

GravityLight

Description of the Concept and its Realization

Problem/context:

Approximately 1/3 of the World's population is off-grid (having no access to mains power). This situation is not set to change in the near future, according to the World Bank and the World Health Organisation, and is identified as a major obstacle to the proliferation of education, and recognised as a limiting factor for growth in developing economies.

The vast proportion of existing solutions for heat and light in remote, off-grid, areas rely on bio-mass (carbon-based fuel sources). Concerns over ecological impact aside, a reliance on burning biomass for lighting (specifically oil) is expensive, keeping millions in fuel poverty, is unhealthy (producing toxic fumes and poor quality light) and dangerous (fire).

Initial Brief for 'Carbon-Free Kerosene Lamp' that led directly on to 'Gravity Light':

The charity SolarAid identified kerosene (known in the UK as paraffin) as the predominant, bio-mass fuel source burned for lighting across developing African nations. They also identified some obstacles to the adoption of alternatives to kerosene that seemed to exist. Consequently, they formulated a brief for us to design a non-kerosene powered product that they felt would be more readily adopted by end users in these markets. This project was started in mid-2008.

They had observed that many individuals own traditional kerosene lamps and have usage patterns that are highly adapted to these devices, such as night fishermen who hang the robust, tin (and fragile glass) products on the end of long poles, erected at the prow of fishing boats. Solar-aid felt that if these kerosene lamp bodies could be adapted to run off a non-biomass power source, while maintaining familiar product semantics, consumer acceptance would be more widely, and quickly, achieved.

In addition to this, SolarAid identified a price barrier, and suggested that any solution should have a maximum target retail price of around \$6 USD to enable the average, low-wage, consumer to make a spontaneous purchase, as and when the opportunity arose, without the need to save-up. This was seen as key due to the lack of consumer credit mechanisms in their target markets.

Lastly, they felt that an additional benefit to the adaptation of existing kerosene lamps would be access to funding mechanisms within the carbon credits scheme for which they could qualify, where they hoped to trade carbon credits through demonstrating quantities of converted lamps that no-longer relied on carbon-based fuel sources.

Drawbacks/limitations of Solar Powered Devices:

Through an analysis of the production costs and bill of materials (BOM) of existing solar products, the cost of the chemical power storage (rechargeable batteries) was found to be proportionally high and fairly fixed. This raised concerns in the context of the target price: the rechargeable batteries typically constitute around 1/3 of the total combined production and BOM cost of micro solar products. These high-cost, chemical stores also have a short useful life, often as little as 18 months, before performance is significantly compromised. The chemicals employed are highly toxic, and at the end of life, there is a risk that they can be liberated into the local environment, polluting ground water and ending up in the food chain. The photo voltaic panels they employ are also relatively expensive to manufacture, although the trend has been for the cost of these to reduce significantly over time. Recharging the units requires a sunny day (not ubiquitous across the target countries), and some forward planning / logistical organisation is needed. Lastly, if the power runs out when the light is still required, there is no way to access more power until the sun reappears.

Drawback/limitations of Human Powered Devices:

Again, an analysis of the production costs and BOM of existing products was undertaken:

In existing products, where rechargeable batteries are employed, the same drawbacks as mentioned above exist. Where a spring is employed as an alternative energy store, for performance to be of an acceptable standard, a special type of spring that can deliver a constant force is required, and these springs are also expensive to manufacture. Constant force springs do not have the drawback of a short useful lifespan when employed correctly, but are limited by the quantity of power they can store in relation to their production cost. They also tend to be too large to fit within existing kerosene lamp bodies, and they tend to be heavy, decreasing portability and increasing transport costs. Human powered devices that employ hand-crank (as the vast majority tend to) create high barriers to consumer acceptance due to the time investment required (it has been found that 3 or 4 minutes of user-winding for 45 minutes, or so, of useful light is not a time investment that consumers find attractive).

The length of this time investment is dictated by the rate of power going in to the device from the user's input, and the overall efficiency of the mechanical and chemical systems. The small muscle groups involved in winding a hand-crank suffer fatigue quickly, and the task is found to be repetitive and boring.

REVISED PROJECT OBJECTIVES - GRAVITY LIGHT:

The initial reasoning that led to Gravity Light can be summarised as follows. The Gravity Light study commenced later in 2008 on conclusion of the SolarAid project.

To address the problems and shortcomings of existing systems, putting all constraints in the original Solar-aid brief (apart from cost) to one side, could a system be developed to harvest and convert a short duration, human-powered input, to give a slow release, low-level power output, as and when it were needed?

