Solar-Charged, Battery-Operated LED Lanterns to Replace Oil Lamps in the Developing World

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Management Summary

Purpose and Background

Two billion people in the developing world lack electricity[1] and must use oil lamps for home lighting. Oil lamps are expensive, inefficient, unhealthy, and dangerous for the impoverished users. For the rest of the world, the lamps represent a significant consumption of limited global petroleum supplies and a major source of greenhouse gases: The lanterns burn an estimated 470 million barrels of oil per year,[2] releasing roughly 400 billion pounds of CO_2 equivalent gases into the atmosphere annually. But until recently, poor rural villagers, who often earn only $1.50 per day or less, had no modern alternative to the ubiquitous oil lamp. Over the past five years, low-power, white light-emitting diodes (LEDs) have dropped in cost and grown in efficiency.

Our institutions were partner recipients of a 2004 Mondialogo award, and team members from both countries spent two months living and working in rural India to implement a successful village electrification project. During this experience on the ground, UIUC students realized that LEDs could be paired with a very small solar panel and battery, to create an economical solar-powered LED lantern. The user charges the lantern battery during the day using the solar panel, which typically sits on the roof. Then at night, when the battery is charged, the user turns on the LEDs for five to six hours of light. This technology is not itself altogether new, but it had not been demonstrated to work in an economically sustainable way.

The first goal was to design a lantern which could be sold off-the-shelf for $20, a price deemed appropriate after onsite research gathered with the help of the 2004 Mondialogo award. Extensive engineering research was conducted by the student team, which included sourcing nearly all lantern components from low-cost Chinese suppliers, and taking a careful look at cost/benefit analysis with respect to the lifestyle and needs of the targeted consumer. The second goal was to prototype the resulting design in India, to directly judge the reaction of poor, risk-averse consumers to this new technology. Students applied for and received another small grant from the U.S. Environmental Protection Agency. This allowed the team from UIUC to travel to India this past winter to conduct onsite prototyping and record face-to-face demonstrations of the product in un-electrified villages. UIUC students lived and worked full-time with JITM students for a month from mid-December 2006 to mid-January 2007.

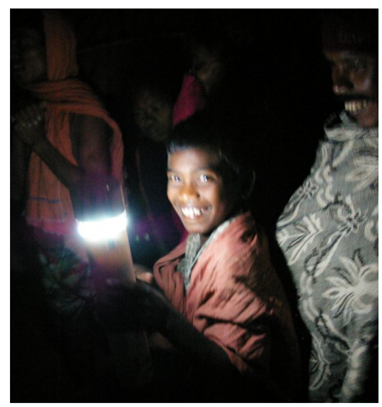
Summary of Findings

The design produced by this international partnership of engineering students yielded an inexpensive yet highly useful lantern design which is attuned to the needs of the impoverished Indian consumer. Keeping in mind the $20 off-the-shelf cost limit, the bulk-manufacturing cost was limited to $10 in order to allow for overhead (profit, transportation, tax) on the way to the consumer. Within this economically-sustainable cost structure, the student team designed a lantern that produces roughly twice as much light as the average kerosene “hurricane” lanterns popular in India and elsewhere, while lasting 5–6 hours per night. Circuitry is included to limit the battery discharge cycle so that the battery will last for three years, eliminating the need for replacement of batteries in locations where they are impossible to procure.

Using this design, prototype lanterns were constructed in a durable housing which is largely waterproof and shockproof. Students built sixty-five prototypes by hand in rural Orissa, India, in the lab space of JITM, which is located just minutes from poor, un-electrified villages. While the initial plan was to simply distribute the prototype lanterns as gifts and ask for feedback, it was quickly realized that a large demand actually existed even for the prototypes, and that there would be no need to give them away. Instead, twenty of the lamps were *sold* for 950 rupees ($21.40) each, directly to poor, kerosene-lamp users in surrounding communities who were eager to adopt the new technology. This market research yielded definitive proof that a grassroots consumer demand exists for the product.

Remarkably, most of the consumers who bought lanterns earned just $1–$2 per day, but were more than willing to make an investment of 950 rupees ($21.40) in order to avoid paying for kerosene lamp fuel in the future. The closest similar lighting device available in Orissa, India, which is a government-subsidized solar-powered fluorescent lantern, is nearly three times the off-the-shelf cost (and six times the manufacturing cost) of our low-power LED-based device.

