Self-Contained LED Lighting System for Use in the Developing World

Challenge Definition
Although citizens of developed nations have come to take electricity and clean lighting for granted, according to the International Energy Agency (IEA), nearly two billion people lack access to electricity. As of the year 2000, the IEA estimates that 14% of urban households and 49% of rural households in developing nations are without electricity [1]. In addition, many of the clinics, schools, workplaces, and markets in these parts of the world are completely without light. In most developing regions of the world, the population is growing significantly faster than the ability to provide electricity to those regions. In those areas without electricity, lighting is currently provided by fuel-based lamps which are inefficient, costly to operate, and produce large amounts of potentially harmful byproducts and green house gas emissions [2]. Fuel-based lighting accounts for 33% of all residential lighting and 12% of all lighting [3]. These fuels include kerosene, diesel, propane, biomass, candles, and yak butter [2, 4]. In addition to the aforementioned portions of the population, there are 35 million people in the world living in refugee camps, most of whom are without any lighting at all [1].

Lighting is one of the principle sources of power consumption. There is a great deal of disparity in the efficiency of these systems. While some may be able to obtain efficiencies of about 100 lumens per watt, there are many who are forced to use systems that operate well below 1 lumen per watt [5]. Additionally, it is important to note that these less efficient light sources provide less light and at a less uniform dispersion than the more efficient systems. For example, a candle provides about 10 lux (lumens/m²) on a workspace if at a distance of 1 foot from the source, while typical on-workspace levels found in industrialized countries range from 400 to 500 lux, and this is accomplished with either desk lamps or ceiling lighting. It is estimated that fuel-burning lighting systems are the primary, if not only, source of light for 25% of the world’s population. These applications consume some 17% of the world lighting energy budget, but produce only about one tenth of one percent of end-use lighting. Thus, the costs of lighting are comparable for a family in a developing nation as for a family in a fully-powered, industrialized nation [4]. The bottom line is that end-users pay a great deal less for a better end product when using electricity rather than burning fuels for their lighting needs. Additionally, the inefficient and low-quality nature of fuel-
based lighting makes it very difficult to use for such applications as working, reading, or cooking, while also posing a health and fire threat.

While the efficiency of these lighting systems has been examined quite thoroughly, the impact to the world as a whole has only recently come under consideration. As stated by Dr. Evan Mills, it is estimated that fuel-based lighting accounts for about 20 billion gallons of fuel annually at a cost of some 38 billion U.S. Dollars \[3, 6\]. In addition to the economic hurdles presented by fuel-based lighting, there is a heavy environmental burden as well. The byproducts of the combustion of these fuels are numerous and vast in nature. A single kerosene lamp will produce a sooty residue which will adhere to all surfaces of the area in which it is used as well as producing more than 200 pounds of carbon dioxide each year. This fact, in conjunction with the number of fuel-burning lighting applications, accounts for nearly 200 million tons of greenhouse gas emissions into the atmosphere every year. The use of biomass as a lighting, cooking, and heating fuel also leads to a great deal of deforestation as cited by the International Energy Agency \[1, 2, 4\].

Looking at the impact to the human element, we must first look at the added burden to the portion of the population who provide light through the use of fuels. Depending on the fuel, between 30 minutes and 7 hours a day may be spent in the pursuit of fuel for domestic use. This task is generally performed by the women and children of the household and could be better spent working or learning. Electric lighting allows for families to read without having to strain or deal with the sound and smell which is a given with the kerosene lamps. Artificial lighting can extend the potential workday so that family members may engage in additional income generating activities in the evening \[2, 4\]. There has been a great deal of research done to show that there is a positive relationship between increased educational opportunities made possible by electric lighting and higher lifetime earnings as well as health benefits and public safety. The byproducts of combustion are hazardous to the health of those exposed. Lack of proper ventilation in the areas of use allows for the buildup of carbon monoxide to levels many times higher than the World Health Organization (WHO) standards. It has been shown that, due to their increased exposure, women and children suffer most from these emissions. The WHO estimates that 2.5 million premature deaths of women and children may be attributed to breathing the fumes from burning biomass for domestic use \[7\].
Innovation and Technical Merit

