Identification of Strategies And Challenges Of Adopting An Off-Grid Renewable Energy Source For The Mercantile Sector

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Abstract

An increased CO₂, a Greenhouse Gas (GhG) emission and its accumulation in the atmosphere is a major climatic concern, and creates an urgent need to control its rate of growth with the goal to reduce or reverse the growth. Reduction is being attempted at macro scales, large GhG producers but relatively small in numbers, at mezzo levels such as mercantile stores which are large in numbers and relatively large consumers in scale and at micro scales such as individual dwelling units which are very large in numbers but relatively small in a GhG producer scale. This research identifies the strategies and challenges of adopting an off-grid renewable energy source for the mercantile sector (retail) sector at the mezzo level. A theoretical model for off-grid renewable energy source considering a parking lot of a retail outlet will be developed. A proposed physical model, future work, should be able to test the assumptions and hypothesis of the theoretical model presented. A multiplying effect of this reduction will be analyzed on a global scale, as part of future work. The proposed hybrid system uses two or more alternative renewable energy sources that are to each other. In the proposed system, solar energy is integrated with a local bio gas plant, which treats waste to produce electricity. The excess energy can be sold to grid using net metering or dual metering or sold to charge plug-in vehicles to earn revenue. The renewable energy produced reduces the grid load on public utilities, thereby reducing the amount of CO₂ emission from the grid providers. In summary, this approach creates a hybrid system that bridges the current grid dependent system and a grid-independent (off grid, or net zero) goal.

Keywords: CO₂ emissions, Energy Consumption, Mercantile Sector, Net metering, Renewable energy, Sustainable Development

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1. Introduction

Governments and scientists have recently agreed that there is an urgent need to control atmospheric CO₂ emissions (Fernandez Solis, 2007a). The article by Pacala & Socolow (2004) on “Stabilization Wedges: Solving the Climate Problem for Next 50 years with current technologies” (discussed later in this paper) suggests some of the current options that can be scaled up in the reduction for CO₂ emissions. One of the 15 such options is achieved through more energy efficient buildings that can cut carbon by one fourth of the current level by 2054 (Pacala & Socolow, 2004).

Projections of energy consumptions as per Annual Energy Outlook, by Energy Information Administration (EIA, 2009a), for the year 2009 suggests that energy consumption in commercial sector in United States of America is growing at a high rate and will surpass residential energy consumption by 2030 (EIA, 2009a). Refer to Figure 1 & 2.

![Figure 1: Energy Consumption Projections for Residential, Commercial, Industrial and Transportation Sectors from 2006 to 2030 (EIA, 2009a)](image)

As has been projected in Figure 1, the rate of energy consumption in commercial sector is increasing. On analyzing the percentage contribution of energy consumption to the total energy consumption by all sectors in 2006 and 2030 (Refer to Figure 2), it has been observed that the energy consumption contribution by Commercial sector will increase from 18% in 2006 to 21% in 2030, Residential and Transportation will remain the same whereas Industrial energy consumption contribution will drop from 33% in 2006 to 30% in 2030. Therefore, more focus needs to be given in controlling energy consumption of Commercial, Residential and Transportation.

Initiatives by various organizations in promoting sustainable construction in retail have started growing. John Lewis partnership, one of the leading retail giants in the United Kingdom has targeted to reduce CO₂ emissions as a percentage of the sales by 10% by 2010 (against 2001/02 baseline) and to improve energy efficiency by 5% by 2008 and 10% by 2013 (against a 2003/04 baseline) (Hamson, 2007). To reach such levels of sustainability (and energy efficiency) we need to identify and analyze various opportunities involved in delivering sustainability in the mercantile sector. These opportunities are at different scales. Large power plants are at macro scale but relatively few in numbers; regional malls and retail centers are at the meso scale and relatively large numbers; dwelling units are at a relatively small scale and relatively large numbers; dwelling units are at a relatively small scale but very large numbers, Refer to Figure 3. We argue that work to reduce energy consumption and emissions generation needs to be done at all scales. The atmosphere’s concentration of carbon dioxide (CO2) has increased by more than 30% over last 250 years, largely due to human activity, whereas, two-thirds of that rise has occurred in the past 50 years (Keeling & Whorf, 2000). An increased CO₂, a greenhouse gas (GhG), emission and accumulation in the atmosphere is a major climatic concern, and creates an urgent need to control its rate of growth with the goal to reduce or reverse the growth.

