# Best Practices for the Sustainable Scaleup of Lighting Technologies in Bottom of the Pyramid Communities

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## ABSTRACT

This thesis deduces a set of best practices for sustainably scaling up lighting technologies in developing countries with a focus on Bottom-of-the-Pyramid (BOP) communities, whose annual incomes are US $3000 or less (in local purchasing power parity).

The best practices are derived from a comparative analysis of two heuristic case studies profiling entrepreneurs based in southern India, who have successfully scaled up lighting technologies in BOP communities. Also discussed is the impact that quality lighting has on our health, safety, socio-economic status and the environment that surrounds us. Not surprisingly the demand for quality artificial lighting is high in these communities, where access is generally limited. SELCO-India, a registered company, sells photovoltaic-based home lighting systems; while THRIVE, a nonprofit organization, sells Light Emitting Diode (LED) lanterns to remote communities in India. Both organizations use alternative models to address the same issue.

While the research presented here focuses on the lighting sector in India, it is also proven that the results are applicable in the context of entrepreneurship in BOP communities around the world.

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# ACKNOWLEDGEMENTS

**I would like to dedicate this thesis to all the forces that have made me possible and continually inspire me to be better. You are the reason that I am.**

Special thanks to all the wonderful people who have helped me throughout this process, especially Professor Richard Locke and Professor Simon Johnson, for taking a chance on an unknown student. Equally important is the help of Professor Sarah Slaughter, the Vistakula family, Dr Ranganayakulu, Dr Harish Hande, the incredible staffs of THRIVE and SELCO, Daniel Hsu, Rohit Wanchoo, the TPP staff and class of 2007, and many more. I hope to pass on your kindness, generosity and wisdom to others as I move through my life.

Thanks to the reader who chooses to read this paper. You have chosen wisely!

**This little light of mine**
**I'm gonna let it shine**

**-unknown-**

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# Chapter 1: INTRODUCTION

This thesis outlines a set of best practices for scaling up businesses selling small-scale technologies in developing countries without compromising social motives.[1] While the evidence presented focuses on lighting technologies in the poorest population (i.e., Bottom of the Pyramid (BOP)) sectors of India, the lessons learned are applicable in a much larger context. The information in this thesis will be of great value to entrepreneurs, investors, and persons generally interested in the scalability of businesses in BOP markets in developing countries.

Before moving forward, it would be best to define two important terms – "scalability" or "scaleup" and "BOP." "Scalability" is an oft-used term in software engineering to describe system robustness. Quite simply, a scalable system is one that can easily expand (possibly infinitely) to handle more throughputs. In the business world, the term is less well defined. As I use it, the term means, the ability of a business to expand and replicate itself beyond its original market in terms of market size and geography.

"Bottom of the Pyramid" or "BOP," is another term that has long been around but only recently popularized by C.K. Prahalad. In his book *Fortune at the Bottom of the Pyramid*, Prahalad defines BOP as the portion of the world's population living on less than US $2 per day (in US Purchasing Power Parity of $1500 per year), approximately four billion people (Prahalad, 2006). The World Resources Institute (WRI, 2007) recently published an extensive demographic study on BOP communities. According to them, these four billion people live on an annual income of less than US $3000 (in local purchasing power) and under. Because of its extensive and in-depth nature, I will use the WRI definition.

There is much debate about the exact size and purchasing power of the BOP sector, as well as the ethics of working in these markets. Jeffrey Sachs, for example, indicates that the poor have limited purchasing power, and what they need are skills and infrastructure before their markets can develop (Sachs, 2005). On the other hand, Prahalad (2006) and the WRI (2007) argue that the poor indeed have significant purchasing power that has consistently been ignored, which has resulted in the formation of informal economies where they are paying much more than communities operating in formal markets in the same areas. They argue for more formal investment by multinational corporations (MNCs) to formalize the informal markets of the poor. Still others, like Aneel Karnani (2006), argue that the BOP market size calculated by Prahalad is hugely bloated, and that the poor should be viewed as producers rather than as consumers, as their purchasing power is not significant.

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[1] As I use it, social motives or being socially motivated means that the organization places the advancement of the client's best interests and the general betterment of society on par with their profit bottom line. In some circles this is also referred to as socially responsible business or corporate social responsibility.

My thesis will not go into the debate on the size or functionality of BOP markets. Rather it will focus on a point of agreement of the four theorists—that there is a significant portion of the world's population that is poor and that they need access to good infrastructure and skills in order to develop. For numerical data, I will primarily rely on the WRI (2007) study. It is an extensive and vital study that measured the variability of BOP markets across continents, countries, income brackets, and sectors, and is one of the most comprehensive studies done to date. Based on the WRI data, almost two-thirds of the world's population— approximately four billion people -— lives at or on less than an annual income of US $3000 (in local purchasing power).

My overall purpose with this thesis is to equip any entrepreneurs, investors or institutions interested in serving these populations, with a set of the best practices or skills that they can use in their attempt towards furthering these goals.

## 1.1 Background and Motivation

In February 2005, I had the unique opportunity to work with a few Development Marketplace (DM) finalists as part of a graduate class at the Massachusetts Institute of Technology Sloan School of Business (MIT-Sloan). The DM is a worldwide grant competition administered by the World Bank (WB) to fund creative small-scale development projects with the potential to replicate. Every year, several thousand entrepreneurs from around the world compete for grants of up to US $200,000 under a rotating theme. In 2005, the theme was "water, sanitation, and energy." For the class, interested DM finalists were paired up with graduate students who offered a range of technical and business expertise with the goal of making the finalists' proposals and business plans more robust.

DM grantees are judged on five overarching benchmarks:

- Innovation
- Practicality and robustness
- Financial viability
- Organizational sustainability
- Scalability

The most interesting questions asked by my DM clients surrounded scalability: what models or literature was available, and what were the best practices. My search for answers yielded little information – both in the regular business sector and within the BOP community. Most entrepreneurs, venture capitalists, and strategists agree that scalability is very hard to predict, which might account for the lack of literature. Still there continues to be great interest in the field, particularly in social ventures where grant-giving agencies and BOP entrepreneurs, like my clients, want to ensure the sustainability of their investments. Some of the WB DM staff also expressed curiosity about why some of their DM winners had successfully scaled up, where several others were struggling. It was an attempt to understand this issue that set me on the course of this thesis.

In order to study scalability more systematically, I decided to do a case-study analysis of successful organizations that had scaled up in comparative industries in BOP communities. An exhaustive search yielded two such organizations—SELCO (Solar Electric Light Company, Private Limited) and THRIVE (Volunteers for Rural Health and Information Technology)—that sell artificial lighting technologies in BOP markets in southern India. Artificial lighting offered a very interesting industry to study because its importance and impact is often overlooked in infrastructure development and poverty alleviation. The United Nations (UN) and the WB agree that infrastructure plays an important role in poverty alleviation, as outlined in the Millennium Development Goals (MDGs), and it is one of the most difficult sectors in which to operate (WB, 2007a). While infrastructure systems such as water, electricity, sanitation, and roads provide the foundation necessary for the operation of human society, they are rarely provided to BOP consumers. This might be because infrastructure is generally publicly owned, developed, and operated, and in the absence of resources or efficient governance, its development falls apart. In many of these cases, private sector involvement or public-private partnerships further complicate infrastructure development in these struggling economies.

Most developing countries have patchy infrastructure systems that favor the higher population density of urban sectors, where residents have a higher ability to pay and more political coercion. There is also the financial incentive of developing in denser areas because there is greater infrastructure use per unit of investment. Conversely, less dense rural sectors and urban poor (BOPs) who are less likely to pay for the services are ignored. Informal and often more expensive economies develop to fill in these gaps (Prahalad, 2006). This is true for artificial lighting as well.

Over 1.6 billion people, nearly a quarter of the world's population, lacks access to electricity. This population relies on kerosene, candles, batteries, and biomass for their lighting, which has a significant impact on their health, socio-economic status, and the global environment. Yet lighting is generally ignored when prioritizing infrastructure development, often taking a backseat to water, transportation, sanitation, and other outcomes of electrification such as the mechanization of industry, even though it is extremely important for economic development. This was obvious from the lack of literature on the subject. For these reasons, lighting was an intriguing subject to study.

Besides their focus on lighting technology, SELCO and THRIVE are interesting for four main reasons:

1. All of their lighting products incorporate the latest and most energy-efficient technologies, like compact fluorescent lights (CFLs), light emitting diodes (LEDs) and solar photovoltaics (PVs).
2. They are strongly socially and environmentally committed organizations, whose goal is to make quality lighting affordable to the poor. Both are unwilling to compromise on their motives.

3. Both organizations were started by and continue to be driven by bottom-up entrepreneurs. They began as small social experiments without access to funding from large MNCs or venture capitalists (VCs) and grew organically from there. The founders used the same local institutions that would be at the disposal of any average Indian citizen in order to develop. Therefore, their stories can serve as models for any other bottom-up entrepreneur in most countries.
4. Both companies had started and successfully scaled up in BOP markets, within relatively short periods of time. In other words, they proved that quality (sometimes expensive) advanced technology was desperately needed, demanded, bought and used by an increasing number of BOP consumers. THRIVE had scaled up sales of their LED-lantern from 120 to over 33,000 clients in one year (2006-07); while SELCO had scaled up their solar PV-based system, from 100 to over 55,000 clients in eight years (1998-2006).

Despite their similarities, SELCO and THRIVE operate very differently. The former is a registered profit-generating company that sells US $200-1000 PV systems to their clients without any subsidies; the latter is a registered nongovernmental organization (NGO) that sells subsidized US $15 LED lanterns. SELCO and THRIVE are presented as heuristic case studies. Each of the organizations has been independently studied and analyzed. Their successes prove that there are alternative models, rather than a single one to solve a similar problem.

## 1.2 Range of Applicability

SELCO and THRIVE's ability to expand successfully within the realm of infrastructure in BOP communities creates new possibilities for other entrepreneurs and investors interested in tapping into this space. Because infrastructure is such a difficult sector to be successful in, the lessons learned from analyzing SELCO and THRIVE are surely applicable to businesses in other sectors.

In addition, BOP sectors are some of the most challenging to operate within for a variety of reasons. Chief among them are the persistent lack of infrastructure, which greatly limits connectivity between markets and hinders supply chains; and a predominantly illiterate client base with extremely limited purchasing power. Often clients with the greatest need are located in rural, often remote communities further compounding market accessibility. To complicate things further, bottom-up entrepreneurs and BOP customers have great difficulty obtaining financing. Most lending institutions cater their financing to non-BOP customers who earn, spend and save differently from a BOP customer. For example, current lending and credit practices require a monthly loan repayment which works well for customers who earn on a monthly or biweekly basis. But most of the BOP earns on varying cycles. For example, farmers earn money on a biannual cycle, coinciding with the harvest seasons. Their spending and savings cycles follow their earning cycle, i.e., they spends a lot immediately before and after the harvest, while spending diminishes as time passes. To complicate matters further, harvest seasons between different crops are staggered, thereby making a single biannual payment cycle ineffective. On the other hand, daily wage laborers subsist on a small daily income and typically save very little for the next day. Considering the varying schedules of the different farmers and daily wage laborers who constitute a part of the larger BOP, it is very difficult to institute a single payment system. It is further understandable why a monthly system most definitely will not work for these communities.

Overcoming the obstacles outlined above, such as the lack of a skilled work force, dependable supply chains, and the constant battle of balancing the quality of their products with affordability, make operating in BOP markets extremely capital intensive. This is why MNCs are able to get past the initial barriers, rather than bottom-up entrepreneurs. For example, during my travels to even the remotest parts of a developing country, I saw ubiquitous bottles of Coca-Cola. Only rarely did I see a regional "brand" competitor drink outside its initial market area. It is in this context that the success stories like THRIVE and SELCO stand out. Entrepreneurs who are able to survive and thrive in these most challenging environments are likely to teach lessons that will apply particularly throughout BOP sectors and even in mainstream business operation.

The fact that SELCO and THRIVE are operating in India adds further dimensions to their success. India is interesting because of its complexity, diversity, and challenging market environment. A country that has been experiencing astounding economic growth, it ranks $126^{th}$ out of 177 countries, on the UN Human Development Index. Almost 40% of the population is still illiterate (UNDP, 2006c), and 60% of the workforce is employed in the agricultural sector, contributing less than 20% to GDP (CIA, 2007). Over 35% of the population or almost 580 million people lack access to electricity, the largest amongst all populations in the world (IEA, 2002). India is also a melting pot of castes, cultures, languages, and colors, each of which poses its own set of issues in terms of scaling up. BOP communities speak, read, and write in different languages both within and across different states, and the caste system further complicates social structure. Considering these immense challenges of basic business operability, the fact that THRIVE and SELCO are able to sell and scale up beyond their original markets is truly remarkable. Lessons from here can surely apply to entrepreneurs across India and the world.

Overall, because these two organizations have scaled up successfully in extremely complex environments (rural India), within the most challenging market segment (BOP consumers), within a sector that is desperately needed and difficult to sell within (infrastructure), I believe the conclusive best practices are robust enough to be applicable outside of this niche.

## 1.3 Methodology

My research was conducted in two segments: background research and field assessments. Background research primarily took place over the autumn of 2006 and the spring of

2007. Theoretical research was augmented by interviews with the WB DM team, business strategists, engineers, venture capitalists, professors, and entrepreneurs. Information collected was primarily qualitative.

The interviews were generally unstructured. No questionnaires were used. My goal in every interview was to understand the perspective of each of these professionals with regards to successful entrepreneurship and scalability. I also asked them to reflect on some of my findings as necessary.

Field assessments took place on-site over January 2007. Assessments were primarily qualitative and consisted of interviews with THRIVE and SELCO staff at all levels, clients, partners, and financiers, as well as extended field visits where staff were shadowed. Of the 28 field days, approximately 19 days were spent on-site with THRIVE, three days were spent with SELCO, and six days interviewing other possible leads, including officials at the Andhra Pradesh State Electricity Board (APSEB) and local energy experts, as well as traveling between sites. The disproportionate difference in time spent between THRIVE and SELCO is because THRIVE had very little of their progress or procedures documented compared to SELCO. This presented a series of challenges, and will be discussed further in Chapter 3. In addition, SELCO had been visited and studied by several student groups whom I interviewed at greater length upon return to MIT.

The field assessments were critical for the development of the case studies. Both SELCO and THRIVE gave me complete freedom to communicate with all of their staff and some clients. I also interviewed several MIT student groups who had visited SELCO over the past year, and sat in on conversations and lectures delivered by Harish and Ranga, the founders and managing directors of SELCO and THRIVE respectively. Their answers have been generally consistent with my observations.

Interviews during the field assessments were also unstructured. Having interviewed clients and staff from across the organization without prior notification, I'm confident that the answers were honest and have proven to be consistent throughout the hierarchy of the organizations.

# Chapter 2: LIGHTING

During site visits in January 2007 to rural and tribal communities in some of the remotest parts of India, I found a significant demand for quality artificial lighting. Tribespeople outlined a seemingly unending list of reasons for why they needed electric lighting over the traditional wick-based lighting that they have been using for centuries. Among others, they said the safer and better quality electric light was essential for their children to study, for hunting during the torrential monsoon rains and to keep the animals away during the harvest without risk of losing their crops to fire. The women talked about the hours they lost everyday collecting wood from the forest to be used for their energy needs.

As indicated by some of the poorest people, access to quality lighting has a significant impact on our health, safety, socio-economic status and the environment. This chapter starts by exploring these issues then introduces the reader to the technical aspects of lighting. The technology is critical for understanding the complexity involved in rectifying lighting accessibility. It will also set the stage for the case studies presented in the next chapter.

## 2.1 Lighting: Introduction and Importance

The International Energy Agency (IEA, 2006) estimates that lighting takes up 19% of global electricity consumption. Yet this only represents three quarters of the world's population. The other 25%, or approximately 1.6 billion people, live in non-electrified households in developing countries. Most of these communities get their lighting from kerosene, biomass and candles, all very poor sources of light. In the developing world, nearly 14% of these households are located in urban areas; 49% are in rural areas. The most staggering statistic is that in the least privileged parts of Africa, less than 1% of households, have access to electricity (Mills, 2005). Many more have only intermittent access.

One might wonder what these communities are using instead of electricity, what impact that might have on their communities and the world at large, and why the developed world should care. As this section and the rest of the chapter will show, these communities use some of the most financially and energy inefficient means of lighting (burning oil and biomass), which on a macro-level contribute significantly to greenhouse gas (GHG) emissions. The use of these fuels also has an immediate impact on the health, livelihoods, and economic status of the community residents. The developed world should care not only because it is morally right, but also because these methods of lighting will affect us.

Combustion-based lighting produces carbon dioxide, water vapor and other GHGs, which are responsible for the climate crisis we are already experiencing. Figure 2.1 shows a distribution of non-electrified households around the world, as well as projections for 2030 in a "business as usual" scenario. The IEA (2006) estimates that by 2030, 1.4 billion people will lack access to electricity. One can only imagine the impact of this dismal scenario. In order for developing countries to reach the UN MDGs, they need to improve the quality and quantity of energy available to their citizens. Of the eight MDGs, at least three are directly linked to lighting. For example, universal access to primary education is impossible if the students have no light to study with. And as the rest of this section will elaborate, both poverty and environmental sustainability are significantly related to electricity access. Additionally, considering current energy prices, environmental conditions, projected population growth, and existing unmet energy demands, the need for better sustainable lighting practices is exceedingly important both in developing countries and the world at large.

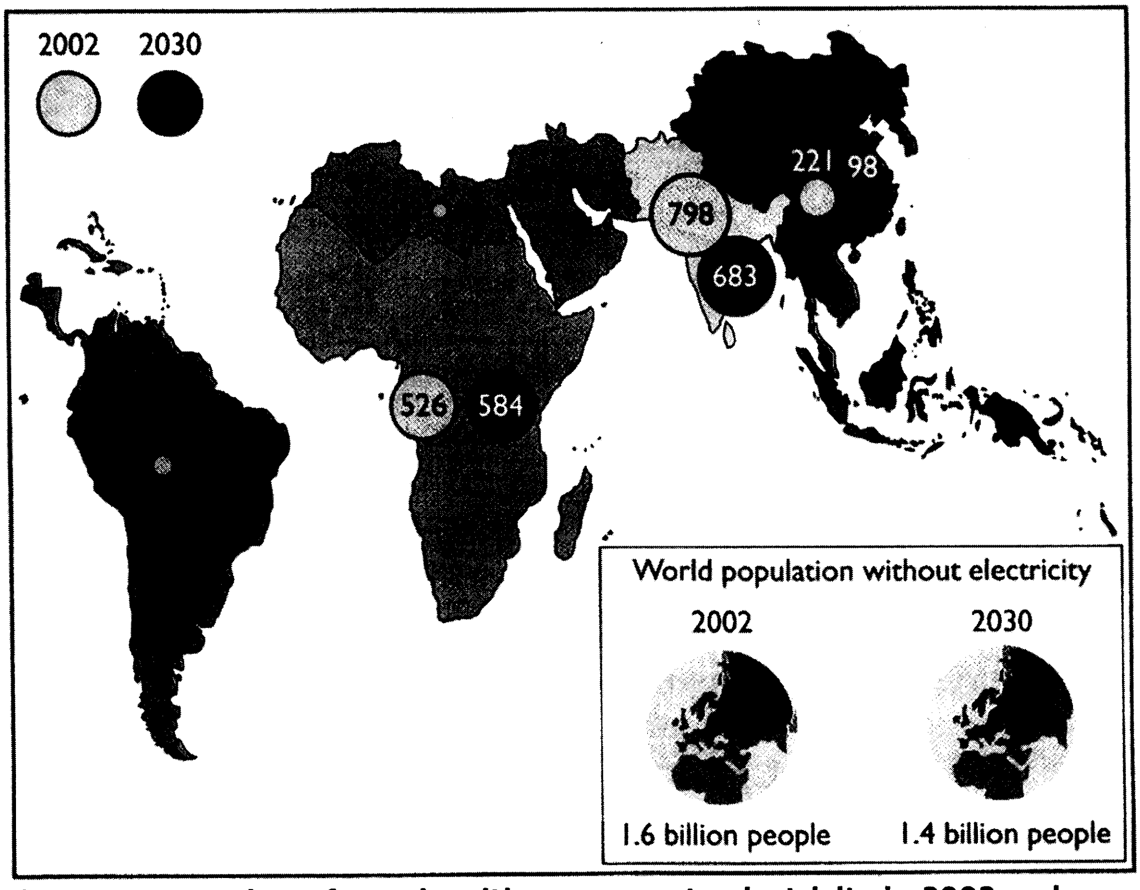


**Figure 2.1: Number of people with no access to electricity in 2002 and projected number in 2030 if no new measures are implemented (IEA, 2006)**

## 2.1.1 The Importance of Lighting in Environmental Sustainability

Lighting contributes significantly to the world's carbon dioxide ($CO_2$) emissions. As stated earlier about 19% of the world's electricity goes to meet our growing appetite for light. The IEA states that "the energy consumed to supply lighting entails GHG emissions of...1,900 Megatons (Mt) of $CO_2$ per year, equivalent to 70% of the emissions from the world's light passenger vehicles" and about three times aviation fuel emissions. The poorer populations that use kerosene and other combustion-based fuels for lighting are the largest emitters of $CO_2$. While these provide only 1% of global lighting, they are responsible for 20% of $CO_2$ emissions from lighting. In an era of tight oil markets, these poor economies consume 3% of the world's oil supply, which is more than the total output of Kuwait (IEA, 2006). Based on available sources and rates of use (fuel lamps burning for about four hours per day), Mills (2005) calculated the overall fuel consumption in the non-electrified sector to be 77 billion liters per day or 1.3 million barrels of oil per day equivalent.

What is of great concern is that many developing countries, like India and China, are rapidly growing and emulating the industrialization of the Organization for Economic Cooperation and Development (OECD) countries whose per capita energy consumption is extremely high compared to developing countries. For example as of 2006, an average North American uses 101 Megalumen-hours (Mlmh) per year, while an average Indian uses approximately 3 Mlmh per year.[2] Considering current practices and growth trends, the IEA (2006) estimates that global demand for lighting will be 80% higher by 2030, and lighting-related $CO_2$ emissions will rise to 3 gigatons by then.

Another problem is that of environmental degradation. Nearly a quarter of the world's population in developing countries is using kerosene, petrol, diesel, biomass (such as wood, dung, biogas, charcoal, and vegetable oils), candles and batteries for lighting. Besides the environmental impact of using these, biomass harvesting leads to increasing deforestation and $CO_2$ emissions. In addition, deforestation leads to environmental degradation. Deforested areas lose their top soil (the most fertile layers of soil) during rainy seasons and flooding and are unable to build back up without green cover. Increased flooding also causes loss of life. Thus, economically challenged communities have lost their livelihoods and lives in an attempt to find fuel for their needs, further entrenching themselves in the cycle of poverty. A sad example of this is the country of Haiti, whose high levels of deforestation have reinforced a continuing cycle of environmental degradation, devastating flooding, loss of life and increasing poverty.

### 2.1.2 The Impact of Lighting on the Health and Safety of BOP Communities

Aside from the macro-health issues that come from increased $CO_2$ emissions, many of BOP communities have to deal with more immediate health and safety issues such as smoke inhalation, visual impairments, and house and forest fires.

The World Health Organization (WHO) estimates that over 3 billion people rely on solid fuels such as wood, dung and biomass for their energy needs (see Figure 2.2) (WHO,

[2] A lumen-hour (lmh) is a measure of light output, or how much light comes out of a source at any given time. A Megalumen-hour (Mlmh) is equal to 1000 lmh.

2006).[3] The resulting indoor air pollution causes 1.5 million deaths annually, and numerous other respiratory illnesses such as pneumonia. Epidemiological studies cite elucidated risks particularly for women and children, who spend most of their time around the burning fuel (see Figure 2.3). They also found that $PM_{10}$ (i.e., particulate matter measuring less than ten microns, which is of consequence because they deposit in the air sacs in the lungs thereby causing adverse health reactions) over a 24-hour period in a biomass-burning house was 300-3000 micrograms per cubic meter ($\mu g/m^3$), with peak counts at 30,000 $\mu g/m^3$. Compare this to the maximum mandates for *outdoor* air pollution of the United States Environmental Protection Agency (USEPA) and the European Union (EU) of 50 $\mu g/m^3$ and 40 $\mu g/m^3$ respectively.

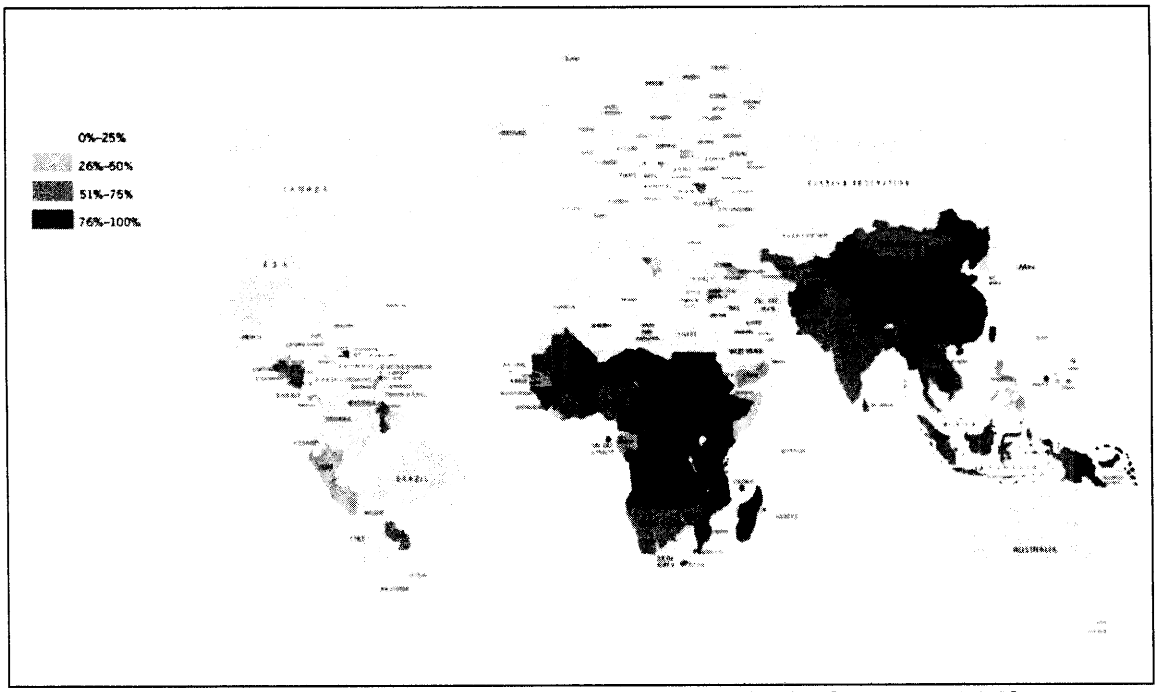


**Figure 2.2: Percentage of population using solid fuels (WHO, 2006)**

In addition to respiratory risks, poor quality light can cause significant visual impairments through continuous eyestrain. What makes it worse is that the poorer populations rarely have access to trained eye-specialists. Without glasses, their vision can deteriorate rapidly affecting their economic productivity.

Finally there are significant safety risks posed by the burning of open fires inside or near the house. During visits to developing countries, including my most recent site visits to India, I frequently saw children who had unwittingly burned different parts of their bodies when they had wandered into burning lamps. In India, I heard of several women who had burned to death when their clothing had caught fire while they were cooking on an open flame or when they had accidentally knocked over a kerosene lamp.

[3] Lighting is bundled in with cooking, heating, and boiling water.

| Health outcome | Evidence[1] | Population | Relative risk[2] | Relative risk (95% confidence interval)[3] | |
|---|---|---|---|---|---|
| Acute infections of the lower respiratory tract | Strong | Children aged 0–4 years | 2.3 | 1.9–2.7 | SUFFICIENT |
| Chronic obstructive pulmonary disease | Strong | Women aged ≥ 30 years | 3.2 | 2.3–4.8 | |
| | Moderate I | Men aged ≥ 30 years | 1.8 | 1.0–3.2 | |
| Lung cancer (coal) | Strong | Women aged ≥ 30 years | 1.9 | 1.1–3.5 | |
| | Moderate I | Men aged ≥ 30 years | 1.5 | 1.0–2.5 | |
| Lung cancer (biomass) | Moderate II | Women aged ≥ 30 years | 1.5 | 1.0–2.1 | INSUFFICIENT |
| Asthma | Moderate II | Children aged 5–14 years | 1.6 | 1.0–2.5 | |
| | Moderate II | Adults aged ≥ 15 years | 1.2 | 1.0–1.5 | |
| Cataracts | Moderate II | Adults aged ≥ 15 years | 1.3 | 1.0–1.7 | |
| Tuberculosis | Moderate II | Adults aged ≥ 15 years | 1.5 | 1.0–2.4 | |

[1] *Strong evidence: Many studies of solid fuel use in developing countries, supported by evidence from studies of active and passive smoking, urban air pollution and biochemical or laboratory studies.*
*Moderate evidence: At least three studies of solid fuel use in developing countries, supported by evidence from studies on active smoking and on animals.*
*Moderate I: strong evidence for specific age/sex groups. Moderate II: limited evidence.*
[2] *The relative risk indicates how many times more likely the disease is to occur in people exposed to indoor air pollution than in unexposed people.*
[3] *The confidence interval represents an uncertainty range. Wide intervals indicate lower precision; narrow intervals indicate greater precision.*

**Figure 2.3: The impact of indoor air pollution on human health (WHO, 2006)**

## 2.1.3 The Impact of Lighting on the Livelihoods of Users

A secondary outcome of the lack of good quality lighting is its effect on poverty. Deforestation and poor health impact economic productivity particularly in BOP communities, which rely heavily on manual labor, agriculture, and herding for their livelihoods. Also energy expenses factor heavily into household income. The IEA (2006) states that on average, non-electrified communities pay significantly more for their lighting than wealthier families for much poorer quality light. Considering the income differential, this constitutes a significant percentage, as shown in Figure 2.4.

There is also the issue of time spent on fuel collection. Surveys of different African countries found that women spent up to four hours per day collecting fuel (see Figure 2.5), which could have been spent on other income-generating activities or for rest. During site visits in southern India in January 2007, I heard frequent complaints about how time-intensive fuel collection was. Surprisingly, this was true even of kerosene collection from the local ration shop. In India, where heavily rationed kerosene is the primary lighting fuel for non-electrified communities, some residents queued for as much as three days every month hoping to get their rations. The supply was never guaranteed, and residents often came home with adulterated versions of kerosene. Even with kerosene access, the women and children spent several hours supplementing it with wood from the forests or vegetable oil that they extracted to burn in their lamps. In fact, workers at a ration shop told me that the Indian government expects rural communities to supplement their kerosene rations with other sources. For example, urban dwellers are given five liters of kerosene per month compared to rural households, which are limited to three liters, for this very same reason.

The risk of fires also poses a significant concern for livelihoods. Farmers, tailors and weavers, for example, are extremely susceptible to fires as their work is light intensive and their wares are highly inflammable. I've seen many weavers and tailors work with a candle precariously placed on or near their mills and sewing machines. Silk farmers can lose an entire season's earnings if a few drops of kerosene or wax fall on their harvest. Additionally, these professions are extremely susceptible to eye strain and resulting visual impairments because of the visually intensive nature of their work. As their eyes weaken, so does the quality of their work and their corresponding economic outcome.

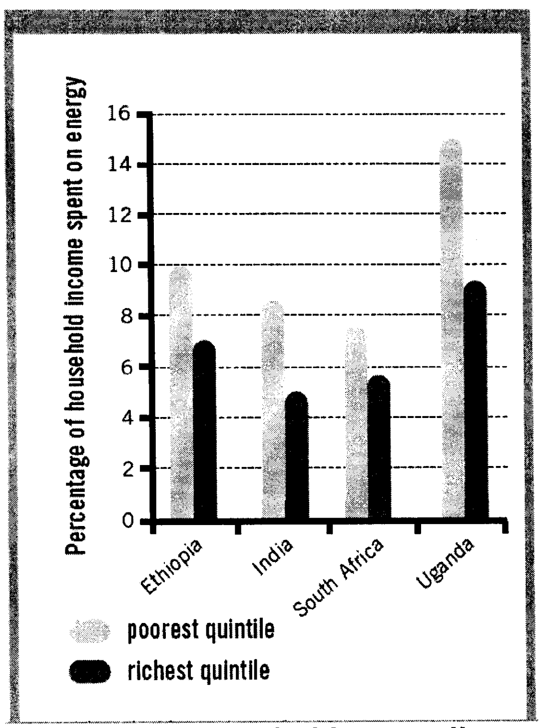


**Figure 2.4: Household expenditure on energy (WHO, 2006).**

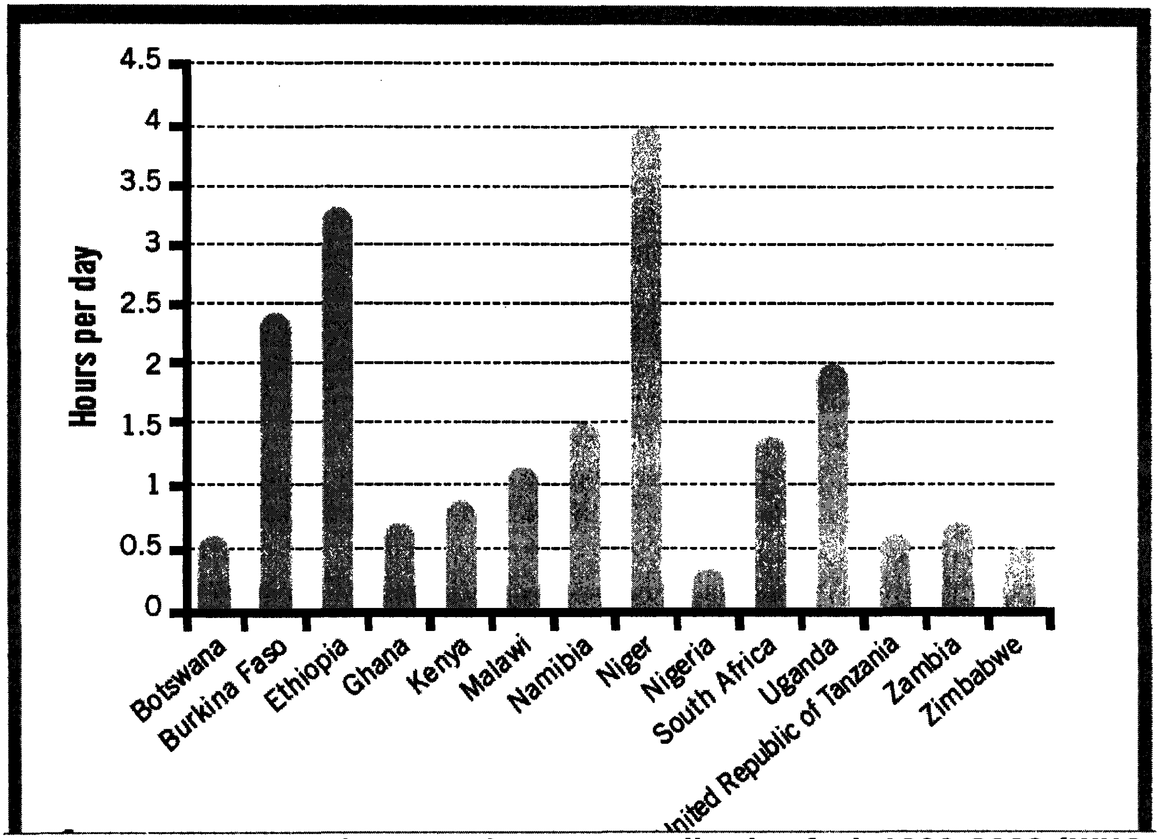


**Figure 2.5: Hours per day spent by women collecting fuel, 1999-2003 (WHO, 2006).**

## 2.1.4 The Socio-Economic Impact of Electricity Access

Access to electricity is positively correlated with socio-economic progress. This was most obvious in the late 1800's when the invention of the light bulb and transformer resulted in the large-scale production of electricity which spurred the industrial revolution, and economic growth rates unseen before.