The student team was quite surprised by the overwhelming success of the trial, and a student-owned company has already spun off of the project. Both the educational institutions and the student-owned company are now working to rapidly bring this technology to the market on a larger scale.



Prototype lanterns built by students in Orissa, India. **A young villager enjoys the new technology.**

Proposed Implementation Objectives and Strategies

The team's goal now is to incorporate feedback gained directly from the end users and to optimize the already-successful design for mass production. Industrial design and manufacturing engineering students and advisers will rework the lantern enclosure and form factor. A team will be dispatched to China to visit component sources, and to make plans with a final manufacturer. Injection molding tooling will be produced which can be used to create an economically sustainable, mass-marketable product. A trial production run of 500 units will then be distributed by a partner NGO based at JITM and by newly interested officials in Africa. The student-owned company which has been incorporated to move the product into the marketplace will have the opportunity to benefit not only the end users, but also to help the entire world, by reducing global warming emissions.

Concept and Proof of Cooperation and Intercultural Dialogue

University of Illinois at Urbana-Champaign

The seed of this work was the idea that solar-powered LEDs could solve an array of problems globally. As American engineering students, our team had the resources to do design work, and had the good fortune to be in a position where funding sources were available. But without contacts in the developing world, we would have been at a loss for how to proceed. Thankfully, Mondialogo 2004 had previously connected us with both a technical institute and a charitable NGO in Orissa, India, which was perhaps the perfect place to test our design.

Working with our old colleagues from JITM was simply indispensable from both practical and educational perspectives. The campus again welcomed us, and JITM students worked with our team nearly full time over the course of the weeks we stayed there. The outcome of the grassroots market research we gathered was amazing even to us, and could never have been accomplished without assistance from our partner in India.

Moving forward, JITM will continue to play an instrumental role in shaping our design as we scale the plan. Our partnership remains the most important piece in the puzzle of how to develop useful, sustainable technologies for rural poor.

Jagannath Institute for Technology and Management

The partnership for the current project stems from a similar project based on partnership between Engineers Without Borders, UIUC Chapter and our Association for India's Development (JITM Chapter), which successfully implemented a bio-fuel based energy center in a remote tribal village of Orissa in India. This project was born out of the idea that solar-based LED Light could help the same communities by a more sustainable means (both environmentally and economically).

The project team was centered around Patrick Walsh - leader of the Bio-diesel project, Maren Somers and Dhanada Mishra from AID, JITM. Subsequently a group of undergraduate engineering students led by Mr. Vikas Kumar from our institute joined the team and played a crucial role in fabrication of prototypes. The U.S. team visited JITM in Orissa and worked with the Indian students for weeks to successfully fabricate a large batch of prototypes for field trials.

The international exchange was hugely beneficial to both the Indian and American students as they got a real-life chance of working together while trying to achieve the goals of the project. Without up-close experience with the impoverished end users, students from the US would be unable to do effective design work.

Evidence of Cooperation

Development of Idea and Project Proposal

The two institutions involved, the University of Illinois at Urbana-Champaign and the Jagannath Institute for Technology and Management, were originally brought together by the NGO Engineers Without Borders and the Mondialogo 2004 Award. The first work on this project began in the summer of 2005, when preliminary research was conducted concurrently with a village electrification project. An off-the-shelf solar-powered lantern (not optimized for village conditions) was brought to the Keonjhar district of Orissa. The lantern was used and demonstrated by students from UIUC over the course of two months, during the course of their work (Fig. 2). The interest among villagers was surprisingly high, and working with a lantern in real-world conditions gave the team a familiarity with the important design parameters.

Fig. 2. Preliminary work with JITM in 2005.

Upon returning from the Mondialogo 2004 Award implementation, a group of motivated students from UIUC and JITM immediately began developing plans for an LED lantern project. The teams applied together for the first round of funding from the U.S. Environmental Protection Agency's "People, Prosperity, and Planet Award." The funding was granted, and received in August 2006, just in time for the Mondialogo 2007 project phase. From August to December, students rapidly worked together to create a design which could be prototyped in large quantities. The team was able to complete the design and secure additional travel funding before the winter holiday.

