the most cost-effective solution for off-grid task lighting, with costs of $0.03 per klxh for the most advanced LED system, versus $2.89 per klxh for the Hurricane-style non-pressurized fuel lantern and $1.20 per klxh for the solar-CFL system. The LED systems are cost-competitive for general lighting, as well, with costs of $0.15 per klmh for the advanced LED system, versus $0.40 and $0.17, for the non-pressurized fuel lantern and the solar-CFL system, respectively. Comparisons to grid-connected lighting must consider that rural electricity may be more expensive than the official estimates of approximately $0.06 per kWh.

The continuing progress in LED light output and efficiency depicted in Figure 1 has important implications for the economic viability of the technology in off-grid applications. In such applications, the driving costs are those of the solar panel and the batteries, which scale with the power requirements of the lighting source. Thus, as efficiencies of LEDs increase, solar-LED systems should become significantly cheaper than comparable solar-fluorescent packages for general lighting applications.

Our analysis shows that switching to the solar-LED system used in Figure 3a would have a payback time of less than two years when replacing the fuel lamps, and less than six months for candles, flashlights and the off-grid CFLs. Alternatively, if financed using micro-credit over a two- or three-year period, the LED systems could create concrete savings (i.e. lower cash outflow) for the user from the outset.

Figure 4 presents our derivation of fuel usage for lighting of unelectrified households in China. Due to the lack of data, this analysis excludes non-residential usage (e.g. in schools, night markets and workplaces), which may be equally significant. Note that the calculations are intended to represent unelectrified households in all of China, and therefore some of the initial assumptions differ from what was observed in the case study in Tibet.

We estimate that over 600 million liters of fuel are used each year for rural household lighting in China, equivalent to 23 petajoules (10^{15} Joules) or 0.5 million tonnes of oil equivalent (MTOE). The

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[3] We do not consider pressurized kerosene lamps, which have a much higher light output as well as significantly higher costs (see Figure 3), to be typical lighting sources for unelectrified populations.

	60W Incandescent Lamp (grid-connected)	0.74W Incandescent Flashlight (alkaline battery)	15W Compact Fluorescent Lamp (grid-connected)	6W Compact Fluorescent Lantern (alkaline battery)	5W Compact Fluorescent Lantern (solar/NiMh battery)	Candle	Simple Kerosene Lamp (wick)	Hurricane Kerosene Lamp (wick)	Pressurized Kerosene Lamp (mantle)	3x0.1W LED Flashlight (solar/NiMh battery)	1W LED with Optics (solar/NiMh battery)
Performance											
Rate of energy use (Watts or liters/hour)	60	0.74	15	6	6		0.01	0.03	0.07	0.30	1.0
Lamp, wick, or mantle service life (hours)	1000	15	5000	3000	3000	2.5	200	400	1000	50000	50000
Replacement bulbs, wicks, or mantles (number per year)	1.5	97.3	0.29	0.49	0.49	584	7.3	3.7	1.5	0.00	0.00
Batteries	0	2 D Alkaline	0	4 D Alkaline	1 NiMh	0	0	0	0	1 AA NiMh	3 AA NiMh
Replacement batteries (number per year)	0	360	0	365	0.73	0	0	0	0	0.730	2.190
Energy services provided											
Light output (lumens--lamp only)	792	3.8	873	131	213	7.8	7.8	45	1300	18	60
Useful illumination (lux, including optical losses at typical working distance)	111	2.4	122	18	30	1.1	1.1	6.3	182	8	320
Efficiency (lumens per watt)	13	5	58	22	36	n/a	n/a	n/a	n/a	60	60
First cost (lamp + fixture)	5	5	10	15	75	0.10	1	3	10	10	25
Annual Energy Consumption											
Electricity from grid (kWh)	88	0	22	0	0	0	0	0	0	0	0
Kerosene (liters)	0	0	0	0	0	0	15	44	109	0	0
Annual Operating Costs											
Energy	$ 5.26	$ -	$ 1.31	$ -	$ -	$ -	$ 7.30	$ 21.90	$ 54.54	$ -	$ -
Replacement batteries, bulbs, wicks and/or mantles	$ 0.44	$ 209.27	$ 1.17	$ 184.45	$ 27.50	$ 58.40	$ 1.62	$ 3.65	$ 2.19	$ 1.46	$ 4.38
Total	$ 5.69	$ 209.27	$ 2.48	$ 184.45	$ 27.50	$ 58.40	$ 8.92	$ 25.55	$ 56.73	$ 1.46	$ 4.38
Carbon Dioxide Emissions (kg)	96	0	24	0	0		40	120	299	0	0
Operating cost per unit of service											
Light production ($/1000-lumen hours)	$ 0.005	$ 37.72	$ 0.002	$ 0.96	$ 0.09	$ 5.13	$ 0.78	$ 0.39	$ 0.030	$ 0.056	$ 0.050
Index: CFL (grid) = 1.00	3	19,370	1	495	45	2,633	402	200	15	29	26
Illuminance ($/1000 lux-hours)	$ 0.04	$ 59.25	$ 0.01	$ 6.89	$ 0.63	$ 36.63	$ 5.60	$ 2.78	$ 0.21	$ 0.13	$ 0.01
Index: CFL (grid) = 1.00	3	4,260	1	495	45	2,633	402	200	15	9.0	0.7
Total cost per unit of service (1st cost amortized over three years)											
Cost of light ($/1000-lumen hours)	$ 0.01	$ 38.02	$ 0.005	$ 0.99	$ 0.17	$ 5.13	$ 0.81	$ 0.40	$ 0.03	$ 0.18	$ 0.15
Cost of illumination ($/1000 lux-hours)	$ 0.05	$ 59.72	$ 0.03	$ 7.08	$ 1.20	$ 36.65	$ 5.81	$ 2.89	$ 0.23	$ 0.41	$ 0.03
Index: CFL (grid) = 1.00	1.4	1,833	1.0	217	37	1,125	178	89	7	13	0.8
Payback time for switching to 1W LED (years)	15.2	0.1	will not payback	0.1	immediate	0.5	5.3	1.0	0.3		