While causality of electricity use to economic growth is still being established, most authors and academics agree that there is a relationship to some degree. For example, an analysis of household lighting in China found a near linear relationship between the two as shown in Figure 2.6 (IEA, 2006). The IEA explains that this type of linear relationship is less likely to hold once income levels rise and income becomes less of a constraint on total service provision. Figure 2.7 shows the correlation between the Human Development Index (HDI) and per capita energy use. Pasternak (2000) theorized that HDI and per capita energy consumption were positively correlated until it reached the threshold value of 4000 kilowatt-hours (kWh) per capita consumption, after which the relationship plateaued, i.e., HDI was largely unaffected. Considering that most developing countries fall under this threshold (see Appendix 1, with 2003 values), it can be theorized that their HDI will increase with increasing rates of electricity consumption. On average, countries with high HDIs tend to use far more electricity than countries with lower HDIs. For example, the average per capita electricity consumption in 2003 for an

OECD country was 8,777 kWh. Compare that to the same for the Least Developed Countries (LDCs), which is 114 kWh (UNDP, 2006c). As the statistics for the LDCs indicate, it can also be shown that the converse is true, i.e., lack of access to electricity is correlated to poverty.

In an extensive study on available lighting sources in developing countries, Mills (2005) found that typical residential electric sources (such as incandescent bulbs, LFLs and CFLs) gave out at least 500 times more light (lumens) at a 1m distance than a wick-based lantern, which is the preferred means of lighting in non-electrified households. Consequently, the ability to function or perform visually oriented tasks is impaired in lower lighting, causing lower economic productivity. For example, I noticed during multiple site visits to non-electrified communities around the world, that many of the residents planned their day's activities around the availability of sunlight. All economically productive work was done while the sun was out. Between dusk and dawn, work slowed down considerably. I also noticed that more children were dropping out of school in communities with poor or no access to electricity. One explanation for this is that the children went to school and did chores (including collecting wood from the forest) while the sun was out. At night, when they finally had time to study, there was only wick-based lighting, which made it very difficult for them to work. Few finished their homework; they would fall behind in school and eventually drop out. These are just a few observed examples of the impact that electricity access has, both in terms of time saved to be more economically productive, and in improving literacy in poor communities.

Probably the most powerful visual example of the electricity-income relationship is shown in Figure 2.8, a satellite picture of the earth at night. What is obvious is that the more developed countries, such as the countries that are part of the OECD have significantly higher rates of electrification than non-OECD countries. For example, per capita energy use in North America is eleven times higher than that of sub-Saharan Africa (WEA, 2004).

It is also true, as discussed earlier and shown in Figure 2.4 that energy takes up a significant percentage of a BOP household's income. An extensive study by the World Resources Institute (WRI, 2007) substantiates the data by the WHO study that on average BOP households spend about 9% of their income on energy. This takes a heavy toll on their ability to save.

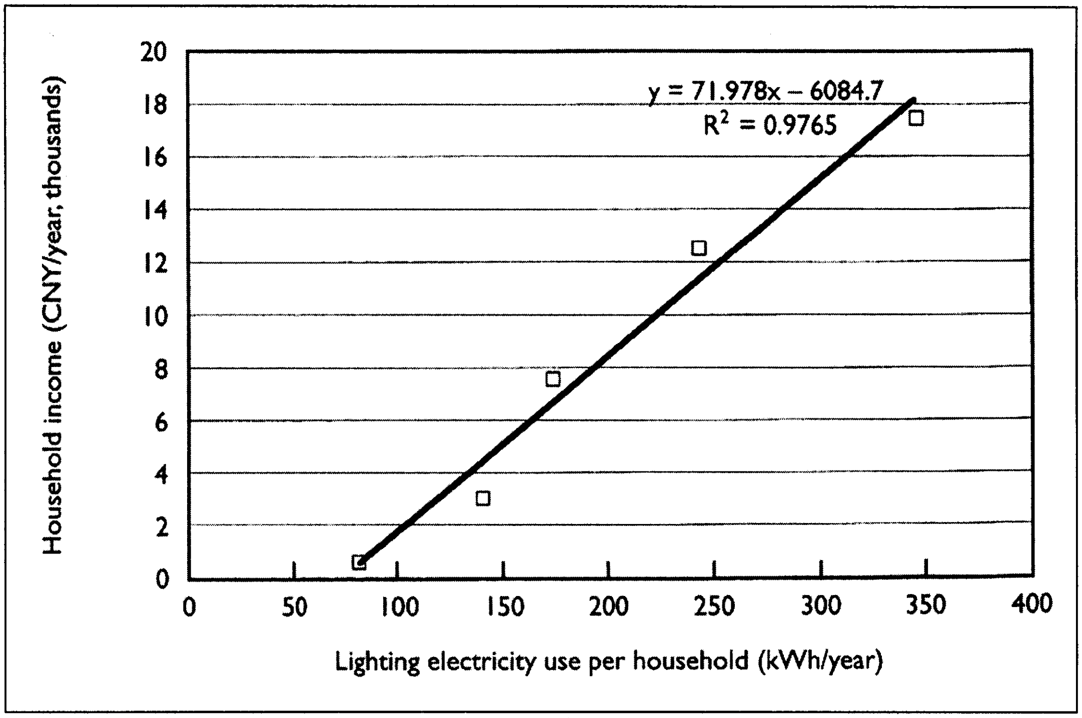


**Figure 2.6: Average annual household-lighting electricity consumption versus income in China (IEA, 2006)**

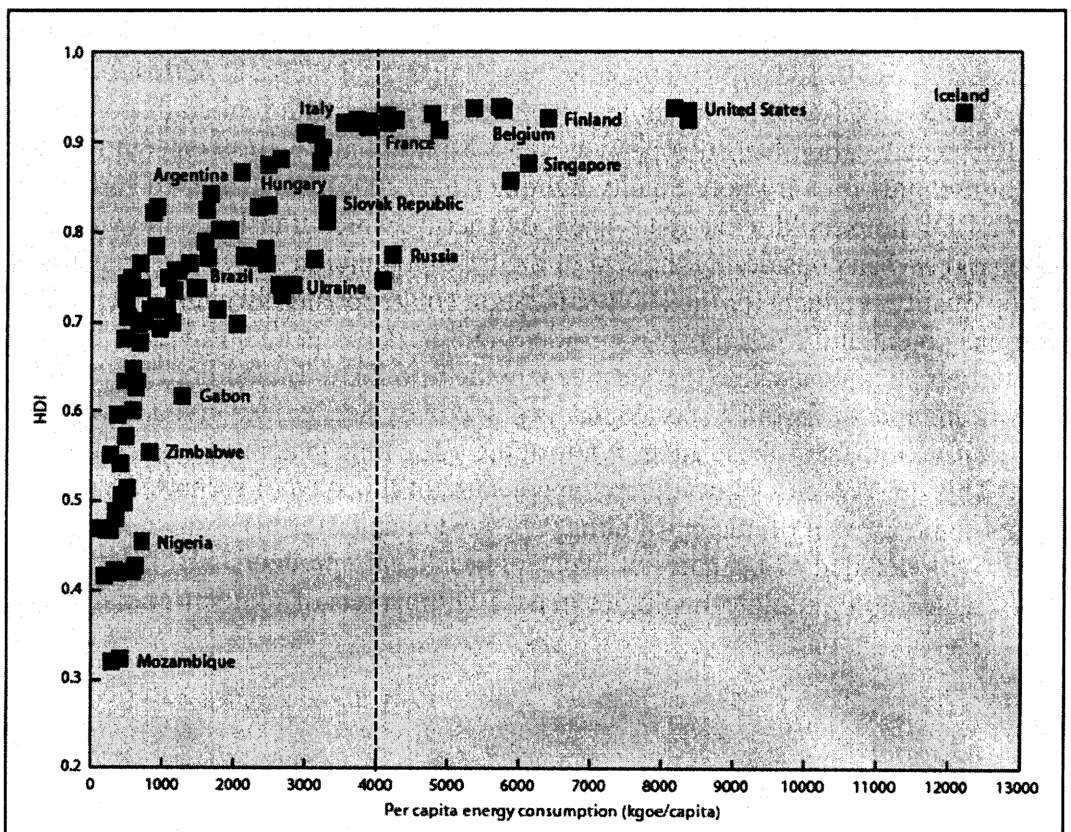


**Figure 2.7: Relationship between HDI and per capita energy consumption, 1999/2000 (WEA, 2004)**

**Figure 2.8: Composite map of the earth at night (NASA, 2000)**

## 2.1.5 The Market Size for Rural Lighting

One of the major upsides to this otherwise dismal view of rural electrification is the potential market size. Small-scale entrepreneurs can tap into a 1.6 billion-consumer market that generates US $38 billion annually (based on annual fuel sold to this sector, IEA 2006). Granted that these communities are in remote areas with limited disposable incomes (BOP sectors), but they still spend as much as, if not more, for their lighting as electrified households for very poor quality lighting (IEA, 2006). As discussed earlier, at least 9% of a BOP household's income is spent on energy, which translates into an enormous market when considering the size of the BOP population. Any entrepreneurs who develop quality products for the BOP population could potentially churn out a profit, with enormous potential for scalability. Consider Figure 2.1 where a "business as usual" scenario, predicts an almost stable market size moving into 2030. In addition, entrepreneurs are able to extend a service that is desperately needed and could have enormous positive impact in these areas, while at the same time generating a profit for themselves. This thesis focuses heavily on the potential of this type of scenario, within the large and stable market of quality lighting. The next chapter further examines exactly this scenario with detailed case studies of two small-scale entrepreneurs who have successfully scaled up lighting technologies in the BOP markets of southern India.

## 2.2 Salient Features of Electricity, Solar Power and Kerosene

This section highlights some of the necessary salient features about electricity, solar power, and kerosene. While this is a simplified version of energy generation in developing countries, it gives some necessary background for some of the issues raised in this chapter, as well as in preparation for the case studies presented in the next chapter.

The primary source for the material provided below is a series of lectures given by Henry Lee and John Holdren, in March and April 2007. Henry Lee is a lecturer and director of the Environment and Natural Resources Program at the John F. Kennedy School of Government (KSG), Harvard University. John Holdren is a professor and director of the Program on Science, Technology and Public Policy at the same, as well as a professor in the Earth and Atmospheric Sciences Department at Harvard University.

### 2.2.1 Electricity

"Electric current" or "electricity" is just one part of a much larger electricity system that consists of generation, transmission, grid or network coordination, distribution, and marketing. While the basic components of electricity, i.e., electric current generation, wiring, transformers and lamps were invented by the late 1800's, the system itself evolved through much of the earlier part of the 1900's to what it is today. Increasing population continues to demand greater efficacy of the system, and some proponents say that it is still evolving.

All the different parts of the electricity system work very differently from each other (in terms of lifespan, capital and operating costs). This is further complicated by the fact that electricity cannot be stored in large amounts. As a result, generation has to keep up with demand, which changes significantly with both micro (daily usage) and macro (annual) usage. Short-term demand elasticity for electricity is very low at high demand levels and supply is very inelastic at such levels. Not surprisingly, most blackouts in developing countries happen because of lack of adequate standby systems and poor transmission systems. Developing countries also have a high rate of theft in their distribution networks. For example, electricity theft in India leads to annual losses estimated at US $4.5 billion or about 1.5% of GDP (Bhatia et al., 2004).

One very important point to note is that transmission systems are very expensive to build, making it most economically viable to provide electricity to high density, largely urban areas where there are a greater number of connections per unit developed, rather than rural areas where electricity demand is scattered and return on investment is much lower. This is the primary reason for the very large disparity in urban and rural electrification. Therefore, it might be best to develop more efficient off-grid systems in rural areas, particularly in developing countries where resources are constrained.

To understand off-grid systems better, one must understand a few more details about the nature of electricity. Electricity can be transmitted in two forms – alternating current (AC) or direct current (DC). AC is the type that is generated in power plants and then transmitted to our homes and offices through the elaborate transmissions systems we see all around us. DC is the type of electricity that is stored in batteries.

Off-grid electricity in developing countries is usually produced in two ways: a generator, which acts as a mini power plant uses liquid or gaseous fuel (generally petrol, diesel, biogas, or kerosene) to generate AC that is transmitted to a mini-grid. The other alternative is to use batteries, which store DC. Both have their limitations. Fuel is an expensive commodity in BOP communities and even the smallest generators burn up a lot of fuel in order to generate electricity. In every off-grid community I visited, only the wealthier residents could afford to use generators for their electricity needs. Batteries were more commonly used among the BOP. While more expensive per unit energy than fuel burned by the generator, batteries are more widely available, procurable, and transportable than the energy produced by the generator. For people whose lighting needs are very specific and limited, like with many BOP households, battery-powered light can be more suited to their needs than grid power. But batteries are limited in how much energy they can store and they also generate significant hazardous waste.

Considering what a major role that batteries will continue to play in off-grid systems, it is very important to select lamps or lighting sources very carefully. Section 2.3 will detail the different types of lamps (like LEDs and CFLs) and their properties. In this context, the most efficient bulb (that gives out most light per unit energy input) that works on the lowest power input is most relevant and useful for off-grid lighting in developing countries.

### 2.2.2 Solar Energy

Solar power is just one of the many renewable sources of energy being sought out to replace oil dependency globally. Solar energy can be captured by different types of collectors of which photovoltaic (PV) cells are the most widely used. PVs use semiconductor materials, like silicon, to capture solar energy through a property known as the "photoelectric effect." Solar energy that hits the PV cells causes free electrons to move about, creating an electric current. Most PV cells are used in conjunction with batteries, which store some of the power for use during times of low to no light, such as downcast days or nights.

PVs are advantageous because they have a long life span (greater than 30 years), are high performance (i.e., their energy generation capacity degrades by around 1% every year) and are relatively low maintenance. The only disadvantages of PV systems are that they require regular cleaning, and run the risk of potential leakage of toxic chemicals in the PV cells. The main drawback in PV (or generally solar energy) usage is that they are very expensive compared to electricity produced from a grid. In the US, PV-based electricity costs three to five times as much as grid electricity (Bullis, 2006). The World Energy

Assessment (WEA) has estimated PV energy to cost approximately US $0.25-0.50/kWh, but they also predict that with increasing research and development, and market growth, the cost can decrease to US $0.05/kWh (WEA, 2000).

On the downside, increasing energy prices and renewable energy policies around the world has increased the demand for PV cells, which has resulted in an increase in global prices. A tight supply of silicon has further created a backlog of demand. For example, the Energy Information Administration (EIA, 2006) states that the US (which is one of the world's largest producers of PV cells) reached record sales of PV in 2005, with PV cell prices rising by 13% over 2004. This has created some difficulty for off-grid applications in developing countries, where consumers are particularly sensitive to price volatility.

Solar energy is most regularly and amply available around the equatorial region, where many developing countries are situated. The abundant availability of solar energy coupled with the long lifespan and other advantages, makes solar PVs an excellent option for off-grid electricity production. The biggest barrier to entry in these markets has been the high cost of PVs and many doubt the possibility of entering the rural, non-electrified household market. SELCO, one of the organizations profiled in the next chapter, is showing that it is indeed possible to "sell solar" in these markets.

### 2.2.3 Kerosene

Kerosene is one of the many byproducts of petroleum distillation. Kerosene, also known as paraffin, has multiple uses including as jet fuel, as a base for paints and petrochemicals, and as a fuel for the poorer populations in developing countries. In general, the price of kerosene fluctuates with the price of oil.

In some countries like India, kerosene is the most commonly used fuel for lighting, cooking, and heating by BOP consumers. Because it is a liquid, it is often easier to transport and distribute than natural gas or Liquid Petroleum Gas (LPG),[4] which is the preferred fuel for domestic use in electrified households. As discussed earlier, kerosene is extremely inefficient as a lighting fuel, and can be much more efficient as a cooking fuel (it provides more energy in heat than light, which makes it more beneficial for cooking), though there are still health issues related to the burning of kerosene. Countries that have high oil subsidies like India, have thus far shielded their consumers from the price fluctuations of kerosene which has created a wealth of inefficiencies including inefficient cookstoves and lighting practices, lack of innovation in these areas, and informal markets, which will be further discussed in Chapter 3.

It is also interesting to note that there are studies that show a correlation between fuel choices, literacy and income level. Studies by Farsi et al (2005) and UNDP (2003), it was found that household income, literacy level and gender of the Head of Household (HH),

[4] LPG consists of butane, propane or a mix of both. It is the preferred cooking fuel in India.

proximity to larger cities and towns had a significant effect on fuel choices. For example, Households who were illiterate or had lower levels of literacy were more likely to choose kerosene, firewood or dung, over Liquid Petroleum Gas (LPG).

## 2.3 The Technical Aspects of Lighting

As shown in the previous section, the quality and quantity of lighting have a significant impact on our lives. The communities who suffer most as a result of inaccessibility to quality and quantity of lighting comprise the BOP. And while they are most affected in the short term, the long-term effects already have and will continue to spillover to include the rest of the population, in terms of increased GHG emissions, environmental degradation, and longer term issues such as immigration resulting from continued poverty. The question then is: *how can we improve access to better quality lighting for the poor*? From a business point of view, one of the easiest ways to do this might be to design, mass-produce and market a single lighting product that would address the needs of the people. This would minimize capital and marginal costs, thereby bringing down the market price of the product. However that would assume the homogeneity BOP communities, which is far from accurate. In fact, their needs can be even more disparate than the non-BOP community. For example, the lighting needs of an illiterate silk farmer who will only use light for sieving through his day's harvest are less intensive than those of a school-age child doing her mathematics homework. In this situation the farmer might want a lighting product that conserves energy (and consequently money) by giving him lower quality light that lasts longer than the child whose priority for better quality light means higher cost per unit time.

Given the technical and cost constraints particularly within the BOP community, it is best for lighting to be viewed in a comprehensive way. This section gives the reader a more comprehensive background on lighting and consequently, a greater appreciation for what THRIVE and SELCO are accomplishing. First the reader is introduced to the human factors involved in lighting, followed by a discussion on lighting standards and different lighting sources within a technical framework. Please note that the field of light and lighting is extremely complex, and this is a simplified version of the issues and terms involved.

### 2.3.1 Human Factors in Lighting

It is impossible to address lighting standards without first understanding the human factors involved in lighting. "Light" is defined by what the human eye can see, or as visible radiant energy. The entire electromagnetic spectrum is far greater than the human eye can "see" or perceive. "Light" and "lighting" generally refer to the portion of the electromagnetic spectrum that is visible to the human eye, specifically between the wavelengths of 380-770 nanometers.[5]

According to the IEA, studies have shown that the human eye can function over a vast range of light levels (IEA, 2006). While higher levels of light or more light per unit area (also defined as "lux") is needed for more visually acute tasks, in general, visual performance is fairly insensitive to the amount of light, once the eye has adapted to prevailing light levels. What is more important for visual task fulfillment is contrast, rather than high light levels. On the other hand, contrast levels that are too high and/or with very bright backgrounds impair vision by producing glare. Consequently, most lighting devices need to incorporate some form of shielding and careful placement to minimize direct eye-to-lamp line of sight. Also because the eye needs time to adjust, it does not perform well in flickering or fluctuating levels of light. This is partially why productivity using wick-based lighting is lower compared to electric sources, including flashlights; and performing more visually intensive tasks in this light can cause significant eyestrain. Eyestrain also hinders the eye's ability to adjust in varying levels of light effectively, further decreasing visual performance.

The human eye's versatility in performing over a range of lighting levels also makes it very hard to standardize lighting recommendations. Quality of light, which is based on personal preferences, is very hard to measure because people's eyes and perceptions are so diverse. It is therefore measured with relation to quantity, which is also called "illuminance" and is measured in terms of "lux" and other terms that are defined in Section 2.2.2. Quantity does not accurately capture the distribution of light, avoidance of glare, and color. Considering these factors, it is not surprising that there is great international diversity in lighting standards. A 1999 study of illuminance recommendations from 19 countries (including all OECD countries) found a wide range of values (Mills et al., 1999), for example:

- General office lighting ranged from 50-1000 lux.
- Reading tasks ranged 75-1000 lux.
- Fine knitting and sewing ranged 50-2000 lux.

Studies cited by the IEA (2006), also found that worker lighting preferences changed across countries. For example, a Canadian study found that North American office workers preferred illuminance levels of around 400 lux, about 25% more than a group of French office workers. The IEA also found that "preferred lighting levels in working environments are often far lower than national recommended values," meaning that national levels were often higher than what workers preferred.

Variability in standards, such as those mentioned above, is very important particularly when considering the minimum level of lighting that small-scale entrepreneurs (like SELCO and THRIVE) should design their lighting technologies around. For example, illiterate populations who are less likely to use the light to read and write may require a

[5] 1 nanometer (nm) = $10^{-9}$ meter (m).

light of lower illuminance, which uses less energy and is cheaper, than school-going children who will need higher lighting levels when doing their homework. In this scenario, an entrepreneur would be able to design a switch that allows the user to set their lighting preferences. But this feature will increase the capital and operating costs (higher chance of breakdown) of the lantern. Also, lighting preferences between different communities are likely to be different. For example, Indian tribal communities who are accustomed to working in primarily natural light (which includes low moonlight) might prefer to work with far lower lighting levels than say a Mumbai slum dweller who might be accustomed to high levels of light as a result of his or her urban surroundings. It is therefore very difficult to design a standardized product for BOP communities.

### 2.3.2 Light Measurability and Standards

In order to appreciate the differences in lighting technology, it is important to define some of the standards for light sources. Please note that lighting standards and terminology are far more complex than the information provided in this chapter, which aims to provide a basic technical context for the case studies. Therefore, these standards and definitions are simplified. The primary resource for this section, unless otherwise cited, is the Lighting Research Center (LRC, 2006).

a. **Light output** is a measure of how much light comes out of a source at any given time. It is commonly measured in lumen-hours (lmh). A lumen is a unit time rate flow of light. The Illuminating Engineering Society of North America (IESNA) defines a lumen as follows:
   *[A lumen is a] Standard International (SI) unit of luminous flux.*[6] *Radiometrically, it is determined from the radiant power. Photometrically, it is the luminous flux emitted within a unit solid angle (one steradian)*[7] *by a point source having a uniform luminous intensity of one candela.*

b. **Efficacy** of a light source is a measure of light output per unit power input into the source, or lumens per Watt (lm/W). System Efficacy includes ballast losses.

   It is important to note that all light sources give out heat, when producing light. A good rule of thumb when gauging the level of efficacy is those sources that "burn hot" (i.e., give out a lot of heat when providing light) have a lower level of efficacy compared to light sources that remain cool. Essentially, energy that goes into the bulb (in the form of electricity or burning fuel) will be converted to an equal amount of energy that is a combination of heat (thermal) and light. Consequently, producing more thermal energy (heat) will compromise the production of light energy.

[6] Luminous Flux is "the rate of flow of light, measured in lumens. The overall light output of a lamp" (LRC, 1995).
[7] A Steradian is "the solid angle subtended at the center of a sphere by an area on the surface of the sphere equal to the square of the sphere radius" (LRC, 1995).

c. **Intensity of light** from a source (also known as candlepower) in a particular direction is measured in candelas (cd). A good way to look at this is how much the light from a source diffuses radially as it moves towards the direction in which it is pointed. For example, a laser is very intense, indicating higher candlepower, and diffuses very little as it moves towards the direction in which it is pointed; while light from an incandescent light bulb diffuses significantly as it moves in its pointed direction.

d. **Illuminance** is a measure of how "well-lit" a particular area is, or light output per unit area. Illuminance is measured in lux (lx) or footcandles (fc), and is very important in determining basic lighting needs.

   lux (lx) = $lm/m^2$; fc = $lm/ft^2$

   1 lx = .0929fc

   A good example of illuminance can be taken from the natural world. Direct sunlight on earth can be around 150,000 lx, while moonlight can be as low as 0.5 lx (IEA, 2006).

e. **Luminance** is a measure of "brightness," or how the human eye perceives the luminous intensity at a certain distance. It is measured in $cd/m^2$. While recommendations for lighting are generally made in terms of illuminance, it is important to note that the visual system responds directly to luminance. Therefore, illuminance is an indirect benchmark for lighting levels.

### 2.3.3 Artificial Lighting Sources

The quality and quantity of light produced by a lighting source or lamp depends on the type of fuel used for the process. For the purposes of this thesis, the most common types of household lighting sources found in developing countries are broadly sorted into two categories: electric and combustion. Electric sources are used by roughly 75% of the world's population, while combustion sources, used by the rest, rely on the burning of fuels such as biomass, kerosene, and candles. These are described in some detail below.

Typically, lighting sources or lamps function and deliver light as part of a system. Each lighting system consists of lamp(s) or lighting sources, luminaries (the lamp casing that helps distribute the light into space), and the control gear (which helps regulate, ignite or turn off the light). The economy of any lighting system is dependent on capital costs, the operating costs (which include the fuel and maintenance charges), and any labor costs for installation.

While all of the sources provided here are of significance, the technologies that will be highlighted in the next chapter are CFLs and LEDs. A discussion of these will be presented later in this section.

### 2.3.3.a Electric Sources, also known as Lamps

There are four broad varieties of electric sources or lamps. Examples of each type are shown in Figure 2.9–Figure 2.14. A comparison table of these lamps is provided in Table 2.1. The most popular of these for residential lighting in developing countries are incandescent bulbs, followed by fluorescent lamps. High Intensity Discharge lamps (HIDLs) are used only in wealthier sectors for residential and commercial lighting, while LEDs have just entered most markets as a lighting competitor and are continuing to grow in market share.

- **Fluorescent Lamps (FLs):** In FLs, low pressure mercury is ionized when a voltage difference is created, producing primarily ultraviolet radiant energy, which causes phosphors to fluoresce.[8] Two of the more popular types of FLs are of significance for this thesis—linear FLs (LFL), which are also the standard fluorescent light or popularly known as a "tube light" in developing countries, and the CFL. FLs use ballasts, controllers that provide a voltage differential necessary for them to function. The quality of a ballast can significantly affect the efficacy of an FL.

  LFLs have some of the highest efficacy levels of lighting sources considered here, at 60-104 lm/W (with ballasts), and life spans of 7,500–30,000 hours. These factors combined with low capital and maintenance costs (per unit delivered light), and vast availability have made them the main source of lighting in the commercial sector.

  CFLs were developed in the 1970's and truly entered the commercial market in the 1980's. They come in two types—with the ballast integrated (as part of the bulb) or separated. The former is the more popular version and directly competes with the incandescent bulb. While CFLs are about 20 times the cost of an incandescent bulb, their efficacy is five-times higher. Therefore, their low operating costs (including electricity costs and longer life-span) make them far more cost-efficient per kWh in the long run. The IEA (2006) estimates that "a market shift from incandescent lamps to CFLs would cut world lighting electricity demand by 18%."

- **Incandescent Lamps**: Incandescent lamps depend on a filament (typically coiled tungsten wire) that heats up to incandescence when current flows through it.[9] Incandescent lamps are the most popular and have the lowest efficacy of all electric lamps. Their design, and consequently performance, has hardly improved since the 1930's.[10]

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[8] Fluoresce: To "light up" through chemical processes.

[9] Incandescence: The emission of electromagnetic radiation due to excitement of atoms and molecules.

[10] Halogen lamps are also part of the incandescent bulb family and were developed in the 1950's. However, for simplicity sake, these are not discussed because they have limited application in the context of lighting within BOP communities who form the focus of this thesis.

Incandescent lamps are popular when compared to other electric sources because they are widely available and familiar, have a warm color, and sell at a low price. However, they have a low life span (~1000 hours), they diffuse widely and "burn" away as much as 95% of their energy input in heat. The standard household incandescent bulb has an efficacy of 6-18 lm/W.

Halogen lamps are a subgroup of incandescent lamps (and the most efficient form) that became commercialized in the 1980's. They are primarily used in vehicles and for mood lighting in households. They are far more efficient than regular incandescent lamps, with 15-33 lm/W and a 2000-6000 hour lifespan. However, they still lag behind the efficacies of FLs and LEDs (see Table 2.1).

- **High Intensity Discharge (HID) Lamps**: These lamps light up when pressurized gases in an arc tube are ionized by current flow between electrodes. Like FLs, they are also dependent on external control gear (like ballasts) to function, which can reduce their overall efficacy. There are three main types of gases that are used in HID lamps:

    - Mercury Vapor: Primarily mercury with small quantities of argon, neon and krypton.
    - Metal Halide: Same as mercury vapor, with iodides of sodium and scandium (halides) or with rare earth metals.
    - High Pressure Sodium: Sodium, mercury amalgam, and xenon.

HID lamps offer several important advantages compared to incandescent lamps and LFLs, including long lifespan, temperature insensitivity, and high illuminance. Mercury Vapor lamps are the cheapest of the HID lamps listed above and consequently more widely available. However, they have the lowest performance characteristics and highest life cycle costs. High Pressure Sodium HID lamps have the highest efficacy of the three.

In spite of all their advantages, HID lamps are not extremely popular because of their long warm-up and ignition times (i.e., they can take 5-15 minutes to reach their full luminosity), and their high tendency to flicker. In addition, they have high lumen depreciation rates.[11] The luminous flux for both Mercury Vapor and Metal Halide lamps tends to depreciate by 50% (i.e., they give out 50% of their peak lumen output) towards the end of their lifespan.

In the context of rural markets in developing countries where lighting needs are limited, HID lamps are expensive, energy intensive, and an unnecessary luxury. They might have limited commercial applications, but hardly any household applications.

[11] Lumen depreciation means that the efficacy (lm output per unit W input) of the bulb drops over its lifespan.

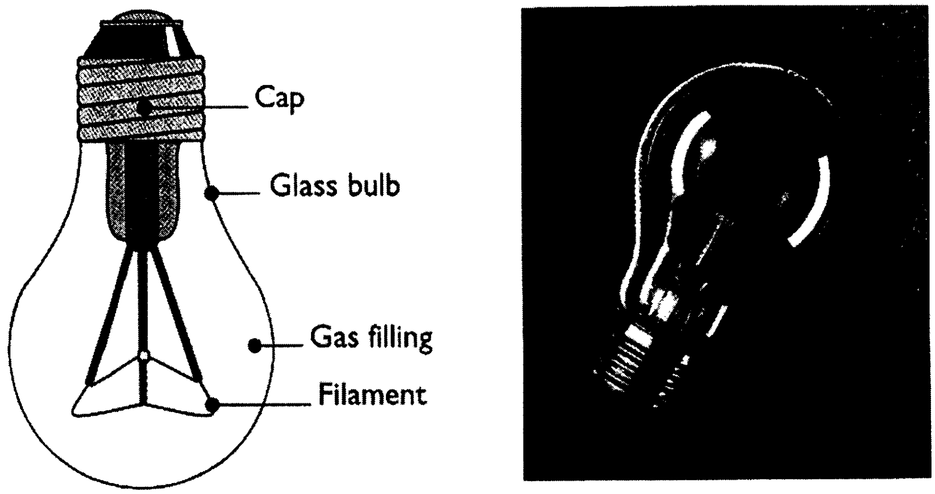
- **Light Emitting Diodes (LEDs):** LEDs are the newest addition to lighting and are still continuously evolving. In fact, the efficacy of LEDs has been nearly doubling every two years (IEA, 2006). LEDs are semiconductor devices that emit light when excited (i.e., when current passes through them). They can illuminate in different colors depending on the type of material used in the device. LEDs have had multiple functions in the past, primarily within the field of electronics. Only recently have they been developed further for lighting purposes.

  LEDs are advantageous because they are extremely sturdy, have long life spans, burn brightly on very little power (high efficacy), and have a range of colors (including white LEDs). LEDs give out very little heat when they light up, making them extremely efficient (i.e., net energy going in as a factor of electricity typically goes entirely into light production). Also, they turn on and off immediately, and rather than burning off suddenly as is common with conventional light sources, like incandescent bulbs and FLs, LEDs gradually dim when they are wearing out. They have a very low depreciation rate of about 1% per year.