Development of Prototypes and Associated Experience

Having secured a total of $14,000 in financing for travel and supplies, the student team was reunited in India in December 2006. Parts to build 65 lanterns were both hand-carried by the students from the United States and shipped in from China. The lantern used components from three different Chinese manufacturers. This presented a great logistical challenge, but with previous experience in India and the help of JITM students and staff, the team readied all the necessary supplies and began constructing prototypes. The prototype lantern's features at a glance are as follows:

- Power consumption: 0.5 watts.
- Solar panel: 1-watt amorphous silicon (in separate frame) with 6-meter cord and jack.

- Light output: 15-20 lumens (equivalent to two or three kerosene "hurricane" lamps).
- Light duration: After day-long charge, yields five to six hours of LED light.
- Longevity: Two to three years, conservatively.
- Durability: Extremely shock-resistant, water-resistant.

Building 65 prototypes lanterns by hand in a period of 10 days required a concerted effort by the entire team. An efficient assembly line was organized (Fig. 3) but work days were still long, as each individual part had to be assembled by hand, including the circuit boards.

After the prototypes were built, they were immediately brought into local un-electrified villages to solicit feedback from end-users. An NGO chapter based at JITM is familiar with many of the local communities. Villagers were universally excited by the technology, and crowds would gather in each village center for the demonstration. Almost immediately, the team received requests to purchase lanterns, and was happy to oblige, glad for the chance to definitively prove the technology's marketability.

Fig. 3. Assembly line production.

Statement of Costs

Costs incurred during the prototyping phase amounted to $10,000 for supplies and minor travel expenses, and $4000 for student airfare. These costs were paid for by a grant from the U.S. Environmental Protection Agency and the UIUC Office of International Programs in Engineering.

Estimated costs for the proposed next phase will include approximately $7,000 in travel expenses, $5,000 for second-round prototyping, $25,000 for injection mold tooling, and $5,000 for production-quality prototypes to be distributed in India. These costs are substantial, and are expected to grow, but the student team has already raised over $25,000 in additional funding (see appendix, p. 8). It should be noted that all funding has been raised entirely by undergraduate-authored grant and award proposals. Academic advisors have been involved in consulting only for design purposes. With years of experience in development work, the team of undergraduates has gained considerable experience with financial logistics.

Time Frame of Project Proposal

As indicated above, partial funding for our next phase has already been received, and work is underway. It is expected that second-round prototypes will be ready within one month, and production-quality prototypes will be produced by January 2008, and distributed in the winter.

Appendix: Evidence of Cooperation

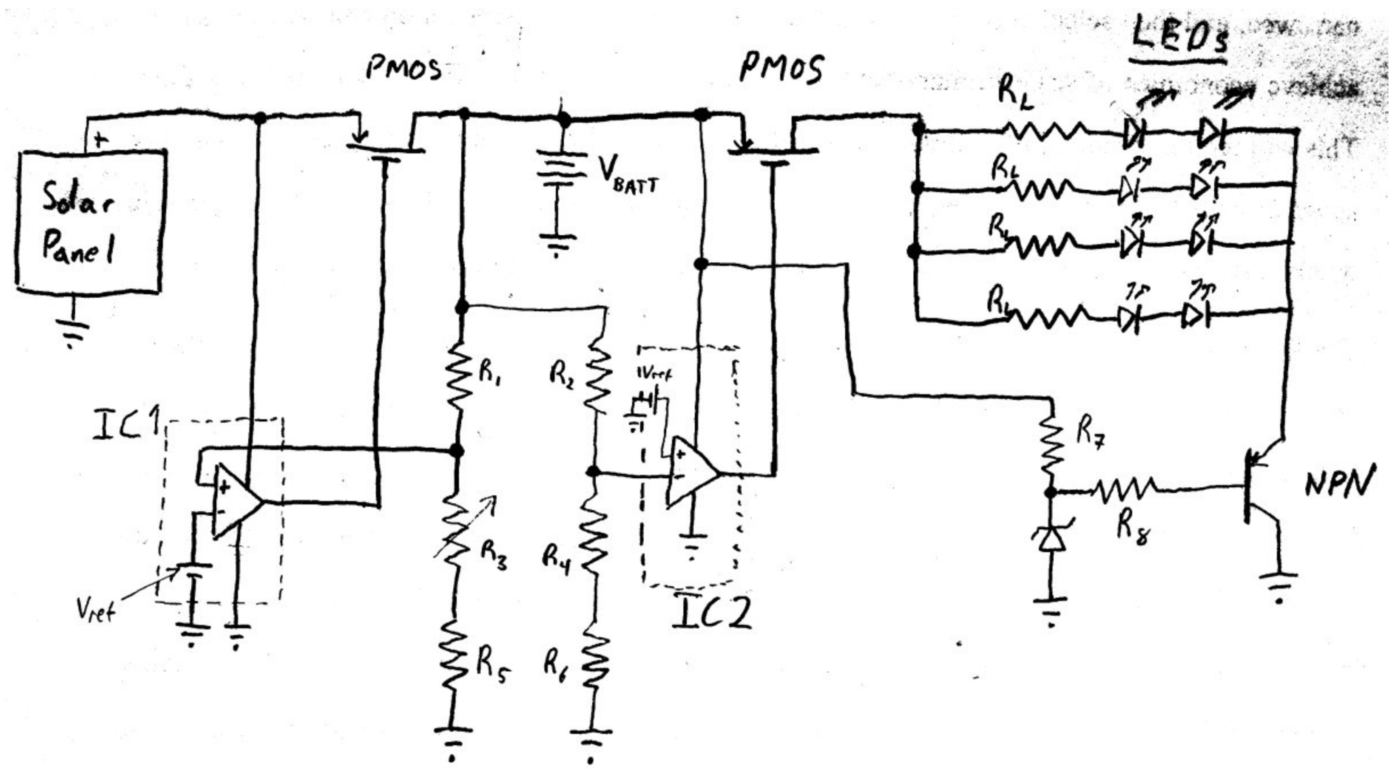
Racks of prototype lanterns built in Orissa, India with the cooperation of UIUC and JITM students.

