Less than 50% of Indian villagers have access to grid electricity. Those who do have access find grid electricity unreliable. Hence, most Indian rural homes, electrified or not, continue to use primitive renewable energy from the sun, biomass, and cow dung for their day to day heating and cooking needs, while depending heavily on subsidized kerosene and diesel for lighting and irrigation pumping. A recent national government electrification plan for 80 million homes proposes $13 billion rural electricity grid investments out of which 90% will be capital cost subsidies. Access to 24 million poor homes will also be assured by 2012 with similar operating cost subsidies. However, my question is whether this grid electrification program is the cheapest way to provide electricity to India's rural poor.

The assumption behind the grid electrification of villages is that consumers prefer an unlimited and available "any time" power supply with no regard for the cost and the demand. With inadequate investigation of the customers' ability and willingness to pay the true cost for good quality grid electricity, the current government's expensive subsidized plan will fail as have numerous past attempts with a continuation of poor quality of service and perpetual subsidies.

Very few studies have paid full attention to demand side factors to make clean energy sustainable and replicable in all villages without long-term subsidies in a competitive market environment. The literature lacks a theoretical framework to show that off-grid renewables like Solar Photovoltaics (SPVs) can be delivered at a lower cost than grid electricity under competitive market conditions now and in the future. Without this theoretical framework, the literature argues in favor of more subsidies to the rural poor for both the fossil-grid and renewables.

A body of literature exists from the 1990s about the role of emerging clean, competitive, culturally compatible, and climate friendly solar and biomass electricity as a rural energy solution. However, all academic literature, case studies, and government programs on renewables believe subsidies are inevitable (Taylor 2000; World Bank 2008). I disprove their belief. More particularly, the questions I will answer in this thesis are the followings. i) Is off-grid SPV electricity cheaper than grid electricity for the rural poor in India? ii) Can off-grid SPV electricity or grid electricity be subsidy free for the rural poor in India? iii) What are the break-even incomes for the grid to be cheaper than off-grid SPV? iv) Can this break-even income and consumption be reached for the electricity grid to be competitive or subsidy free by 2020?

A real life experiment lasting over 5 years in a poor electrified village in the Indian state of Orissa provides me the opportunity to model the demand for and supply of SPV and grid electricity together. I show the potential for modern, off-grid SPVs to electrify the rural poor irrespective of their income level in this village, which has been electrified for more than 30 years but with a grid connection of less than 40% of households.

I use a "dominant firm" model to show the demand and supply interactions of both fossil-grid and off-grid renewables, contrasting their abilities to create and sustain a competitive market equilibrium. The model shows the theoretical possibility of a subsidy-free rural energy transition from an inefficient fossil-grid to more efficient renewable electricity. In particular, modern SPV electricity, though very expensive at present, is modeled as a decreasing cost, emerging technology with the added advantages of safety and portability. I find SPVs can displace the fossil-grid system at a lower one-time cost of $50-$350 per rural poor household, which is 10-70%% the cost of a grid connection. Operating costs for SPVs are lower as well.

The analysis suggests that with the current average rural income level of less than $100/month, the rural grid cannot be subsidy free. For household electricity consumption of less than 20 kWh/month, SPV electricity is clearly cheaper than the grid. The required threshold income to make grid electricity subsidy free is $196-$400/month. Even with the optimistic assumption of rural Indian income growth of 10% per year, these threshold incomes and a subsidy-free grid cannot be achieved in rural India by 2020 or beyond as the SPV prices are coming down but grid prices are not. The SPV supply, however, can be subsidy free at any level of income by designing small, modular, and very efficient end-use devices that are perfect for highly valuable portable rural applications that fit the conservation culture of the rural poor.

There are a number of implications of my study. Off-grid SPVs can not only challenge the dominant firm in the face of open access with no regulatory or market barrier subsidies to a particular technology, but they will eventually become dominant and competitive themselves. Not only should all subsidies for fossil fuels be removed, but appropriate taxes should be added so that consumers see the true costs of their consumption. The urban fossil-grid system should be separated from the rural off-grid renewables to improve the technical efficiency of end- use consumption, the commercial and market efficiency of the electricity supply chain, and economy-wide efficiency to make the off-grid renewables the lowest cost resources for sustainable development. Subsidizing the grid as well as off-grid technologies in rural India works at cross purposes, lacks focus on the most promising clean energy intervention, and destroys markets for both the electric grid and off-grid systems to achieve the critical scale of operation of both. Thus, I explore a long-term and least-cost solution to providing off-grid but modern renewable electricity from SPVs to over 80 million homes in Indian villages. These villages should be modernized and subsidies minimized with the overall economy set in a clean development path without the burden of rural energy subsidies and externality costs. Only recently, with the global climate debate, World Bank (2009) and IEA (2008) have picked up the fight against fossil-fuel subsidies. Thus, this study will be a timely addition to the literature of the technological possibility and economic success of off-grid renewables for providing subsidy-free modern rural energy for sustainable development

without fossil fuel subsidies.

My experience working in the power sectors in both India and the USA along with my rural up bringing around the poverty stricken Orissa villages provide much of the first-hand information for this thesis. My interest in this topic was partly sparked by my 15 years of work in the Indian Ministries of Industries, Central Electricity Authority, and Central Electricity Regulatory Commissions. Over 5 years of recent experience working in a large investor owned diversified utility, Integrys Energy Group, dealing with both urban and rural Wisconsin and Michigan and competitive power markets across the USA, brought more insights to the potential for a competitive market for rural India. My graduate academic studies in electrical engineering, economics, and business finance, of course, provided the theoretical basis to effectively deal with the complicated interactions of electricity and economics in this thesis.