  Their disadvantages are their high cost per lumen, particularly compared to more conventional forms of electric lighting, such as fluorescent and incandescent bulbs. It must be understood that this is a young technology, that continues to evolve and that we can expect prices to decrease with increasing LED applications, particularly with mass production. Further, they are extremely sensitive to voltage fluctuations and work best when a steady current is supplied. Finally, they are primarily unipolar; they only burn on a positive polarity (or DC, the type of electricity stored in batteries). While they can process AC, they will only light up when the AC has a positive polarity.

  An interesting feature of LEDs is that they are high intensity and have lower diffusion levels. In terms of human factors, LEDs encourage task lighting (higher illumination around the task area or direction in which they are shown) and lower ambient lighting, which is one of the recommendations for improving overall world energy efficiency in lighting by the IEA (2006).

  For all these reasons, they are ideal lighting sources for resource-constrained situations, and are increasingly sought out for use in off-grid areas and developing countries. One of the case studies examined in the next chapter features a small-scale entrepreneur in India who has designed and successfully scaled up LED lanterns in extremely resource-constrained environments around the world.

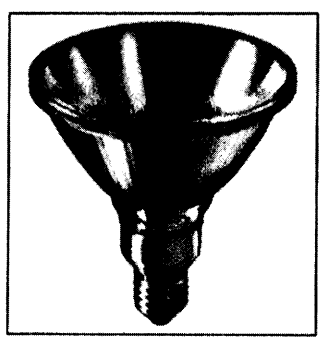



*Sources:* CADDET, 1991 (left); Courtesy of European Lamp Companies Federation (right).
*Abbreviation:* GLS = general lighting service.

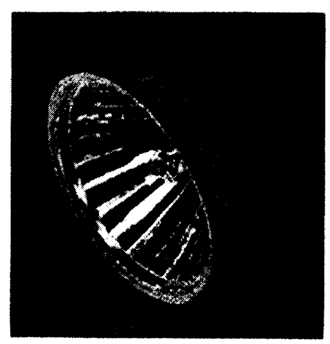
**Figure 2.9: Example of an incandescent light bulb (IEA, 2006)**

Linear double-ended halogen lamp.

Halogen capsule lamp.



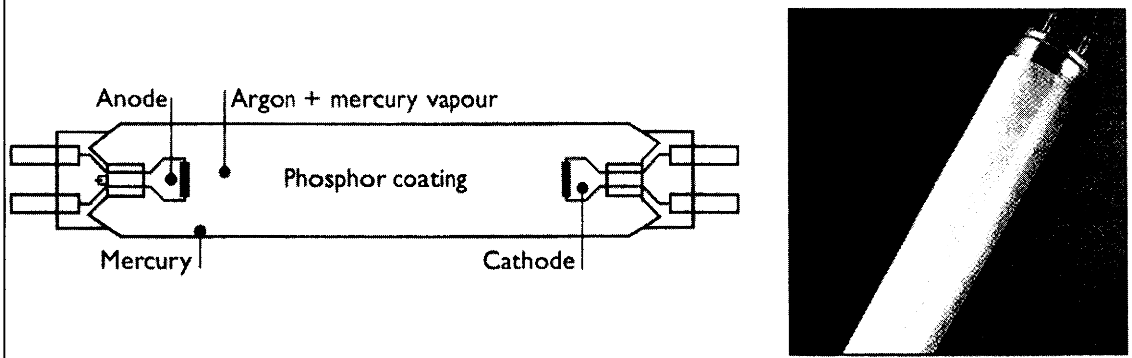
Halogen PAR lamp.



Halogen reflector lamp.

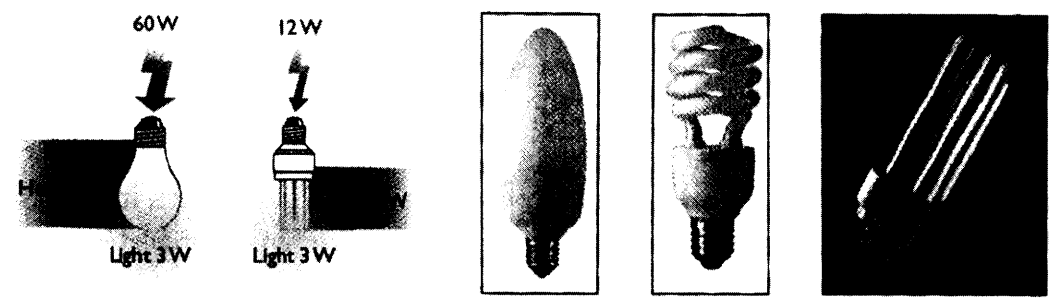
*Sources:* Courtesy of Philips Lighting (top and centre); Courtesy of European Lamp Companies Federation (bottom right and bottom left).

**Figure 2.10: Examples of common halogen lamps (IEA, 2006)**




*Source:* CADDET, 1991 (left); Courtesy of European Lamp Companies Federation (right).
*Abbreviation:* LFLs = linear fluorescent lamps.

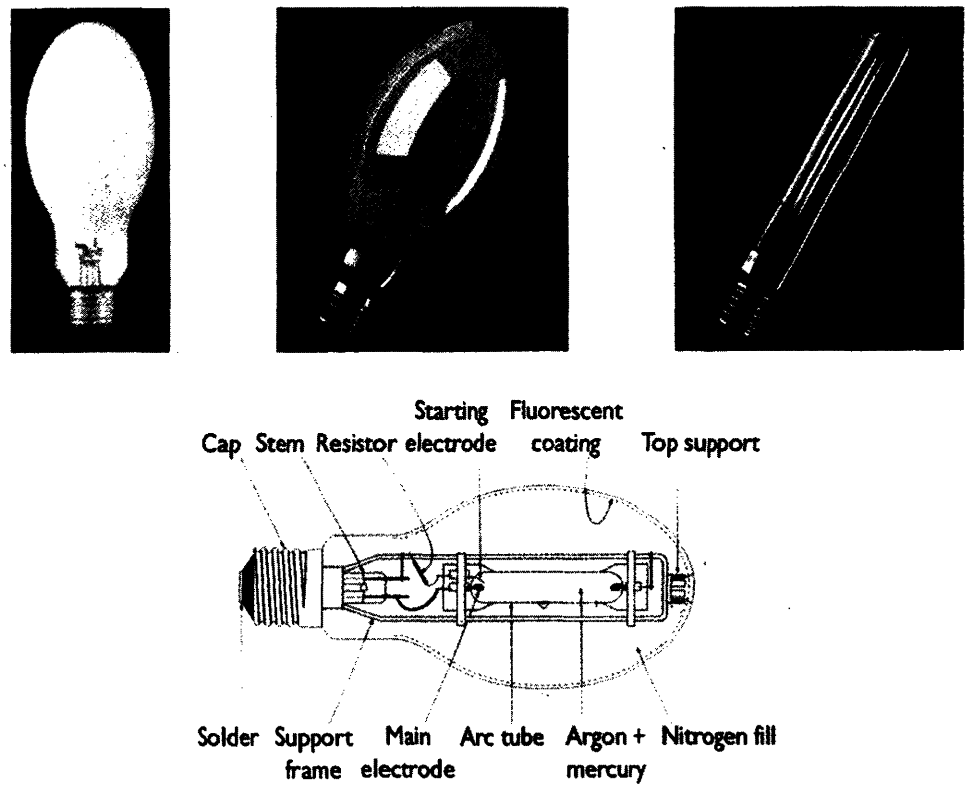
**Figure 2.11: Features of a linear fluorescent lamp (IEA, 2006)**




Heat losses from GLS lamps and CFLs. | Spiral CFL. | Candle-shaped CFL. | Stick CFL.

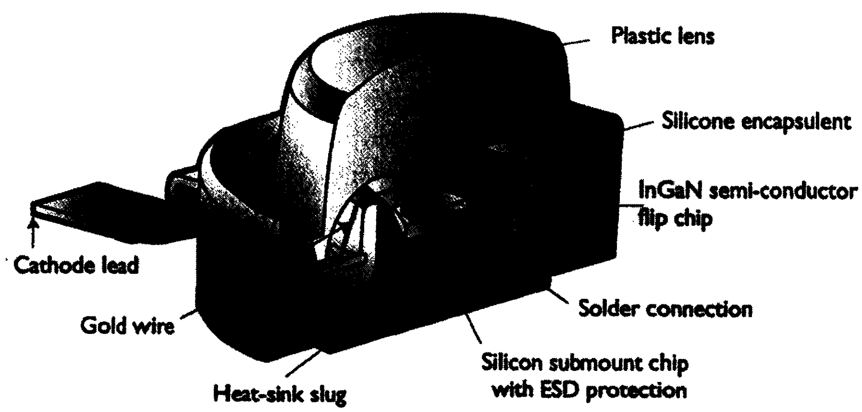
*Sources:* Faktor licht, 2000 (reproduced with permission) (far left); Courtesy of Philips Lighting (centre left and centre right: Courtesy of European Lamp Companies Federation (far right).
*Abbreviations:* CFL = compact fluorescent lamp; GLS = general lighting service.

**Figure 2.12: Features of a compact fluorescent light bulb (CFL) (IEA, 2006)**




*Source:* Photos courtesy of European Lamp Companies Federation; Lamptech, 2005 (mercury vapour graphic).
*Abbreviation:* HID = high-intensity discharge.

**Figure 2.13: Features of HID lamps (IEA, 2006)**




*Source:* Courtesy of Lumileds Lighting LLC.
*Abbreviations:* ESD = electrostatic discharge; LED = light-emitting diode.

**Figure 2.14: Composition of an LED (IEA, 2006)**

| Type of Light Source | Watts (W) | Lifespan in Hours (h) | Efficacy, with Ballasts, (lm/W) | Energy Converted to Visible Light (%) | Fraction of Global Sales (%) |
|---|---|---|---|---|---|
| **FLs:** | | | | | 20% |
| LFLs | 14-40 | 7,500-30,000 | 60–104 | 60% | 12% |
| CFLs | 4-120 | 5,000-25,000 | 35-80 | 25% | 8% |
| | | | | | |
| **Incandescents** | 15-150 | 750-1,000 | 6–18 | 5% | 79% |
| | | | | | |
| **HIDLs:** | | | | | 1% |
| Mercury Vapor | 50-400[12] | 6,000-28,000 | 14.4-60 | | |
| Sodium | 40-400 | 5,000-28,000 | 70-140 | | |
| Metal Halide | 35-1,500[13] | 6,000-20,000 | 47-105 | | |
| | | | | | |
| **LEDs** | 0.1-1 | 50,000-100,000 | 20-100[14] | 25-35% | <1% |

**Table 2.1: Comparison of electric lighting sources or lamps (IEA, 2006)**

## 2.3.3.b Combustion Sources

Combustion sources provide over 25% of the world's non-electrified households with lighting, through the direct burning of solid or liquid fuels. As stated earlier, over 49% of rural households in developing countries are non-electrified (15% of urban households have no access to electricity). Not surprisingly, these households rely heavily on the land around them to provide them with resources. The most common sources of lighting are wick-based and rely on liquid-based fuels such as kerosene, oils (vegetable or animal), diesel and petrol; and solid-based fuels, such as candles, battery-powered flashlights, wood, dung, and other biomass.

These are by far the most inefficient, unhealthy and unsafe sources of light, for many of the reasons discussed earlier, such as poor lighting quality, indoor air pollution and fire-

[12] Mercury Vapor Lamps can have up to 1,000W capacity, but they are not commonly used.
[13] Metal Halide HID Lamps can extend wattage to 12,000 W.
[14] This is for white LEDs (WLEDs), as of 2005. Single commercially available WLEDs are in the 20-40 lm/W range.

hazards. Yet many of these communities spend more on their energy consumption than consumers in the electrified markets (see Figure 2.4).

Wick-based lighting is extremely inefficient. As stated earlier, Mills (2005) did an extensive study on lighting in developing countries and found that on average a wick-based lantern gave about 1 lx of illuminance at a 1 m distance, compared to 500 lx at the same distance provided by the most inefficient incandescent lamp available in most developed countries (minimum lighting requirement for reading and writing start at 75 lx).

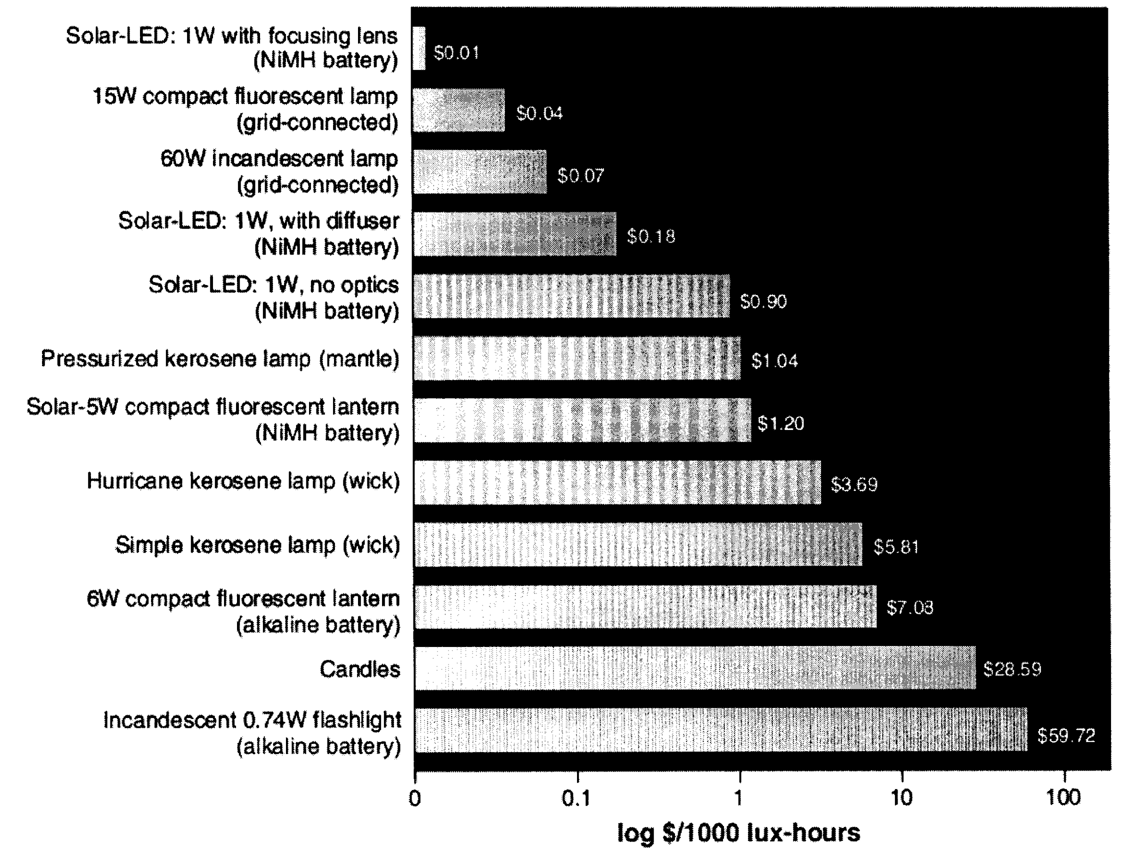
Mills (2005) also did an elaborate cost comparison among the most commonly available lighting sources in developing countries. One of his conclusions was that, "Fuel-based lighting embodies enormous economic and human inequities. The cost per useful lighting energy service ($/lux-hour of light, including capital and operating costs) for fuel-based lighting is up to ~150 times that for premium-efficiency fluorescent lighting…The total annual light output (about 12,000 lumen-hours) from a simple wick lamp is equivalent to that produced by a 100-watt incandescent bulb in a mere ten hours." Figure 2.15 shows his complete findings. Mills' research clearly shows that the BOP who primarily use wick-based lighting are getting poor quality lighting for a very high price. Therefore, it should not be surprising that organizations like THRIVE and SELCO, who are offering more cost and energy efficient lighting systems, are expanding so rapidly in the BOP community.

### 2.3.3.c LEDs versus CFLs

The next chapter focuses on the business models of two small-scale entrepreneurs based in southern India who are capitalizing on this largely untapped BOP lighting market. One entrepreneur (SELCO) has built a business on selling solar energy based CFL systems, while the other (THRIVE) sells grid and solar energy based LED lanterns. Both are primarily competing against grid-connected incandescent lamps and wick-based lighting. There are many reasons that consumers are choosing these products over their current lighting, including cost competitiveness, quality, and reliability of lighting.

As shown in Figure 2.15, CFLs and LEDs are extremely competitive technologies in terms of pricing, and illuminance, particularly in comparison to incandescent lamps and wick-based lighting. How they compare with each other is of great significance.

The most significant feature for lighting sources within off-grid communities is their ability to give quality lighting for long periods of time, on batteries or DC current. Again, quality is extremely variable here, but for our purposes, we mean the highest efficacy at the lowest wattages (how much power the lamp needs). During my site visits, the most common constraints regarding accessibility to electricity in off-grid communities were the availability and reliability of the grid. Batteries are able to bridge both gaps because they are mobile and can store energy from renewable energy sources (like the sun) or the grid when it functions, for use later. So it is imperative that you have a lighting source that gives out the most amount of light with the least amount of input (efficacy) and works on low wattage.




**Total cost of illumination services.** Costs include equipment purchase price amortized over 3 years, fuel, electricity, wicks, mantles, replacement lamps, and batteries. Performance characteristics of light sources vary; values shown reflect common equipment configurations (see table S3) and include dirt depreciation factors for fuel lanterns and standard service depreciation factors for electric light per Illuminating Engineering Society of North America. Assumptions are 4 hours/day operation over a 1-year period in each case, $0.1/kWh electricity price, $0.5/liter fuel price. NiMH, nickel metal hydride. (Range of market prices for kerosene shown in table S5.) We estimate an average of 11 liters (*1*) of lighting fuel per household per month; oberved values vary from 2 to 20 liters (table S4).

**Figure 2.15: Illumination cost comparison (Mills, 2005)**

Of all the types of lamps we have discussed in Section 2.3.3.a, LEDs and CFLs meet the criteria of working best on batteries. While LFLs have the highest efficacy, they are available primarily in higher wattages and can drain a battery relatively quickly. Incandescent bulbs, which have the lowest cost and are most widely available, provide low quality light at high wattages and are consequently extremely inefficient in rural lighting. A comparison table of the three most widely available lighting sources within the context of these site visits is provided in Table 2.2. LEDs are primarily available in urban areas and are extremely variable in quality. This information was taken by surveying local kiosks in the areas where I did site visits in January 2007.

| Lighting Source | Available model (in W) | Average Cost in Indian Rupees (US $) |
|---|---|---|
| LFL | 40, 50, 100W | 150 (US $3.60) |
| CFL | 15, 20W | 500 (US $11.90) |
| Incandescent bulb | 40, 60, 100 W | 20 (US $0.60) |
| LEDs | Variable<br>*THRIVE's LED Lantern is 0.6W* | Variable<br>*Cost of THRIVE's LED console is US $3.00* |

**Table 2.2: Comparison of lighting sources during site visits in India**

From a technological standpoint, LEDs are far more durable, longer lasting, and work on much lower wattages than CFLs. Still, LEDs lack the efficiency of CFLs. From a marketing and supply chain standpoint, CFLs are a far better option because of the maturity of the technology. They are consequently more standardized and far more widely available than LEDs. Consumers are much more familiar with them and know what to do with them as they behave much like an incandescent bulb. LEDs are still relatively unknown and can only be changed by trained electronics specialists. They are continually evolving, with an efficacy that has doubled nearly every two years since their inception in the 1960's. This has created a nonstandardized market, which is dangerous for developing countries. Consumers are often cheated in terms of price and product reliability, as they have to rely on the distributors to provide quality information. The quality of an LED is extremely important in terms of reliability and LED application. The lifespan of an LED is directly proportional to its ability to dissipate the heat built up during lighting, which is why the quality of the materials used to build the LEDs and the circuitry is extremely important.

LEDs turn "on" and "off" instantly and do not require warm-up times, while CFLs do. In terms of environmental impact and toxicities, LEDs are much better than CFLs since they are made of all non-toxic materials and are fully recyclable. CFLs have phosphors and mercury that can be hazardous.

There are other differences between LEDs and CFLs that can be advantageous or disadvantageous depending on how they are used. LEDs are extremely directionally intense, while CFLs are quite diffused in their output. Therefore, CFLs work better in general illumination settings, while LEDs are best in directional or task illumination. LEDs are also very small and light, and can be configured to work in extremely small, flat or confined spaces. Unlike CFLs, LED applications consequently have the advantage of being much more flexible and customizable for different applications and users. The color of the light that White LEDs (WLEDs) and CFLs emit is generally comparable, however LEDs generally cannot guarantee the exact same color between batches. This is because each LED is very sensitive to the amounts of coloring material put into them. So while the color may appear to not vary that much to the human eye, it is measurable by a chromatograph. LEDs are DC-dependent, and work extremely well on batteries. CFLs can use both AC and DC.

Overall, given quality components and considering the lighting levels requested in rural southern Indian communities, both CFLs and LEDs compete well and complement each other. CFLs have lower capital costs and higher operating costs, while LEDs have higher capital costs and very low operating costs. CFLs work better for general illumination, while LEDs work better for task lighting.

# Chapter 3: CASE STUDIES IN LIGHTING

The previous chapter touched on the importance of improving accessibility to quality lighting for BOP communities. It also discussed the complex technical and business challenges that must be taken into consideration when bridging this accessibility gap.

This chapter introduces the reader to two socially and environmentally committed organizations that are bridging the accessibility gap by selling customized lighting technologies to the poorest people in the world. SELCO-India (Solar Electric Light Company) and THRIVE (Volunteers for Rural Health and Information Technology) have used extremely different approaches to successfully scaleup their products. SELCO-India is a maturing profit-generating company that is shattering the myths that solar energy is too expensive for the poor, and that socially responsible business within a BOP community is financially unsustainable. Through innovative financing, doorstep customer service and quality solar technology, SELCO has garnered a steadily growing BOP customer base that includes 55,000 rural homes and businesses. Like SELCO, a very young organization called THRIVE has shown that the poor need, use and can pay for advanced technology. In just over a year, THRIVE has electrified over 33,000 homes with their LED lantern. However unlike SELCO, THRIVE is a nonprofit venture that promotes a single product and focuses mostly on indigenous communities located in some of the remotest parts of India.

This chapter starts by presenting the case studies of SELCO and THRIVE, with background information on the Indian kerosene and electricity markets. It finishes with a discussion of the cases. Studying these two uniquely different organizations proves that alternative approaches can be used to solve a similar problem. Also it will yield an optimum set of best practices that can be used by other small-scale technology entrepreneurs hoping to scaleup in similar markets.

## 3.1 Background: Why SELCO-India and THRIVE

SELCO and THRIVE have successfully scaled up in some of the most challenging markets in the world – BOP markets, in developing countries. While they are very different, they also compare well in the following ways:

- **Socially Motivated**: Both are committed to improving the lives of underprivileged people (the BOP). They are led by visionaries who will not compromise on their social goals.

- **Business Focused**: Both treat the poor as customers. Nothing is given away for free.[15] Profits drive the financial sustainability and growth of their businesses.

- **Sell Hi-Tech Lighting**: Both make some of the latest lighting technologies, such as solar energy and LED technology, affordable and available to the poor.

- **Successful Scaleup**: They have successfully scaled up sales beyond their original market. Their primary customers are at or below the poverty line (BPL) in southern India.

- **Compete in the Same Market**: Both are based in adjoining states in southern India (see Figure 3.1), and target people in the same income bracket.

SELCO-India and THRIVE have very different approaches to their goal, which is to make good quality lighting technologies available and affordable to the poor. These are summarized succinctly in Table 3.1. The case studies will expand further on these features.

| | THRIVE | SELCO-India |
|---|---|---|
| **Year Established** | 2001 | 1994 |
| **Type of Organization** | Registered Nonprofit NGO | Registered For-profit, Corporation |
| **Headquarters (both are based in India)** | Hyderabad, Andhra Pradesh | Bangalore, Karnataka |
| **CEO Qualifications** | Ph.D., Health Informatics | Ph.D., Energy Engineering |
| **Product Line** | One Lantern | Various Systems (Each system includes 1-10 lights, wiring, installation, solar panel, control box and battery)[16] |
| **Price Range** | US $15/Lantern | US $200 - $1600/System |
| **Power Source** | Primarily Electric Grid | Primarily Solar PV |
| **Lighting Source** | LEDs | CFLs |
| **% Clientele BOP** | 100% | 40% (another 40% are borderline BOP) |
| **Mode of Operation** | Decentralized | Centralized |
| **Expansion** | International | Local (Karnataka primarily) |
| **No. of Units Sold as of March 2007** | 33,000+ | 55,000+ |

**Table 3.1: Comparison of THRIVE versus SELCO-India**

[15] For SELCO and THRIVE's pilot projects, the recipients were given the technologies for free. Since then SELCO has sold all their items at a profit. THRIVE's following projects have required the clients to buy their lanterns at a subsidized rate. Combined with the subsidies, the lanterns generate a small profit, which goes to train highly motivated unemployed youth.

[16] SELCO's most popular home lighting systems include 1-3 lights.

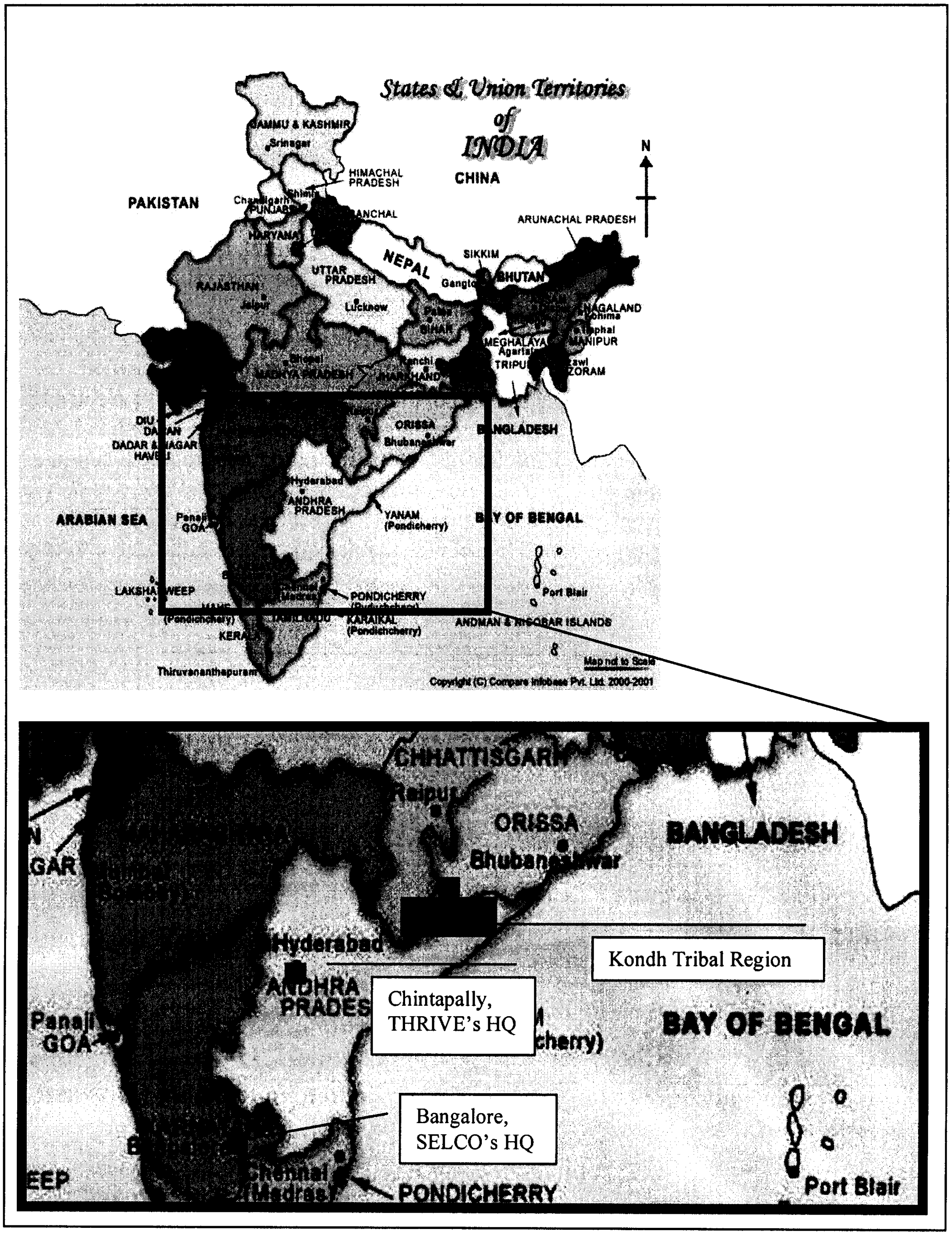



**Figure 3.1: Location of SELCO, THRIVE and Ankuran (MapsofIndia.com, 2005)**

## 3.2 The Lighting Market in India

The WRI (2007) estimates that India has the largest measured energy market in Asia and one of the largest in the world, with US $163 billion in household spending. Rural areas account for 63% or US $102 billion of the national energy market (70% of this market is considered BOP). Rural BOP households spend an average of US $2 per day on energy, while urban BOP households spend an average of US $2.75. This amounts to at least 20% of their income. These figures, particularly for the BOP market, bundle together lighting, heating and cooking; and it is difficult to unbundle these costs. But one does get a sense of the immense size of the energy market in India.

The irony of this situation is that India also has the largest number of non-electrified households in the world. In general, the Indian population relies on kerosene or electricity for their lighting needs (see Figure 3.2). It is important to note that access to both is extremely limited and dependent on a number of factors, including geographic location and income level. For example, kerosene access is limited by income level and can only be accessed through a government-run ration shop; electricity access might depend on proximity to an industrial or urban area. Households that lack access to either have to rely on their own wits.

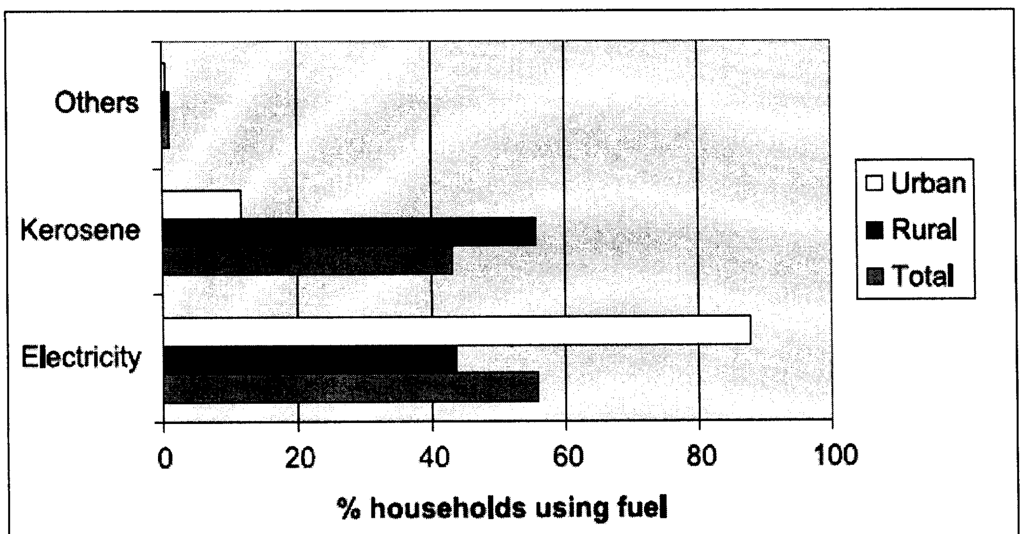



**Figure 3.2: Energy sources for lighting among Indian households (Ailawadi et al., 2006)**

### 3.2.1 The Indian Kerosene Market

Kerosene is the primary lighting source for BOP consumers. According to the 2001 Census of India, approximately 85 million people rely mainly on kerosene or other forms (other than electricity), and 92% of these consumers live in rural areas (Ailawadi, 2006). This is the sizeable market that THRIVE and SELCO-India are targeting.

The Indian kerosene market is tightly controlled by the Indian government, and is disbursed monthly to select populations. Only BOP communities who cannot afford to buy LPG (for cooking) have access to kerosene. [17] All rural BOP households are given up to three liters of kerosene per month; urban households are given five liters per month. This difference in amount is based on the fact that the government expects rural households to supplement their kerosene ration with other biomass sources (dung, wood or charcoal) collected from the surrounding area. Urban BOP households often need to supplement theirs with candles and cheap flashlights. As of January 2007, subsidized kerosene was sold at INR 10.50 per liter (US $0.24).[18] Outside of ration shops, there is a very limited supply of kerosene on the black market sold at exorbitant rates. In January 2007, the black market price of kerosene was INR 36 (US $0.82) per liter. This almost producer surplus has created a very large market for affordable, good quality lighting alternatives. THRIVE's lighting products for the most part have hit this market head on, and benefited greatly from it. Approximately 80% of SELCO-India's clients are from the BOP sector, of which 40% are well under the BOP line and 40% are at the BOP line. Households above the poverty line typically rely on some form of electricity, though there is a large urban to rural differential in terms of access, as shown in Figure 3.2 (Ailawadi et al., 2006).

## 3.2.2 The Indian Electricity Market

India has the largest population without access to electricity, according to a recent study by the International Energy Agency (IEA) (Ailawadi et al., 2006). Over 35% of the world's non-electrified population is in India. Table 3.2 presents a comparison of heavily populated countries without access to electricity. Again this indicates a sizable population that could be reached by THRIVE or SELCO-India. Electricity access ranges drastically between different states, as shown in Figure 3.3 (Ailawadi et al., 2006). Note the numbers for the states of Karnataka, and Andhra Pradesh where SELCO-India and THRIVE are based respectively (in the case of SELCO-India, their entire market is based within the state of Karnataka). If SELCO and THRIVE could successfully scale up into the states of Uttar Pradesh and Bihar, they would be tapping into potentially huge markets. But this will depend on the strength of financial institutions in the area as will be discussed later in this chapter.