![Figure 3: Scales of Number in a Time Line (Fernandez-Solis, 2007b)](image)
energy source, integrated with a local bio gas plant, which treats waste to produce electricity. The excess energy can be sold to grid using net metering or dual metering or sold to charge plug-in vehicles to earn revenue. The renewable energy produced reduces the grid load on public utilities, thereby reducing the amount of CO₂ emission from the grid providers. The aim is to produce at the meso scale, commercial facilities that require on-site parking lot illumination, a hybrid system that bridges the current grid dependent design and the grid independent (off-grid or net zero) sustainable design target.

2. Definition

Off-Grid: The traditional model of electric power generation and delivery is based on the construction of large, centrally located power plants. "Central," in this case, ideally means that the power plants are located on hubs surrounded by major electrical load centers. Off-Grid in this paper refers to making energy generation independent of traditional power plants.

Commercial Buildings: EIA categorizes commercial buildings into education, food sales, food service, health care, lodging, mercantile (retail other than mall and enclosed and strip malls), office, public assembly, public order and safety, religious worship, service, warehouse and storage, other and vacant (EIA, 2003a).

Retail and Service Buildings: Retail and service buildings include all buildings including Service buildings, Strip malls and Retail other than malls such as department stores, automobile showrooms, drugstores, building material supply stores, and wholesale shopping clubs.

Mercantile Buildings: Mercantile buildings are those used for the sale and display of goods other than food (buildings used for the sales of food are classified as food sales). This category includes enclosed malls and strip shopping centers (EIA, 2003b).

3. Strategies for Emission Reduction

The article by Pacala & Socolow (2004) on “Stabilization Wedges: Solving the Climate Problem for Next 50 years with current technologies” suggests stabilization and control of atmospheric CO₂ emissions in the first half of this century by scaling up current options available. The focus is on a goal of achieving stabilization of 500 parts per million (ppm) concentration of CO₂ (current concentration is ~375ppm) which requires emissions be held at present level of 7 billion tons of carbon per year (7GtC/year) for next 50 years (which is expected to rise to 14 GtC/year in 2054 at the current rate). Pacala and Socolow have suggested various options that could be scaled up to produce at least one wedge (i.e. 1 GtC/year). The options include Energy Efficiency & Conservation, Decarbonization of Electricity & Fuels and Natural Sinks. Furthermore, Pacala and Socolow (2004) assert that more energy efficient buildings could reduce emissions from buildings by one-fourth by 2054. About half of potential savings are in the buildings in developing countries.

3.1 The Forces Behind the Problem

The projected growth in resource consumption and emissions generation in response to global population growth (on the short term horizon) and especially improving standards of living (on the long term horizon), point towards unsustainable future within the next 75 years (Fernandez-Solis, 2007b). In 1992 the National Academy of Sciences and the Royal Society of London issued a statement (Speth 2005). “If population growth continues at currently predicted levels, much of the world will experience irreversible environmental degradation and continued poverty”. People overpopulation is defined as environmental worsening as there are too many people placing a demand on resources to meet basic needs. Over consumption occurs when a population consumes too large a share of resources. (Fernández-Solis, 2008). The link between exploitation of resources, wealth and population is the subject of numerous studies. Ludwig et al (1993) observe that the history of resource exploitation is remarkably consistent: ‘Resources are inevitably overexploited’, often to the point of collapse or extinction (Fernández-Solis, 2007a). Fernández-Solis (2008) suggested a framework of assumptions and facts shared between the artificial and natural worlds. The framework suggests that we had been assuming an unlimited supply of natural resources (for e.g. fossil fuels), whereas limited flow of capital from artificial world, Refer to Figure 4.
3.2 Energy Currency

Turnbull (1983) argues that the energy currency is a concept used towards the creation of an energy economy. Energy as a currency in an energy economy works like local exchange trading systems that are local, non-profit exchange networks in which goods and services can be traded without the need for printed currency. Renewable energy as a currency in an economy that has both renewable and non-renewable energy achieves the goal of establishing an accounting system where trade-offs can take place (Appropedia, 2008) without the intermediary of money. The production of electrical energy has now become a basic activity for all modern communities. Modern technology, using renewable energy sources, has made the financial cost of production relatively constant throughout the world.

The technology of power production from renewable energy sources has diseconomies of scale and so favors small discrete autonomous communities. For this reason, the unit of electrical power, the kilowatt-hour (kWh) has much appeal as a universal unit of value for an autonomous community banking and monetary system. Turnbull (1983) argues that the owners of the power generator would create a voucher or contract note to supply a specified number of kWh at a specified time in the future. The notes with a specified maturity date would represent the "primary" currency. Such currency notes would mainly be held by investors, investment banks, and banks. According to Turnbull (1983) the renewable energy currency would be far more democratic than gold dollars, as sun, wind, and/or wave energy is available to all communities in the world, whereas gold is not. It is also very democratic within communities since each individual could own his own renewable electrical energy source to supply his own needs and/or to supply to others (Turnbull, 1983). The object of this energy currency approach is to incentivize those at the meso and micro levels to become producers of energy (hybrid or non-grid, self sufficient, non-zero). In order to understand an energy economy we first need to relate the cost of producing the gadget that produces energy from different sources.