If this could be achieved, we felt that we should be able to address the following drawbacks that exist with current solutions:

Solar:

1. Sunshine is unreliable - sunshine would not be required
2. Storing power 'chemically' is expensive, resource hungry, and can be toxic when disposed of - no chemical store would be employed
3. Rechargeable batteries have a short life - solutions without rechargeable batteries have the potential for greatly increased life-spans
4. If the power runs out, no immediate recharge is available - a system could be 'recharged' as needed
5. Forward planning is required - power could be available as the need arises
6. Photo voltaic (PV) panels are expensive - no PV panels would be employed
7. Macro solar infrastructure is slow and expensive to proliferate - no infrastructure would be required

Human powered:

1. Drawbacks 2 and 3 above relating to batteries for Solar are common to many Human Powered devices
2. Time input from the user to charge is a barrier to adoption - time input could potentially be reduced by a factor of fifty (i.e. 1/50th of the user's time would be required)
3. Chemical power storage introduces efficiency losses (which matters when the user is required to crank a handle) - no chemical storage would be employed, thus such losses could be avoided
4. Constant force springs are expensive and heavy - no constant force spring would be used

TECHNOLOGICAL UNCERTAINTIES

1. For the product proposal to make sense, in the context of departing from existing consumer behaviour patterns and experiences with a solution that would likely be quite novel, it would need to fully meet the very low (and ambitious) cost requirements of the target market to be attractive, otherwise it would run a high risk of failure / would not be viable.
2. Successfully realising an innovative solution would require the product to communicate its purpose/function to the end user in an explicit way, while the end user may have no frame of reference from previous experience, and levels of literacy would be highly variable.
3. It was not clear at the outset how we could engineer proposals to meet the cost target or what technologies could be employed, if any existed.
4. We were aware that data did not exist to support some of the applications for components that we were considering, so an unknown amount of experimentation would be needed to build data around performance characteristics.
5. We were aware that meeting the cost targets could require a questioning/re-evaluation of all commonly applied methods of delivering the proposed functionality/efficiencies.
6. We anticipated that to achieve the short charge input and slow return of power, a very high ratio, low cost, step-up gearbox may be required, or a very innovative means of converting power would have to be identified/developed. Traditional step-up gearboxes can be very noisy and inefficient, even when engineered without tight cost constraints, and they are subject to efficiency losses. We would need to develop an approach that could be very low-cost, yet highly efficient.

At the outset, a wide range of potential avenues were explored. Information was gathered on the various technologies that could deliver light, in order to establish which ones would offer the greatest opportunities for the application. A wide range of technologies were considered, from conventional technologies, such as LED (Light Emitting Diode) and CFL (Compact Fluorescent) through to the much less conventional, such as bio-luminescence.

Armed with this information it was then possible to put some numbers next to potential lighting technologies in terms of production costs, efficiencies in use, brightness and projected lifespan. This confirmed LED as the most sensible light technology, scoring highest on all metrics.

Similarly, various means of storing power from short duration human powered inputs were investigated and brainstormed. The vast majority of this scoping and concept generation was undertaken in-house, but some of the concepts that arose, while looking at more unorthodox areas, required analysis beyond our in-house expertise. Consequently, we engaged with a consultancy: Intelligent Fluid Solutions, to help us explore, in quantitative terms, systems that might utilise pressurised liquid or gas mediums to store energy that could then be harnessed on slow release, with the potential benefit of minimised mechanical inefficiencies.

Although some of the results from these pressure-store investigations looked highly promising, at least in theory, the practical realisation of them into physical devices embodied so many fundamental challenges, that other options were favoured.

We had also concluded, from our broader initial scoping, that to drive LED light sources, the wide availability of very low cost, high production volume DC motors offered potentially the lowest cost method of converting input energy into electric power, as conventional DC motors, when run in reverse via a torque input, will act as electric power generators.

Also with a view to minimising costs (this time in the distribution of any potential solution), the raising of a weight via a whole-body, short duration physical input, seemed like a very attractive and suitably low-tech approach, as mass is one of the few global resources that is practically unlimited, completely ubiquitous, and free. The weight could be sourced locally rather than shipped, and the human effort to lift it is renewable.

Initial consideration was given to what size and volume the weight should be. We felt it appropriate that any adult, or older child, should be able to charge the device, yet the larger the weight that was employed, the larger the energy reserve we would have to work with, so a compromise of 10kg was decided upon for the design weight, which would be reviewed and subject to trials.

In scoping out likely performance, some further numbers were needed next to important parameters. For these, a lift height of 6 feet was set (1.8m), as this is achievable by a short adult with arms raised above their head, and a drop time target of 30 minutes between lifts (charges) was set. These parameters were important in allowing us to estimate the potential power output of the system and to calculate the efficiencies that would need to be achieved.

With three main aspects defined: LED(s) as the light source, a DC motor as the generator, and the storage of input energy in potential form, the requirement for a highly efficient and low-cost step-up gearbox was indeed confirmed, as the DC motor would require a high speed input drive, and the raised weight must descend slowly in order for a charge to last for the target duration.

In considering how this high step-up ratio may be achieved, a key observation was made: a large ratio change can be obtained by rolling the edges of two plain metal wheels (or shafts), with greatly differing diameters, against each other. It was hypothesised that this could have the benefit of lower noise at high speeds when compared to conventional spur gears, and may not be susceptible to the energy losses and degradation normally associated with compliant material interfaces (such as rubber belt drives).