Funding Received During Project Period	Month Received	Amount
U.S. Environmental Protection Agency (Grant #SU 83315501)	Aug-06	$10,000
UIUC International Programs Office (Travel funding)	Nov-06	$4,200
Project Lead the Way (Speaking stipend)	Dec-06	$500
UIUC Engineering Design Council	Feb-07	$4,348
Cozad Business Plan Competition	Mar-07	$5,000
UIUC Student Organizations Resource Fund	Mar-07	$1,100
National Collegiate Inventors and Innovators Alliance (Grant #4343-07)	Mar-07	$16,800
Total		**$41,948**

Of the nearly $42,000 raised thus far, the team has spent approximately $17,000. The remainder, plus additional funding, will be required for the next phase (see p. 7).

The next two pages are a technical document sent from UIUC to JITM representative of our international correspondence, which took place mainly over email.

Solar-Charged Battery-Operated LED Lantern Circuitry



Components:

Solar Panel: 1 W; 8.1 V Maximum Power Point (MPP); Amorphous Crystalline (A-Si). Manufacturer: Topray (China). Power output at 1V difference from MPP (i.e. 7.1V or 9.1V) is approx. 0.8W.

V_{BATT}: Series of two 4V Sealed Lead-Acid Batteries (8V total). Capacity ~1 amp-hour (Ah).

LEDs: 3.2 V, 20 mA, ~1/16 W. Dealer: besthongkong.com (China) part# BUWC433W100BC08.

PMOS: P-Channel MOSFET. Manufacturer: Supertex, part# LP0701N3-G

IC1, IC2: Micro-power comparator with built-in 1.182 V voltage reference. Linear Technologies part# LTC1440IN8.

NPN: NPN bipolar-junction transistor (BJT), 2N4401 (a common "small-signal" BJT).

Zener diode (Unlabeled in drawing): 2.4 V reverse-bias zener diode. 1N5221B.

Voltage Divider Resistors (for comparator input):

R1, R2: 1 megaohm, 1%-tolerance Metal-oxide.
R2, R3: 50 kiloohm, single-turn trimmer potentiometers.
R5: 154 kiloohm, 1%-tolerance Metal-oxide.
R6: 124 kiloohm, 1%-tolerance Metal-oxide.

R7, R8: 3.3 kiloohm, 1%-tolerance Metal-oxide.

R_L (four of these): 2 ohm, 5%-tolerance ceramic composition.
The circuit performs two main functions. The first is regulating the battery charge and discharge, which must be done for the battery to last for 1000 cycles or more. The second is to regulate the current through the LEDs when the lantern is turned on, so that the LEDs output a constant brightness even as battery voltage changes over the discharge cycle.

Battery Regulation
Regulation is accomplished using two solid-state switches (p-channel enhancement-mode MOSFET transistors, commonly referred to as PMOS) and two IC comparators (which flip the switches according to the battery voltage).