Assumptions:

Lamp usage	4	hours/day
Electricity price (from grid; non-urban)	0.06	$/kWh (can vary widely depending on local conditions).
D-cell Alkaline price	0.50	$ per battery (non-rechargable)
D-cell capacity	3.00	wh (range 1.5-6)
AA-cell NiMh Battery cost	2.00	$ per battery (rechargable)
AA NiMh Battery life	500	cycles
Large NiMh Solar Lantern Battery Life	500	cycles
CFL Solar Lantern NiMh Battery price	35	$ per battery,
Incandescent lamp price	0.30	$ (60-watt)
Kerosene wick price	0.22	(10Rs reported in Stanford Entrepreneurial Startup Course India survey)
Hurricane lamp wick price	1.00	$, est.
Kerosene tie-on mantle price	1.50	$, est.
Flashlight lamp ("bulb") wattage	0.74	2 D ind. cell flashlight; PR6; Philips
Flashlight lamp ("bulb") price	0.30	$, est.
Fixture price for grid-connected CFL or incandescent	5.00	$, simple hard-wired connection or plug-in lamp
Compact fluorescent lamp price (grid-based)	4.00	$
CFL price for solar lantern	4.00	$ per lamp, assumes whole lantern doesn't have to be replaced when lamp burns out
Fuel Price	0.50	$/liter, avg
Fuel Energy	37	MJ/liter
Fuel w/v (diesel)	0.87	kg/liter
Fuel emissions factor (diesel)	0.074	kg CO2/MJ
Electricity emissions factor	1100	grams CO2/kWh

Notes & Sources:

• Most assumptions for electric light sources reflect high-quality western manufacturing (e.g. lamp life, efficiency); performance of Asian-made product can be much lower.

• LED efficacies projected for end of 2005.

• Lumen output values for standard electric sources are average mid-life values (including depreciation "maintenance factors" where applicable, based on IESNA Handbook Maintenance factor from fig. 6-40 of the IESNA handbook). Values for kerosene lamps are averages of tested levels.

• Derivation of lux values: for general electric sources, assumes even radiation in all directions from source 0.3 m high and 0.5 m from task (lux = 12% lumens). Room contributes another 2% from inter-reflections (3x3x2.5 m room with 50% surfaces). LED values are measurements of Stanford Environmental Startup course prototypes. Kerosene measurements by LBNL goniophotometer in reading plane.

• Cost values shown are estimated retail prices. Costs estimated for the LED systems reflect Ignite Innovations' target market price.