Electricity is generally reasonably priced when access is available. For example, on an average, electricity costs INR 4.50 (US $0.101) per kWh. In the United States, the average cost of a kWh in 2005 was US $0.094 (EIA, 2006). But what these statistics do not cover is the unreliability of the electric power grid. Often the census might count households who are connected to the grid as using electricity, even though they hardly ever get access to it. This inaccessibility might be due to the frequent blackouts, brownouts and transmission problems that seem to plague the overloaded Indian power

[17] LPG is also monitored by the Indian government and sold at a subsidized rate. All patrons must pay an initial deposit of INR 3600 (US $81.50) to get two gas cylinders, a regulator and a pipe. Subsequent fillings cost INR 320 (US $7.24) and last a family of four for two months.

[18] INR = Indian Rupee. US $1 = INR 44.17 on January 2, 2007.

system. This was true of many households that I visited while in the field. Some households used candles and biomass as primary lighting sources because electricity came through their transmission lines only once a week.

| Country | Population without access to electricity | | Per capita GDP (US$95) | Per capita PEC (toe) | Per capita electricity consumption (kWh) |
|---|---|---|---|---|---|
| | Million | % of world total | | | |
| India | 579.10 | 35.44% | 459.37 | 0.49 | 393 |
| Bangladesh | 104.40 | 6.39% | 373.22 | 0.14 | 102 |
| Indonesia | 98.00 | 6.00% | 993.73 | 0.69 | 390 |
| Nigeria | 76.15 | 4.66% | 253.57 | 0.71 | 85 |
| Pakistan | 65.00 | 3.98% | 516.22 | 0.46 | 374 |
| Ethiopia | 61.28 | 3.75% | 115.86 | 0.29 | 24 |
| Myanmar | 45.30 | 2.77% | 288.80 | 0.26 | 74 |
| Tanzania | 30.16 | 1.85% | 190.50 | 0.46 | 55 |
| Kenya | 27.71 | 1.70% | 328.35 | 0.51 | 107 |
| Nepal | 19.50 | 1.19% | 241.32 | 0.34 | 61 |
| DPR of Korea | 17.80 | 1.09% | 373.15 | 2.07 | 1288 |
| Mozambique | 16.42 | 1.00% | 191.07 | 0.40 | 47 |
| World Total | 1634.20 | 100.00% | 5650.00 | 1.68 | 2343 |

*Source*: IEA (2002).
*Note*: PEC — primary energy consumption.

**Table 3.2: Countries with large populations without electricity access in 2000 (Ailawadi et al., 2006)**

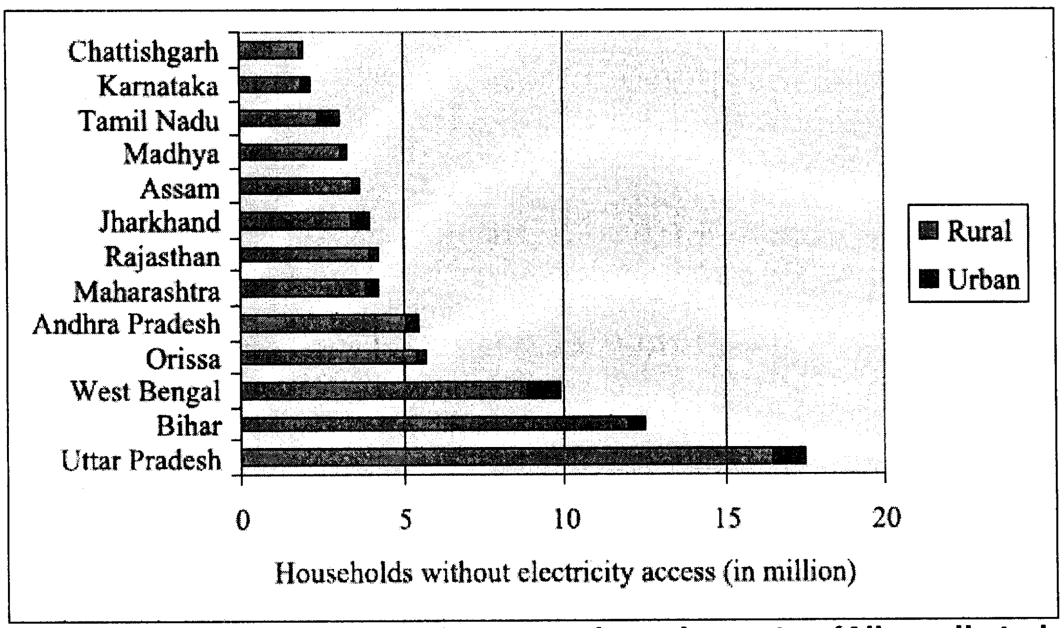



**Figure 3.3: Status of electricity access in major states (Ailawadi et al., 2006)**

What small-scale entrepreneurs who sell lighting, like THRIVE and SELCO-India, aim to do is replace the current lighting sources with better ones. They are essentially giving their customers a better deal for their money because they are replacing often expensive, extremely unreliable fuels that are in short supply with more controllable, accessible, tangible, reliable power sources, using the same client investment. This means that THRIVE and SELCO-India have been very smart about operating in a market of

THRIVE and SELCO-India have been very smart about operating in a market of immense potential. But as the case studies will elaborate, market size is only one part of a successful business venture.

## 3.3 Case Study I: SELCO-India

Unless otherwise cited, the primary resources for this section are interviews with the CEO and employees of SELCO-India, their partners, investors, guests, and affiliates conducted on-site in January 2007 and off their premises in February 2007.

### 3.3.1 Background

SELCO-India (SELCO stands for Solar Electric Lighting Company) was founded in 1994 "to sell and service solar electric home lighting systems in areas of the world lacking access to reliable electricity" (SELCO, 2007). It is the flagship (Williams, 2003) and Indian subsidiary of SELCO USA, the parent company that is "selling solar" to the masses.[19]

The dream of rural solar lighting that SELCO-India now epitomizes began long before 1995. Managing Director and Founding Partner, Harish Hande, was introduced to solar energy while studying in the prestigious Indian Institute of Technology in Kharaghpur (IIT-Kh). He visualized the immense impact that the technology could have in rural India and aimed to improve its efficiency and affordability. This became the focus of his doctoral research in Energy Engineering at the University of Massachusetts at Lowell. During the summer between his second and third year, Harish went to the Dominican Republic to help set up Solar Home Systems (SHS, which consists of solar panels, a control box, battery, and lights – a complete kit to light up a single-family home) in rural communities. He quickly learned that the challenges he encountered in the field went far beyond technical issues. Soon after completing his coursework, Harish went to Sri Lanka to do field research. For a year, he worked with a local organization to install free state-of-the-art SHS's in rural farming communities; most failed. Harish theorized that a missing sense of ownership, and good operation and maintenance (O&M) were responsible for the failure. He began to seriously consider starting his own commercial venture where he would take the lessons and knowledge from his past and put it to use.

Harish described his Sri Lankan experience as "critical" for SELCO-India's later success. For one thing, he developed a very clear idea of what it took to "sell" solar energy to the poor. In 1994, he returned to the southern Indian state of Karnataka, where he had spent a great part of his early life, to embark on his dream.

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[19] SELCO USA came after SELCO-India was established. Therefore SELCO-India is sometimes simply known as SELCO, and as used intermittently throughout this thesis.

## 3.3.2 SELCO: 1994-1998

At the tail end of his Sri Lankan venture, Harish met Neville Williams, Founder of the Solar Electric Lighting Fund (SELF), a nonprofit organization that invests in providing SHS to rural communities worldwide. Neville had just received a US $25,000 grant from the Rockefeller Center to "light" 100 houses in India with solar energy. Harish convinced him to use the funds as seed money for a small solar energy company. He promised to take care of the 100 houses and then expand the concept to include more. Thus in 1994, SELCO-India Solar Lighting Private Limited was born; three years later, they formed SELCO-USA.

Harish and Neville decided to run their organization like a company for three reasons:

1. To maintain financial transparency
2. To have access to venture capital and other traditional investment sources
3. To prove that it was possible to run a profitable, commercial venture in BOP communities while being socially and environmentally responsible.

Harish decided to focus his efforts on his home state of Karnataka, where he had support and knew the language, culture and communities well. Based on his experiences in the Dominican Republic, Sri Lanka, and India, Harish knew that the company's success hinged on three cornerstones of operation:

- **Quality Technology:** Harish already knew SHS technology fairly well. He focused on offering a few simple, good quality state-of-the-art systems (similar to what he had used in Sri Lanka) that incorporated CFLs. The light bulbs were easily available from local hardware stores and easily replaceable. Their quality also meant dependability and lower operating costs.

- **Doorstep Service**: Like several other countries and organizations, the Indian government had just completed a series of failed pilot solar lighting projects in rural communities. Harish argued that a healthy market for SHS would develop if the products could last long enough to prove their value within BOP households. SHS required regular maintenance, which none of these rural communities had been trained for or provided with. The systems were either never properly installed, or broke down soon after installation and were never fixed. Regular O&M was key to the success of future SHS. Thus, "Doorstep Service" became the second cornerstone of SELCO's operating model.

- **Doorstep Financing:** SHS is expensive, far beyond the reach of a poor farmer. Systems ranged from US $200 to US $1600 (see Appendix 2), which to a poor farmer meant an entire harvest's income (at least four months of income) for the cheapest systems. Harish believed that the rural markets for SHS would open significantly if financing were provided. His experiences in the Dominican Republic, Sri Lanka and India indicated that the poor had different earning, saving and spending habits from the middle or upper classes. Financing would have to be

> customized. For example, a tailor had a monthly income, while a paddy farmer had a biannual income that coincided with the harvests. Consequently, he would have to customize their payments based on their income cycles. "Doorstep Financing" became another of SELCO's cornerstones.

The first two principles – service and technology were the easiest to set up. Harish used the seed money to buy and install SHS for the first 100 houses he had promised Neville that he would take care of providing solar lighting for, and to hire and train two technicians who would do the servicing.

The SHS technology was already fairly mature in 1994 and Harish was familiar with all the models that were out at that point. Each SHS consists of PV panels, a controller, batteries, wiring, and CFL lamps. Considering that there were few technical issues that he knew about, Harish bought all his first components off-the-shelf. Over time, he developed a series of reliable local providers for each of these components who would customize the components per his specifications. For example, the SELCO technicians started noticing recurring problems with the circuitry shortly after their installation on the first 100 houses. The circuitry was not designed for the rugged Indian outdoors, and was in need of frequent replacement. Harish presented this information to a local electronics business, Anand Electronics, and asked for the new circuitry to be customized for hardiness and ease of installation. Almost immediately, client service calls started to drop significantly. SELCO continued fostering their relationship with Anand Electronics. In 1997, Anand became the sole provider of controllers and wiring for SELCO-India.

Providing financing would prove to be a barrier of monumental proportions. In all, it would take Harish almost three years to convince local financial institutions to buy into his model. Even while setting up the 100 houses, he began to get requests from surrounding communities for his SHS's. The problem was that no one could get loans, and Harish lacked the capital to finance the customers himself. He had three choices – to start his own bank (like Grameen Bank Founder, Muhammad Yunus), to use existing or new microcredit and microfinance programs, or to keep working to convince the local financial institutions to buy into his clients. He chose the third option for three reasons: he lacked the capital himself, the loans were too large for a microfinance system to work, and most importantly, he believed that the key to financial sustainability was to help his clients build relationships (and credit) with their local institutions.

For three years, Harish combed the state looking for local banks willing to take a chance on his BOP clients. He also looked earnestly for investors, but had a difficult time convincing them of the profitability of his business. During this time, the company barely stayed alive. As Harish put it, "he begged and borrowed, and did whatever [he] could to keep going." Essentially, he had just enough to give a salary to his loyal technicians.

## 3.3.3 Growth: 1998-2006

The period between late 1997 and early 1998 proved to be crucial for Harish and SELCO-India. First of all, he finally completed and successfully defended his thesis and was awarded his doctorate. Second and most importantly, his incessant persistence for financial support paid off. A bank manager in Dharwad, 400 kilometers north of his base in Mangalore, finally agreed to take a chance. The bank manager said he gave in because he was "sick and tired of listening to [Harish]." Harish set up a regional office, and then worked with the bank manager and his clients to customize financing plans. Less than six months later, just when things started to fall into place, the bank manager was transferred to another district. This was a major blow that threatened to sideline all the years of hard work. Harish refused to bow out. After successfully convincing the incoming manager, he started training en-masse any interested bank managers about how to customize financial packages for BOP clients. The banks resisted earlier on, but over time the prospect of increasing their clientele won them over. While the training programs were an expensive investment for SELCO, they had significant long-term payoffs.

In Dharwad, Dr. Hande continued to hone and tweak his operating model until it was good enough to replicate. It incorporated all three cornerstones and is to date a revolutionary model in many ways. It works thus:

- **Financing:** Once a local bank buys into the idea of financing their clients, SELCO sets up a regional office or SELCO Solar Service Center (SSC).

  "All clients are offered a 'lease-to-own' scheme whereby they pay 25 per cent of the system cost as an upfront payment. They then repay a loan to cover the remaining cost at 12 per cent interest per annum, in keeping with the average monthly expenditure budget of a typical family in the region. For many the benefit of having lighting in the home or business means they have additional time for income creation activities" (*Hands On*, 2006).

  Financing is further customized based on a client's income and payment cycle. For example, a rice farmer may make two large biannual payments (to coincide with the harvest season when his or her payment is generated), while a tailor with a monthly income can make smaller monthly payments.

- **Customer Service:** Each SSC serves communities within a two-hour traveling radius of the SSC. Sales calls outside of this area are often deferred and followed up on when aggregated demand is large enough to constitute the establishment of a new SSC. Following up on his promise for "doorstep service," Harish instituted a 24-48 hour customer service guarantee. This means that if a client calls in with a complaint, a technician will call back in 24 hours to assess the situation, and show up within 48 hours to fix the problem. A two-hour traveling time ensures that this guarantee is possible. This level of customer service is unheard of in most parts of India, urban or rural.

Customers are given a toll-free number to call for service. Those with cellular phones can text message their technicians or SSC. In addition, SELCO-India has set up deals with local telephone kiosks to allow customers without phone access to call toll-free. This ensures that everyone has the ability to make a service call.

- **Staff:** Each SSC has a showroom of SELCO's products and a telephone, and is staffed by seven employees – two service technicians, at least two sales personnel, one accountant, and one manager.[20] All SSC staff are hired from within the local communities. This has been extremely useful for building trust and local capacity within communities. The staff members are hired by reference through local NGOs, community members or current staff members.

  Any person who calls or walks into the SSC, regardless of caste, creed or religion is treated with respect. In India, where caste and religious differences run deep, this is a revolutionary stance. Harish has insisted that this be an important quality in all hires. Considering that most staff members are from communities where these ideologies run deep, it is hard in the beginning. But they have learned by example. Current staff members seek and hire new members who adopt these values. In addition, nepotism is strongly discouraged.

  All potential customers have the option of receiving a home sales-call. This means that a staff member will do a house call with the customer in order to assess their needs and customize a system that works around those needs. For example, there was a customer who was enticed by the village headman's SHS and wanted one for himself. He wanted the same system as the headman (which was a midrange model), but could not afford the price.

  A SELCO sales associate offered to come to the gentleman's house (a semi-permanent structure, with concrete walls and thatched roof) and do an assessment of his requirements. The associate determined that the gentleman really needed a one-light SHS as opposed to the three-light system he wanted. This greatly cut down the cost while meeting the client's needs. In addition, they also worked out a financing scheme that worked favorably for him. This level of customization has garnered a high level of client satisfaction, which pays off in terms of referrals. Over 90% of sales are through word-of-mouth referrals.

- **Technology:** All SELCO-India Photovoltaic (PV) Panels come with a ten-year guarantee and batteries with a three-year guarantee. There is a 90-day money back guarantee along with a year's free service (i.e., technicians will service any problems on the system for free for the first year). Again this is unheard of in India, particularly in the rural market segment.

  All SELCO-India's SHS components are manufactured in India. SELCO-India gets their PV panels and batteries from different wholesale distributors, depending

[20] In 1998, cellular phones were just beginning to permeate the Indian market. Now, all service personnel have a cell phone and communicate regularly.

on who gives the most competitive price; the controllers and wiring are exclusively purchased from a local company, Anand Electronics. The components are then custom-assembled by trained technicians for each client. Each SHS consists of PV panels, batteries, wiring, a controller and CFLs. SHS models range in price from US $200 for a single-light system to US $1600 for a streetlight system. Product specifications for SELCO-India are provided in Appendix 2.

- **Training:** All hiring and training of staff for the first office were conducted by Harish. Subsequent hiring and training sessions have been conducted by senior regional staff, and done through apprenticeships. This ensures that new hires integrate well into the existing teams, and continue to propagate the core values of the company.

  In addition, all bank managers are regularly trained in flexible financing for poor, rural customers. This creates a win-win-win situation for the banks, customers and SELCO. The banks acquire more skills and customers; SELCO gets more customers; and the customers are able to build credit for future ventures.

- **Scaling Up:** All growth is organic. Once one or more calls come from an area outside the two-hour radius, SELCO-India staff scope the place for partner banks; after which they replicate the process outlined above.

- **Organizational Structure:** SELCO-India's organizational structure is shown in Figure 3.4. Every SSC reports to a Regional Business Office (RBO); typically one to five SSCs report to one RBO. The RBOs are managed by the head office located in Bangalore, India.

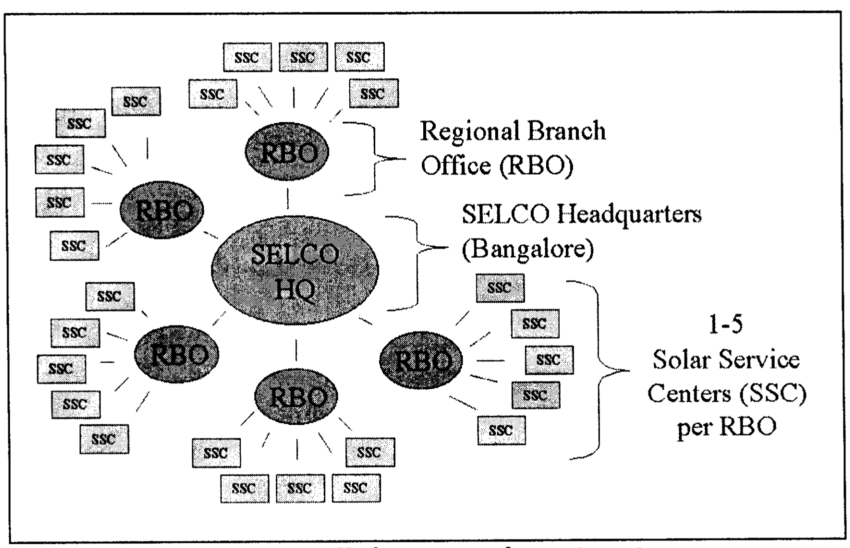


**Figure 3.4: SELCO-India's operation structure**

- **Transparency:** Financial and administrative transparency, and institutional support are at the heart of the program. Every SSC has daily meetings to assess any issues that have come up in the office, field or administration. This ensures clear communication and transparency. All staff members are equally heard and supported, and are encouraged to be involved in company and office decisions. SSC managers and SELCO's upper management hold weekly meetings in which all items are discussed.

- **Institutional Support:** Besides being internally supportive, SELCO-India relies heavily on local NGOs, banks and other institutions to provide support in terms of human resources, training, references and financial support. This is critical in communities where illiteracy is a huge problem. For example, when SELCO moves into a new area, NGOs are asked for support in terms of office space, staff recommendations, training help, and resource recommendations.

- **Business, with Heart:** The bottom line of SELCO is that it is a business (with social goals). Its business bottom line coupled with financial transparency keep the organization efficient. For example, SELCO-India has strict rules for their CFO and other financial staff, who are not allowed to go into the field. They want their staff to focus on the financial health of the organization, and not be moved by their social motives. Dr. Hande says that this has sometimes led to heated discussions on decision-making, but has been responsible for keeping the organization sustainable.

  The entire staff is clear about and extraordinarily dedicated to the company's social goals. For example, as solar panel prices increased recently threatening to send SHS prices sky-rocketing, the CFO voiced concerns about decreasing sales and profit margins. Staff members from all levels of the company, immediately came forward asking for voluntary salary cuts. Another example happened recently when a technician decided to go on strike to show his disapproval about some decision made by upper management. Rather than miss work, he worked for continuously for two weeks (weekends included) refusing pay until the management caved in. They negotiated, and fully compensated him for the time he was "on strike."

With such extraordinary dedication, the company's success is not surprising. The company started posting profits in early 1999, only a year after their first bank signed on to collaborate. They proved that the poor needed, could afford, use, and maintain advanced technology. Ultimately, the company has garnered a reputation for trustworthiness amongst its clients and partner financial institutions. Dr. Hande proudly states that over 90% of sales have been through word-of-mouth referrals. This referral rate has also carried over to client selection, in the sense that good clients typically refer other good clients to the company; and good banks act as references for other good banks. This might explain the continued growth and quality of his clients who boast a loan repayment rate of over 90% (Chakraborty, 2007).

SELCO-India has experienced incredible growth since 1998. From one SSC in 1998, they have now grown to include 25 centers in 2006, with more being planned this year. From a little over 100 homes in 1998, they have now electrified 55,000 homes and rural businesses, and continue to grow. The company's annual sales are at nearly INR 12.7 crore (US $2.97 million) in 2005-06, with revenues expected to touch INR 16 crore (US $3.72 million) by the end of 2007-08 (Chakraborty, 2007).

### 3.3.4 Expanding Scope: 2007 and Beyond

SELCO-India's success has received worldwide recognition, including winning prestigious awards and publicity in the international press. The publicity has brought increased investments and partnership propositions, lending the possibility of growth in other spheres. Now that the scaleup model for the lighting market is successfully replicating, SELCO-India's management finally has the chance to reflect on their success and decide on a long-term growth model.

One of the many strategies Dr. Hande is considering is to increase SELCO's scope of products to include efficient cookstoves, and small-scale lighting fixtures like flashlights, lanterns or headlamps. He has already started working with one of India's largest and most well respected women's NGOs called SEWA (Self Empowerment Women's Association) to develop these. One big advantage of partnering with SEWA is access to their cooperative bank, which boasts a membership of 700,000 women! He hopes to use these banks to finance a line of products that are customized to the needs of women (like the efficient cookstoves and headlamps).

Another venture he is considering involves the development of an innovation arm to help with the income generation of his current clients. For example, a tailor can stitch five extra shirts an hour using the new SHS s/he has installed in his or her house. However, the extra shirts have no value if the tailor has nowhere to sell these. Dr. Hande proposes that by connecting this tailor with a buyer elsewhere, he can create a win-win situation where he can increase the tailor's income, as well as the likelihood of ensuring that his loan is paid off in a timely manner. In addition, the tailor will highly recommend SELCO products to his acquaintances.

Essentially, it will be interesting to watch SELCO-India expand further, for whichever direction SELCO ultimately goes it will be interesting and undoubtedly successful.

### 3.3.5 Challenges

SELCO's biggest challenges came early on, when it was trying to convince banks to extend credit and offer financing to some of its poorest customers. However, two challenges have been plaguing the organization since it began growing in 2000.

- **Global Solar Panel Prices**: Starting in 2004, global solar panel prices started to increase, thanks to the massive demand generated by alternative energy policies in the European Union. Several EU countries, most notably Germany, have instituted major tax credits for residents who use alternative energy. This has hiked up demand and consequently the global price of solar panels. This price differential is most keenly felt by SELCO's customers who have negligible disposable incomes.

  In addition, the demand has changed the design of PV panels, particularly in today's mass-manufacturing industry. For example, specs (specifications) of PV panels for customers in Germany are different from those of the rural markets that SELCO sells to, as the average German consumer needs larger and more powerful PV panels, than the average SELCO-India customer. Finding a manufacturer who will mass-produce to SELCO's specs is increasingly difficult. And using the German PV panels greatly increases prices for the rural Indian customers.

- **Geographic Expansion**: In 2001, SELCO-India briefly expanded into neighboring Andhra Pradesh and Kerala. It must be noted that the cultures, languages and populations differ between states, adding a level of complexity that takes time to overcome. In addition, the spillover learning that took place between banks in Karnataka had not moved into Kerala or Andhra Pradesh. This meant that Dr. Hande had to restart the recruiting and training of bank employees, as he had done in 1995. Fatigued from that process, he opted instead to limit expansion to within the state of Karnataka, until banks from these states approached him (as they have with SEWA in Gujarat).

SELCO has shown that a business built around the needs of a BOP community can be profitable and rewarding for the company and the community at large. In spite of a significant price barrier where their cheapest SHS is at least 100 times the daily income of a BOP household, SELCO has continued to expand in scale and scope, proving that the BOP community will invest heavily in products that are of value to them. Harish believes that SELCO's strong business framework has been fundamental for their success because it promotes efficient governance and transparency.

While the corporate business model has worked well for SELCO, THRIVE has shown that a nonprofit framework can also successfully address lighting accessibility in developing countries. THRIVE founder, Ranga Bodavala, credits their nonprofit framework for the success of their organization. Strained financial resources have forced THRIVE to innovate operationally as well as focus their resources on developing and marketing a single product. In a little over a year, THRIVE has scaled up from 120 to over 33,000 clients. Their story is presented in the next section.

## 3.4 Case Study II: THRIVE

The primary resources for all information in this section are interviews with the CEO and employees of THRIVE, their project partners, and clients conducted during site visits over January 2007.

### 3.4.1 Background

THRIVE (Volunteers for Rural Health and Information Technology) was founded in January 2001 with an aim to "develop, showcase and implement technologies and processes [for the] comprehensive development of the rural and underdeveloped communities in the areas of education, health, communication, rural lighting and water lifting" (THRIVE, 2007). Founder and President, Dr. Ranganayakulu (Ranga), stated that his own interest in the organization's mission came from having grown up on a farm in rural Andhra Pradesh, not far from where THRIVE is now situated. Intimately familiar with the conditions of rural farmers who primarily comprise India's poorest, Dr. Ranga strongly believes that advances in technology can greatly alleviate the difficulties associated with poverty, such as access to better healthcare, lighting, water, sanitation, and information technology, and that technologies catered to the poor will be adopted and used by them. This is why he founded THRIVE and he has already proven that this is possible through his work in rural lighting.

THRIVE was first founded with an emphasis on rural health and information technology improvement prompted by Dr. Ranga's own background. He holds a Ph.D. in Health Informatics and has done numerous international consulting assignments with the Indian government, the World Bank, and UNICEF (United Nations Children's Fund). He has also served as a professor at the Administrative Staff College of India, a prestigious university where all of India's elite civil service administrators are trained.

### 3.4.2 Lighting: 2002-2003

THRIVE's foray into lighting began in early 2002 when Dr. Ranga moved the organization's headquarters into a rural area (Chintapally, in Nalgonda District; see Figure 3.1) about 100 kilometers outside of Hyderabad, "to be closer to the people [he] wanted to serve." This primarily tribal area was still largely underdeveloped in 2002. Although connected to the Andhra Pradesh State Electricity Board (APSEB)[21] grid, few residents had access to any power either because they lacked the money to connect, as the grid rarely extended beyond a small area, and/or because it was unreliable. Residents reported that power was often available only during daylight hours, when they were out tending to their fields, herding livestock or fetching water. In the nights, they had to rely on candles, kerosene, and dung or other biomass.

[21] Electricity systems in India are generally owned and operated by the various state governments. Only union territories are run by the central government.

Frustrated by the lack of lighting in his own rural center, Dr. Ranga began experimenting with different sources and types of lighting. By the end of 2002, he had settled on solar-powered LEDs. Solar power fulfilled two objectives: it is abundantly and freely available in these parts; and it can provide an environmentally friendly alternative to the increasing deforestation that was plaguing the region. While cost was a problem, the LEDs seemed to fit their needs because they gave light for long periods of time using very little power, were bright, lightweight, and sturdy. The only disadvantages he noted were that they were expensive and very unidirectional (i.e., they lit only the area or objects on which the light was directed).

To mitigate the high cost of LEDs, Dr. Ranga began investigating the different components to increase efficiency and decrease operating costs. Over the next few years, he became intimately familiar with the markets and technology of the different components—the circuit boards, box materials, batteries, LEDs, and solar panels—and began buying from manufacturers who offered the most competitive prices. He also worked with experts to increase the technical efficiency of the LEDs, circuit design and the batteries. Finally, he collaborated with a local partner to manufacture a lighting case to put the components together.

Ranga also started recruiting highly motivated youth from the surrounding communities and training them in the design and development of LED technology. They would become his primary workforce.

Finally, Dr. Ranga needed to address the unidirectional lighting component of the LEDs. To truly mitigate this, however, he felt he had to start a pilot project in order to understand user adoptability, and tweak his model based on their reactions. He further studied the lighting habits of the surrounding communities. Particularly he was interested in the types of sources they used, and how and when they used the light that these sources produced. The LED light was replacing candles, kerosene and biomass (dung, wood) torches; and considering that the LED's luminosity (see Figure 2.15) far outweighed that of a candle, he felt safe to move on. Over the years, he has continued to study and tweak the lantern design to meet the needs of his customers.

### 3.4.3 First Lighting Project: 2003-05

By February 2003, THRIVE had its first LED lighting models. These were designed exactly like light bulbs – consisting of LED lights that were permanently installed on a wall and wired to the home's electrical system; which in this case was a battery that was connected to a solar panel (see Figure 3.5). Pictures and details about this first model are attached in Appendix 3. The very first models were installed in THRIVE's HQ in Chintapally and in a local (Lambada) tribal village. The model was so successful and on the cutting edge that it garnered publicity from all over the country, including from the then President of India. The media blitz also brought the plight of the people to the attention of the Andhra Pradesh State Electricity Board (APSEB), who quickly (and amidst great hype) installed transmission lines and ensured a continuous supply of power to this community. With a fully functioning gridline, THRIVE dismantled the systems from the village for use elsewhere.

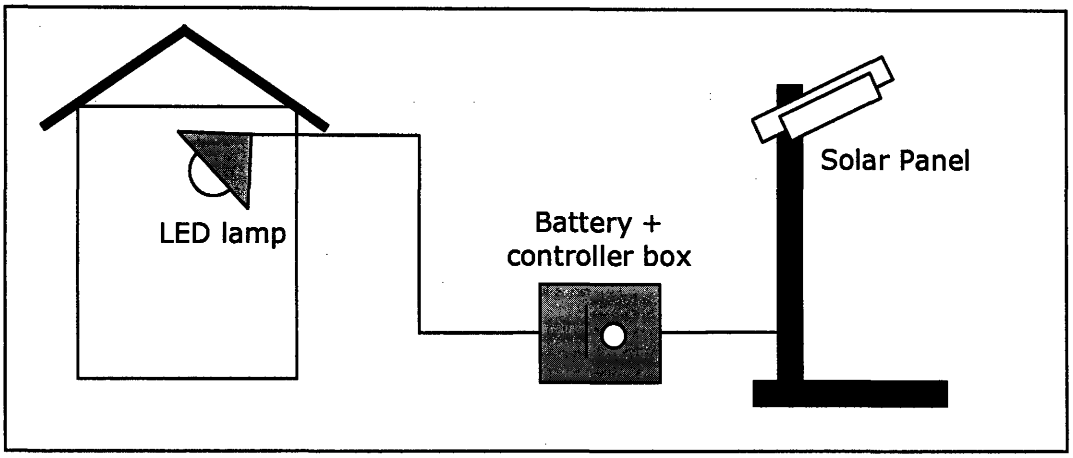


**Figure 3.5: THRIVE's first LED lighting model**

THRIVE began earnestly looking for other communities to start a larger pilot project. Their goal was to test out the lights and study their acceptability and adoption on a larger scale. They outlined 22 tribal (Chenchu) villages in the Nallamala forest area, about 160 kilometers away. These villages were chosen because they were within a four-hour traveling radius and were unlikely to get grid access in the near future.

Like other indigenous communities in the world, tribal communities like the Chenchus, and Lambadas in India also have different cultures from traditional Indian culture. They are recognized by Indian government as "Scheduled Tribes" or ST's—a distinctive minority—who are eligible for various affirmative action policies. These ST's live in restricted areas where the government does not interfere. Unfortunately this "noninterference" also means underdevelopment in terms of infrastructure and other amenities. Illiteracy, and lack of proper roads, transportation, developed water facilities and electricity are common. For all these reasons, working with tribal communities can be more challenging and complex than working with rural communities.

The pilot project ran from April 2003–May 2005, when communities were phased into the project at the rate of two to three per month. All 22 villages were fitted with versions of the first model (see Figure 3.5 and 3.6), powered by solar energy.[22] Over the course of the two years, five different models were tested and implemented, each building on feedback collected from these communities. Each model included significant technical and design improvements, including improved LED and battery quality, and a move from being permanently installed to being hand-held and mobile (from lamp to handheld lantern, see Figure 3.6).

[22] Only the common areas were fitted with the units. These typically included the chief's house, the main watering hole(s), and the main community gathering sites.

