



RURAL LIGHTING

Introduction

Lighting is taken for granted in industrial countries. It is hard for many people to imagine living at night without being able to obtain light at the flick of a switch. But grid electricity does not extend to many rural areas in developing countries and is not likely to be in the near future, and even in for many urban households people have difficulty accessing clean energy sources as they are not connected to the grid or have unreliable power supplies.

Lighting in the rural areas of developing countries is often provided by candles or kerosene lamps. To a lesser extent, biogas, diesel generators and renewable energy systems are used. Torches (or flash-lights) powered by expensive, disposable dry-cells are used as a portable source of light for intermittent use. Access to modern energy products is hindered by poor market-supply chains, low awareness of existing technologies and lack of access to finance for consumers and entrepreneurs.

What is light?

Light is electromagnetic radiation; the human eye is sensitive to a spectrum with visible colours as seen in a rainbow. When these colours are mixed they appear as white light. More energy is present in the violet/blue end of the spectrum than at the red end. Therefore, more energy is generally necessary to produce the blue-violet component needed to produce what to the eye appears as white light. So the quality of light (in colour terms) influences the energy requirement; if colour does not matter then it is at least theoretically more efficient to use a red or orange light, and this in fact is common practice in the case of street lighting where energy-efficient lights are used, namely orange/yellow sodium lights. For domestic purposes people prefer to pay extra to get white or near-white light.

Light intensity, or illuminating power of a light source in any one direction is commonly defined in candela, which although it has a rigorous scientific definition, for practical purposes can be thought of as 'candle-power'; i.e. the output from a standard paraffin-wax candle. The rate at which light is emitted is measured in lumens, which are defined as the rate of flow of light from a light source of one candela through a solid angle of one steradian. A more easily understood approximation of this would be to imagine a one candela candle at the apex of a conical lampshade with its sides sloping at about 70 degrees to each other; the conical beam emitted, diverging at about 70 degrees lighting an area of 1m^2 , would be about one lumen. Lamps are often rated in lumens. Another unit measuring lighting is the lux which is used where the area to be lit is accounted for. When measuring the light intensity in a room rather than the power of a lamp the lux can be used.



Figure 1: Low energy lamps help with studies, Nepal.

Photo: Practical Action Nepal.

technical brief

Methods of providing light

There are three main physical principles by which light may be produced:

- incandescent
- fluorescent
- electroluminescence

The incandescent principle depends on heating a source to a temperature in the region of 2000, 4000 or 6000°C to obtain reddish, yellowish or white light, respectively. Typical examples are candles and lamps utilising a bright flame (where white hot or incandescent particles of carbon in the flame produce the light) and incandescent filament light bulbs where a fine coil of tungsten wire is heated (in a vacuum or inert low pressure gas to prevent the filament oxidising or burning) by an electric current passing through it. All incandescent light sources, whether flames or electrically heated filaments, tend to produce more heat than light and are therefore relatively inefficient in the rate of conversion of energy to light.

Fluorescence occurs under certain conditions when a material can be made to glow with a 'cold light'. Fluorescence is a phenomenon in which the atoms of a gas, vapour or solid are excited in such a way that they emit light. In some cases such as sodium and mercury vapour discharge lamps (used commonly for street lighting) vapour in a glass tube emits the light. In other cases such as the commonly used fluorescent tube lights, ultraviolet light, which is invisible to the eye, is emitted by exciting mercury vapour atoms within the tube, and this in turn causes a white translucent coating in the tube to fluoresce with a whitish light. In other words, the coating converts invisible ultraviolet light into visible white (or near-white) light. Most fluorescent processes involve some expenditure of energy, so they are accompanied by the production of some heat. (Non-electrical fluorescence is used where the mantles of pressure lamps and gas lamps are heated and emit a much brighter and whiter light than would occur simply as a result of their temperature.)

White Light Emitting Diodes (WLEDs) produce electroluminescence when electrons recombine with holes releasing photons. The colour of the light depends on the energy the photons have which is determined by the jump the electrons make in the semiconductor.