• Wick-based kerosene lamp performance is an estimate of typical values (averaging across a range of types of lamps within each category, rather than lamp-specific results such as those shown in Figure 2); mantle values from "Rural Lighting", by Louineau, Dicko, Fraenkel, Barlow & Bokalders, The Stockholm Environment Institute 1994.

• Mills, E. 1999. "Fuel-based Light: Large CO2 Source". Newsletter of the International Association for Energy-Efficient Lighting (2/98), pp. 1-9. http://195.178.164.205/IAEEL/iaeel/newsl/1999/tva1999/ett299.html

Figure 3a: Comparative analysis of performance and costs of different lighting systems for developing countries. Also included is the payback time for switching from each source to the one-watt LED system.

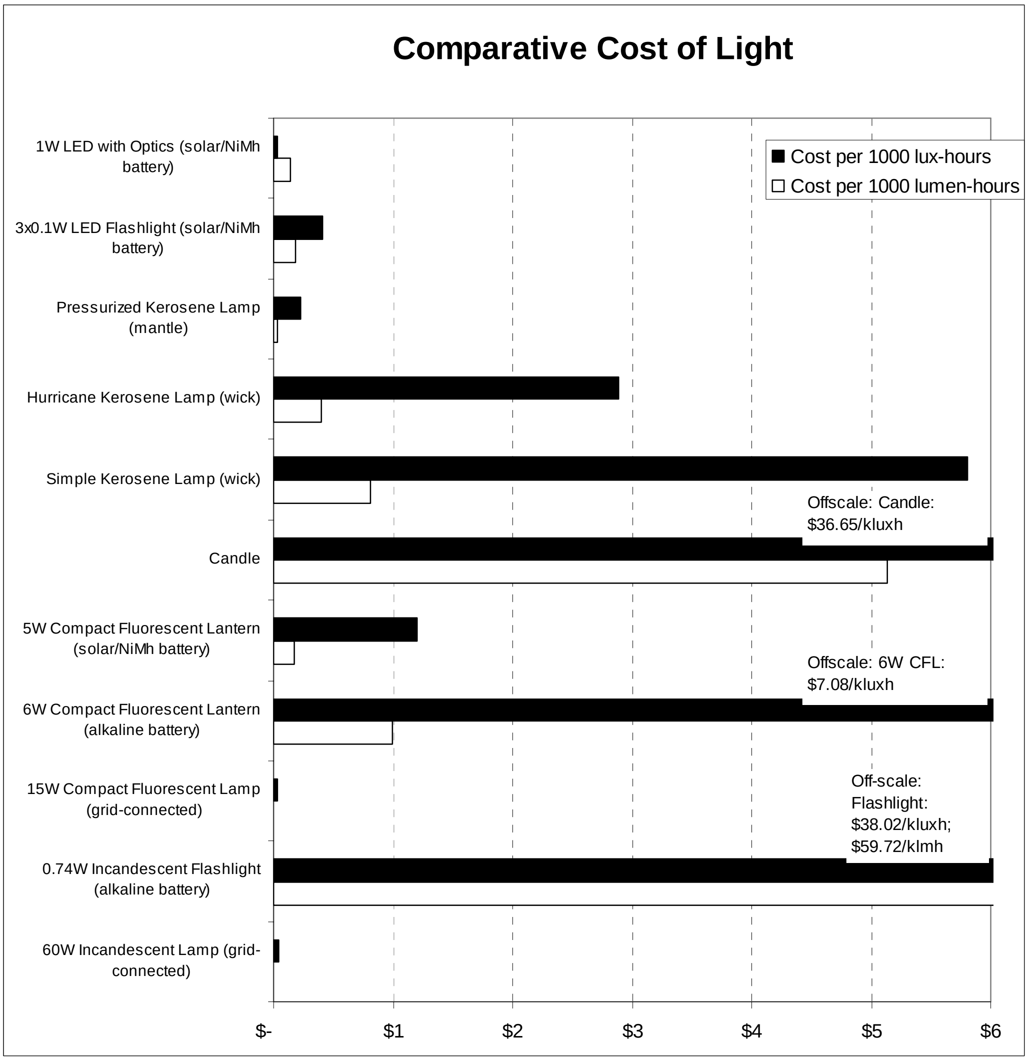

Figure 3b: Graphical depiction of cost per thousand lumen-hours and per thousand lux-hours, by source. (Data from Figure 3a)

cost of this energy is approximately $300 million annually, and it results in 1.6 million tonnes of carbon dioxide emissions each year. The energy services delivered to households by fuel lamps are about 20 times less than what would be provided by 60-watt incandescent lamps powered by electricity. Notably, the per-household energy expenditure for lighting is nearly as high for the rural poor relying on fuel-based lighting as for electrified households in industrialized countries, despite significantly more light sources and more light output per source in electrified households.