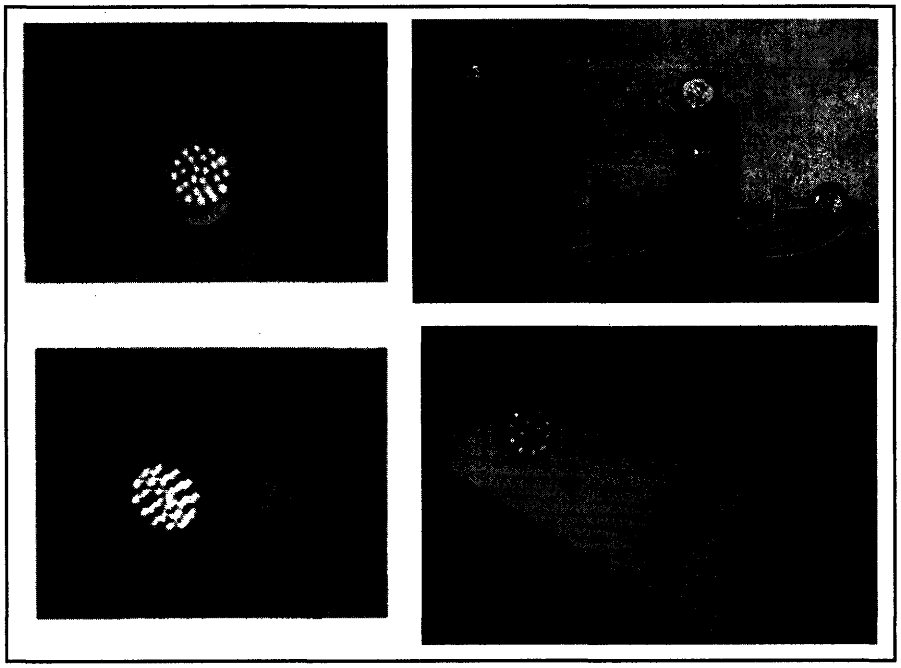

**Figure 3.6: THRIVE lighting units. Clockwise from bottom left are the 2003 (both are wall-mounted), 2004, and 2005 models respectively.**

All lights and components were given free of charge to the pilot communities. O&M were done regularly by THRIVE staff. Essentially all costs (both capital and operating) were borne by THRIVE. By December 2003, six months after the pilot project had started THRIVE started to notice problems. The systems were constantly burgled and misused; accountability was minimal. The cost of maintaining the systems got to be too high. They tried to introduce payment mechanisms hoping to increase accountability, but the users refused even minimal payments. By mid-2005, they phased out of all the communities. Only two of the original 22 projects were still operating (as of January 2007, they still are in operation). Dr. Ranga believes that the distinctive feature of these two communities is the dedication of the village headmen, who understood the value of the systems and took responsibility for their upkeep.

The pilot model served as a great learning experience for THRIVE. They deduced that:

1. **The technology worked and met their needs**: For the most part, the LED lights served the communities' lighting needs well. The lights were easy to operate; they lasted for long periods of time, lit the area well and were sturdy. Based on the feedback he had gotten from the communities, the lights were easily adopted and had tremendous scalability. Complaints had more to do with the design of the lantern, than the lighting quality itself. Thus he decided to improve on the model some more.

2. **Financial incentives and ownership were absolutely necessary for sustainability**: The lanterns had to be offered as a competitive commodity.

Financial incentives increased accountability, responsibility, and ultimately sustainability.

3. **O&M capacity building was critical**: Basic O&M skills had to be transferred very early on into these communities. This would decrease tampering of the devices, as well as fix the problems before they got worse.

## 3.4.4 Second Lighting Project: 2005-06

In early 2005, as THRIVE was phasing out of their pilot communities in Nallamala, they began earnestly looking for partners to expand into primarily tribal and extremely remote areas in the states of Orissa and Chhattisgarh, where the need was great. Dr. Ranga wanted a good partner who knew and had gained the trust of the surrounding communities, and could compensate for THRIVE's limited human resources. This time he wanted to test scalability. THRIVE linked with Ankuran, an NGO based in Rayagada, Orissa, some 600 kilometers northeast of THRIVE's Chintapally HQ (see Figure 3.1). Ankuran was well respected for their work with the Kondh tribal community. So THRIVE and Ankuran began scoping out communities to scale into.

THRIVE had learned from their experience in Chintapally and tweaked the model to ensure sustainability:

- They worked in ten communities where they were well known, had a strong presence, and had built up a high level of trust. This ensured that there would be honest and regular feedback sessions that would help hone the technical and operating model.

- Community members would be responsible for all operating costs. Capital costs (the lantern and charging station costs) would be borne by THRIVE and Ankuran. The lanterns were given away free because the communities had no understanding of their value in their lives. In addition, Ankuran knew these areas well and their work was well respected. This meant that what they gave out would be taken seriously, even if it was given away free.

- Solar-powered charging stations were set up within walking distance of the communities. A volunteer, who was chosen by the community for his or her dependability, was charged with the responsibility of collecting the lanterns for regular charging. The community was aware of who had the time, energy and maturity to take on such a role. While the volunteers were offered minimal financial incentives, it was clear that their social status within the communities increased significantly over time. This ensured a high level of continued motivation.

- To build up technical capacity, five youth who volunteered from within the communities were put through an intensive six-month training program by

> THRIVE that covered electronics, LED operation, welding and fabrication. Their role on return was to take care of all O&M issues in these communities. During the initial months, while the youth were still in training, THRIVE staff lived within the communities and took care of all issues.

It was soon clear that this scheme was operating far smoother than the pilot model in the Nallamala area. The few technical issues were quickly fixed. Word spread rapidly and demand for the lanterns in surrounding communities increased. Ankuran was soon flooded with requests, some by people who were willing to pay for the lanterns. They decided to test the users' willingness to pay.

All of these communities relied primarily on kerosene (which was rationed to three liters per month) for their lighting needs. Kerosene was further supplemented by the use of candles, cheap flashlights and biomass fuels (wood, dung and oil) as necessary. On an average, each household spent about INR 30 (US $0.68) per month on kerosene (INR 10.50 per liter), with an excess of INR 10-20 (US $0.23-0.45) per month on supplemental sources. THRIVE and Ankuran approached the communities with a conservative INR 20 (US $0.45), which would go to support the village volunteer and the maintenance of the solar panels. The users readily agreed to the amount, even offering to pay more. Kerosene disbursement is flawed (as discussed earlier) by politics, limited supply, and adulteration. These problems are exacerbated in remote tribal areas such as these, where the community members often have to queue for days before the ration shops open, without a guarantee for their ration. It was not uncommon for members to come back empty-handed because the supply had diminished before they got their turn. This was a source of great frustration within these communities and ensured a consistent market for alternative lighting.

It was clear that there were tremendous demand and potential for scalability of the product in these communities. The users' willingness to pay also held the promise of making the model entirely financially sustainable. Operating costs would be covered, but the capital costs which were fairly high still had to be factored into the model. THRIVE continued collecting feedback to improve the technical and operational design of the lantern. Dr. Ranga had many ideas for improving efficiency (to bring down operating costs of the lantern), but it would require capital that he did not have. Also increasing scale would require investments in the supply chain, particularly in procurement and production.

In October 2005, THRIVE applied for the WB DM award. In addition to the financial rewards, the grantees have access to a wide range of resources, including valuable networks through their national WB offices. The DM grant process is extremely competitive and long-drawn (applications are due in October, with winners announced in May), during which time potential grantees are encouraged to hone and preen their proposals or business plans. THRIVE used this time to work on their lantern design, monitor the current project and think through their implementation plan.

### 3.4.5 Development Marketplace Lighting Project: 2006-present

In May 2006, THRIVE (and Ankuran) won the DM Award. THRIVE had agreed to take primary responsibility for the development, planning and coordination of the implementation. Ankuran would provide support as and when necessary. Based on the calculated demand in that region, THRIVE and Ankuran planned to scale up supply and services to 20,000 households over the next three years (The DM Award is typically disbursed over one to two years, and in this case would only fund the first 10,000). All were communities surrounding the successful Orissa project where demand for their services had already been voiced.

The salient features of the business model were as follows:

- Scaleup would occur in two phases and last three years: Phase I would last two years, the first of which would involve the incorporation of 10,000 households at the rate of 1000 households per month over ten months. The second year, THRIVE and Ankuran would monitor, improve and enhance the capacity of the existing programs. Phase II would follow in the third year and incorporate 10,000 households at the rate of 2000 households per month over five months.

- Phase I communities would be targeted in the following manner. First communities that were within a 15-kilometer radius of the electrical grid would be incorporated. There was a very insignificant electrical grid that ran through the general forest area of these tribal communities, often far away from where the villages were physically located. Using the grid (as opposed to installing new solar panels) would greatly reduce capital costs of the system, and use whatever resources the government was already providing. Ankuran had monitored the grid and ensured that the electricity was regular enough to support a steady supply of charged batteries to the communities. Electricity was generally available during the day when multiple lantern batteries could be left to charge at once.

  Second and in conjunction with the first set of communities, solar charging stations could be developed in communities outside the 15-20 kilometer grid radius (this distance will work if lantern development goes as planned; THRIVE is currently developing a lantern that can go for a month without charging, making it one long walk once a month for the entrepreneur, as opposed to four times a month). These are communities that skirt the grid communities that have already been introduced to this system of lighting. This would ensure easier spillover of lantern distribution, training and implementation. Solar stations were also more capital intensive, and required especially skilled technicians, both of which were more time intensive. Targeting communities in this manner would buy time to develop any necessary extra capital or capacity.

- Each household would contribute INR 100 (US $2.30) per lantern. The shortfall of approximately INR 500 (US $13) would be covered by the DM grant. In addition, they would pay INR 20 (US $0.45) per month to cover all service and O&M charges, and four battery charges (on average one of those lanterns required four battery charges per month, if used at full-power for five hours a day, and night-light for six hours a day) for the month. Each extra battery charge would cost INR 5 (US $0.10).

- Each village would elect an "entrepreneur" (in the pilot model, the entrepreneur was a volunteer; in this case, he would be paid) who would be trained in basic lantern maintenance, battery charging, and bookkeeping. His job would be to remove the battery from the lantern, replace it with a fully charged one; then trek over to the charging station to charge the discharged batteries and deliver any problematic lanterns to the technician to fix. In addition, he would collect the monthly fee (INR 20 or US $0.45 per month) from each of his patrons – half of which he kept for himself as salary, and half of which would go to Ankuran for O&M of the charging station, and the technician's salary. Both the technician and Ankuran would monitor the number of lanterns per month to ensure that the entrepreneur was being honest about his earnings.

- Each service station would have an assigned technician who was put through three to six months of intensive electronics training. His job is to maintain and monitor the charging station and fix any problematic lanterns that were delivered to him. He was also required to record community usages and problems, and report abnormalities to Ankuran. Expended batteries, lanterns and lantern parts would be sent back to THRIVE for recycling. Part of the technician's salary would come from the monthly community service charge, with the shortfall subsidized by the DM. It was also hoped that train-the-trainer programs would become a salient feature in the scaleup.

A new lantern model (see Figure 3.7) was developed and began production in May 2006. It incorporated the following changes:

- **Decreased battery size and capacity.** The lantern went from housing a 12-volt battery to 6-volt, 4.5 Amp battery. This decreased overall lantern weight, size and cost. The difference in cost between the 2006 model and the earlier one is about US $4 per lantern (this is also because the LEDs went down in price).

- **Greater reliance on grid power, less on solar power**. As mentioned before, using existing grid power decreased overall capital as well as operating costs. Relying on grid power meant using existing resources as opposed to new ones. Grid power was cheaper in the shorter term, i.e., it takes ten years for the solar PV stations to regain capital costs and be competitive. Considering India's growth rate, Dr. Ranga assumed that grid power access might increase. In addition, training for solar PV technicians was more time and capital intensive.

- **More efficient circuit design**. Decreased battery size meant that they had to be charged more often. To mitigate this Dr. Ranga hired a circuit expert to make the LEDs burn more efficiently. The new circuit incorporated fewer, brighter LEDs (thereby slightly increasing overall luminosity, but decreasing price) and increased battery life by over 30%.

- **Better aesthetic features**. Besides being lighter in weight, the LEDs were roof-mounted and included a night-light. In addition, the lantern had a slanted roof to work better outdoors and indoors for cooking.

- **More user-friendly**. For easier access to the circuit and battery, the back panel incorporated fewer screws. Considering that most of the entrepreneurs and clients were illiterate, the electronics and wires were clearly color-coded and padded for added safety (see Figure 3.7). Among other features, it now boasts a slanted roof for protection, a top-mounted LED panel, and a night-light. The back panel is much easier to remove with only three screws. Everything is neatly and clearly color-coded and protected for fast and easy access for operation. The black wire is plugged into the black terminal of a battery and the red wire to the red-terminal.

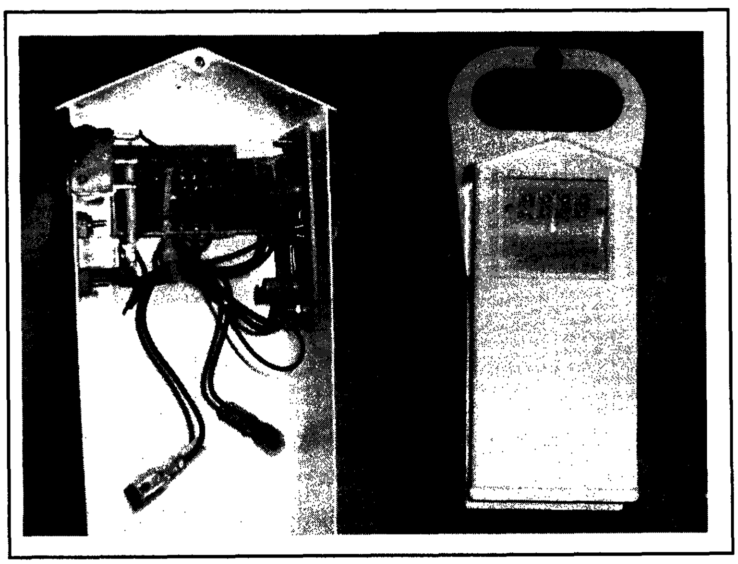

**Figure 3.7: The 2006 version of THRIVE's LED lantern. The left side shows the wiring and circuitry that powers the lantern. The two dangling wires are easily plugged into the terminals of a battery. The battery takes 4-6 hours to charge.**

## 3.4.6 Challenges of Scalability

THRIVE soon learned about the challenges of scaling up.

The first hurdle came from the manufacturing unit shortly after winning the DM grant. After the awards were announced, Dr. Ranga quickly put in an order for lanterns to be produced at the rate of 1000 per month. The batteries came from Korea by ship and were transported directly to an assembly factory in Hyderabad. The LEDs came from China and were shipped to the circuit board manufacturer in Hyderabad (separate from the lantern assembly manufacturer).[23] Assembled circuit boards were combined with LEDs, and then sent to the assembly factory. The assembly factory is fairly rudimentary and primarily relies on manual labor rather than machinery. The collected components were combined with the locally made chassis and painstakingly assembled by hand in the factory. While all the components that were transported in kept up with the demand, the hand assembly units could not. The factory owner is a friend of Dr. Ranga, and was going through a series of family emergencies that kept him from effectively managing the situation. Over time, the quality and quantity of the products suffered. The lanterns churned out were of increasingly poorer quality and they were often not uniform in design. Plus, supply was simply not keeping up with demand.

To make matters worse, the DM money was not disbursed in June as promised. The assembly factory desperately needed to pay their workers, who were all day laborers and relied heavily on their daily wages. These late wages may explain some of the ensuing delays and quality issues.

In the meantime, THRIVE found itself caught in a post-DM publicity blitz. In a matter of a few months, Dr. Ranga was getting calls and emails from all around the country, and the world, including Afghanistan, Cambodia, and Kenya, all asking for lanterns.

In June 2006, just around the time that Dr. Ranga heard about the delay in DM fund disbursements, the United Nations Assistance Mission in Afghanistan (UNAMA) contacted him with a proposition to expand into Afghanistan. They had heard about his project through the World Bank, while searching for lighting models that were low-cost, low-maintenance and self-sufficient. THRIVE's lights and model seemed to fit the bill.

The Afghanistan project would involve manufacturing and supplying 2000 lanterns over three months (June to September, 2006). UNAMA was willing to pay all costs starting immediately and would monitor and run the project. Since THRIVE was stymied and desperately in need of funds, they sent half of their first order (about 500 lanterns) with their best trainer to set up the project as well as train the local UNAMA staff (who would do train-the-trainer programs). In February 2007, the other 1500 lanterns were finally delivered and the project was completed. The delay in delivery was largely a result of factory problems outlined above. UNAMA's partner NGO staff have been trained and the THRIVE business model has been successfully implemented in the area where the 500 are already in place. The trainer has reported that, except for the delayed delivery of the lanterns, the project has gone smoothly, and is likely to be sustainable. It should be noted that in this case as well, UNAMA funds were not disbursed until mid-December 2006 and the factory could not afford to continue with its production.

[23] The upstream supply chain for THRIVE's 2007 model will be modified. For example, the LEDs will be produced and shipped from Japan, as will be true of the other components.

Following UNAMA, THRIVE began working with interested organizations on the following basis. They had to do the following:

- Demonstrate need for LED lighting
- Demonstrate motivation and capacity for imbibing THRIVE's operating model.
- Be within a 20-kilometer radius of a semi-reliable electric grid line (in its absence, they had to be able to set up and maintain solar charging stations, or as in Afghanistan have access to an affordable generator).
- Have the ability to disburse funds immediately on delivery of lanterns.

The expansion is noted in Table 3.3 (please note all figures were recorded as of March, 2007).

| Training Start Date | Training Completion Date | Location | Partner Organization | No. of Lanterns Ordered | No. of Lanterns Delivered |
|---|---|---|---|---|---|
| June 2006 | Jan 2007 | Afghanistan | UNAMA | 2,000 | 2000 |
| Oct 2006 | Oct 2006 | Tamil Nadu, India | Tribal Women Welfare Society | 36 | 36 |
| Nov 2006 | Nov 2006 | Andhra Pradesh, India | S$^3$IDF | 80 | 80 |
| Dec 2006 | June 2007 | Orissa, India | Ankuran | 10,000 | 2,250 |
| Dec 2006 | Jan 2007 | Maharashtra, India | Malghat Mitra | 150 | 150 |
| Jan 2007 | June 2007 | Andhra Pradesh, India | CCN | 20,000 | 150 |
| Jan 2007 | Unknown | Cambodia | Private | 170 | 70 |
| Feb 2007 | Unknown | Jharkhand, India | State Government | 1,000 | Unknown |
| June 2006-Feb 2007 (9 months) = | | | | 33,436 | 4,736+ |

**Table 3.3: Expansion of THRIVE from June 2006-March 2007**

DM funds were finally released in late November 2006. By this time, the lantern supply was already suffering. THRIVE found itself in the middle of a quandary. Firstly, they had expanded very quickly—their trainers (who were originally supposed to be entirely focused on the Orissa project) were dispersed around other places. Training new trainers would take some time. Secondly, their lantern quantity and quality were suffering. Thirdly and most importantly, Dr. Ranga realized that he had grossly underestimated the overhead costs of the program. For example, staff salaries, experts, shipments and office space costs had not been factored correctly into the cost price of the lantern, or the DM proposal. These were now mounting and costing him far more than he could personally afford. Since then, he has been desperately searching for schemes to help make his organization more financially sustainable. This has led him to debate whether the organization should continue to be a nonprofit or convert into a for-profit venture, which will be discussed in great detail later in this chapter.

As of March 2007, Ranga has finally floated a company called THRIVE Energy Technologies, Private Limited and is in the process of acquiring investors. At the moment it is operating independently of THRIVE, the NGO.

## 3.5 Discussion and Comparative Analysis of THRIVE and SELCO

The different cases of THRIVE and SELCO show that there are alternative ways to successfully address the same problem. THRIVE is an up and coming, rapidly growing organization using a nonprofit model to provide LED lighting to some of the poorest people in the world; SELCO is a maturing company that is slowly expanding its scale and diversifying its scope to provide its clients with more energy efficient products. Having presented the case studies, this section presents a comparative analysis of these two very different organizations in order to derive a set of best practices.

What is most striking about THRIVE and SELCO is their outstanding leadership. Ranga and Harish have shown extraordinary dedication and commitment in order to see their visions become successful realities.

BOP markets are extremely risky to work in—highly unreliable, unpredictable, and poorly connected. There is a persistent lack of access to capital and financing options, customers lack basic education and live on extremely limited disposable incomes, and infrastructure (which factors heavily into the supply chain) is practically nonexistent. Any entrepreneur hoping to work in these markets must have clarity of vision. In India where languages, castes, and cultures vary across the states and the country, the challenges are heightened. Clear vision provides the solution. It includes a clearly visualized and practically achievable goal, an idea of the obstacles on the way, and a clear map of how to get to that goal. But because BOP markets are hardly ventured into and researched, entrepreneurs must invest considerable time studying the landscape themselves. They have few mentors or resources to reach into.

Both Harish and Ranga have invested considerable time concretizing their visions. They started with a clear idea of *whom* they wanted to serve, *what* they wanted to do and *why* they were doing it. Both had similar professional and social goals, of using their preferred lighting technologies (CFL solar lighting or LED lighting) to provide quality lighting to the poor. They also decided to be uncompromising on their social motives. What Harish and Ranga were unclear about was *how* to reach their dream, which is the part that takes the most amount of time.

Harish and Ranga started out with vague, albeit different, methodologies that would provide the general guidelines for their navigation or *how* map. For example, Harish was committed to a socially motivated profit-generating venture that would operate entirely free of subsidies; while Ranga believed in operating an NGO that used grants and subsidies. What is important is that no one ideology is better than another. Rather, it is most important for the leaders to pick an ideology that is most in-line with their thinking, and then focusing on applying it consistently throughout the organization.

The *how* map required the extensive collection of three fields of knowledge—market knowledge, customer knowledge and technical knowledge. In terms of market or customer knowledge, neither were businessmen (though Ranga had pursued an MBA without ever applying his knowledge as a consultant or professor), nor were they from BOP communities. Harish had grown up as the son of a civil servant in middle class neighborhoods in mostly urban Orissa and Karnataka, while Ranga had grown up with a middle income agricultural family in rural Andhra Pradesh. What both had was a general knowledge of the geography, cultures, and languages of their states, and an insatiable desire to learn more about these issues. In some ways, Ranga's rural upbringing prepared him far more than Harish to take on the challenges of working with the BOP.

In terms of technical knowledge, Harish was far ahead of Ranga. When he founded SELCO in 1994, Harish had already spent almost seven years studying solar energy technologies, two of which were spent in the field. Ranga had to start from the beginning.

In all, gathering their market, customer and technical data would take Harish and Ranga an average of four to five years. During this period, they lived as their BOP customers did, on very low incomes and on extremely modest material means, in rural or tribal areas experiencing the problems that their clients were. Any extra money they made went to fund their ventures. All their time was spent understanding their markets, technologies and customers better. They learned that their BOP customer base spent, saved and used technology differently from non-BOP customers, and learned how to customize their technologies.

During his first few years in the field, Harish became convinced that a corporate environment would force efficiency, transparency, and uniformity into the implementation. He also developed an increasing aversion to subsidies as their availability was unpredictable and they created seller and buyer dependency. Both waited for the subsidies to come in before making orders, thereby making business unpredictable. In addition, there was a non-uniform policy towards customers. Desperate customers would sometimes buy the unsubsidized item and feel angry or duped by the seller, when subsidies came through for the others.

Having shut his door on traditional sources of funding available to BOP clients namely, subsidies and grants, Harish was forced to find creative ways of financing. Thus, having started his company in 1994, it took him nearly four years to broker his first few deals (past what the original seed money had given him), largely because he had to convince financial institutions in the area to support his clients. During this time, he studied customer habits intently, built his supply chain, trained his human resources, and actively sought capital for his venture. His vision became increasingly clear, and would factor significantly into setting the stage for the company's ensuing growth.

Ranga, for his part, had a much better understanding of the BOP market. Having grown up in an off-grid area in rural India, he knew what his customers used, and how the markets operated. What he lacked was technical knowledge. Having moved back to an off-grid, fairly remote tribal area in 2001, he was able to simultaneously study client habits and needs, and mould his technology to them. It took him a year to find the right technology (LEDs), and three to four years to build a product that greatly embodied client needs. LEDs used for lighting are a fairly new technology and have been evolving at a rapid rate as described earlier. This lack of maturity had and continues to challenge Ranga in the most difficult way. The great variability in design, quality, price, and manufacturing, took him several years to build up a trustworthy supply chain. In fact, he is still battling these issues today. Besides gaining increasing product knowledge, Ranga spent these years studying customer habits, his competitors, building human resources, and finding quality partners. His strong ideological views led him to keep THRIVE as an NGO.

To complicate matters, neither Harish nor Ranga had very many competitors. Healthy competition can be good for businesses particularly in cases where so little about the market or processes is known. Harish had almost no competition, while Ranga had very little.[24] Both were primarily competing against candles, kerosene, and extremely unreliable grids, which presented challenges of their own.

Competing against kerosene, candles and biomass is not as easy as one might think. BOP consumers have three tendencies that give traditional combustion lighting an upper hand over competitors. First, BOP consumers are extremely risk-averse because they have so much at stake. They tend to buy products they trust, rather than adopting new ones, especially when the cost of the competitor is higher. It consequently takes a long time to win them over or to get them to change their spending habits. The payoff is that they are extremely loyal once you win them over. Second, word-of-mouth marketing is most effective in these consumer groups. To understand trustworthiness of a product, they rely heavily on the opinions of members in their networks. Any BOP entrepreneur must be very patient particularly in the beginning because it takes some time for these networks to develop. Third, they tend to buy in small amounts rather than in bulk, as they tend to earn and/or live on a limited daily allowance or income. All three of these behaviors favor the

[24] Two copycat competitors entered SELCO's markets (selling solar PV to poor consumers) at different points in the past five years, but they both struggled and went out of business in less than a year. One tried to grow too quickly before it was fully established; the second was unable to compete with SELCO's level of customer service.

continued use of dung, biomass and kerosene for lighting. So how exactly would they win over their customers?

The big challenge in working with BOP consumers lies in gaining their trust and establishing value. Both SELCO and THRIVE have had to prove that their more expensive systems are worth the money and are an investment. For BOP consumers, a product is valuable if it caters to a *need* rather than a *want*. A *need* is something you cannot compromise on, whereas on *wants* you can. In the non-BOP world, there is no need to distinguish between needs and wants, because clients are often educated or at least have access to information in order to make informed decisions, and have significant disposable incomes. This is not true of the BOP consumers. Entrepreneurs have a greater responsibility to their clients, to make educated decisions for them. Entrepreneurs have added incentive to customize their products to the needs of a BOP consumer because the "fit" is better, thereby making it more valuable and worthy of investment. Having thus established trust and value, entrepreneurs are further able to enjoy the loyalty of the BOP consumers.

For both Ranga and Harish, finding out what BOP consumers found valuable was critical. They found a subset of BOP consumers (with no specific demographic characteristics) who *needed* more reliable and better quality lighting but had nowhere to turn to. These consumers became the focus of their initial marketing. Ranga was also able to use his competition to improve his own technology. For example, competing LED lanterns catering to BOP consumers began entering the market in 2002. A complete market analysis of these competitors is provided in Appendix 4.[25] His most threatening competitor is the MightyLight (see Appendix 4) whose catchy design and low weight were getting much attention. Notwithstanding these features, Ranga continued innovating THRIVE's lantern to make it more flexible (can be powered through the grid or solar-powered), increase its lifespan between charges (the MightyLight can go for up to seven hours on one charge, while THRIVE's lantern can go for up to 45 hours) and keep the cost down (MightyLight costs about US $55, while THRIVE's lantern costs US $15).[26]

Harish's lack of competition was not surprising considering that solar energy had long been considered too expensive for the poor. The Indian government and several NGOs had subsidized several sporadic projects, all of which had failed. This was true also of the projects that Harish had worked on in the Dominican Republic and Sri Lanka. Having no or primarily failed competition had its own set of issues. Harish had to spend much more time convincing investors and financial institutions to finance his company and his clients. Innovation was entirely fueled by his own drive and by issues he saw in the field, rather than in response to competition.

[25] A complete market analysis of LED lanterns catered to the Indian BOP market is provided Appendix 4. It is reproduced in its entirety with permission from authors Daniel Hsu and Rohit Wanchoo, business students at the MIT Sloan School of Management.

[26] Information about the lifespan between charges is recorded as verbally reported by users in a Kondh Tribe community in northern Andhra Pradesh.

In the end, Harish and Ranga created the following general navigation or *how* map by creating value for their products in the following way:

- First, they established the boundaries of their primary consumer group. It consisted of BOP consumers who wanted better lighting, but did not know where to turn. Thenceforth, they relied on word-of-mouth marketing to reach their secondary consumer group, which consisted of all consumers in their networks.

- Second, they have only produced quality, trustworthy products that were customized around their clients' needs. This ensured high client satisfaction, established value and further reinforced word-of-mouth marketing. For example, THRIVE went through five versions of their lantern, each with a period of extensive testing in consumer homes. It was their sixth and most recent version that finally "hit the jackpot," and they are still improving on it. (A new version of the lantern is expected to be issued in June 2007, which is supposed to run for 70 hours on one charge). With their mature technology and permanently installed systems, SELCO sends technicians to assess each client's requirements, and installs a customized system. In both cases, there is high client satisfaction; which has translated into continuous sales growth primarily through word-of-mouth referrals.

- Third, they provide money-back guarantees on their products, thereby absorbing most of the risk. SELCO offers a ten-year warranty on their PV panels and wiring, a 90-day money-back guarantee on the entire system, and a year of free servicing on all newly installed systems. THRIVE services and replaces all faulty lanterns for the life of the lantern.[27]

- Fourth, they provide their clients with innovative customized financing mechanisms. Both are aware that their clients earn, spend and save differently. For example, rice farmers earn differently from silk farmers, tailors, or cobblers. Consequently, each client needs to have a financing mechanism to suit his or her needs. This is particularly true of SELCO whose cheapest system is at least 100 times the daily income of a daily wage laborer. SELCO and THRIVE also use local financial institutions to help their clients build credit, thereby benefiting the financial institutions and the clients. In terms of operation and maintenance, they price competitively based on kerosene prices, and then adjust the price based on each community's willingness to pay. Thus, financing is customized for their clients.

- Fifth and finally, they provide excellent customer service. Both are aware that their consumers lack access to electronic skills and knowledge. Therefore, both have provided customer and technical service using locally available human resources. SELCO has a 24-hour customer service guarantee, where clients will

[27] Considering that LEDs are rapidly evolving, THRIVE expects to update their clients' lanterns every few years. This is why they expect their clients only to put out two-thirds of the capital cost, while subsidies will cover the rest.

get technical assistance within 24-hours of putting in a request. Clients also have access to a SELCO service center, which is within a two-hour travel radius of their systems. SELCO also has several female technicians who can make day calls while the men are out of the house. THRIVE's customer service module involves recruiting and training local NGO partners and community users to be technicians. Since the majority of THRIVE's customers are tribal communities where wireless and wired communication have yet to make a foray, users are informed of the location of their nearest technician (typically located in each community).

Together, these five principles have helped both organizations to stay focused, standardize their operations and grow organically. Both SELCO and THRIVE have grown primarily through word-of-mouth marketing. The most important piece of their success is their heavy reliance on local institutions. In the absence of reliable market, client or community information, both have relied heavily on local financial, governmental, and nongovernmental organizations to fill in the information gaps. From them they find out about potential clients, human resources, local culture, local banks, current money-lending practices, community and infrastructure challenges from local NGOs. THRIVE relies far more heavily on NGOs because they tend to outsource their operations and implementation through them. SELCO also relies heavily on local banks and NGOs for their operations. In the process, both SELCO and THRIVE have created strong local support systems for their clients. And the NGOs have reciprocated by providing valuable information, as well as improving their visibility.

It must also be mentioned that Harish's and Ranga's education has greatly helped them succeed in their ventures. This is for several reasons. While a Ph.D. may not be necessary, a higher level of education certainly brings credibility among peers, donors and investors, and helps raise the awareness of their organizations, which can bring in capital and more visibility. It also gives them access to information as they need, as well as the ability to interpret what they find. Both are also well traveled and are able to comprehend the global aspects of doing business. Entrepreneurs who are not as well educated should not feel discouraged. They can easily bridge this gap by finding resources, such as mentors or organizations, which can fill this role.

## 3.6 Challenges

It is evident throughout the course of this document that entrepreneurship in BOP markets is extremely challenging. The list of challenges mentioned here are not comprehensive; rather I have outlined only the most salient.

- **Staying Motivated:** Both Harish and Ranga have said that their jobs have been the most challenging and fulfilling experiences of their lives. They have also said that this professional success has come at great cost to their personal lives, including time away from their families and a persistent lack of material wealth. Their constant struggles in this extremely challenging have made it very hard to stay motivated. It does not help that there are few models or mentors they can look to for guidance. Like all other pioneers, Harish and Ranga have had to give up a great deal to get as far as they have. But they also insist that the fulfillment they get from doing what they love is unparalleled.

- **Raising Capital:** Both Ranga and Harish have said that raising money has been one of the most difficult aspects of running their organizations. The fact that they are so strongly socially motivated makes things harder. Investors are hesitant to give money because they know there is little or no return on their investment (ROI); and both Ranga and Harish are hesitant to take money from investors whose values are not in line with their social goals. Again, having seen so few succeed, investors have no models for good social entrepreneurs. Besides the social aspect, both are working to promote products that have long been considered unnecessary or not adoptable into BOP markets, i.e., investors do not believe that illiterate farmers need, will use or pay for high-tech gadgets like solar lighting. So investors or financial institutions are hesitant to extend credit to both of them.

  Not enough can be said about the ethical challenges of raising early capital. Taking on an investor means selling a piece of your business, and your vision. Social entrepreneurs often have such limited options, that they take what they can get with the hope of starting up and regaining their company. Even someone as cautious as Harish found that this is far easier said than done. Harish had taken a loan from the IFC after much discussion with their representatives. It seemed they reached a mutual understanding that worked well for both. He thought he'd use it to get started, so that he could attract the type of investors he wanted. Unfortunately, soon after he signed, Harish's loan representatives left the IFC. The replacement representatives were of a different mindset and had not been properly primed on the verbal rapport and agreements that Harish had developed with their predecessors. When loan repayments did not come in as demanded, the replacement representatives began to interfere by offering advice, and raising interest rates. This whole dilemma will be further discussed later in this chapter.

- **Rapidly Evolving Technology:** This is a problem for both SELCO and THRIVE, though the latter is most affected by it. Both solar PV panels and LEDs are hot technologies that are rapidly evolving at a phenomenal rate. LEDs particularly have been experiencing incredible growth, doubling in efficacy biennially. This evolution causes prices, quality and the market in general to fluctuate constantly, making it extremely challenging to standardize a product.