The advantages of WLEDs over other lighting sources include their very low energy requirements, their long working life, robustness and reliability. WLEDs are becoming more popular because of their low energy demand although their availability is still limited in many regions and they are still relatively costly. Current high performance WLEDs cost roughly twice as much as regular LEDs and more than incandescent bulbs. Although WLEDs consume very little energy compared to an incandescent bulb, luminous efficiency (lumens /



Figure 2: A biogas powered lamp in Bandarawella, Sri Lanka. Biogas is piped directly into the home and used for cooking and lighting. Photo: Practical Action / Zul.



Figure 3: A WLED lamp helps cook dinner, Nepal. Photo: Practical Action / Rakesh Shrestha

technical brief

watt) can vary considerably between different products. There can also be a high degree of variation within individual batches of products.

The number and configuration of the diodes will vary between different lamps. The light from WLEDs is very directional which is not always best suited for general lighting in a room; reflective lampshades can improve the situation.

One of Practical Action's projects in Nepal promoted WLED lamps incorporating 3 diodes and rechargeable batteries that were made by trained local community members in partnership with Krishna Grill & Engg. (P) Ltd., a local manufacturing company.

Light up the World, another organisation that promotes lighting to poor rural communities in Nepal using WLEDs, used simple hand-powered generators to power the low-energy lighting systems in remote parts of the country.

For practical purposes, the options for lighting reduce generally either to lamps that run on fuels, or electric lights. Table 1 indicates the options and their relative lighting capability.

Type of light	Energy source	Intensity (lumens)	Efficiency (lumen/W)
Candle	Paraffin wax	1	0.01
Oil lamp (wick)	Kerosene	1-10	0.01-0.1
Hurricane lamp (wick)	Kerosene	10-100	0.1-0.2
Oil lamp (mantle)	Kerosene	1000	1
Gas lamp (mantle)	l.p.g (e.g. butane or biogas)	1000	1
Filament lamp 3W	Electricity	10	3
Filament lamp 40W	Electricity	400	10
Filament lamp 100W	Electricity	1300	13
Fluorescent 15W	Electricity	600	40
Fluorescent 30W	Electricity	1500	50
Mercury 80W	Electricity	3200	40
Sodium sox 35W	Electricity	4500	128
White Light Emitting Diode 1W	Electricity	25 - 50	25 - 50

Table 1: Lighting capacity

More important to the user than the efficiency in lumen/watt is the cost per lumen, however, this is difficult to determine as prices will vary depending on where items are purchased and on the quantity bought as well as the actual life of the item.

Wicked lighting options such as kerosene lamps and candle wax are often the cheapest sources of watts which partially makes up for their inefficiency, but not for their poor quality light. Kerosene pressure lamps produce better light, but they are unpleasantly noisy and uncomfortably hot to be

near in a tropical climate; they also use much more fuel than wick lamps, and are troublesome to start. Cylinder gas lights provide a slightly more expensive but a more convenient alternative.

All combustion lamps and candles pose a real fire risk and contribute to indoor air pollution and its related health problems. They also emit greenhouse gases which increase global temperatures and change weather patterns. Kerosene and butane are expensive and sometimes in short supply in developing countries. Not only does fuel need to be bought but it may also mean a long journey to the market to acquire it.

Therefore the rest of the technical brief addresses the use of electric lighting in rural 'off-grid' locations.

Electrical lighting in rural areas

Solar photovoltaic lanterns

Solar lanterns are an all in one system that houses the battery storage and controls along with the lighting unit. They are easy to use and do not require any installation. There are many solar powered lanterns available. Practical Action (then ITDG) formed a partnership with Sollatek, a company that specialises in solar and electronics manufacture, to develop two versions of a robust solar lantern called the Glowstar and the Glowstar plus. Costs for a solar powered lantern can range from less than £10 to more than £100 with varying performance.