Case Study: Solar-LED Lighting for Semi-Nomadic Populations of Rural Tibet

This case study examines the lighting use behaviors and preferences of a significant off-grid population segment: semi-nomadic herders in rural regions of the province of Tibet. Data and observations presented have been gathered from three focus groups and 15 household interviews, conducted in five villages in the Lhasa area of Tibet and one village in the Shannan area. The villages ranged in size from 13 to 248 households. Typical income levels were $100 to $250 annually, and the average household size was at least six members. The villages were designated as “semi-nomadic” because part of the family would leave the village-based domicile for a portion of the year in order to tend to a herd consisting of primarily of yak. Subjects for focus groups and household interviews were generally gathered by the official from the county seat who accompanied us to the village. Focus groups were 10 to 20 people in size, and consisted of most adults that were present in the village at the time of the visit, while interviews involved extensive examination of individual households.

	High	**Central Estimate**	Low
Household Lighting Characteristics			
Population without electricity	30,000,000	**28,000,000**	25,000,000
People per un-electrified household	4	**4**	4
Unelectrified households	7,500,000	**7,000,000**	6,250,000
Fuel lamps per household	4.0	**2.0**	1.0
Number of lamps	30,000,000	**14,000,000**	6,250,000
Lamps per capita	1.00	**0.50**	0.25
Fuel consumption per lamp (liters per hour)	0.05	**0.03**	0.01
Average daily lamp use (hours per lamp)	6	**4**	2
Daily lamp-hours/capita	6.0	2.0	0.5
Annual energy use			
(liters kerosene)	3,285,000,000	**613,200,000**	45,625,000
(GJ)	121,545,000	**22,688,400**	1,688,125
(PJ)	122	**22.69**	2
(MTOE)	2.9	**0.53**	0.04
Liters fuel per month per household	36.5	7.3	0.6
Liters fuel per month per capita	9.1	1.8	0.2
Cost Comparision			
Cost of fuel-based lighting ($Billion/yr)	1.6	**0.31**	0.02
Household Emissions Comparison			
CO2 emissions from fuel-based lighting (MT CO2/yr)	8.5	1.6	0.12
Per Household			
Lighting services provided (1000 lumen-hours per household -- per lamp)			
Fuel-based lighting	394	**131**	33
Electric Lighting (60-watt lamps instead of fuel)	7008	**2336**	584
Ratio:	18	**18**	18
Cost ($/year-household; all lamps)			
Electrified (IEA countries, assume 2.5 people/hh)	82	**82**	82
Fuel-based (at $0.50/liter)	219	**44**	4

Assumptions:

Fuel Price	0.50	$/liter, avg
Output of fuel-based lamp	45	lumens
Output of 60W Incandescent Bulb	800	lumens

Conversion Factors:

0.070	Million Tonnes CO2/PJ fuel
37	MJ/ liter fuel
42.6	PJ/MTOE

Figure 4: Estimates of the energy used for household fuel-based lighting in China. The table does not include non-residential usage (e.g. in schools, night markets, workplaces), which could be equally significant. Note that these numbers refer to all of China; the assumptions of household size and fuel or lamp use do not always match what was observed in the case study in Tibet.

Current System of Lighting Use

Villagers reported using artificial lighting for three to six hours per day, divided into periods before sunrise and after sunset, for cooking, eating, cleaning, weaving, spinning and studying, if there were children in the house enrolled in school. Respondents cited one of two sources as their primary light source, either a solar home system or diesel[4] fuel lamps. Diesel lamps and candles were cited as supplementary lighting sources in some households, while all households reported using flashlights for outdoor transit and for tending to animals. Two respondents reported using yak oil or dung for lighting, and, uniquely, households in the Shara village had used kerosene prior to obtaining solar home systems. Details on each of the various lighting sources were collected and are summarized below.