- **Globalization:** Globalization has a major impact on businesses today. Its effect is felt most acutely in the poorest regions of the world. Small fluctuations of supply and demand in one part of the world can have huge implications on the price and product in another part. This is true of LEDs and PV panels, whose recent popularity has caused a surge in prices. For example, the high demand for PV panels in Germany has caused major challenges for SELCO's BOP customers. It has resulted in a significant increase in price and change in the specs. The demand for larger solar panels has caused manufacturers who were originally supplying SELCO with smaller and cheaper panels to start doing theirs bigger. Smaller panels, because of the lower supply, cost more. And while the price differential may be only a few US dollars, it factors heavily into a BOP customer's meager savings, which can be measured in cents.

- **Human Resources and Infrastructure:** One of the aspects of BOP marketing is really knowing your clients. As stated before, BOP clients come from a range of backgrounds, castes, languages, and professions, which make BOP markets extremely complex. To build trust in these communities, it is often best to hire from within them. As part of their commitment to social upliftment and developing the skills of these populations, both THRIVE and SELCO hire many of their employees from within their communities. But their lack of education and skills can slow down the efficiency of their organizations significantly.

  Operational efficiency is further plagued by the lack of general infrastructure. For example, the lack of quality roads, transportation between communities, and telephone communication limits connectivity and hinders the supply chain. Infrastructure and lack of human resources can greatly hinder quality control of the products, as discussed later in this section. Donors, investors and social entrepreneurs must be extremely aware of the vital importance of human resources and infrastructure for the smooth operation in BOP markets.

- **Intellectual Property (IP) Issues:** Copycat models and intellectual property issues are a major hurdle for BOP entrepreneurs. THRIVE has found its lanterns particularly susceptible to this. Because LEDs are continuously evolving and have no reliable standards or supply, they are extremely research and development (R&D) intensive. Having invested considerable capital on R&D, Ranga has developed an amazing product that is fairly reliable, dependable and low-cost. Driven by his social goal of making lighting freely available, Ranga has shared technical information with other seemingly well-meaning people, who are now threatening to spawn businesses of their own using his technology. Others have simply mimicked his circuit designs and are trying to build copycat products. This is dangerous because THRIVE is still an unbranded, fledgling group that can easily lose their clientele to poor quality copycat imitators, who can easily break the trust that THRIVE has worked so hard to build. Another reason is that they need to maintain the higher cost of their product if they want to maintain the quality and recover some return on their capital investment. Ranga has already applied to patent aspects of his technology, but its constantly evolving nature, as well as the financial and time intensive process of the patent-application make this a very difficult situation for him.

- **Quality Control:** Related to the issues of strained capital and human resources, globalization, and poor infrastructure is the challenge of maintaining quality control. Harish started his business fully understanding the critical nature of ensuring quality control and its correlation with customer trust. From the very beginning he kept a sharp eye on the quality of his products, and made changes as necessary. It is also why he has not ventured into the still maturing market of LED-lighting.

  Ranga has taken a different approach to quality control. He has done an excellent job of finding good, reliable international suppliers; but has had immense challenges with the local manufacturers. THRIVE's lack of excess capital and human resources make it difficult to monitor the factory where the lanterns are being manufactured.

- **Investor and Donor Fatigue:** The main distinction between donors and investors is the type of sector they are investing in. Donors typically "invest" in NGOs, while investors are more likely associated with profit-making ventures or companies. Both expect returns on their investments, however the former expect more social returns, while the latter expect mostly monetary returns. When ROIs are not met in the donor's or investor's expected period of time, they become "fatigued," causing them to interfere with the organization's operations. Donors are particularly susceptible to this because social ROI is difficult to measure; it is intangible and needs a longer time to show results.

  Both investors and donors must incorporate a level of patience when dealing with BOP entrepreneurs because of the learning curve involved. BOP entrepreneurs need time to develop business mechanisms robust enough to manage the lack of infrastructure, lack of information about the market or consumer base, and other issues outlined in this section. Only after these mechanisms have been successfully tested and implemented can they begin to generate profits.

  When "fatigued," an investor might interfere in the organization's operations, which could cause serious problems for both. Harish experienced this to some extent when the IFC became frustrated with his lack of quick profit-generation and started to hike up interest rates. The IFC consultants pressured him to take their advice, which he has resisted. He still has a substantial loan to pay off to them, but the progress of his company in the last few years has been promising and he is confident that he will pay of the loan soon. Not all entrepreneurs have the courage to stand up to their investors, and the resulting investor interference is a significant problem.

  Donor fatigue is a major problem for legitimate NGOs[28] for two main reasons. Firstly, donors have a difficult time sieving through the maze of NGOs to find genuine ones. For protection, donors will withdraw funding from an NGO if their expectations are not adequately met in a set period of time. Secondly, they tend to

[28] I say legitimate NGOs because there are several NGOs that pilfer and embezzle money.

be fickle in their expectations and interests, causing a general sense of instability. Donors have a range of fuzzy expectations, unlike investors. Some of these expectations can be very difficult to measure or implement. When an NGO is unable to deliver on these, the donor may get "fatigued" and discontinue support or begin to interfere. I've personally noticed this with several donors and NGOs, and the results are often negative. For their part, few NGOs are blessed with long-term donors, which means that most NGOs spend a substantial amount of their resources on fundraising rather than on doing the work they have promised. This has significant impact on efficiency and productivity. Interference in some of these cases might be good and necessary, but it can also be detrimental. Essentially, this is something that both NGOs and donors must guard against. NGOs need to be more honest and clear in what they can realistically deliver to their donors, while donors need to be more patient and cognizant of the challenging environment that NGOs are operating in. One mechanism of interference that might be of positive value is for a donor to offer aid in terms of skilled labor, rather than money. NGOs are often forced to spend all a donor's money on a program rather than on building up their own operational capacity. This is counter-intuitive in that an NGO is unable to output increased quality or quantity without improving the skills of its workforce.

One example that comes to mind in this context is of an organization called BioGeneration, which was also a recent DM grant-winner.[29] For several years now, they have been fundraising with the idea of scaling up their biogas generation project from a single plant in a village to several plants in several villages. Donors have yet to see results from their investments. There continues to be only one biogas generator in the same village, and it has not changed at all. While in India in January 2007, several donors I came across expressed outrage at the World Bank's award, claiming that BioGeneration was a "fake" and an "embezzler."

In February 2007, I interviewed a team of MIT-Sloan Business students who had gone to work with BioGeneration in India. As part of the Global Entrepreneurship Lab (G-Lab), a popular course at MIT-Sloan, the team had spent their fall 2006 semester consulting virtually for BioGeneration, followed by a month of intensive fieldwork in January 2007. Their goal was to help set up a women's training program in the same village in India. Having experienced everything first hand, they were able to say with great confidence that the organization was indeed genuine. The biogas generator had been powering the village for several years now and it had created a vibrant mini-economy along with a bustling open-air market. Yet, there were no profits, growth or changes generated.

We were quickly able to deduce the problem as follows: BioGeneration, like many other NGOs, is a victim of their own operational inefficiency. Like THRIVE, but to a much greater extent, they have and continue to hire primarily unskilled labor from within the village community for both social and financial

[29] Organization's name has been changed.

reasons. Unskilled labor is cheaper to hire in the short-run, but very expensive in the long run. They take a long time to train, make costly mistakes and often need to be replaced, which ends up being even more costly. In addition, BioGeneration refused to charge money for any of their services, making it extremely financially unsustainable. In the end, all incoming funding was going to sustain their single biogas generation unit thereby curtailing any possibility of expansion. In the meantime, an oblivious BioGeneration continues to fundraise with the hope of expanding, while fatigued donors have become outraged. Should this pattern continue BioGeneration will dissolve along with all the good they have done.

As Ranga has taken money from only one donor (the World Bank) and delivered on his promises thus far, he is still free of this problem. But once the DM support fades (by 2008), this is an issue for which Ranga must find solutions.

### 3.6.1 The Debate of Ideologies: NGO versus Corporate

There is a growing debate between social entrepreneurs whether they should take the nonprofit route or the corporate route. Each has its own set of advantages and disadvantages, which has been true of THRIVE and SELCO.

As mentioned earlier, Harish was determined to make SELCO into a socially responsible company. He wanted it to combine the motives of an NGO along with the efficiency and transparency of the corporate environment, both of which he has succeeded in doing. The key is that he has been very discerning in teaming up with investors (including the IFC when he first signed on), and hiring capable and committed human resources. Many venture capitalists I spoke to talked about the trade-offs of letting in corporate investors. While the money they give can significantly ease the stress associated with the early stages of a start-up, it also means relinquishing a part of your company. Harish has stubbornly managed to remain autonomous while maintaining the focus of the company as he has visualized it. The tradeoff has been the extreme stress of keeping the company financially afloat, particularly in the beginning, and now as he is scaling up in product scope. But it has paid off in terms of maintaining his dream and keeping a tight, well-run operation. Also making profits allows him to invest in capable human resources.

THRIVE on the other hand has been struggling against an ideological conflict. Ranga strongly believes that THRIVE should remain a nonprofit venture, thereby embodying the values of truly serving the poor. His heavy reliance on grants makes his products much more affordable (through subsidies) to even the poorest BOP clients. It also takes the pressure off profit making and more on serving the poor.

THRIVE's NGO status also has several drawbacks: firstly, NGOs like THRIVE become extremely dependent on grants, which can interfere with the projects. Secondly, this lack of funding has serious implications on the efficiency and performance of the NGO. Donors rarely give money out for administrative purposes. Therefore, NGOs are rarely able to invest in building or improving human capacity. Their lack of funds limits their ability to hire more qualified or educated staff, or train existing staff to be more skilled. This lack of human resources and finances leads to all kinds of inefficiency, including poor business practices. While there, I was worried about the lack of basic business documentation. The most educated person in THRIVE was Ranga, who had tucked away all the bookkeeping in his head. His partner was a retired economist, a nice gentleman of great knowledge, but lacking the enthusiasm or energy to perform at the level needed at this stage. For any sort of information, I had to go through Ranga. His staff consists primarily of motivated, high school educated youth, whom he is personally training. While this socially motivated stance is laudable, they are simply unable to perform advanced functions necessary for the operation of the organization. But Ranga is simply unable to afford more qualified staff for his operations.

This lack of basic bookkeeping has already taken a toll on THRIVE's finances. In January 2007, Ranga was extremely worried about this aspect and was thinking about launching a for-profit venture to give him the stable capital he needed to continue. This venture threatened to take away Ranga's focus from THRIVE at a point when he was most needed. When I last communicated with him (May 2007), he was very aware of these challenges and was working to address these by hiring more qualified staff. But his lack of finances makes it difficult for him to hire anyone of his intellectual capacity, mirroring the same values.

THRIVE has also had to adapt its operation by slipping into a more decentralized mode, which incorporates technology transfer and outsourcing to local NGOs. This has allowed great scalability nationally and internationally, a very quick and strong local presence, and higher adoptability. The disadvantage is that THRIVE must relinquish a great deal of control and standardization of their model they have outsourced to the local NGO. This means that the primary operation of each community's lighting model is wholly dependent on the dedication of the local NGO. Ranga has sought to mitigate this risk by only partnering with reliable, dependable NGOs. But it is still an issue of significant consideration.

# Chapter 4: RESULTS AND CONCLUSIONS

## 4.1 Summary

The research presented in this thesis aims to provide the reader with a set of best practices and effective mechanisms for sustainably scaling up small-scale technologies in BOP communities. It also outlines a series of critical challenges involved in the process of scalability. This study was motivated by a group of socially motivated entrepreneurs I had worked with during an MIT-Sloan class in 2006 who were desperately seeking literature on the subject, as well as successful models to emulate. Research was conducted over the course of the 2006-07 academic year, including infield study made over January 2007.

The conclusions presented here are derived from a comparative analysis of two heuristic case studies profiling entrepreneurs based in southern India, who have successfully scaled up lighting technologies in BOP communities without compromising their social motives. SELCO-India is a registered profit-generating company that sells photovoltaic-based home lighting systems, while THRIVE is a nonprofit organization that sells LED lanterns to primarily tribal and remote rural communities. THRIVE's LED lantern is priced at $15 and has scaled up from 120 to over 33,000 clients in one year; SELCO's SHS's start at $200 and have scaled up from 100 to over 55,000 homes and businesses in eight years. Both organizations demonstrate that there are alternative models to address the same issue.

Lighting is the focus of this thesis because it is a commonly ignored issue in infrastructure development, even though it has a significant impact on our health, safety, socio-economic status and the environment that surrounds us. Nearly 1.6 billion people or a quarter of the world's population lacks access to electricity proving that there is a desperate need for quality lighting and tremendous potential for scalability.

The analysis of these two very different yet comparable organizations, has yielded a robust set of best practices, challenges and effective mechanisms for addressing scalability of lighting in southern India. The conclusions of this research can be further extrapolated to apply not just to all infrastructure systems, but other BOP enterprises in developing countries for three main reasons:

- India is one of the most complex environments in which to operate. Its diverse set of tribes, religions, castes, languages, cultures, population pressures, and high illiteracy both inter- and intra-provincially make it an extremely challenging business environment. These issues are particularly magnified in BOP markets. Business practices derived here will surely be applicable in other parts of the world.

- Infrastructure is one of the most difficult sectors to scaleup in. This is largely because infrastructure is a public entity. Among other things, the risk of losing clients is high if the governments choose to expand quality services into their areas. Best practices gauged from within such a difficult sector should be applicable within a larger context.

- Lighting is a secondary necessity, particularly when compared with water, sanitation, transportation and healthcare, which are of far greater importance for civilization. Consequently, clients are less likely to invest in lighting when they have existing problems that demand the use of their already limited disposable incomes. Essentially, if these organizations can scale up in a secondary infrastructure environment, surely these set of practices can lead to success in primary infrastructure or other markets where there is a higher willingness to pay.

For all these reasons, my conclusions can be extrapolated to a wider group of entrepreneurs interested in scalability in BOP communities.

### 4.1.1 Best Practices

The comprehensive study of THRIVE and SELCO yielded the following set of best practices for successful business operability as well as scalability in BOP markets:

- **Good Bookkeeping and Accounting**: Sound, basic business practices such as bookkeeping and accounting ensure the financial health of the company, including maintaining good supply chains, as well as ensuring transparency. This has proven to be particularly true of SELCO, which has been most sustainable in the long run. SELCO has all their operations and financial information well documented and available to anyone inside or outside the company. THRIVE, on the other hand, has been struggling with their financial sustainability, and it is almost impossible for someone to make it better without the availability of financial records. As they have been scaling up, so too have the errors that they have been making. But without access to the information, it is impossible to properly pinpoint and correct the problems. Moving forward THRIVE is working to rectify this situation.

- **Leadership—Clear Vision, Intense Dedication and Persistence**: It is not surprising that only a few models of successful scalability exist in BOP markets. Few entrepreneurs have the clarity of vision or the dedication and persistence to see that vision through. Operating in the complex world of BOP markets mandates that entrepreneurs have a thorough understanding of the challenges and obstacles, so that they are prepared to navigate them as they appear. Because so little research has been conducted and documented about the complexity of the BOP environment, entrepreneurs must commit long and difficult hours to the study of their customers and the market. Both Ranga and Harish epitomized this level of dedication, persistence and clear vision. They have never lost sight of their goals, no matter how challenging the environment has gotten. This persistence has paid tremendously in terms of the success they are now enjoying.

- **Education, and Well-Trained Human Resources**: Both Ranga and Harish are highly educated with advanced degrees, which has greatly helped them to analyze, search, interpret and absorb the information they have needed in order to succeed, as well as communicate and engage investors. While graduate degrees are hardly necessary, a good education gives you credibility among peers and the ability to leverage necessary resources and networks. It also mitigates an entrepreneur's risk of failure, in that he or she will always be able to fall back on their educations should their businesses fail to materialize. Further, entrepreneurs who are well-traveled and well-educated will have a better understanding of the cause and effect of globalization in their businesses.

  As a caveat, bottom-up entrepreneurs who are not well educated have just as much ability to succeed if they are aware of their own network and resource gaps. Incorporating the other business practices outlined here, and finding appropriately qualified mentors or other support mechanisms can sufficiently bridge these gaps for them.

  Entrepreneurs should also invest in skilled personnel, particularly for upper management positions as they provide the foundation for the organization. Harish insists that his investment in upper management has been vital for the successful and efficient operation of SELCO. Good management gives the organization structure, grounding and financial health. Other positions can be filled with local personnel who are trained as necessary. On the other hand, THRIVE's financial, operational and technical problems have surfaced because of their lack of skilled personnel. Upper management roles are primarily consolidated and taken on by Ranga. The rest of the staff consists of volunteers and highly motivated youth who may not be qualified to take on a responsibility of such magnitude.

- **Staying Focused**: Both THRIVE and SELCO spent the first several years focusing and perfecting a niche product, in a niche market. THRIVE focused on developing LED technologies catered to primarily tribal and remote rural communities in India (and abroad). SELCO has focused on selling PV-based SHS's to BOP communities in Karnataka. Both have also remained committed to their business philosophies, in that THRIVE has remained an NGO and SELCO a company. This level of focus has allowed them to develop and perfect a few good quality products, which are customized to the needs of their clients, and have been instrumental in gaining their clients' trust, which is extremely critical for business in BOP markets. Now that SELCO has their primary business model running sustainably, they are able to focus on scaling up their scope and expanding into other markets. For example, SELCO is now expanding into Gujarat and looking to include efficient cook-stoves and portable lighting systems.

- **Extensive Knowledge of Consumers**: Harish and Ranga understood early on that they had to customize their products and operations around the markets and consumer habits of the BOP. For example, their consumers have varying literacy levels; spending, earning and savings cycles; and needs for lighting. A rice farmer earns on a biannual cycle during his harvests, which is different from a flower picker who gets a daily wage. Consequently, Harish and Ranga have had to customize their products and services around their needs.

  An important aspect of customization requires the understanding of the difference between a *need* and a *want*. BOP consumers are more likely to invest in a product that incorporates their *needs* rather than their *wants*.

  Because of the lack of properly researched and documented information available, both Harish and Ranga have spent several years studying their consumers and gauging their needs. At the same time, there is no reason why any other entrepreneur should spend the same number of years getting this knowledge. If they are aware that they need to understand their customers better, they can collect this information from other successful or unsuccessful BOP entrepreneurs or other institutions who might have access to that information, thereby decreasing their time investment. For example, a BOP entrepreneur who wants to work in a community largely inhabited by rice farmers can get information about their specific needs by talking to the NGOs, successful businessmen in the market area or even the local farmers' unions.

- **Customized Technology:** THRIVE and SELCO have customized their products around BOP needs, making their products an extremely valuable investment for these communities. For example, THRIVE's lantern features roof-mounted lighting, a slanted roof for quick water drainage, the general shape and feel of a kerosene lantern, and a case built for rugged terrain. The lantern is further color-coded for easy operability and maintenance, as many consumers might be illiterate. Similarly, SELCO performs comprehensive needs assessments in order to customize SHS's for each of their consumers.

  Customized technology makes the product *valuable*—it is more likely to be used and be talked about in peer groups, which is necessary for growth in these markets. This is important considering that close 90% of sales happen through word-of-mouth referrals.

- **Customized Financing:** Because BOP consumers earn, spend, and save differently, have fewer assets, and consequently credit issues; BOP entrepreneurs must offer financing options that surround their clients' needs. This creates a win-win situation where clients can build up credit, support local financial institutions, as well as buy an entrepreneur's products. Both SELCO and THRIVE have found different ways to customize financing options. SELCO relies on local banks to create and support innovative flexible financing options; THRIVE uses grant subsidies to support capital costs and customizes operating cost payments using community recommendations.

Financing is essential for making a product *affordable*, particularly in the debate of product cost relative to BOP income. SELCO has proven that some of the poorest people will invest in a relatively expensive valuable commodity, if financing schemes are provided.

- **Customer Service**: Loyalty is critical to being successful in any market, particularly in BOP markets. Customer service is a huge part of creating value, improving usability and establishing loyalty. Once consumers know that a product is dependable and reliable, they are more likely to invest in it. In addition, BOP entrepreneurs often lack the literacy, knowledge or resources to fix technical impediments. Customer loyalty will develop if the company provides good strong customer service, gives them support where they need it most, and reinforces faith in the product and organization. Both SELCO and THRIVE have excellent, reliable customer service as a cornerstone of their models. SELCO has a 24-hour service guarantee, while THRIVE's technicians are easily accessible by foot to user communities.

- **Organic Growth**: BOP consumers rely heavily on word-of-mouth marketing. Therefore it is best to let growth happen organically. Creating a market through aggressive advertising could prove unnecessarily capital intensive for entrepreneurs who can use those resources elsewhere. Both SELCO and THRIVE spent their resources on developing human capital and bettering their operations and products, which generated value, loyalty, and caused enormous growth. These have already been described above.

- **Creating Win-Win Situations**: Both THRIVE and SELCO have focused on creating win-win situations. Examples of this include SELCO and THRIVE's customized technology and financing models which give the customers technology they want and help them build credit, while at the same time reinforcing customer loyalty.

- **Strong Local Presence**: Local presence is vitally important when establishing trust and working on low capital within a BOP community. They need to know that you are reliable, dependable and trustworthy, all issues that can be overcome by being locally present. Both THRIVE and SELCO rely heavily on local institutions to create this presence. They hire from within these communities, use local NGOs, financial institutions and networks to create a relationship with the community. In some sense, Wal-Mart has done the same thing in the United States. They also tend to hire low-income workers from within local communities, and their primary clientele are from that income bracket as well.

- **Separating the Social from the Financial Motives**: The bottom line for SELCO and THRIVE is to "stay in business." This means that all their final decisions must consider the financial health of their organizations. SELCO credits their continuing success to this exact practice, where their financial staff is not allowed in the field. THRIVE is still learning the value of separating the financial staff from the field staff. A consultant for the IFC, who monitors grassroots business initiatives like THRIVE and SELCO, agrees that this is often the biggest mistake that socially motivated entrepreneurs make. Because of limited resources, BOP entrepreneurs tend to consolidate professions within their organizations. For example at THRIVE, the Chief Executive Office (CEO), Chief Financial Offer (CFO) and Chief Technology Officer (CTO) positions are all consolidated and taken on by one person — Ranga. This position consolidation results in a series of problems including the inability to separate or prioritize decision-making. In the case of THRIVE, Ranga is often swayed by what he views in the field and his own moral imperatives to make decisions that can be financially detrimental to the organization. In addition, as discussed before, Ranga has primarily staffed THRIVE with high school educated youth who are highly motivated but ill-prepared to take on the duties of upper management. He has done this primarily for social reasons.

In the case of SELCO-India, Harish realized his own tendency to prioritize social upliftment over financial health and has taken steps to avoid a conflict of interest. Firstly, he has prioritized the overall financial health of the company by hiring extremely well-qualified personnel for his upper management. Secondly, he has separated himself and other unrelated staff from the financial nuances of the company. In addition, the financial staff have strict instructions to stay away from the field. At board meetings, SELCO-India's CFO has often been the only opposing viewpoint during a decision deliberation. But having that viewpoint and respecting it has kept SELCO-India sustainable. Essentially, by not separating the financial decisions from the social needs of the mission can compromise the financial health of BOP organizations, which are particularly susceptible to failure given their low profit margins and inability to mitigate financial losses. Finally, the people they most wanted to help are failed yet again.

### 4.1.2 Challenges of Scalability

While the best practices are critical to the success of any BOP entrepreneur, it is equally important to be aware and prepared for the challenges of operating in these markets. Related to the information presented in the previous section and on the discussion presented in greater detail in Chapter 3, the following set of challenges were deduced.

- **Staying Motivated**: The long hours, dedication, continuous challenges, and low income, particularly early on are extremely tedious and draining. Both Ranga and Harish had an average of three to four years when their work was particularly challenging and their organizations struggled to become realities. During this time, Ranga, Harish and their families sacrificed significant material, and financial wealth to keep their visions on track. While it paid off in the long run, it was exceedingly difficult during the time that it happened.

- **Raising Capital**: Because of the low return on investment, it is very hard to convince investors to foray into BOP ventures. Entrepreneurs should also be discerning of investors, as they have the potential to be very frustrating when "fatigue" sets in. Harish has already been burned by some of his investors, and Ranga is having to think through his financial sustainability as WB funding runs out. Both agree that clarity of vision and the ensuing implementation plan as well as honesty with investors and donors and a good track record can keep expectations real.

- **Gaining Trust, Building Networks**: Because BOP consumers rely so heavily on trust and BOP entrepreneurs are capital deficient, the entrepreneurs must rely heavily on developing strong social networks in the local communities. These can take long periods of time and can be very frustrating for entrepreneurs. For Ranga and Harish, their most valuable sources of institutional support and information have been NGOs. But it took them about 3-4 years to find the right NGOs, customers and financial institutions to get them started. Once established however, the process grew organically and became much easier.

- **Rapidly Evolving Technology**: This was particularly true of THRIVE who is dealing with the issues of a continuously evolving technology like LEDs. The positive side is that it makes the technology development very exciting. On the other hand, it is very resource intensive to stay abreast of the technology, and ensure stable and quality supply chains. THRIVE has had repeated quality control problems and the rapidly evolving technology means constantly updating their lantern, making it extremely capital intensive.

- **Globalization**: Both THRIVE and SELCO have truly global supply chains, and market fluctuations with regards to their products and related products such as kerosene have a significant impact on their consumers who are extremely price sensitive. For example, the increased demand for PVs in Germany has negatively affected the prices and specifications of PV panels in India. The resulting price increase is difficult for an illiterate farmer in remote India who has almost no disposable income and a limited understanding of globalization.

- **Human Resources**: Considering the lack of education, high illiteracy, differences in language, culture and castes in rural India, finding local skilled labor is extremely difficult. Local labor is essential for establishing local presence and trust. Both THRIVE and SELCO consistently find this to be extremely challenging. THRIVE, which operates in primarily indigenous communities that are remote has had difficulty staffing their operations with skilled personnel. However they have instituted excellent training programs to turn people in these communities into skilled technicians.

- **Lack of Infrastructure**: Good infrastructure (such roads, transportation, water and sanitation systems) is vital for developing reliable supply chains and distribution networks, without which good business is impossible. Both THRIVE and SELCO have and continue to battle against the extremely unreliable and poorly developed infrastructure in rural India. This is particularly true of THRIVE's clients who include primarily disenfranchised populations in extremely remote regions making supply chain management very difficult.

- **Intellectual Property**: Patents are often the only way to control ownership of technology; but they are also extremely expensive and time intensive. THRIVE has been most susceptible to intellectual property issues. LED technology is extremely R&D and consequently capital intensive because of the rapidly evolving nature of LEDs. Several copycats are stealing their hard earned technology, to sell or use elsewhere. This is costing them lots of money because it takes away their competition, as well as is destroying their reputation with clients because the quality of their copycat's products may be lacking. At the same time, Ranga is torn by his desire to see BOP communities with good access to some kind of lighting on a regular basis.

- **Investor and Donor Fatigue**: What is very challenging about BOP entrepreneurship is that investors and donors are hard to come by, and can be very easy to lose largely because of the risks involved and the low return on investment (ROI). BOP entrepreneurs are under tremendous pressure to produce results at often unreasonable rates because the investors and donors are not familiar with the complexities involved in working in BOP markets. Potential entrepreneurs and donors and investors foraying into BOP markets must consider the time and other challenges involved, as well ensure good communication to be open and honest about the realities of expectations. SELCO and THRIVE, both dedicated and successful organizations, took four to five years to show profits or growth.

## 4.2 Conclusions

While there are a common set of best practices and challenges, there is no "silver bullet" or single way to approach entrepreneurship in BOP markets. SELCO and THRIVE have clearly shown that alternative models can be used to solve the same problem. Entrepreneurs should use methodologies that they are most comfortable with and that line up best with their own ideologies. This allows them to focus on the details of operational or technological development, which needs their attention particularly when they first start.

SELCO and THRIVE have also proven beyond a doubt that socially motivated entrepreneurship is not only possible, but also lucrative and successful. Even the poorest people will invest in and use advanced technology, provided the technology is customized to their needs and institutional support such as financing and customer service, is provided to help them when they need it.

Overall, I believe that the success of scalability comes down to the "ripeness" or maturity of five broadly defined factors. Combined with the best practices listed above, I strongly believe organizations can successfully scale up their technologies in BOP markets in developing countries once they are "ripe" in all of the following fields:

1. **Human Factors**: This includes good organizational leadership, including a leader with focused, clear vision of a path for achieving growth, with tremendous perseverance and determination to see it through till the goal is reached. Human factors also include the incorporation of skilled, educated human resources personnel to provide the foundation for growth, and a good training program for new, unskilled labor to be incorporated into the organization as it scales up. In the end, good people with good leadership can steer an organization on the path of successful growth.

2. **Operations**: All operations should be standardized, structured and sustainable in their original market before scaleup begins. This includes organizational structure, and a sustainable value chain from product development through implementation. A raw, unplanned organization that scales up may achieve success in the short term, but will likely fail in the long run.

3. **Financing**: BOP consumers have significant income, asset, and credit limitations, yet their need for small-scale technologies, like lighting, is the greatest. Therefore, entrepreneurs should be willing to find innovative financing mechanisms to bridge these gaps. Above all, BOP consumers earn, spend and save differently. This variability and diversity requires that entrepreneurs develop flexible, customized financing around the needs of their clients, preferably incorporating local institutions such as local banks and microfinance groups.

4. **Technology**: The technology should be reliable, dependable and customized to the needs of the consumer. The level of demand for it from within the original market, which actually fuels organic growth, can gauge acceptance and user-friendliness of the product.

5. **Time**: There is an obvious learning curve involved here which spans over a period of about four to five years, to understand the BOP market trends and consumer habits, building supply chains, finding initial capital, building up institutional capacity, customizing technology and financing, and surpassing the multitude of challenges (listed earlier) that surround working in such a complex and challenging environment.

   The time span for the learning curve can be reduced by up to two years under certain circumstances, such as if there are fewer technological barriers, if the entrepreneur is already extremely familiar with BOP markets and consumers, or if they have a mentor or model to learn from. But in general, because of the diversity and variability of BOP markets, entrepreneurs should expect to spend at least a few years addressing the learning curve.

## 4.3 Recommendations for Future Work

In the future I believe developing an assessment tool incorporating these five criteria might help investors and social entrepreneurs know how ripe they are for scaling up.

Overall, I am deeply grateful for the experience of working and learning from some truly courageous entrepreneurs. I have seen the impact of what they have done for other people. It is truly inspiring. I sincerely hope that I can do half as much with my life as they have done with theirs. Thank you!