Modernization and electrification are spreading to all reaches of the planet but they are unable to keep up with the ever increasing demand. In many developing communities it is not feasible to connect these rural areas to the power grid and power companies are hesitant at best to supply power due to the high risk of power theft [8, 9]. Thus, a self contained lighting system would seem to be the solution to the current problem. White LED’s have recently undergone a great technological advance, whereby these solid state light emitters can now reach efficiencies of up to 100 lumens/watt, as opposed to 0.1 lumens/watt for the average flame-based lantern. Additionally, a 1-watt, white LED requires 20% of the electricity needed to power the most efficient compact fluorescent light on the market [4]. These facts indicate that a self-sustaining lighting system centered on the use of white LED’s to provide illumination may be an answer to the developing world’s lighting ills [10].

The objective of this proposal is to create and advise a multidisciplinary engineering student team to design, build, and conduct preliminary tests of a prototype self-sustained white LED lighting fixture. A novel technological approach will be to integrate energy collection and storage, as well as light emission in one manageable package. It will also be the mission of the student team to determine the most durable and efficient manner in which to collect and store the energy necessary to supply the device. The integration of the system has the potential to reduce the overall cost and to increase the durability of the device. The design process will especially take into consideration the reduction of cost and the feasibility for mass production by micro enterprises in the target nations to help bolster the local economies. Product sustainability will also be a primary consideration during the design stage, so a cradle-to-grave analysis will be conducted during the material selection phase of the design. The student team will be challenged to work with representatives of, or the end users themselves to set the specifications for the lighting system such that it may be used for applications such as cooking, reading, and working. The device will be designed to withstand all climatic regions and to have a lifetime of at least 10 years with minimal maintenance needs.

The basis of the proposed project, LED’s, are themselves at the forefront of innovation and technology [11]. Unlike their incandescent and fluorescent forefathers, the efficiency of LED’s are not limited by insurmountable fundamental factors, but rather only by our own imagination and ingenuity. Solid state lighting systems also offer a great deal of flexibility in their spectral range,
spatial distribution, color temperature, and polarization properties, lending themselves ideally to an extremely wide gambit of applications. Due to the nature of their operation, LED’s have a lifetime of over 100,000 hours. It is a combination of all these factors that has led to the serious consideration of LED’s as an answer to the problem of lighting in developing nations [12, 13].

During the conceptual design phase of the design process two renewable energy sources, solar and human power, will be considered for powering the self-contained lighting system. Solar energy is readily available in many of the regions of the world where there is a lighting deficit. Recent advancements in the efficiency and manufacturing processes of photovoltaic cells has greatly reduced their price and made them more feasible for small, portable applications. Solar technologies require some sort of energy storage for which there are several options that will be considered during the design stage of the proposed project. Sealed lead-acid batteries are readily available, relatively cheap, and have the potential to be recycled, but suffer from low energy density (30-50 Wh/kg), use some toxic materials, and have moderate cycle life. NiMH based batteries have moderate energy density (60-120 Wh/kg), reasonably priced, uses no toxic metals, but have moderate cycle life. Advances in Lithium-ion based batteries enable high energy densities (100-190 Wh/kg) making them ideal for portable applications, can have moderate to high cycle life, are low toxicity, but are more expensive [14]. Unfortunately, batteries contain chemicals which may be harmful to those who come in contact with them as well as the environment if disposed of incorrectly. At this time there are limited or no battery recycling programs in place in many of the target locations. Additionally, the batteries in the system would require periodic replacement. It is therefore proposed that the multidisciplinary student design team look at an alternate means of collecting and storing energy.