<u>Solar Home Systems:</u> In most cases, solar home systems had been donated or subsidized by the central or local governments or outside organizations, such as the U.S. Department of Energy or the World Bank; otherwise, the systems had been purchased independently in Lhasa. Villagers reported paying between no fee and $150 for their systems, depending on the amount of subsidy (100% subsidy to no subsidy). Different brands of systems were found in the different villages. Systems were based on either a 10- or 20-watt solar panel, which powered one to three (usually two) CFL bulbs of five to 11 watts each. Some systems also operated radio, tape player or television, but these features were not frequently utilized due to their intensive power consumption. In terms of standard maintenance, CFL bulbs were reported to cost $2 to $3 to replace, and their replacement time varied from two months to two years. They were purchased during infrequent trips to the county seat or, in some cases, from traveling salespeople.

<u>Diesel Lamps:</u> Diesel lamps, consisting of small jars of fuel, each with a thick wick inside, were the second most-cited primary lighting source, but were also reported as a supplemental source to solar-powered lighting. Many of the nomadic family members also reported using diesel lamps as a primary lighting source in tents when tending yak away from the domicile, if they did not take their solar home system. One to three lamps were used concurrently in houses where diesel was the primary lighting source, although it was most common to use only one. The lamps each held close to 100 milliliters of fuel, sufficient to burn for about three hours. Reported fuel costs were approximately $0.50 per liter, and fuel was purchased during trips to the county seat or the xiang (town). In households for which diesel lamps were the primary lighting source, the reported usage varied from one to five liters per month, which amounted to a fuel cost of between $6 and $30 per year. There was no cost for wick replacement, as wicks were made from yak hair. The major grievance with diesel-fueled lighting was that it caused “black spit” and coughing among users. During observation of the lamp in use, thick black smoke was readily observed, and was seen to coat a white sheet of paper held above the lamp within several seconds. The light output of the diesel lamp appeared very low (exact lumens could not be calculated) in comparison to LED and CFL sources, although it was diffuse enough to pervade the room.

<u>Candles:</u> Wax candles were universally preferred to diesel lamps as a lighting source because they burned more cleanly while outputting similar levels of light; however, they were seldom used due to their comparably high cost. In nearly all cases, candles were reported as prohibitively expensive for anything but special occasions. Candles, which were approximately two centimeters in diameter and 15 centimeters tall, cost approximately $0.10 each, and were most often purchased from traveling salespeople. According to respondents, each candle would last between 1.5 and 3.5 hours.

<u>Flashlights:</u> Regardless of a household’s primary lighting source, flashlights were universally used for transit outdoors, as other lighting alternatives were impractical due to lack of portability and/or weather considerations (e.g. wicks did not burn outside because of the wind). The exact type of flashlight used varied between households and villages, but all were reported to cost between $0.60 and $0.75 per device. Batteries cost less than $0.20 per pack and needed replacement every three to ten days. This amounts to a cost of between $7 and $22 per year for 70 to 240 batteries. Batteries were purchased from the county seat or from traveling salespeople that visited the village every one to three months.

Reactions to LED Lighting Products

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[4] Kerosene is a more common fuel globally, and perhaps elsewhere in China. As the costs and performance do not differ significantly, the analysis of kerosene lamps above may be applied to the diesel lamps discussed here.

After establishing the current system of lighting use, we surveyed reactions to two white LED products that were considered exemplar technologies. One was a free-standing luminaire based on a relatively high-power Luxeon LED with good lighting quality. The quality was achieved at the expense of efficiency, which was only 25 lpw. The other test-product was a higher efficiency LED bulb composed of 12 distinct low-power LEDs of relatively low quality, including a strong blue component. The interviewees and focus groups were asked to qualitatively compare these samples with one another and with traditional CFL bulbs, diesel lamps, flashlights and candles in the areas of directionality, perceived luminance and color rendition, and lifetime and power conservation. The responses are summarized below.

Directionality: The strong directionality of LED light was a major complaint among those surveyed, reflecting the finding that illumination throughout a room was generally valued above brighter task-specific lighting. As a result of this trait, LEDs were universally ranked below CFL bulbs (the standard in households with solar home systems) for general illumination. Still, LEDs were strongly preferred to diesel lamps and candles, and there was strong and widespread support for application of LEDs in flashlights, where directional lighting is the norm. We should note that households in other countries have shown a stronger interest in task lighting (Mills 2002).