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| μg | Micrograms |
| AC | Alternating Current |
| APSEB | Andhra Pradesh State Electricity Board |
| AREED | African Rural Enterprise Energy Development |
| BPL | Below Poverty Line |
| BOP | Bottom of the Pyramid |
| cd | Candela |
| CFL | Compact Fluorescent Lamp |
| CIA | Central Intelligence Agency |
| CNY | Chinese Yen |
| $CO_2$ | Carbon Dioxide |
| DC | Direct Current |
| DM | Development Marketplace |
| EIA | Energy Information Administration |
| EU | European Union |
| fc | Footcandle |
| ft | Foot |
| FL | Fluorescent Lamp |
| GHG | Greenhouse Gas |
| HDI | Human Development Index |
| HH | Head of Household |
| HID | High Intensity Discharge (Lamp) |
| IEA | International Energy Agency |
| IFC | International Finance Corporation |
| IIT-Kh | Indian Institute of Technology at Kharaghpur |
| INR | Indian Rupee |
| kgoe | Kilograms of Oil Equivalent |
| kWh | Kilowatt-hour |
| LDC | Least Developed Country |
| LED | Light Emitting Diode |
| LFL | Linear Fluorescent Lamp |
| lm | Lumen |
| lmh | Lumen-hour |
| lx | Lux |
| LPG | Liquefied Petroleum Gas |
| LRC | Lighting Research Center |
| m | Meter |
| MDGs | Millennium Development Goals |
| MIT | Massachusetts Institute of Technology |
| MIT-Sloan | MIT Sloan School of Management |
| Mlmh | Megalumen-hour |
| MNC | Multinational Corporation |

| | |
|---|---|
| Mt | Megaton (one Megaton = $10^5$ Tons) |
| NGO | Nongovernmental Organization |
| nm | Nanometer |
| OECD | Organization for Economic Cooperation and Development |
| O&M | Operation and Maintenance |
| $PM_{10}$ | Particulate Matter measuring less than 10 microns |
| PV | Photovoltaic |
| R&D | Research and Development |
| RBO | Regional Business Office (part of SELCO-India) |
| ROI | Return on Investment |
| $S^3$IDF | Small Scale Sustainable Infrastructure Development Fund |
| SELCO | Solar Electric Light Company, Private Limited |
| SELF | Solar Electric Light Fund |
| SEWA | Self Empowerment Women's Association (registered NGO) |
| SHS | Solar Home System |
| SSC | Solar Service Center (part of SELCO-India) |
| ST | Scheduled Tribe, indigenous communities recognized by the Constitution of India |
| THRIVE | Volunteers for Rural Health and Information Technology (registered NGO) |
| UN | United Nations |
| UNDP | United Nations Development Program |
| UNDESA | United Nations Department of Economic and Social Affairs |
| UNEP | United Nations Environmental Program |
| USEPA | United Stated Environmental Protection Agency |
| UNICEF | United Nations Children's Fund |
| USAID | United States Association for International Development |
| US $ | United States Dollar |
| VC | Venture Capitalist |
| W | Watt |
| WB | World Bank |
| WEA | World Energy Association |
| WHO | World Health Organization |
| WLED | White Light Emitting Diode |
| WRI | World Resources Institute |

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# Appendix 1: HDI to Electricity Consumption Per Capita

## (Source: UNDP, 2006b)

| HDI rank | | Traditional fuel consumption (% of total energy requirements) | Electricity consumption per capita (kilowatt-hours) | | MDG GDP per unit of energy use (2000 PPP US$ per kg of oil equivalent) | | MDG Carbon dioxide emissions Per capita (metric tons) | | MDG Carbon dioxide emissions Share of world total[b] (%) | Ratification of environmental treaties[a] Cartagena Protocol on Biosafety | Framework Convention on Climate Change | Kyoto Protocol to the Framework Convention on Climate Change | Convention on Biological Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2003 | 1980 | 2003 | 1980 | 2003 | 1980 | 2003 | 2003 | | | | |
| 1 | Norway | 6.1[c,d] | 22,400[e] | 25,295[e] | 4.5 | 6.8 | 8.2[e] | 9.9[e] | 0.2[e] | ● | ● | ● | ● |
| 2 | Iceland | 0.0 | 13,838 | 29,412 | 3.1 | 2.5 | 8.2 | 7.6 | (.) | ○ | ● | ● | ● |
| 3 | Australia | 7.1 | 6,599 | 11,446 | 3.6 | 4.8 | 13.9 | 18.0 | 1.4 | | ● | ○ | ● |
| 4 | Ireland | 1.0 | 3,106 | 6,660 | 4.2 | 9.3 | 7.7 | 10.3 | 0.2 | ● | ● | ● | ● |
| 5 | Sweden | 20.4 | 11,700 | 16,603 | 3.7 | 4.6 | 8.6 | 5.9 | 0.2 | ● | ● | ● | ● |
| 6 | Canada | 4.3 | 14,243 | 18,329 | 2.5 | 3.4 | 17.2 | 17.9 | 2.3 | ○ | ● | ● | ● |
| 7 | Japan | 1.2 | 4,944 | 8,212 | 5.7 | 6.5 | 7.9 | 9.7 | 4.9 | ● | ● | ● | ● |
| 8 | United States | 3.1 | 10,336 | 14,057 | 2.8 | 4.5 | 20.1[f] | 19.8[f] | 23.0[f] | | ● | ○ | ○ |
| 9 | Switzerland | 5.8[g] | 5,878[g] | 8,701[g] | 7.8 | 8.1 | 6.5 | 5.6 | 0.2 | ● | ● | ● | ● |
| 10 | Netherlands | 1.4 | 4,560 | 7,026 | 4.2 | 5.8 | 10.9 | 8.7 | 0.8 | ● | ● | ● | ● |
| 11 | Finland | 22.0 | 8,372 | 17,111 | 3.2 | 3.7 | 11.9 | 13.0 | 0.3 | ● | ● | ● | ● |
| 12 | Luxembourg | 1.2 | 10,879 | 16,348 | 2.4 | 6.5 | 29.1 | 22.0 | (.) | ● | ● | ● | ● |
| 13 | Belgium | 1.5 | 5,177 | 8,791 | 4.0 | 4.9 | 13.3 | 8.3 | 0.3 | ● | ● | ● | ● |
| 14 | Austria | 13.2 | 4,988 | 8,527 | 6.1 | 7.2 | 6.9 | 8.6 | 0.3 | ● | ● | ● | ● |
| 15 | Denmark | 11.8 | 5,059 | 7,138 | 5.2 | 7.5 | 12.3 | 10.1 | 0.2 | ● | ● | ● | ● |
| 16 | France | 4.6[h] | 4,633[h] | 8,319[h] | 4.9 | 5.9 | 9.0[h] | 6.2[h] | 1.5[h] | ● | ● | ● | ● |
| 17 | Italy | 1.8[i] | 3,364[i] | 5,943[i] | 7.4 | 8.2 | 6.6[i] | 7.7[i] | 1.8[i] | ● | ● | ● | ● |
| 18 | United Kingdom | 0.6 | 5,022 | 6,755 | 4.8 | 7.1 | 10.5 | 9.4 | 2.2 | ● | ● | ● | ● |
| 19 | Spain | 3.7 | 2,906 | 6,325 | 7.4 | 7.0 | 5.3 | 7.3 | 1.2 | ● | ● | ● | ● |
| 20 | New Zealand | 4.5 | 7,270 | 10,453 | 5.0 | 4.8 | 5.6 | 8.8 | 0.1 | ● | ● | ● | ● |
| 21 | Germany | 2.7 | .. | 7,258 | 3.7 | 6.1 | .. | 9.8 | 3.2 | ● | ● | ● | ● |
| 22 | Hong Kong, China (SAR) | 0.4[d] | 2,449 | 6,103 | 11.1 | 10.9 | 3.3 | 5.5 | 0.2 | | | | |
| 23 | Israel | 0.0 | 3,187 | 6,843 | 7.0 | 7.1 | 5.6 | 10.6 | 0.3 | | ● | ● | ● |
| 24 | Greece | 3.9 | 2,413 | 5,497 | 8.7 | 7.3 | 5.4 | 8.7 | 0.4 | ● | ● | ● | ● |
| 25 | Singapore | 0.2 | 2,836 | 8,087 | 3.9 | 4.5 | 12.5 | 11.3 | 0.2 | | ● | ● | ● |
| 26 | Korea, Rep. of | 1.8[d] | 1,051 | 7,338 | 4.5 | 4.2 | 3.3 | 9.6 | 1.8 | ○ | ● | ● | ● |
| 27 | Slovenia | 7.5 | .. | 7,109 | .. | 5.2 | .. | 7.8 | 0.1 | ● | ● | ● | ● |
| 28 | Portugal | 12.8 | 1,750 | 4,770 | 10.1 | 7.2 | 2.8 | 5.6 | 0.2 | ● | ● | ● | ● |
| 29 | Cyprus | 1.1 | 1,692 | 5,656 | 5.7 | 6.3 | 5.2 | 8.9 | (.) | ● | ● | ● | ● |
| 30 | Czech Republic | 3.0 | .. | 6,567 | .. | 3.9 | .. | 11.4 | 0.5 | ● | ● | ● | ● |
| 31 | Barbados | 6.3 | 1,333 | 3,226 | .. | .. | 2.7 | 4.4 | (.) | ● | ● | ● | ● |
| 32 | Malta | 0.0 | 1,627 | 5,632 | 6.7 | 7.7 | 3.1 | 6.2 | (.) | | ● | ● | ● |
| 33 | Kuwait | 0.0[j] | 6,849 | 16,379 | 1.8 | 1.8 | 19.7[j] | 31.1[j] | 0.3[j] | | ● | ● | ● |
| 34 | Brunei Darussalam | 1.1 | 2,430 | 9,133 | .. | .. | 35.6 | 12.7 | (.) | | | | |
| 35 | Hungary | 5.0 | 2,920 | 4,051 | 3.7 | 5.6 | 7.7 | 5.7 | 0.2 | ● | ● | ● | ● |
| 36 | Argentina | 4.1 | 1,413 | 2,543 | 7.9 | 7.2 | 3.8 | 3.4 | 0.5 | ○ | ● | ● | ● |
| 37 | Poland | 5.7 | 3,419 | 3,702 | .. | 4.6 | 12.8 | 7.9 | 1.2 | ● | ● | ● | ● |
| 38 | Chile | 11.5 | 1,054 | 3,092 | 5.4 | 5.9 | 2.5 | 3.7 | 0.2 | ○ | ● | ● | ● |
| 39 | Bahrain | .. | 4,784 | 11,274 | 1.6 | 1.8 | 22.6 | 31.0 | 0.1 | | ● | ● | ● |
| 40 | Estonia | 17.1 | .. | 6,094 | .. | 3.4 | .. | 13.6 | 0.1 | ● | ● | ● | ● |
| 41 | Lithuania | 13.0 | .. | 3,453 | .. | 4.3 | .. | 3.7 | 0.1 | ● | ● | ● | ● |
| 42 | Slovakia | 2.2 | .. | 5,377 | .. | 3.7 | .. | 7.0 | 0.1 | ● | ● | ● | ● |
| 43 | Uruguay | 23.1 | 1,163 | 2,310 | 8.5 | 10.5 | 2.0 | 1.3 | (.) | ○ | ● | ● | ● |
| 44 | Croatia | 6.2 | .. | 3,733 | .. | 5.6 | .. | 5.3 | 0.1 | ● | ● | ○ | ● |
| 45 | Latvia | 46.5 | .. | 2,835 | .. | 5.3 | .. | 2.9 | (.) | ● | ● | ● | ● |
| 46 | Qatar | 0.0 | 10,616 | 19,374 | .. | .. | 57.2 | 63.1 | 0.2 | | ● | ● | ● |
| 47 | Seychelles | .. | 794 | 2,716[d] | .. | .. | 1.5 | 6.9 | (.) | ● | ● | ● | ● |
| 48 | Costa Rica | 29.6 | 964 | 1,764 | 10.2 | 9.9 | 1.1 | 1.5 | (.) | ○ | ● | ● | ● |
| 49 | United Arab Emirates | 0.0 | 6,204 | 15,878 | 6.5 | 2.2 | 36.4 | 33.6 | 0.5 | | ● | ● | ● |
| 50 | Cuba | 17.7 | 1,029 | 1,407 | .. | .. | 3.2 | 2.3 | 0.1 | ● | ● | ● | ● |
| 51 | Saint Kitts and Nevis | .. | .. | 3,256 | .. | .. | .. | 3.0 | (.) | ● | ● | | ● |
| 52 | Bahamas | .. | 4,062 | 6,700 | .. | .. | 38.1 | 6.0 | (.) | ● | ● | ● | ● |
| 53 | Mexico | 13.0 | 999 | 2,108 | 5.5 | 5.6 | 4.2 | 4.0 | 1.7 | ● | ● | ● | ● |

| HDI rank | | Traditional fuel consumption (% of total energy requirements) | Electricity consumption per capita (kilowatt-hours) | | MDG GDP per unit of energy use (2000 PPP US$ per kg of oil equivalent) | | MDG Carbon dioxide emissions Per capita (metric tons) | | Share of world total[b] (%) | Ratification of environmental treaties[a] Cartagena Protocol on Biosafety | Framework Convention on Climate Change | Kyoto Protocol to the Framework Convention on Climate Change | Convention on Biological Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2003 | 1980 | 2003 | 1980 | 2003 | 1980 | 2003 | 2003 | | | | |
| 54 | Bulgaria | 6.5 | 4,371 | 4,735 | 1.6 | 2.8 | 8.5 | 5.6 | 0.2 | ● | ● | ● | ● |
| 55 | Tonga | 0.0[d] | 109 | 356[d] | .. | .. | 0.4 | 1.1 | (.) | ● | ● | | ● |
| 56 | Oman | 0.0 | 847 | 3,817 | 8.5 | 2.8 | 5.0 | 12.9 | 0.1 | ● | ● | ● | ● |
| 57 | Trinidad and Tobago | 0.6 | 1,900 | 4,925 | 2.7 | 1.2 | 15.4 | 22.1 | 0.1 | ● | ● | ● | ● |
| 58 | Panama | 28.5 | 930 | 1,733 | 7.3 | 7.6 | 1.8 | 1.9 | (.) | ● | ● | ● | ● |
| 59 | Antigua and Barbuda | .. | 984 | 1,603[d] | .. | .. | 2.2 | 5.0 | (.) | ● | ● | ● | ● |
| 60 | Romania | 12.4 | 3,061 | 2,441 | .. | 4.0 | 8.7 | 4.2 | 0.4 | ● | ● | ● | ● |
| 61 | Malaysia | 6.5[d] | 740 | 3,196 | 4.5 | 3.9 | 2.0 | 6.4 | 0.6 | ● | ● | ● | ● |
| 62 | Bosnia and Herzegovina | 7.9 | .. | 2,636 | .. | 5.3 | .. | 4.9 | 0.1 | | ● | | ● |
| 63 | Mauritius | 25.5 | 482 | 1,683 | .. | .. | 0.6 | 2.6 | (.) | ● | ● | ● | ● |
| **MEDIUM HUMAN DEVELOPMENT** | | | | | | | | | | | | | |
| 64 | Libyan Arab Jamahiriya | 1.7 | 1,588 | 3,347 | .. | .. | 8.9 | 8.9 | 0.2 | ● | ● | | ● |
| 65 | Russian Federation | 2.7 | .. | 6,303 | .. | 1.9 | .. | 10.3 | 5.9 | | ● | ● | ● |
| 66 | Macedonia, TFYR | 9.7 | .. | 3,794 | .. | .. | .. | 5.2 | (.) | ● | ● | ● | ● |
| 67 | Belarus | 5.5 | .. | 3,388 | .. | 2.2 | .. | 6.4 | 0.2 | ● | ● | ● | ● |
| 68 | Dominica | .. | 149 | 1,243[d] | .. | .. | 0.5 | 1.8 | (.) | ● | ● | ● | ● |
| 69 | Brazil | 29.1 | 1,145 | 2,246 | 7.5 | 6.9 | 1.5 | 1.6 | 1.2 | ● | ● | ● | ● |
| 70 | Colombia | 15.8 | 726 | 1,045 | 7.4 | 10.1 | 1.4 | 1.3 | 0.2 | ● | ● | ● | ● |
| 71 | Saint Lucia | .. | 504 | 1,851[d] | .. | .. | 0.9 | 2.1 | (.) | ● | ● | ● | ● |
| 72 | Venezuela, RB | 2.5 | 2,379 | 3,510 | 2.9 | 2.3 | 5.8 | 5.6 | 0.6 | ● | ● | ● | ● |
| 73 | Albania | 6.3 | 1,204 | 1,743 | .. | 6.4 | 1.8 | 1.0 | (.) | ● | ● | ● | ● |
| 74 | Thailand | 17.7 | 340 | 1,896[d] | 5.1 | 5.0 | 0.9 | 3.9 | 1.0 | ● | ● | ● | ● |
| 75 | Samoa (Western) | .. | 252 | 613[d] | .. | .. | 0.6 | 0.8 | (.) | ● | ● | ● | ● |
| 76 | Saudi Arabia | (.)[j] | 1,969 | 6,749 | 6.6 | 2.2 | 17.3[j] | 13.0[j] | 1.2[j] | | ● | ● | ● |
| 77 | Ukraine | 1.6 | .. | 3,683 | .. | 1.9 | .. | 6.6 | 1.3 | ● | ● | ● | ● |
| 78 | Lebanon | 0.4 | 1,056 | 2,829 | .. | 3.0 | 2.3 | 5.4 | 0.1 | | ● | | ● |
| 79 | Kazakhstan | 0.2 | .. | 4,114 | .. | 1.9 | .. | 10.7 | 0.6 | | ● | ○ | ● |
| 80 | Armenia | 1.1 | .. | 1,375 | .. | 5.2 | .. | 1.1 | (.) | ● | ● | ● | ● |
| 81 | China | 4.6 | 307 | 1,440 | 1.3 | 4.5 | 1.5 | 3.2 | 16.5 | ● | ● | ● | ● |
| 82 | Peru | 24.7 | 579 | 868 | 7.9 | 11.3 | 1.4 | 1.0 | 0.1 | ● | ● | ● | ● |
| 83 | Ecuador | 18.7 | 423 | 950 | 5.2 | 4.9 | 1.7 | 1.8 | 0.1 | ● | ● | ● | ● |
| 84 | Philippines | 33.2 | 373 | 655 | 9.8 | 7.8 | 0.8 | 1.0 | 0.3 | ○ | ● | ● | ● |
| 85 | Grenada | 0.0 | 281 | 1,628 | .. | .. | 0.5 | 2.2 | (.) | ● | ● | ● | ● |
| 86 | Jordan | 1.3 | 366 | 1,524 | 5.5 | 4.0 | 2.1 | 3.2 | 0.1 | ● | ● | ● | ● |
| 87 | Tunisia | 8.6 | 434 | 1,200 | 6.9 | 8.1 | 1.5 | 2.1 | 0.1 | ● | ● | ● | ● |
| 88 | Saint Vincent and the Grenadines | .. | 276 | 940[d] | .. | .. | 0.4 | 1.6 | (.) | ● | ● | ● | ● |
| 89 | Suriname | 3.3 | 4,442 | 3,537 | .. | .. | 6.7 | 5.1 | (.) | | ● | | ● |
| 90 | Fiji | 36.0[d] | 489 | 627[d] | .. | .. | 1.2 | 1.3 | (.) | ● | ● | ● | ● |
| 91 | Paraguay | 55.0 | 233 | 1,113 | 7.3 | 6.4 | 0.5 | 0.7 | (.) | ● | ● | ● | ● |
| 92 | Turkey | 9.1 | 554 | 1,979 | 5.9 | 6.0 | 1.7 | 3.1 | 0.9 | ● | ● | | ● |
| 93 | Sri Lanka | 60.4 | 113 | 407 | 5.8 | 8.8 | 0.2 | 0.5 | (.) | ● | ● | ● | ● |
| 94 | Dominican Republic | 26.9 | 582 | 1,532 | 6.5 | 7.4 | 1.1 | 2.5 | 0.1 | ● | ● | ● | ● |
| 95 | Belize | 25.0[d] | 370 | 708[d] | .. | .. | 1.3 | 3.0 | (.) | ● | ● | ● | ● |
| 96 | Iran, Islamic Rep. of | 0.7 | 570 | 2,304 | 4.9 | 3.2 | 3.0 | 5.6 | 1.5 | ● | ● | ● | ● |
| 97 | Georgia | 23.9 | .. | 1,566 | .. | 4.1 | .. | 0.8 | (.) | | ● | ● | ● |
| 98 | Maldives | 0.0 | 25 | 490 | .. | .. | 0.3 | 1.4 | (.) | ● | ● | ● | ● |
| 99 | Azerbaijan | 0.0 | .. | 2,815 | .. | 2.3 | .. | 3.5 | 0.1 | ● | ● | ● | ● |
| 100 | Occupied Palestinian Territories | .. | .. | .. | .. | .. | .. | .. | .. | | | | |
| 101 | El Salvador | 46.3 | 336 | 663 | 7.6 | 6.9 | 0.5 | 1.0 | (.) | ● | ● | ● | ● |
| 102 | Algeria | 6.4 | 381 | 929 | 8.5 | 5.6 | 3.5 | 5.1 | 0.7 | ● | ● | ● | ● |
| 103 | Guyana | 43.6 | 545 | 1,172[d] | .. | .. | 2.3 | 2.2 | (.) | | ● | ● | ● |
| 104 | Jamaica | 17.0 | 834 | 2,696 | 2.9 | 2.5 | 4.0 | 4.1 | (.) | ○ | ● | ● | ● |
| 105 | Turkmenistan | 0.0 | .. | 1,999 | .. | .. | .. | 9.2 | 0.2 | | ● | ● | ● |
| 106 | Cape Verde | 0.0[d] | 55 | 100[d] | .. | .. | 0.4 | 0.3 | (.) | ● | ● | ● | ● |

| HDI rank | Traditional fuel consumption (% of total energy requirements) | Electricity consumption per capita (kilowatt-hours) | | MDG GDP per unit of energy use (2000 PPP US$ per kg of oil equivalent) | | MDG Carbon dioxide emissions: Per capita (metric tons) | | MDG Carbon dioxide emissions: Share of world total[b] (%) | Ratification of environmental treaties[a]: Cartagena Protocol on Biosafety | Framework Convention on Climate Change | Kyoto Protocol to the Framework Convention on Climate Change | Convention on Biological Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2003 | 1980 | 2003 | 1980 | 2003 | 1980 | 2003 | 2003 | | | | |
| 107 Syrian Arab Republic | 0.0 | 433 | 1,683 | 4.7 | 3.4 | 2.2 | 2.7 | 0.2 | ● | ● | ● | ● |
| 108 Indonesia | 15.9 | 94 | 498 | 3.9 | 4.3 | 0.6 | 1.4 | 1.2 | ● | ● | ● | ● |
| 109 Viet Nam | 23.3 | 78 | 503[d] | .. | 4.4 | 0.3 | 0.9 | 0.3 | ● | ● | ● | ● |
| 110 Kyrgyzstan | 0.0 | .. | 2,417 | .. | 3.2 | .. | 1.0 | (.) | ● | ● | ● | ● |
| 111 Egypt | 9.4[d] | 433 | 1,340[d] | 6.4 | 5.1 | 1.0 | 2.0 | 0.6 | ● | ● | ● | ● |
| 112 Nicaragua | 69.3 | 363 | 492 | 8.7 | 5.5 | 0.7 | 0.7 | (.) | ● | ● | ● | ● |
| 113 Uzbekistan | 0.0 | .. | 1,890 | .. | 0.8 | .. | 4.8 | 0.5 | ● | ● | ● | ● |
| 114 Moldova, Rep. of | 2.1 | .. | 1,900 | .. | 1.9 | .. | 1.7 | (.) | ● | ● | ● | ● |
| 115 Bolivia | 18.8 | 292 | 461 | 5.4 | 4.9 | 0.8 | 0.9 | (.) | ● | ● | ● | ● |
| 116 Mongolia | 2.2 | 1,119 | 1,273 | .. | .. | 4.1 | 3.1 | (.) | ● | ● | ● | ● |
| 117 Honduras | 63.6 | 259 | 694 | 5.0 | 4.9 | 0.6 | 0.9 | (.) | ○ | ● | ● | ● |
| 118 Guatemala | 72.1 | 245 | 501 | 7.0 | 6.5 | 0.6 | 0.9 | (.) | ● | ● | ● | ● |
| 119 Vanuatu | 50.0[d] | 171 | 208[d] | .. | .. | 0.5 | 0.4 | (.) | | ● | ● | ● |
| 120 Equatorial Guinea | 57.1 | 83 | 51[d] | .. | .. | 0.3 | 0.3 | (.) | | ● | ● | ● |
| 121 South Africa | 11.6[k] | 3,181[k] | 4,595[k] | 4.5 | 3.9 | 7.2 | 7.8 | 1.4 | ● | ● | ● | ● |
| 122 Tajikistan | .. | .. | 2,645 | .. | 2.1 | .. | 0.7 | (.) | ● | ● | | ● |
| 123 Morocco | 6.1 | 254 | 649 | 11.3 | 10.2 | 0.8 | 1.2 | 0.2 | ○ | ● | ● | ● |
| 124 Gabon | 65.8 | 766 | 1,229 | 3.5 | 4.9 | 8.9 | 0.9 | (.) | | ● | | ● |
| 125 Namibia | ..[l] | ..[l] | ..[l] | .. | 9.9 | .. | 1.2 | (.) | ● | ● | ● | ● |
| 126 India | 19.8 | 173 | 594 | 3.3 | 5.3 | 0.5 | 1.2 | 5.1 | ● | ● | ● | ● |
| 127 São Tomé and Principe | .. | 96 | 102[d] | .. | .. | 0.4 | 0.6 | (.) | | ● | | ● |
| 128 Solomon Islands | 50.0[d] | 93 | 69[d] | .. | .. | 0.4 | 0.4 | (.) | ● | ● | ● | ● |
| 129 Cambodia | 92.2 | 15 | 9[d] | .. | .. | (.) | (.) | (.) | ● | ● | ● | ● |
| 130 Myanmar | 83.9 | 44 | 126 | .. | .. | 0.1 | 0.2 | (.) | ○ | ● | ● | ● |
| 131 Botswana | ..[l] | ..[l] | ..[l] | .. | .. | 0.9 | 2.3 | (.) | ● | ● | ● | ● |
| 132 Comoros | .. | 26 | 32[d] | .. | .. | 0.1 | 0.1 | (.) | | ● | | ● |
| 133 Lao People's Dem. Rep. | 78.4 | 68 | 135[d] | .. | .. | 0.1 | 0.2 | (.) | ● | ● | ● | ● |
| 134 Pakistan | 23.5 | 176 | 493 | 3.5 | 4.2 | 0.4 | 0.8 | 0.5 | ○ | ● | ● | ● |
| 135 Bhutan | 87.8 | 17 | 218[d] | .. | .. | (.) | 0.2 | (.) | ● | ● | ● | ● |
| 136 Ghana | 84.7 | 450 | 285 | 4.8 | 5.0 | 0.2 | 0.4 | (.) | ● | ● | ● | ● |
| 137 Bangladesh | 51.5 | 30 | 145 | 10.8 | 10.4 | 0.1 | 0.3 | 0.1 | ● | ● | ● | ● |
| 138 Nepal | 93.2 | 17 | 91 | 2.7 | 4.0 | (.) | 0.1 | (.) | ○ | ● | ● | ● |
| 139 Papua New Guinea | 62.2 | 406 | 251[d] | .. | .. | 0.6 | 0.4 | (.) | ● | ● | ● | ● |
| 140 Congo | 69.0 | 98 | 206 | 1.6 | 3.3 | 0.2 | 0.4 | (.) | ● | ● | | ● |
| 141 Sudan | 86.5 | 47 | 101 | 2.5 | 3.7 | 0.2 | 0.3 | (.) | ● | ● | ● | ● |
| 142 Timor-Leste | .. | .. | 301[d] | .. | .. | .. | 0.2 | (.) | | | | |
| 143 Madagascar | 81.9 | 49 | 50[d] | .. | .. | 0.2 | 0.1 | (.) | ● | ● | ● | ● |
| 144 Cameroon | 86.3 | 168 | 226 | 5.3 | 4.6 | 0.4 | 0.2 | (.) | ● | ● | ● | ● |
| 145 Uganda | 93.5 | 28 | 59[d] | .. | .. | 0.1 | 0.1 | (.) | ● | ● | ● | ● |
| 146 Swaziland | ..[l] | ..[l] | ..[l] | .. | .. | 0.8 | 0.9 | (.) | ● | ● | ● | ● |
| [illegible] | | | | | | | | | | | | |
| 147 Togo | 84.4 | 74 | 91 | 6.4 | 3.2 | 0.2 | 0.4 | (.) | ● | ● | ● | ● |
| 148 Djibouti | .. | 416 | 455[d] | .. | .. | 0.9 | 0.5 | (.) | ● | ● | ● | ● |
| 149 Lesotho | ..[l] | ..[l] | ..[l] | .. | .. | .. | .. | .. | ● | ● | ● | ● |
| 150 Yemen | 4.0 | .. | 212 | .. | 2.8 | .. | 0.9 | 0.1 | ● | ● | ● | ● |
| 151 Zimbabwe | 67.2 | 1,020 | 998 | 2.8 | 2.6 | 1.3 | 0.9 | (.) | ● | ● | | ● |
| 152 Kenya | 83.1 | 109 | 154 | 1.8 | 2.1 | 0.4 | 0.3 | (.) | ● | ● | ● | ● |
| 153 Mauritania | 35.8[d] | 60 | 60[d] | .. | .. | 0.4 | 0.9 | (.) | ● | ● | ● | ● |
| 154 Haiti | 79.5 | 58 | 61 | 8.2 | 6.4 | 0.1 | 0.2 | (.) | ○ | ● | ● | ● |
| 155 Gambia | 66.7 | 70 | 101[d] | .. | .. | 0.2 | 0.2 | (.) | ● | ● | ● | ● |
| 156 Senegal | 70.9 | 115 | 192[d] | 4.3 | 5.2 | 0.6 | 0.4 | (.) | ● | ● | ● | ● |
| 157 Eritrea | 85.2 | .. | 62 | .. | .. | .. | 0.2 | (.) | ● | ● | ● | ● |
| 158 Rwanda | 84.7 | 32 | 39[d] | .. | .. | 0.1 | 0.1 | (.) | ● | ● | ● | ● |
| 159 Nigeria | 82.9 | 108 | 162 | 1.3 | 1.3 | 1.0 | 0.4 | 0.2 | ● | ● | ● | ● |

| HDI rank | Traditional fuel consumption (% of total energy requirements) | Electricity consumption per capita (kilowatt-hours) | | MDG GDP per unit of energy use (2000 PPP US$ per kg of oil equivalent) | | MDG Carbon dioxide emissions: Per capita (metric tons) | | MDG Carbon dioxide emissions: Share of world total[b] (%) | Ratification of environmental treaties[a]: Cartagena Protocol on Biosafety | Framework Convention on Climate Change | Kyoto Protocol to the Framework Convention on Climate Change | Convention on Biological Diversity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2003 | 1980 | 2003 | 1980 | 2003 | 1980 | 2003 | 2003 | | | | |
| 160 Guinea | 87.1 | 85 | 89[e] | .. | .. | 0.2 | 0.1 | (.) | ○ | ● | ● | ● |
| 161 Angola | 74.4 | 214 | 178 | .. | 3.1 | 0.7 | 0.6 | (.) | | ● | | ● |
| 162 Tanzania, U. Rep. of | 94.4 | 41 | 78 | .. | 1.3 | 0.1 | 0.1 | (.) | ● | ● | ● | ● |
| 163 Benin | 81.3 | 37 | 82 | 2.4 | 3.5 | 0.1 | 0.3 | (.) | ● | ● | ● | ● |
| 164 Côte d'Ivoire | 75.5 | 220 | 209 | 5.2 | 3.8 | 0.7 | 0.3 | (.) | | ● | | ● |
| 165 Zambia | 87.2 | 1,125 | 631 | 1.5 | 1.4 | 0.6 | 0.2 | (.) | ● | ● | ● | ● |
| 166 Malawi | 82.9 | 66 | 77[d] | .. | .. | 0.1 | 0.1 | (.) | ○ | ● | ● | ● |
| 167 *Congo, Dem. Rep. of the* | 97.2 | 161 | 86 | 6.0 | 2.1 | 0.1 | (.) | (.) | ● | ● | ● | ● |
| 168 Mozambique | 90.9 | 364 | 399 | 1.0 | 2.5 | 0.3 | 0.1 | (.) | ● | ● | ● | ● |
| 169 Burundi | 95.7 | 12 | 23[d] | .. | .. | (.) | (.) | (.) | | ● | ● | ● |
| 170 Ethiopia | 96.5 | .. | 33 | .. | 2.1 | (.) | 0.1 | (.) | ● | ● | ● | ● |
| 171 Chad | 98.6 | 10 | 11[d] | .. | .. | (.) | (.) | (.) | ○ | ● | | ● |
| 172 Central African Republic | 93.3 | 29 | 35[d] | .. | .. | (.) | 0.1 | (.) | ○ | ● | | ● |
| 173 Guinea-Bissau | 50.0 | 18 | 45[d] | .. | .. | 0.2 | 0.2 | (.) | | ● | ● | ● |
| 174 Burkina Faso | 93.3 | 16 | 32[d] | .. | .. | 0.1 | 0.1 | (.) | ● | ● | ● | ● |
| 175 Mali | 86.7 | 15 | 38[d] | .. | .. | 0.1 | (.) | (.) | ● | ● | ● | ● |
| 176 Sierra Leone | 91.2 | 62 | 49[d] | .. | .. | 0.2 | 0.1 | (.) | | ● | | ● |
| 177 Niger | 85.6 | .. | 40[d] | .. | .. | 0.1 | 0.1 | (.) | ● | ● | ● | ● |
| Developing countries | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Least developed countries | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Arab States | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| South Asia | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Sub-Saharan Africa | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Central and Eastern Europe and the CIS | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| OECD | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| High-income OECD | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| High human development | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Medium human development | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Low human development | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| High income | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Middle income | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| Low income | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |
| World | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | | |

● Ratification, acceptance, approval, accession or succession.
○ Signature.

**NOTES**

a Information is as of 28 August 2006. The Cartagena Protocol on Biosafety was signed in Cartagena in 2000, the United Nations Framework Convention on Climate Change in New York in 1992, the Kyoto Protocol to the United Nations Framework Convention on Climate Change in Kyoto in 1997 and the Convention on Biological Diversity in Rio de Janeiro in 1992.

b The world total includes carbon dioxide emissions not included in national totals, such as those from bunker fuels and oxidation of nonfuel hydrocarbon products, and emissions by countries not shown in the main indicator tables. These emissions amount to approximately 0.2% of the world total. Thus the shares listed for individual countries in this table do not sum to 100%.

c Includes Svalbard and Jan Mayen Islands.

d Data are estimates produced by the United Nations, Department of Economic and Social Affairs, Statistics Division.

e Preliminary data.

f Based on natural gas data.

g Includes Liechtenstein.

h Includes Monaco.

i Includes San Marino.

j Includes part of the Neutral Zone.

k Data refer to the South African Customs Union, which includes Botswana, Lesotho, Namibia and Swaziland.

l Included in data for South Africa.

m Figure is the aggregate from UN 2006a.

**SOURCES**

**Column 1:** calculated on the basis of data on traditional fuel consumption and total energy requirements from UN 2006a.
**Columns 2 and 3:** UN 2006f.
**Columns 4 and 5:** World Bank 2006, based on data from the International Energy Agency.
**Columns 6–8:** UN 2006c, based on data from the Carbon Dioxide Information Analysis Center.
**Columns 9–12:** UN 2006d.