Figure 4: Testing a solar WLED lantern in Nepal. Photo: Practical Action Nepal.

Home electrical systems

Low-cost systems that require a small amount of electricity usually from a renewable energy source and using florescent lighting (or increasingly WLEDs) can be installed into many locations. They sometimes are provided in kit form and are linked to a mini grid or are linked to their own energy supply such as a wind turbine or solar panel when there is a reasonable source of power. Correct assessment and placement of solar panels and wind turbines is important in making these technologies work efficiently.

Batteries

Energy generated by a solar panel or wind turbine needs to be stored until it is required and this is done using batteries. Solar lanterns have an inbuilt rechargeable battery.

It is possible to use disposable batteries (i.e. dry cells) which are bought ready charged and thrown away when exhausted. These are convenient to use but extremely expensive in terms of electrical energy costs and need to be transported and

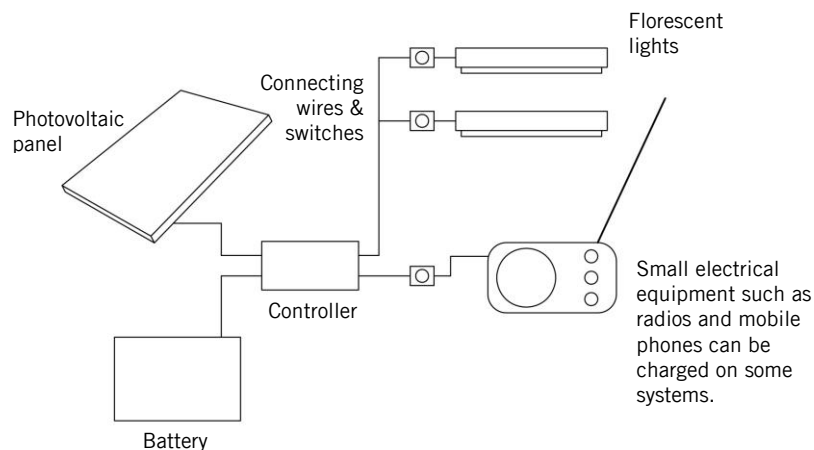


Figure 5: A simple solar system for lighting. Illustration: Practical Action / Neil Noble.

distribution to rural areas raising the cost even more and making the supply unreliable. There is also an issue of waste disposal once they are finished with.

Rechargeable batteries are more cost-effective than disposable batteries but recharge equipment then becomes necessary. The two main options available are

- nickel-cadmium batteries
- lead-acid batteries

Nickel-cadmium batteries are generally less widely available (except as dry-cell substitutes) and cost more, but they can be more robust and tolerant of abuse than lead-acid batteries. However they self-discharge quite quickly if not used. Electrical energy from a lead-acid battery can cost as little as one twentieth to one fifth as much for the same amount of energy delivered from primary (dry) batteries.

Lead-acid batteries are similar to the batteries used in cars and in many cases car batteries are used in lighting systems as these are the most widely available type of battery. For most lighting purposes these are the easiest and cheapest option. Lead-acid batteries are also available as deep-discharge batteries which have a longer life than car batteries, and if looked after tend to be better for general electrical storage.

Most lead-acid and nickel-cadmium batteries require regular checking of their electrolyte level and topping up with distilled or deionised water, (not with acid). Rain water can be used for this purpose, providing it has not been contaminated in any way. Low maintenance and maintenance-free lead-acid batteries are also available, at slightly increased cost.

An important point to note with lead-acid batteries is that their life is considerably shortened if they are over-discharged. Ideally they should only be discharged to about 50% of their full rating; i.e. a 60Ah (ampere-hour) battery should only be discharged to 30Ah before recharging it.

Typically deep-discharge lead-acid battery costs are in the region of £60/kWh of total rated capacity or £120/kWh of usable storage, while nickel-cadmium will be about three times this level. The cost increases with some specialist types and very small batteries.