Service levels and color rendition: Villagers were generally insensitive to coloration of light delivered by the LEDs, but instead placed a high value on the perceived luminance of the source. The LED bulb, while providing much poorer color rendition, was consistently preferred to the Luxeon light solely based on its greater perceived luminance.

Lifetime and Power Consumption: Research subjects appreciated the economic benefits of the extremely long rated lifetimes of LEDs, but this factor was not enough to offset dissatisfaction in the directional nature or higher initial cost of LED light; the standard CFL bulbs were preferred to both LED lights, even with recognition of the potential bulb-replacement savings. Villagers did place a high value on daily operating time, a function of power consumption, but did not express a significant deficiency in the operating time of fluorescent systems.

Toward Widespread Application of Solar-LED Lighting in Tibet

The local market for solar home systems in Tibet is largely driven by subsidies from the central government. A consumer market for solar home systems exists in the city of Lhasa, but its sales volume did not appear comparable to the subsidized market. It is estimated that the National Development and Reform Commission (NDRC) budgets roughly $2.4 billion each year to support economic development in Tibet (Zhao 2004). A portion of this budget, as well as additional funds from projects such as the Township Electrification Project and the Village Electrification Project, directly promotes electrification, including the installation of donated or subsidized solar home systems (Zhao 2004).

The management of these government projects is as follows. NDRC issues project requirements and technical details to companies that have gone through an independent approval process to obtain qualified status. The companies then submit bids for the project. It is typical for projects to be divided into small sub-projects, according to measures such as geographic area. NDRC evaluates the bids and usually awards the projects to several companies. In the recently completed Township Electrification Project in Tibet, for example, Beijing Jike won the project for the Shannan area, while another company, Hua Guan, was awarded the project in the Lhasa area (Wang 2004).

Provincial governments support solar-home-system projects in Tibet, as well. For instance, Beijing Sanpu, a company specializing in solar home systems, has installed more than 200 systems in Tibet using subsidies from the Beijing Municipal Government (Zhao 2004). Finally, external governments and international organizations have also contributed to this donation-based market. The U.S. Department of Energy, for example, has sponsored the installation of at least six kilowatts of photovoltaic power in Tibet (Pandan 2004).

There are several noteworthy limitations associated with the current system of development and distribution of solar-lighting technologies in Tibet. First, because most projects are subsidized or fully funded by the central or local governments, companies are motivated to develop products based solely on the government-issued specifications. Local Tibetans, the end-users of the products, therefore have little influence on product design and improvement. As such, there is no strong driver for innovation, and product development occurs sluggishly by means of a “top-down” approach rather than based on end-user feedback. Moreover, because the products are provided free, or at low cost, there may be little incentive for the end-users to invest in maintenance of the product. This situation is exacerbated by remote geographies and limited communication channels, which generally leave the end-user without the necessary means to seek repair or replacement, or to take advantage of product warranties even when donation programs do provide nominal maintenance plans and guarantees. A significant percentage of the solar-home systems encountered during this field study were non-operational, either due to minor maintenance issues that could not be repaired by local villagers or due to defective products that could not be returned. This same problem has been observed in early efforts to distribute solar-LED systems (Fairley 2004).

A market-driven approach (which would still likely require significant government investment) to the development and distribution of solar-lighting systems in this region would undoubtedly allow for higher quality products to reach the end-users, with stronger incentives for effective maintenance and warranty plans. Unfortunately, until such a system is implemented, the prospect of LED-based technologies reaching this market seems low, due to the lack of incentive for innovation. Moreover, global developers of LED lighting technologies will be hard-pressed to find a sustainable model to serve the population in Tibet; donated and subsidized systems prevent any reliable independent market from emerging, and government contracts are only issued to domestic manufacturers.

Should an accommodating market be developed, however, the landscape for the development of LED lighting technologies for rural populations in China is promising. While China has been a dominant player in the product assembly of LED-based systems for foreign markets, the central government now seems to recognize the domestic potential of LED technologies and is strongly supporting research in the field. The Ministry of Science and Technology (MOST) established an independent organization, the National Advanced Materials Productivity Promotion Center, to coordinate the research and development of LED technologies in China, and the Energy Research Institute of NDRC is playing an increasing role in promoting LED development and dissemination. Challenges do remain; for instance, a national standard for LED performance has yet to be developed in China. Nevertheless, China is well positioned to become a global leader in LED technologies, and has the opportunity to reduce the cost of household LED-lighting solutions for its rural populations.