To avoid the difficulties of an intermittent solar resource which requires batteries for energy storage and daily relocation of the lighting system for charging, a human powered dynamo will be considered for a power source. Several applications already exist where clockwork (spiral power) springs are wound and then used to convert the potential energy stored in the spring into electricity to directly power an application such as a radio. White LED’s require little power that such a clockwork mechanism may in fact suffice to power the proposed lighting fixture. Such a power system would require no batteries, use benign materials, and eliminate the need for daily charging, except for an occasional wind-up by the user. A portion of the project design phase will be to assess
the various power generation/collection and storage systems and determine which or what combination thereof makes the most sense for the application when looked at from the economic, safety, environmental, and sustainability standpoints.

The proposed student project will apply the knowledge from the students’ classes in mechanical, industrial, and electrical engineering, sustainability, industrial design, and business to develop a simple and inexpensive prototype that could potentially be mass produced in the developing world. The students will be faced with many design challenges such as evaluation of the available technologies, smart system design, design for manufacturing, material evaluation and selection, and system robustness. This design process will be highly multidisciplinary in nature requiring a wide range of expertise in the areas of design for durability and ease of use, energy system design, material selection, manufacturing, and cost analysis. The multidisciplinary design team will 1) review the available LED and lighting standards literature, 2) define appropriate design specifications, 3) review the constraints imposed by resource availability in developing countries, 4) develop a series of self-contained LED lighting system concepts, 5) select design concepts to develop further based on appropriate criteria (effectiveness, costs, manufacturability, etc), 6) present design to a scientific review panel and technical partners in the developing world and at RIT, 7) build prototype, and 8) conduct preliminary performance testing. This process will expose students to a multidisciplinary design process with a focus on social, economic, and environmental issues.

**Sustainability**

Having access electrical lighting will greatly alleviate the lighting burden on the people of developing nations. Firstly the generation of hazardous byproducts due to the combustion of fuels in the home will be eliminated by electrical lighting. This fact alone will help to increase the health and longevity of those exposed to these pollutants. Additionally, the elimination of fuel for lighting will help to reduce the overall time needed to collect fuel for use in developing homes. This work generally falls to the women and children. With the reduction in fuel gathering time, they would be able to partake in more productive activities such as income-generating work, reading, or studying. The additional income would be of direct economic benefit to the family, while the ability to read, study, and pursue an education would carry with it the potential for a better future for generations to come.
It has been shown that there is a direct link between education and income generating ability—therefore, it is foreseeable that, given the opportunity to pursue an education, inhabitants of the developing world could advance their economic and social status leading to a more prosperous future. In addition, it is the goal of this project that the end product is fit for production by micro enterprises in the regions of the world in which they will ultimately be used. Thus, not only will the fixtures provide the benefits mentioned above, but also an additional income generating product for the region.

From the environmental standpoint, the reduction of fuel based lighting will greatly reduce the emissions of greenhouse gasses into the atmosphere. As previously stated, some 200 million tons of the greenhouse gasses generated each year may be attributed to fuel based lighting, thus, it behooves the planet to replace as many of these harmful sources as possible with clean electric systems. Finally, in addition to the effect of the byproducts on the environment, fuel based lighting, especially the burning of biomass, leads to deforestation and depletion of other natural resources. If a cost effective way to bring electric LED lighting to developing nations could be devised, the benefits to people and the planet would be significant.

**Measurable Results, Evaluation Method, and Demonstration Strategy**

Within RIT’s Kate Gleason College of Engineering, graduating engineering students are required to participate in a “capstone” design experience which consists of a two-quarter “Multidisciplinary Design Experience” (MDE). During this experience students from Industrial and Systems Engineering, Mechanical Engineering, and Electrical Engineering form teams to work on projects for a wide variety of clients, thus providing real-world business interactions. The teams may also attract students from disciplines beyond the College of Engineering. Our students consistently blend excellence and entrepreneurship into this experience with over forty teams participating per year. More details of this multidisciplinary experience can be found at the following URL: [http://edge.rit.edu](http://edge.rit.edu). As the team moves forward with their MDE projects, our proposed student team will evaluate their design against the cost and productivity criteria which will include appropriate environmental and social externalities.
During the MDE, which is approximately 22 weeks long, student teams follow the following multi-faceted methodology to solve a design problem:

- Recognize and Quantify the Need
- Concept Development
- Feasibility Assessment
- Establishing Design Objectives and Criteria
- Analysis of Problems & Synthesis into the Design
- Preliminary Design
- Engineering Models - Simulation and/or Hardware
- Detailed Design (DFx)
- Production Planning and Tooling Design
- Pilot Production
- Transition to Commercial Production
- Product Stewardship

Twice during the overall MDE, each student team presents their progress to date to a technical panel of professional engineers from academia and industry. The panel then scrutinizes the design and gives feedback. In addition, for this project the student team will be in direct communication with technical partners, with whom we are in the process of developing contacts in El Salvador, Venezuela, Guatemala, and Malawi, who will be able to provide regular feedback and a final design review. This will help sensitize the students to issues of fabricating and operating a system in an environment where the systems might ultimately be fabricated and deployed.

During the second half of the MDE, the students will build the LED lighting system and complete preliminary testing. A testing protocol will be developed to ensure that LED system meet the specifications developed during the early stage of the design in cooperation with partners. This will most likely involve cycle testing, light intensity mapping, and fatigue analysis. Several prototypes will also be built for field testing by partners in the developing world, which would include performance testing as well as end user surveys. In addition to experimental assessments, the team will also assess the system based on ease of use and maintainability, product life and end of life considerations, and benign disposal. Finally the team will be responsible for developing a list of recommendations and
a cost benefit analysis for future versions of the LED lighting system based on their overall assessment.

Integration of P3 Concepts as an Educational Tool
During the MDE, students from Mechanical Engineering, Industrial and Systems Engineering, and Electrical Engineering form teams to work on projects for a wide variety of industrial, government, and academic clients. In the past, teams have also included interested students from other colleges within RIT, including students who major in business, industrial design, and various science departments. Recently there has been a growing interest in sustainable technology projects, so much so that now RIT’s Engineering College has a track of projects dedicated to sustainable technology which normally includes one to two projects focused on developing world applications.

Students enrolled in the MDE work through a formal engineering design process to complete their projects as discussed previously. In the proposed project, students will evaluate their conceptual designs against both traditional cost and productivity criteria as well as against broader sustainability criteria. Standard methods and metrics which ignore environmental and social externalities may not be appropriate for a project or product that is to be evaluated against broader sustainability criteria. An important step forward in increasing the awareness of students with respect to the impacts of their designs on people, prosperity and the planet will have been made once awareness of sustainability issues has been assimilated into the standard design process.

This project also will serve as one of the first MDE projects specifically initiated to enhance the new Energy and Environment Option being developed in the Mechanical Engineering department at RIT. This option will consist of a series of electives, co-op experiences, and a MDE that provides students with exposure to a wide range of opportunities and careers associated with energy systems, and how they relate to the environment. The project also supports the recent undergraduate minor developed in sustainable product development and the graduate sustainable engineering program. Finally, The project will be highlighted in RIT’s annual Innovation and Creativity Festival which plans to draw 30,000 visitors from the Rochester community and upstate New York.

Project Schedule
The first phase of this project will include a senior design MDE followed by field studies. The second phase of the project would be to improve the initial prototype, continue field testing the
improved LED lighting system, initiate preliminary construction in country, and perform more detailed effectiveness and reliability testing. The schedule for the first phase is as follows:

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References

[7] W. Floor and R. Masse, "Peri-urban electricity consumers, a forgotten but important group: What can we do to electrify them?," Joint UNDP/World Bank World Bank Energy Sector Management Assistance Programme (ESMAP), Washington D.C.