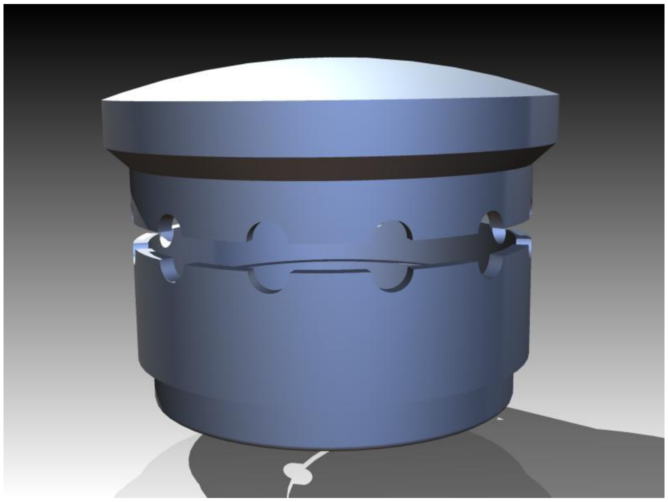
When the battery voltage goes too high, the first PMOS transistor switches the solar-panel charging off. When the battery voltage goes too low, the second PMOS transistor switches the LED (discharging) circuitry off. For a PMOS transistor, when the base is grounded, the emitter-collector resistance drops very low (approximately 1 ohm), meaning the switch is "on." When the base is biased to the voltage of the collector (ie, the solar panel voltage, in the case of the first PMOS, or the battery voltage, in the case of the second PMOS), the switch turns off.

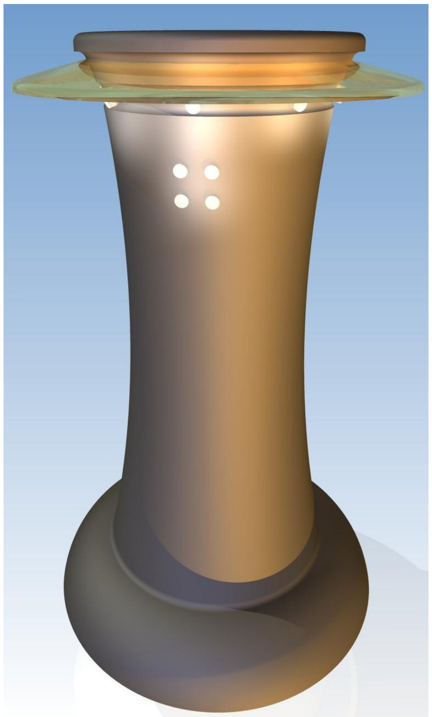
To apply the right base voltage, we use micro-power IC comparators, which can monitor the battery voltage continuously and apply the proper base bias to the PMOSs, while drawing only ~10 microamps. What can we compare the battery voltage to? The comparators include built-in voltage references, which put out 1.182V. We divide the desired battery voltage on/off setpoints (using a trimmable resistor voltage divider) down to 1.182 V.

LED Drive
LEDs are like any other diode, in that the current through them cannot be controlled by simply applying a constant voltage (Think of the exponential I-V curve for a standard .7V diode. If you don't understand this, just try applying 3.2V to a 3.2V LED, and see if your current is actually what you want it to be). The current itself must be regulated. To do this we use a low-current constant-current source combined with a current amplifier. The low-current constant-current source is a zener diode with a couple of resistors. R7 supplies the zener with enough current from the battery (about 2 mA) to put it in its active region. Then we get a constant reverse-bias voltage from the zener, independent of the changing battery voltage. This constant voltage is fed through another resistor, R8, which leads to the base of an NPN BJT. The BJT acts as our current amplifier, taking the constant current through R8 and multiplying it by h_{fe}, also called "beta," to allow 80 mA to flow through the LEDs. That R7 and R8 happen to have the same value (3.3 k) is a total coincidence.

Appendix (Continued)

The JITM team provided crucial access to local villages and translation services, which resulted in an extremely encouraging market research response.