# Appendix 2: SELCO-India Product Specifications

The following products are offered by SELCO-India as of March 2007:

**Solar Lighting Systems – Product Specifications**

| Model | Load Details | Module | Battery | Controller | L5/7 W-DC | L7 W-DC | L11W-DC | F15 W-DC | MMS | LMS | System Price | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Wp | Ah | Amps | Nos | Nos | Nos | Nos | Set | Nos | INR | US $ |
| SHLS1 | 1 Light | 10 | 15 | 5 | 1 | | | | 1 | 1 | 8100 | 199.26 |
| SHLS2 | 2-Light | 20 | 30 | 5 | | 2 | | | 1 | 2 | 12,600 | 309.96 |
| SHLS3 | 2- Light + 1 Fan | 40 | 60 | 10 | | 2 | | 1 | 1 | 2 | 21,600 | 531.36 |
| SHLS4 | 4-Light | 40 | 60 | 10 | | 3 | 1 | | 1 | 4 | 21,700 | 533.82 |
| SHLS5 | 3 Lights + 1 Fan | 50 | 80 | 10 | | 2 | 1 | 1 | 1 | 3 | 26,400 | 649.44 |
| SHLS6 | 6-Light | 60 | 80 | 10 | 2 | 2 | 2 | | 1 | 4 | 30,150 | 741.69 |
| SHLS7 | 4- Light + 1 Fan | 60 | 80 | 10 | | 3 | 1 | 1 | 1 | 4 | 30,150 | 741.69 |
| SHLS8 | 8-Light | 75 | 110 | 10 | 2 | 4 | 2 | | 1 | 6 | 39,200 | 964.32 |
| SHLS9 | 4- Light + 2 Fan | 75 | 110 | 10 | | 3 | 1 | 2 | 1 | 4 | 39,600 | 974.16 |
| SHLS10 | 10-Light | 100 | 150 | 10 | 2 | 4 | 4 | | 1 | 8 | 51,700 | 1271.8 |
| SHLS11 | 8- Light + 1 Fan | 100 | 150 | 10 | 2 | 4 | 2 | 1 | 1 | 6 | 51,700 | 1271.8 |
| SHLS12 | 10- Light + 2 Fan | 120 | 240 | 10 | 2 | 4 | 4 | 2 | 1 | 8 | 66,200 | 1628.5 |
| SSTL 2 | St Light | 60 | 80 | 10 | | | 1 | | 1 | | 29,000 | 713.40 |

Acronyms:

SHLS: Solar Home Lighting System
SSTL: Solar Street Light
Module (Wp) – Solar Panel Wattage (peak Wattage)
Battery (Ah) – Battery Capacity (Ampere-hour)
Controller (Amps)– Also called Charge Regulator (Amperes)
L5/7w – read as Luminaire 5 watts/7 watts
F15W-DC – read as 15 watts DC fan
MMS – Module Mounting Structure
LMS – Luminaire Mounting Structure

# Appendix 3: THRIVE Lighting Manual

**(Source: THRIVE, 2007)**

**This manual was prepared by Dr Ranganayakulu Bodavala in 2003. It has been reproduced in full with the expressed consent of the author. No edits have been made.**

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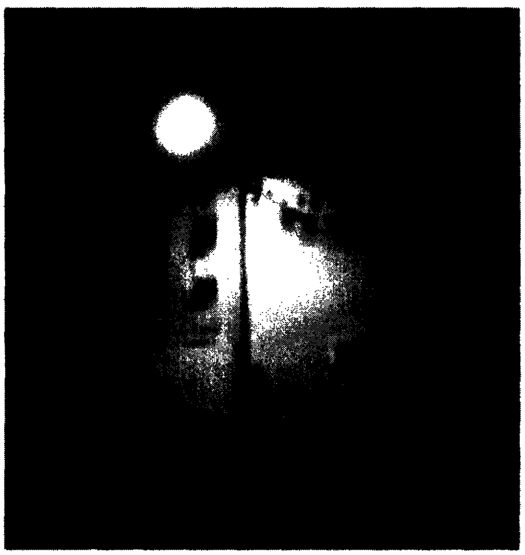
## LED LIGHTING INSTALLATION MANUAL AND FRAMEWORK



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Fax: 91 9849107886
Email: ranga@thethrive.org

## LED LIGHTING INSTALLATION MANUAL AND FRAMEWORK

### Main components of the LED LIGHTINGS SYSTEM

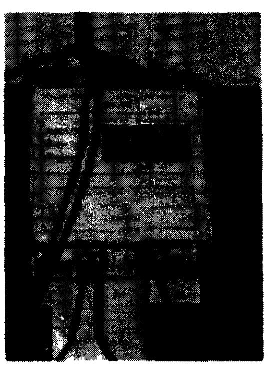
1. LED light units (available in 12/15/24/36 clusters) LED lighting features and properties and photos are available in Annex I.

2. 12 volts DC battery of different amperes based on the requirement 7/9/20/40. The battery is sealed and maintenance free. In case the village is quite aware with the maintenance issue, tubular long life battery can be used. Tubular battery needs distill water taping once in 6 months.

3. Solar panel: Solar panel converts the solar radiation into DC voltage. Usually 12 volts panels are used. Different sizes of panels based on the requirement can be used. They vary from 10 watt to 70-watt power output.

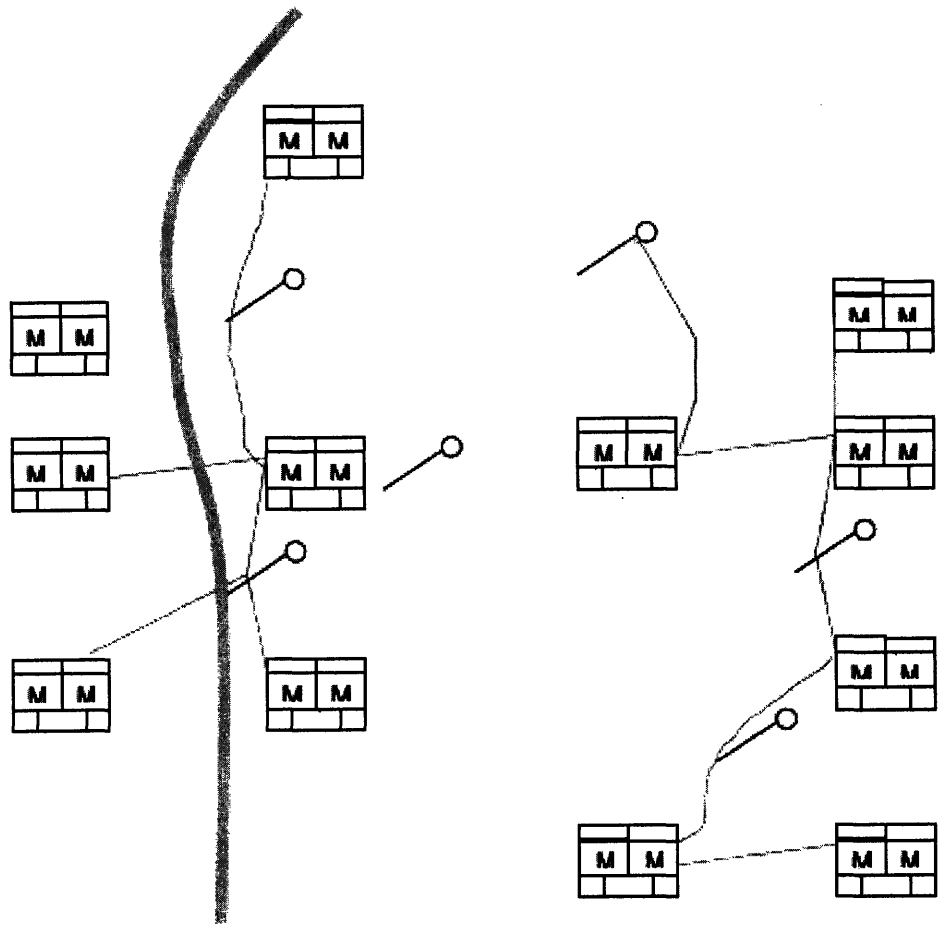
4. Charge control units: this unit stays between the solar panel and the battery. It regulates the charging to the battery and cuts of the charge once the battery is fully charged. Different types of CCUs are available in the market. The main supply to the lighting is provided through sockets from the CCU. Up to 4 sockets are available and each can be connected to one house. The CCU has a built in fuse to protect over voltage or accidental short circuit. Some of them have built in mechanism to switch of the power load once the battery reaches 20% of the power storage. This is to help the battery not to get fully discharged. Some of the CCUs have a built in day and night switch which works automatically.

5. Wires, switches, fuse boxes



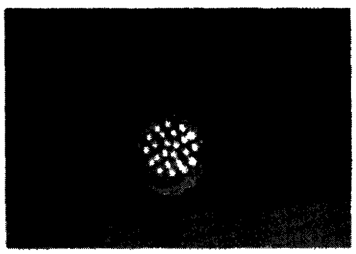
**Size of the village**

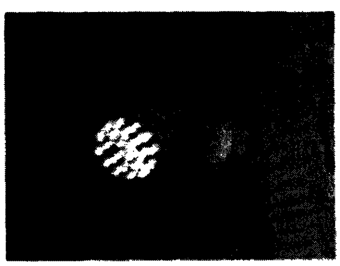
Technically LED lighting can be installed in any size of the village. But an interior village that has no other source of power and where it is difficult to supply the grid power is preferred. Tribal hamlets located in deep forests are the first choice. The hamlets can be any size from 5 units of house to 100 or more. Before commencing the installation proper village social map can be prepared and the lighting clusters can be planned.



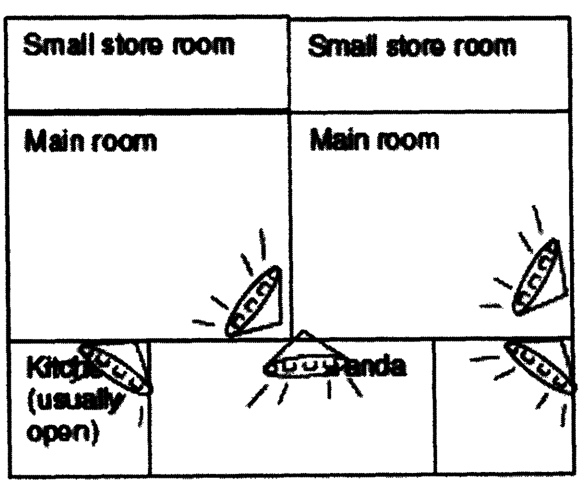
**Lighting:**

Usually the tribal houses are small and generally consist of one big room and one verandah in some cases one anteroom also. 2 to 3 lights are sufficient for each house. 24 LEDs are used in the main room and 15 LEDs are used in the small rooms and in the veranda. A proper house may be made so that wiring plan becomes easy and wire runs for lesser length thus protecting the proper voltage.
24 LED units consume 2 watts of power, 15 LED units consumes 1.3 watts of power. Theoretically 40-amp battery has around 480 watts of storage power. It can supply power to 20 numbers of 24 LEDs for nearly 24 hrs. But generally at least one-day back power has to be built in to the system so that the lighting goes unaffected in the cloudy day.





**Sample House Plan:**



**Batteries:**

Different types of battery systems both branded and unbranded are available in the market. It is preferred to use the batteries from the main suppliers like EXIDE, SF, Panasonic and others.

Lead acid low maintenance battery (LALM) is one of the options. In the LALM again tubular battery is the most preferred option. This battery needs taping once in 4/6 months. It is said that Maintenance free battery is the best option.

**Wiring:**

Wiring is done inside the house as well as outside. Inside wiring can be regular two core 1/2 mm. Outside wiring has to be 2 core 1 mm is used. Distance from the CCU to the houses is the main factor that affects the luminosity. DC voltage generally drops over distances; there can be one-volt drop for every 10 meter. If the voltage drops more than 2 volts, the lighting is affected. THRIVE is making efforts now to make lights that can be boost up the voltage by 2 volts.

Care has to be taken to put the wiring very neatly and at a height (over 10 feet) so that it cannot be accidentally cut or tampered. When pulling the wire for more than 7 meters it is better to use some pole support (strong bamboo or locally available pole post) in case the wire is cut it is better to replace the entire length than attaching/jointing the wires in the open. Any joints have to be inside the housing/casing. DC voltage gets affected by rain and other weather factors.

**Switches:**

Main switch is provided in the CCU. Again DC switches with built in fuses are used in each house. At present one switch is provided to each use. THRIVE is now developing a dimmer so that in the night instead of the whole 24 LEDs lighting 4 or 6 can be used for dimming (a kind of night bulb).

**Fuses:**

Usage of fuses increases the safety of the system prevents the damages from any short circuit. Main fuse is provided in the CCU and every house is provided with one more fuse.

**Installation notes:**

Based on the type of the houses and distances from each other, total load has to be calculated. Generally 40-amp battery can provide lighting for 20 light units or 10 houses. But if the houses are apart, 15 or less light units can be used. It is preferred to put the solar panel on top of any concrete roof. Proper care has to be taken to remove any debris, dry grass or any flammable material from that roof. If mounted on a wooden post, the post has to be erected very strong.

Termites may work on the wooden post and GE pipe can be used to mount the panel. The clams and others have to be heavy gauge. The wiring has to be supported by bamboo posts and should not be hanging low. At least they have to be over 10 feet height.

CCU has to be properly protected from weather factors. It has to be mounted inside in one of the beneficiary house. CCU, main fuses and wiring may be put in one big wall mounted base and one lock be employed for further safety.

Light units have to be properly fixed to the wall using the right type of screw/nail. Pegs have to be used in case of cement construction wall. It has to be seen that there are no water leakages from the roof or on the wall directly falling on the light unit.

## Other services

### Television and Tape recorder

It is possible to connect Television and regular Tape recorders to the DC power line. Many of the black and white televisions have 12 volts DC inlet provided. Color TVs work at a different voltage and THRIVE is now making an adaptor (power booster) to supply power to a color television. Many tape recorders that run in the automobiles use 12 volts DC. Regular amplifiers and mike systems also use 12 volts DC and it is safe and easy to power them from the CCU load. As a thumb rule a 40 AMP battery can power a television for nearly 25 hrs and an amplifier for 20 hrs. The lighting load on that particular battery has to be utilized keeping this point in view. If the village is big a separate battery and panel can be used for this purpose.

### Computer

THRIVE has made a power booster/adaptor to supply power to a laptop computer. Usually a laptop works at 14/16/19 dc volts. There is a need for a power booster from the 12 volts of the battery. A general laptop consumes 10 to 15 watts of power. This way the laptop can work nearly 40 hrs on a 12-volt 40-amp battery (the battery that is used in the small cars). If the laptop is used on the DC power, there is no need for having the laptop built in battery and charging it.

### Cell phone charging

Usually mobiles get charged at 6 volts DC. Simple adaptors are available that can charge any mobile phones from the 12 volts battery. A socket can be provided in one of the battery for charging the mobile.

## ANNEX I

## TECHNICAL FEATURES OF LEDs

White LEDs are 'Light Emitting Diodes', a type of semiconductor. They are the newest item in today's lighting technology. Unlike other light sources, these WHITE LEDs can take a lot of punishment from vibration, heat and severe cold. WHITE LEDs can be made waterproof, and put into a lighting package with 2 to 1000 WHITE LEDs. They can be used for streetlights, sign lighting, spot lighting or anything else.

WHITE LEDs need 3.6VDC and use approximately 30 milliamps of current, a power dissipation of 110 milliwatts. The positive power is applied to one side of the LED semiconductor through a lead and a whisker. The other side of the semiconductor is attached to the top of the anvil that is the negative power lead. It is the chemical makeup of the LED semiconductor that determines the color of the light that the LED produces. The plastic housing has three functions: it is designed to allow the most light to escape from the semiconductor; it focuses the light, and it protects the semiconductor from the elements.

**Some Basic Facts About White LEDs**

- White LEDs can be placed in abusive environments.
- White LEDs can be "AC" or "DC" powered depending on the model.
- White LEDs are the newest lighting device on the market today.
- White LEDs do not produce "RF" to interfere with radio equipment.
- White LEDs are a proven technology.
- White LEDs last about 100, 000 hours of continuous use.
- White LEDs radiate light at a 15 to 45 degree angle depending on the model.
- White LEDs can be made completely waterproof for use in many marine applications.
- White LEDs are polarity protected, so it is hard to make an installation mistake.

# Appendix 4: LED Market Study

**This report was prepared by two MIT-Sloan Business students for the completion of one of their academic requirements in February 2007. Their report has been reproduced in full with the expressed consent of the authors. No edits have been made.**

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## LED Lighting in India:
## A Brief Survey of the LED Enterprise Landscape

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Rohit Wanchoo
February 2007

# A4.1 Introduction

A vast number of people in the developing world live without electricity, or "off the grid." One of the many consequences of their lack of access to electricity is poor lighting in their homes at night. This contributes to a low quality of life for example, by reducing their productivity or limiting their children's ability to study after dark. Most resort to fuel-based lighting (i.e., kerosene) which introduces additional health and safety hazards.

Traditional lighting technologies have been too costly or fragile for the developing world to remedy this situation. However, recent advances in lighting technology are yielding promising solutions. In particular, the emergence of solid-state lighting technology, specifically light-emitting diodes (LEDs), has made possible a source of light which is significantly more efficient than incandescent bulbs, more durable than compact fluorescent lamps (CFLs), and yet affordable enough to be considered for developing world applications. Coupled with innovative power sources, LEDs hold promise in bringing light to those around the world without electricity.

The following table compares the different types of lighting technology[30]:

| *Lamp Type* | Kerosene | Incandescent | CFL | **LED** |
|---|---|---|---|---|
| *Lumens/Watt* | 0.03 | 5-18 | 30-79 | **25-50** |
| *Rated Life (K Hours)* | Supply of Kerosene | 1 | 6.5 – 15 | **50** |
| *Power Consumption* | 0.04 – 0.06 L/hr | 5W | 4W | **1W** |
| *Durability* | Fragile & Dangerous | Very Fragile | Very Fragile | **Durable** |

Because such a large population currently lives beyond the reach of the electric grid, a significant market exists for a product which could bring brighter and more cost-effective light to their homes. The IFC has estimated the world population without access to electricity at 1.6 billion and the associated market for lighting at US $38 billion each year. With the advance of technology, costs will decrease and the economic potential will only increase. Already, several enterprises are attempting to enter this market.

This report will explore the market for LED lighting as it currently exists in India, starting with a high-level survey of the market in rural India. A detailed description of the current players will then be given, focusing first on their products and then on their business models. Finally, an alternative business model will be proposed, taking into account the limitations of the current players, as well as the particular characteristics of the overall market.

[30] Available online at: http://www.lutw.org/technology.htm

## A4.2 Market Survey

The size of the market for alternative lighting solutions in India is uncertain, but can be very roughly estimated at one to four billion US dollars per year. This number is arrived at by calculating the amount of money currently being spent in rural India on kerosene, the primary source of light for those without access to the electric grid. The logic in this approach is that the money currently being spent on kerosene represents the amount which rural Indians allocate for lighting, and thus is the amount available to alternatively be spent on LED technologies. In rural Indian households, kerosene is not used for cooking, but almost exclusively for lighting[31].

The specific calculations involved in this estimate are detailed in the following table:

| | *Low-side* | *High-side* | *Units* |
|---|---|---|---|
| Population in rural India without access to electricity[32] | 580M | - | Persons |
| ÷ Average household size[33] | 5 | - | Persons/household |
| = Households in rural India without access to electricity | 116M | - | Households |
| × Average kerosene consumption in rural India | 48[34] | 180[35] | L/yr-household |
| = Total kerosene consumption in rural India for lighting | 5.57B | 20.9B | L/yr |
| × Subsidized kerosene price[36] | 9 | 9 | Rs./L |
| = Money currently spent on lighting in rural India | 50B | 188B | Rs./yr |
| **Money currently spent on lighting in rural India[37]** | **1.1B** | **4.3B** | **US$/yr** |

The main difference between the high-side and low-side estimates lies in assumptions as to kerosene consumption. In the low-side estimate, monthly kerosene consumption is taken to be 4L per household, as measured by a 2003 World Bank study. In the high-side estimate, the calculations of Dr. Evan Mills at Lawrence Berkeley National Laboratory are used, resulting in a monthly kerosene consumption of 15L per household (based on an average of 3 kerosene lamps in each household operating 3.5 hours each day burning 0.05L every hour).

31 World Bank. 2003. (Table 3.1, p.30)
32 International Energy Agency. 2002. (p.376)
33 Census of India. 2001. (p.1)
34 World Bank. 2003. (Table 3.7, p.41)
35 Mills, Evan. 2002. (Table 3, p.15)
36 The Hindu. 2007.
37 Assuming foreign exchange rate of 44 Rs/US$

Note that this estimate includes a subsidy provided by the Indian government for kerosene of approximately 15 Rs./L[38]. If this subsidy were repealed or reduced, the market would increase significantly. For the purposes of this report, it is assumed that the subsidy will remain in place for the foreseeable future.

Another upside factor to this estimate is the fact that LED lighting may also appeal to grid-connected populations, not so much for the power itself, but for its reliability. Like power grids in many developing countries, India's is subject to frequent outages. Grid users dissatisfied by the poor quality of power supply may constitute additional buyers for a reliable LED lighting product. Indeed, there seems to be a number of outlets that already cater to this market. This however is beyond the scope of this report, which will only analyze those populations who have no access to electricity.

On the other hand, it cannot be immediately assumed that LED lighting will capture all of this market. Several risks exist which would reduce the proportion of the market which might convert to LED lighting. First, the population in question is diverse geographically, culturally, and technologically, complicating and slowing the conversion to LED lighting. Second, there are other alternatives to LEDs which might also capture some market share. For example, SELCO is one enterprise currently providing solar home lighting systems in southern India using CFLs as light sources, not LEDs.

In summary, while the precise market size is uncertain, it remains that there exists a sizable and dynamic market for viable LED lighting solutions in rural India.

## A4.3 Major Players

There are currently four organizations in India's LED lighting market large enough to have a web presence. They are:

- GSBF – Grameen Surya Bijlee Foundation
- THRIVE – Volunteers for Rural Health, Education, and Information Technology
- Cosmos Ignite Innovations
- LUTW – Light Up The World Foundation

Each has an LED lighting solution, but their products and services vary significantly.

<u>GSBF</u>[39]

Based in Bombay, GSBF is a nonprofit organization whose mission is to provide lighting to villages using renewable energy sources. Although GSBF also offers solar street lighting systems, their focus is on solar home lighting systems. Their home lighting system includes a solar panel, battery, charge controller, and LED lamps. They guarantee

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[38] The Hindu. 2007.

[39] More information at: http://www.suryabijlee.com/

the system against manufacturing defects for the first year. To date, they have installed these home systems in villages in Tamil Nadu and are planning to continue ramping up production.

THRIVE[40]

Based in Hyderabad, THRIVE is a research organization with the stated mission of applying technology to the development of rural communities. THRIVE's LED lamp is unique in that it does not have a power source, but is instead charged periodically from the grid. The responsibility of charging the lamps falls on youth entrepreneurs trained by THRIVE also to install and maintain the lamps as a source of income. Currently, one of their main projects is installing LED lamps in tribal villages in the state of Orissa in partnership with Ankuran, a local NGO. THRIVE is the winner of a World Bank Development Marketplace Award which it is using to fund the project's upfront capital costs.

Cosmos Ignite Innovations[41]

Based in New Delhi, Cosmos Ignite Innovations is the combination of the Indian company, Cosmos Energy, and the American company, Ignite Innovations Incorporated. This social venture's mission is to remove darkness for those at the bottom of the economic pyramid. Their product is the MightyLight LED lamp, developed originally through a partnership between Stanford University and LUTW. The MightyLight is designed to be hand-held or hung on a wall of a room. A small solar panel is included with the light which charges the MightyLight via a wire during the day. MightyLights have been distributed in southern India, as well as in different countries around the world.

Light Up The World Foundation (LUTW)[42]

LUTW is a nonprofit based in Canada dedicated to bringing light to developing countries specifically using solid-state lighting technologies. While LUTW receives its primary funding through grants and donations, it advocates self-sustaining entities in its projects overseas. Its founder being Prof. David Irvine-Halliday, a very visible figure in the developmental lighting area, LUTW may have some advantage in receiving preferential pricing from manufacturers or using grants to subsidize its LEDs. LUTW's largest project in India was in Andhra Pradesh state, where it was supplying a local NGO consortium which is providing home lighting systems to marginalized social groups. The project goal was to provide a livelihood for local women's groups in assembling and distributing lighting systems. However, there has been no news on this project in several years, which may indicate that it never progressed further than the original pilot program. However, LUTW remains engaged in the India market.

Thus, the major LED lighting players currently active in India are summarized in the table below:

[40] More information at: http://www.thrive.in/
[41] More information at: http://www.cosmosignite.com/
[42] More information at: http://www.lutw.org/

| Name | Home Office | Founder | Areas of Work | Product Power Source |
|---|---|---|---|---|
| GSBF | Bombay | Jasjeet Singh Chaddah | Tamil Nadu | Solar Panel |
| THRIVE | Hyderabad | Ranganayakulu Bodavala | Orissa | Electric Grid |
| Cosmos Ignite | New Delhi | Matthew Scott, Amit Chugh | Southern India | Solar Panel |
| LUTW | Calgary | David Irvine-Halliday | Andhra Pradesh | Solar Panel |

## A4.4 Current Operational Models

Given the size of the Indian LED and electricity market, much of the electricity demand (on and off-grid) has gone unmet. As the active players attempt to scaleup[43] they are faced with the decision on how best to organize: either as not-for-profit foundations or as for-profit business. In this section, we will discuss the advantages and disadvantages of each model.

The major players all seem to be struggling with the basic operational issue of how to organize their group to be most effective as an organization. In particular, THRIVE has been struggling to expand as a business, while foundation models such as Grameen Surya Bijlee Foundation (GSBF) and Light Up the World Foundation (LUTW) appear to be flourishing. THRIVE clearly faces operational challenges to expansion as a business, however it is unclear that it would be better served under the foundation model.

Both the foundation and business models appear to have associated operational benefits and challenges. In particular, although foundations have the benefit of providing their services at zero cost, they are limited to the charity they receive, and there is limited incentive for these foundations to be innovative to provide cheaper technologies. Moreover, these foundations appear to be plagued by issues common to not-for-profit enterprises: lumpy funding cycles, disparate and voluminous reporting metrics (other than profit) for varying donors, and little financing for maintenance expenditures (versus upfront capital investments).

LUTW has tried to manage and mitigate some of these issues by organizing their work in different projects. Each project is coordinated and implemented with the help of "project proponents" and implementing partners (usually local nongovernmental organizations).

[43] "Scaleup" means to take a product (or model) and increase the scale of production, distribution, and or market of that product. ("Scaleup" of a model would involve replicating it on a larger scale, e.g. taking one McDonald's and copying/pasting the model across a country).

LUTW is properly staffed to handle many of the administrative issues including funding and reporting, while the partner organizations focus on the service delivery for the project. This model has allowed LUTW to maintain a very impressive presence (i.e., website, and marketing) in the Western media while expanding the organization's reach. However, the underlying issues related to the foundation model still remain.

On the other hand, the for-profit business model has its own advantages and disadvantages. Although the end consumer will have to pay for services, incentives for all elements of the value chain (manufacturing, wholesale, retail, services, and customer) are aligned. The enterprise is not held hostage to mismatched funding cycles and extraneous layers of management.

Moreover, because LED lighting is more cost effective than current alternatives, the product lends itself well to a business framework. Not only will the additional light increase the productivity for those who purchase it (by allowing these individuals to work during dark hours), but the sheer cost differential also implies that the product "pays for itself" within one year. These factors all make the LED opportunity ripe for introduction to the markets. Importantly, this should also free foundation and charitable money for funding projects that are less market ready.

The businesses at hand are all postured as one-stop-shops in which one entity manufactures, sells, and services the LED product. From conversations with THRIVE's founder, Ranganayakulu Bodavala, it appears that these businesses are also at crossroads – they are unsure how to price their product, whether to price differentiate to customer segments, and perhaps most importantly, how to replicate this process to expand their business.

## A4.5 Alternative Solution

Scaling up has proven to be a very clear challenge for those in the business model of LED service delivery. From our discussions with THRIVE, it appears that many of the challenges surface because the enterprise is completely vertically integrated[44] (including

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[44] Vertical Integration *describes a style of ownership and control. Vertically integrated companies are united through a hierarchy and share a common owner. Usually each member of the hierarchy produces a different product or service, and the products combine to satisfy a common need. It is contrasted with horizontal integration. Vertical integration is one method of avoiding the hold-up problem.*

*One of the earliest, largest and most famous examples of vertical integration was the Carnegie Steel company. The company controlled not only the mills where the steel was manufactured, but also the mines where the iron ore was extracted, the coal mines that supplied the coal, the ships that transported the iron ore and the railroads that transported the coal to the factory, the coke ovens where the coal was coked, etc.* (source: wikipedia.org) manufacturing, wholesaling, retailing, and service). Not only does any bottleneck in production prevent growth for the entire enterprise, but also managing all the different systems can be both distracting and inefficient.

In particular, the scaling up issue appears to be the product of two separate problems. First, there is a clear upfront capital investment requirement to begin the business. Even though this form of electrification requires far less capital than traditional electrification solutions, the upfront costs still need to be financed.

Second, there is a significant amount of coordination required between the different elements of the value chain. That is to say the manufacturer needs to coordinate with the wholesaler, who needs to coordinate with the retailer. The current players are vertically integrated entities that participate in all segments of the chain with varying levels of expertise and success.

For example, THRIVE appears to have one of the cheapest LED technologies on the market, but its management team is struggling with the business implementation. Against the backdrop of a clear demand for lighting in rural India, THRIVE is struggling to acquire the human and financial capital to facilitate any expansion. It currently is making small margins, and its single general manager is struggling to juggle all of the moving pieces.

One commonly proposed solution to address the issue of high upfront costs is to partner with an existing MNC or large organization. This organization would provide capital for the project in exchange for marketing rights on or with the product. This model has been successfully employed for example in the education sector, most recently by LapDesk in South Africa. Unfortunately, LED lighting solutions do not have the same portability or visibility as a portable desk and may not be as well-suited to this approach. Moreover, even in the best scenario, while seeking an intermediate funding partner solves the upfront funding issue, it does not address the coordination problem discussed above.

Perhaps a more viable alternative is to encourage each player to focus on one particular piece of the 'value chain' instead of having multiple vertically integrated enterprises. This strategy would allow each player to specialize in his particular field, as well as potentially capture the benefits of economies of scale. For example, since THRIVE seems to have a comparative advantage in LED manufacturing, it could specialize in that aspect of the value chain. THRIVE would then sell to a wholesaler, who would in turn sell to a retailer, who finally would sell the product to the end consumer. Servicing and recharging could either be done by the retail outlet that sold the product to the consumer, or by a third-party vendor.

However, this model requires a coordination agent. Although firms would be able to specialize in a specific sub-business, the entire value chain must be working in synchronization to affect a real increase in rural electrification. Under traditional circumstances, this might prove to be a coordination problem, in which each agent's actions are dependent upon the success of the entire system so no agent actually enters the market. For example, an LED manufacturer is dependent upon a functioning wholesaler, and retailer. Similarly, the wholesaler is dependent on the manufacturer and retailer, so on and so forth. So no segment of a value chain can enter the market unless the other pieces already exist and are functioning properly.

Importantly, the absence of a fully functioning value chain may explain why all current players (including THRIVE) have opted to be fully integrated service providers. They need to fill all the gaps in the value chain in order to ensure that the LED light is actually provided to the end user.

Fortunately, IFC has begun a program to coordinate the different aspects of the value chain[45] (see Figure A4.1). The IFC would provide funding for all aspects of the value chain, facilitating the specialization of the industry. For example, THRIVE as a technology leader could simply act as a manufacturing agent, whose goods would then be purchased by wholesalers. This would allow THRIVE management to focus on lowering the cost of their product, and concern themselves less with pricing and servicing. Other agents would enter the other pieces of the value chain.

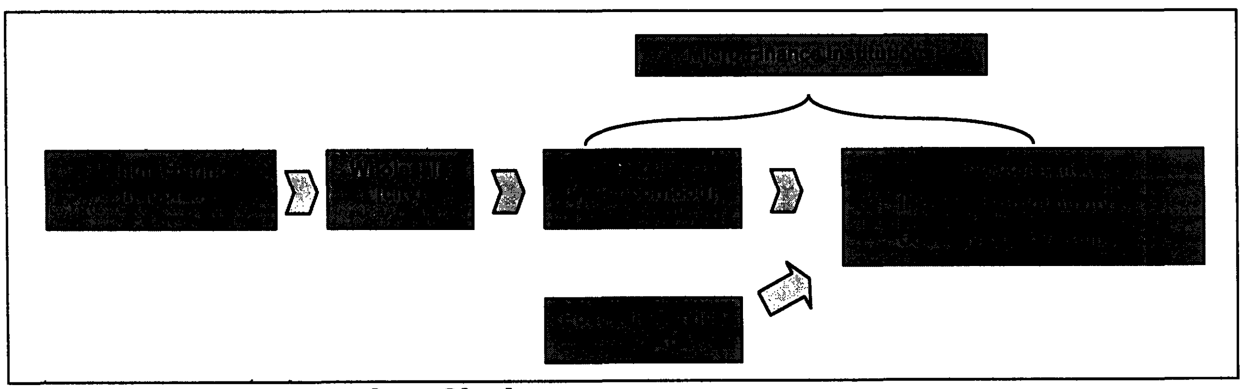

**Figure A4.1: LED Value Chain**

Moreover, because IFC may be able to bridge any financing needs of these players to enter the industry, the entrants can enter with little risk of immediate financial failure. In this way, IFC can not only be sure that there are players at all levels of the value chain, but it gives the entire system the push it needs to get started.

Of course, this mechanism has its own associated risks. There is a very clear tension between efficiency and potential price increases. As each link of the value chain adds its own margin, there is a greater potential for price increases. In theory these margin increases should be offset by market competition. As the IFC can act as a true brokering agent, it may be able to ensure that prices at each segment are kept to a reasonable level. Moreover, IFC has the scope to invest appropriately into specific sub-sectors to ensure the entire system is working efficiently.

45 International Finance Corporation. 2006.

This high-level analysis makes several assumptions about how these different players will all interact together. To begin with, there is no guarantee that IFC will act as an efficient coordinating agent, or that they have the resources to facilitate all the investments required to bridge all the upfront investments. Similarly, there is no guarantee that players will specialize if allowed to do so, or that other cultural or idiosyncratic barriers will surface to prevent the lights from being sold in the retail market. Despite these assumptions, there is a compelling story for the IFC jumpstarting the competitive LED market in India.

## A4.6 Conclusion

Recent advances in solid-state lighting have positioned LED lamps as a potential breakthrough technology with applications in the developing world. Although estimates vary, it is apparent that a large, commercially attractive market exists in India for rural lighting solutions. There are several players currently in rural India's LED market, each attempting to be a holistic service provider of LED lights, providing everything from manufacturing to post-sales service. Projects under this model have been "successful" but only on a limited scale.

Perhaps because of their access to upfront capital, foundations currently appear to be a much more formidable force in the LED space. They are able to provide their products for free and while there is available funding, there are relatively fewer issues with scaleup. However, this solution may not be viable in the long run. The model is dependent on the funding preferences of donors. At worst, this money may dry up. At best, the foundation capital provides a natural ceiling for expansion.

A for-profit mechanism would perhaps provide a more viable solution to the electrification problem. This business solution requires two elements. First the upfront capital requirements need to be bridged. Second, players should specialize into various pieces of the value chain (i.e., manufacturing, wholesale, and retail). This specialization could allow firms to be more efficient and competitive in the area of their specific function. In theory, once the market is in place, competition could then fuel innovation and price reductions in the specific segments.

The IFC has the potential to bridge both the upfront capital and coordination problem to jumpstart the market. As long as the efficiency benefits of this scheme outweigh costs added at each point along in the value chain, this could be a highly effective model.

If the above model is implemented successfully, everyone wins: India's rural poor get access to electricity, and India's businesses make money—all in a self-sustaining manner.

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