Conclusion

There remains a need in rural China for solar-electric lighting. This need persists in remote villages where connection to a main grid is not viable, for semi-nomadic populations away from their permanent home, and potentially also for users that experience grid intermittency. Beyond the well-known environmental and health concerns of fuel-based lighting, we have demonstrated a clear inferiority to solar-electric solutions in technical and economic terms.

Currently, solar-electric home systems utilize compact fluorescent lamps (CFLs); however recent advances in light-emitting diode (LED) technology suggest that LEDs have increasing potential to become a more economical alternative, due to decreased power requirements and longer lifetime. Moreover, continued improvements in LED efficiencies are nearly guaranteed, while the fluorescent technology is already mature.

Our survey of semi-nomadic populations in Tibet found that CFL bulbs were universally preferred to LEDs for room illumination, primarily due to a preference for diffusivity over the strong directionality of LED light. While diffusivity could be accomplished by incorporating simple diffusers into a configuration of smaller LED bulbs, higher costs would be incurred and some economic advantage might be lost. There may be an opportunity to reduce the cost of high-intensity LEDs by compromising the light quality, as quality was not strongly valued by the surveyed population. Still, it is unlikely that LED options will find widespread appeal in this, and potentially other rural populations worldwide, until they become significantly cheaper than CFL alternatives.

We find that LED lights could offer immediate benefits for application in flashlights, where their directional nature is advantageous, and their long lifetime and high efficiency could be exploited. From our fieldwork, we estimate that the average semi-nomadic household in Tibet uses and disposes of at least 70 batteries per year, which suggests significant negative environmental impacts. The replacement of incandescent flashlight bulbs by more efficient LEDs would substantially increase the battery lifetimes, helping to alleviate this waste while reducing household expenditures. In the best-case scenario, a small battery charger could be integrated into existing solar home systems for use with rechargeable batteries for LED flashlights. Unfortunately, it is clear that without some change in the local market and distribution system, the benefits from such innovations and the widespread impact of

LED-lighting technologies in Tibet will hinge on the adoption of solar-LED technologies by the governments and other organizations funding the donation and subsidy of the solar home systems.

While the results presented here on the technological and economic merits of LED lighting are clearly applicable to a broad range of markets, one must be careful in attempting to draw generalized conclusions from a qualitative case study, especially one of small sample size. We have performed a preliminary investigation of the utility and viability of LED technologies in serving the lighting needs of semi-nomadic populations in Tibet, the results of which may or may not be applicable to other off-grid populations. Still, despite differences in available resources, distribution channels, and local culture, the observations and conclusions presented here give evidence of the potential for solar-LED lighting to serve rural populations worldwide, while illustrating key challenges and barriers to widespread adoption of these technologies by an exemplary population in rural Tibet.

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Acknowledgements

In writing this article, we have benefited from the support and advice of many people. We would like to specially thank Charlie Gay, an advisor for Sun Power Corporation, who introduced us to invaluable contacts both in the U.S. and in China, and who advised us on research protocol and design. Wang Sicheng, general manager of Beijing Jike New Energy Development Company; Zhao Yongping, general manager of Lhasa Li Huo Photovoltaic Company; and Lhobsang Pandan greatly assisted our field research in Tibet. Jean Ku from the National Renewable Energy Laboratory, and Ryan Wiser and David Fridley from Lawrence Berkeley National Laboratory shared with us their knowledge of energy trends in China, and facilitated our contact with Chinese government officials. Matt Scott, founder of Ignite Innovations, gave us valuable input during our planning process. Stephen Johnson and Kate Conway provided useful comments on the draft. The Light up the World Foundation facilitated our use of their one-watt LED test product in our research. We also thank Hansjoerg Mueller and Frank Haugwitz from GTZ Beijing for helping with logistics for our trip to Tibet and for sharing with us their previous research findings. Finally, we are grateful for support and advice provided by Dean Richard Newton of the School of Engineering, and Professors Drew Isaacs and Kristi Raube of the Haas School of Business at the University of California Berkeley. Support for this work was provided by a Berkeley-UNIDO Bridging the Divide Fellowship.