Batteries are generally provided with nominal voltages in multiples of 2V; common larger capacity lead-acid batteries will be 12V or 24V nominal voltage.

Cable runs should be kept as short as possible with low voltage supplies, (or heavier cable must be used) otherwise significant losses will occur in the cables. A 1.2V voltage drop in a 12V system represents a loss of 10% of the power transmitted down the cable.

The voltage drop is numerically equal to the current in amps multiplied by the resistance of the cable in ohms. A 10m length of 0.75mm² cable with a specific electrical resistance of 0.042 ohms carrying 1.25A will have a voltage drop of $1.25 \times 0.042 \times 10 = 0.525V$. This represents about 96% cable efficiency, which is acceptable. However, 100m of the same cable will cause a voltage drop of 5.25V which will cause the light not to work and in any case represents a quite unacceptable loss of nearly 50% of the energy supplied.

A 30W fluorescent light (for example) running off a battery with an inverter for six hours per night will consume 180Wh each 24 hours. Losses in the inverter, cables and the battery will increase this requirement to about 300Wh/24h. To avoid more than 50% discharge and provide a nominal 24 hours storage capacity would require, with the above example, a battery with a usable capacity of 600Wh (1200Wh to total discharge), costing in the region of £80.

The energy sources

The main methods by which the electricity for charging may be provided:

- taking the battery to the nearest mains supply and putting it on charge
- using a small engine-powered generating set

- using renewable energy such as photovoltaic or wind charging systems
- using a hybrid system

Using a generating set imposes considerable problems as, unless power is being generated for other purposes too, the charging current, which is acceptable for small battery storage for just one or two lights is rather low for even the smallest generating sets; hence the engine needs to be run at part load which results in inefficient fuel use and is bad for the engine.

A photovoltaic system is often the most applicable stand alone option, as adequate sun for charging can be found in most parts of the world, and such a system, apart from occasional cleaning of the array, requires little attention.

The main drawback is that solar photovoltaic arrays are still expensive. Current cost (delivered and installed) are in the region of £3-5/Wp (peak watt); the supplier should be able to advise on the size needed (and can generally supply a battery and lighting system too).

To run a 30W light for six hours would typically require, in a sunny tropical location, two nominal 40W solar modules, and would therefore cost in the region of £400. Areas with extended cloudy periods may need up to twice this capacity.

Another option is to use a small wind generator; this can be cheaper than solar power in locations with mean wind speeds above 4.0m/s in the least windy months. Some of the WLED lamps used in Practical Action’s Nepal project were charged by small wind turbines rated at 200 watts also supplied by Krishna Grill & Engg. (P) Ltd. A separate technical brief gives further information on wind turbines and gives a rule of thumb that the required rotor area of the wind generator for small-scale applications like lighting will be:

$$\text{Rotor area (m}^2\text{)} = \frac{\text{Energy demand (kWh/day)}}{0.0048 V^3}$$

Where V is the mean windspeed in the least windy month of the year. For the 30W lamp for six hours example, it follows that a 0.5m² rotor wind generator will suffice at 5m/s, a 1m² rotor is needed at 4m/s and a 2.3m³ rotor at 3m/s. The typical cost of wind generators is around £400-600/m² for small machines (installed).

In our example of a 30W fluorescent light, which is comparable in illuminating power to a 100W tungsten filament lamp and brighter than a pressure kerosene lantern with a mantle, in a rural 'off-grid' location using wind or solar power, the following items would be needed:

Item	Approximate cost
12V 30W fluorescent light with built-in inverter unit	£ 10
10m cable, connectors, etc	£ 10
1200Wh battery (rated) giving 6000Wh usable capacity	£ 80
plus either:	
60-90W (rated) solar array with battery charge regulator (depending on solar irradiation)	£200-500
or	
0.5 to 2m ² rotor area wind generator with battery charge regulator	£200-900

This may sound a lot to pay for 2 to 5 lights, but the running costs will be negligible and good quality light will be reliably available. A pressure lantern, which is much less satisfactory, would cost only about £15-30, but it would consume in the region of 5 litres of kerosene per week on

technical brief

the same duty cycle which would cost typically £75-150 per year.