CAD modeling of proposed designs for next-phase molded lantern, incorporating suggestions from JITM and UIUC

Conclusion

Reflections on Project Proposal Development and Associated Teamwork

When our team set out to design a solar-powered LED lantern, we knew that the technology could be beneficial, if it were adopted. The biggest preliminary question was what exactly the target consumer would be willing to buy. Would a poor person be willing to make a relatively large one-time investment in order to save money on kerosene in the long term? What was of value to the consumer? Was a brighter light or a longer-lasting light more important? Or did the consumer not care much about what the lamp produced, but only about how much the lamp cost up-front? American engineering students could help design a product only if they first knew the answers to these questions. The only way to get the answers was by going to the communities of interest and experiencing life in rural India. To get a sense of what the answers might be, American students asked Indian students in 2005 to interview villagers. While American students stood by, villager after villager gave their thoughts, and waited for them to be translated back to English. Gradually, the pieces came together, and design choices were guided by the local research.

With JITM's input, it was possible for the team as a whole to develop a desirable lantern. But even with the prototypes built, the big question that remained in everyone's mind was whether or not people would be willing to pay for them. The team thought that it could be a hard sell. The lanterns each cost the equivalent of two or three weeks' salary for many of the consumers in question. But upon visiting villages with a product in-hand, the lanterns sold amazingly easily. On the first night out, within a couple of hours, the team showed the lamps to one man who, without more than five minutes of thought, asked to purchase *two* lamps. The reception was better than anyone had hoped. This success would never have been possible without a concerted intercultural dialogue during the design process.

Importance of International Cooperation in the Development of the Project Proposal

Having won a previous Mondialogo Award, interest was high among all involved in preparing a functional, sustainable design which would turn heads. But additionally, there was a much greater level of interest this time around from the Indian students in being part of the preparation of the proposal itself. Many of the newer students on the JITM team were excited to spin off their own projects, having seen how this project evolved from a relatively unrelated successful venture. Many of the younger Indian students had general questions about how to start a project and how to gain success in fundraising. Funding opportunities in India are fewer and less lucrative than in the United States, so preparation for this proposal was an especially good educational opportunity for the team in India.

Plans to Develop and Implement the Project Proposal

When this project began, it was the students' stated goal simply to "demonstrate to larger investors" the marketability of solar LED lanterns. But over the past nine months, two things have changed: First, market research was overwhelmingly positive at the grassroots level. And second, the team has had even greater sustained success in fundraising. As older team members prepare to graduate from university, the possibilities for incubating a sustainable socially-minded business are great.

Instead of waiting for larger investors to catch on, GreenLight Planet Inc., a student-owned company, plans to demonstrate the benefits of solar LED lighting for poor people. In the next phase, student-run academic research will continue at UIUC and JITM, and work will continue in concert with the fledgling company to develop a mass-producible design which can be efficiently manufactured for the large consumer base. It is our goal to distribute no fewer than 500,000 units per year within three years. Though this may seem like a large number, it would really only scratch the surface. In the state of Orissa alone, there are tens of millions of people who will benefit from the technology, and the team's research has proved that they want to buy it. And in addition to India, distributors from Africa (including Ghana and Kenya) have already contacted the company to request samples.

The design of a refined second-run prototype began a month ago, and within another month, that design will be complete. The new design is 30% more efficient at converting battery power into light, and it uses one less battery. The manufacturing cost is therefore already quite low, at around $7.75 (including the solar panel, see Table 4), but further refinements should bring it below $7.00. The next step will be to purchase injection-mold tooling to manufacture the lantern enclosures. Designing and producing these tools will be quite expensive, so our team hopes to raise another $15,000 to $30,000 in the coming months. Once the tools are made, an initial run of 500 units will be distributed in India to end-users, NGOs, retailers, and distributors. A marketing team will solicit purchase orders, and then full-scale production can begin in India with just a small investment of working capital. The plan recently won first place in the UIUC business plan competition, which is open to all students and faculty.

Component	Cost per Unit
Solar Panel	$ 3.00
Battery	$ 1.55
LEDs	$ 0.89
Circuit Components	$ 1.10
Printed Circuit Board	$ 0.20
Enclosure	$ 0.70
Assembly	$ 0.30
Total Manufacturing Cost per Lantern	$ 7.74

Table 1. Manufacturing costs with refined design.

References

[1] Goldemberg, J., and Johansson, T.B., 2004. "World Energy Assessment: Overview, 2004 Update," United Nations Development Program, United Nations Department of Economic and Social Affairs, and World Energy Council, New York.

[2] E. Mills, "The Specter of Fuel-Based Lighting," *Science* 308, May 27, 2005.