Although the price of solar panels and small-wind generators is still high they are declining in real terms as production increases, markets expand and awareness increases while the price of kerosene will continue to rise. There are tens of thousands of small photovoltaic lighting systems in use in developing countries and tens of thousands of wind-powered lighting systems, particularly in China.

To overcome the difficulties associated with the high initial costs of renewable energy systems for low income households in developing countries, financing schemes are often set up where the user can pay for the equipment in installments or rent the equipment off the supplier. Grameen Skakti has managed to install 300,000 solar home systems in Bangladesh using small loan schemes.

Further information

- [Candle Making](#) Practical Action Technical Brief
- [Kerosene and Liquid Petroleum Gas \(LPG\)](#) Practical Action Technical Brief
- [Biogas](#) Practical Action Technical Brief
- [Energy for Rural Communities](#) Practical Action Technical Brief
- [Batteries](#) Practical Action Technical Brief
- [Wind for Electricity Generation](#) Practical Action Technical Brief
- [Solar Photovoltaic Energy](#) Practical Action Technical Brief
- [Solar Energy: A Reference Guide for Users](#) Practical Action Technical Brief
- [Rural Lighting: A guide for development workers](#) Jean-Paul Louineau, Modibo Dicko, Peter Fraenkel, Roy Barlow & Varis Bokalders, Practical Action Publishing, 1994
- The Lumina Project <http://light.lbl.gov/technology-assessment.html>
<http://light.lbl.gov/best-practices.html>
- [Solar Lanterns Tests](#), GTZ (now GIZ)
http://www.lightingafrica.org/files/1938-09_GTZ_Solarleuchten_engl02.pdf

Also see further information from Lighting Africa

<http://www.lightingafrica.org/resource/briefing-notes.html>

<http://www.lightingafrica.org/resource/market-research.html>

<http://www.lightingafrica.org/resource/technical-research.html>

<http://www.lightingafrica.org/resource/resources-other-organizations.html>

<http://www.lightingafrica.org/newsroom/latest-publications.html>

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Solar home systems for Bangladesh

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Winrock developed a solar lantern for India.

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Website: www.lightsforlearning.org
LED lighting systems for educational projects in Africa.

SolarAid
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Fax: +44 (0)20 7490 3321
E-mail: info@solar-aid.org
Website: <http://solar-aid.org/>
Developed a solar LED lantern kit to fit kerosene lamps. This project is focused on Malawi.

The Solar Electric Light Fund (SELF)
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Fax: 202-328-9512
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Website: <http://www.self.org/>
The Solar Electric Light Fund, Inc. (SELF) is a non-profit charitable organisation. SELF seeks to help communities and governments in the acquisition, financing and installation of decentralised household solar electric systems in the developing world.

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Website: <http://www.lightingafrica.org/>
Lighting Africa, a joint IFC and World Bank program, is helping develop commercial off-grid lighting markets in Sub-Saharan Africa as part of the World Bank Group's wider efforts to improve access to energy.

Equipment suppliers

Sollatek UK Limited
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 Tel: +44 1753 688300
 E-mail: sales@sollatek.com
 Website: <http://www.glowstar.net/>
 Supplier of the Glowstar lantern and other equipment.

NEST - Noble Energy Solar Technologies Ltd.
 A-9, Aero View Towers, Shamlal Buildings
 Begumpet, Hyderabad - 500 016
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 Website: <http://www.solarnest.net/>
 Manufacture and sell solar lanterns and other solar equipment.

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 Website: <http://www.freeplayfoundation.org/>
 Wind-up WLED Lantern using Freeplay technology. Freeplay also produce a foot powered generator.

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 A range of lamps and lighting systems using WLEDS and aimed at promoting clean energy lighting to rural communities.

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