3.3 Grid Parity

Grid parity means that the cost of producing solar energy would be comparable to obtaining electricity from fossil fuels (FT, 2008). It is being achieved first in areas with abundant sun and high costs for electricity such as in California (BP Solar, 2008). General Electric predicts grid parity without subsidies in sunny parts of the United States by around 2015. Other companies predict an earlier date. (Reuters, 2007). Tom Werner, chief executive of SunPower Corp, the largest North American solar company by sales, sees such "grid parity" for solar power in the United States and elsewhere happening in about five years, or possibly as soon as 2010. (Reuters, 2008). Refer to Figure 5.

4. Renewable Energy Sources

As per Energy Information administration, renewable energy sources can be replenished in a short period of time. The five renewable sources used most often are (Refer to Figure 6) Biomass, Wind Energy, Solar Energy, Geothermal Energy and Hydroelectric

Figure 6: The Role of Renewable Energy Consumption in the Nation’s (United States of America) Energy Supply, 2007 (Energy...
Figure 7: Renewable Energy Consumption by Energy Use Sector, 2003-2007 (EIA, 2007)

Figure 7 suggests that the consumption of renewable energy in commercial sector has been near to constant, whereas there has been growth in the consumption of renewable energy sources in residential sector. This suggests a need for more efficient systems for commercial sector and a need for awareness of the benefits of renewable energy in the commercial sector.

This study will analyze various alternative renewable energy sources (as identified by Energy Information Administration) and will propose the best suited renewable energy source for the mercantile sector. The renewable energy sources identified and analyzed in this study include:

- Biomass
- Wind Energy
- Solar Energy
- Geothermal Energy

Further details of each of the four energy sources discussed below.

4.1 Biomass

Biogas is a clean environment friendly fuel that contains about 55–65% methane (CH4), 30–45% carbon dioxide (CO2), traces of hydrogen sulfide (H2S) and fractions of water vapors. Biogas is produced by anaerobic digestion of biological wastes such as cattle dung, vegetable wastes, sheep and poultry droppings, municipal solid waste, industrial waste water, land fill, etc. It is an environment friendly, clean, cheap and versatile fuel (Kapdi, Vijay, Rajesh, & Prasad, 2005).

Type of Biogas Plants: Two types of biogas plants are currently found, plants operated at mesophilic conditions (35–37 °C) and thermophilic biogas reactors run at more elevated temperatures (55–60 °C). Mesophilic biogas reactors are typically of smaller scale and run on silage of so-called “energy-crops”, while thermophilic biogas reactors tend to be larger and are favored for the processing of municipal waste, i.e. a complex mixture of liquid manure, industrial food processing waste, waste from slaughter houses, oil and grease from kitchens and canteens, organic households waste, as well as leftovers and food stuffs no longer suited for human consumption. (Weiss, Jerome, Freitag, & Mayer, 2008).

Thermophilic Biogas Plant Developed by Bhabha Atomic Research Center: Biogas Plant at Trombay (Maharashtra, India) produces biogas from kitchen waste by using thermophilic microorganisms that flourish in extreme environment. The biogas plant has following components, Please Refer to Figure 9 (Kale & Mehetre, 2002):

Figure 9: BARC Biogas Plant Model (Kale, 2002)

The waste generated in kitchen in the form of vegetable refuge, stale cooked and uncooked food, extracted tea powder, waste milk and milk products can all be processed in this plant. Based on the understanding of thermophilic microorganisms in particular and microbial processes in general, there are two important modifications made in the conventional design of the biogas plant in BARC (Kale & Mehetre, 2002):

A Bio Gas Plant would serve many purposes such as (BARC, 2002):

- Environment friendly disposal of waste
- Generation of fairly good amount of fuel gas, which will definitely support the energy resources.
• Generation of high quality manure, which would be weed less and an excellent soil conditioner. This is very important for replenishing fast decreasing resources of productive soils.

• Biogas is a colorless, odorless and inflammable gas. The gas generated in this plant can also be used as a source of natural gas. The composition of biogas is Methane (CH4): 70-75%, Carbon Dioxide (CO2): 10-15% and Water vapors: 5-10%

**Biogas Production Incentive Act of 2009:** A bipartisan group of U.S. senators introduced legislation on 22 January 2009, to promote the development of biogas. Under the Biogas Production Incentive Act of 2009, producers would receive a tax credit of $4.27 for every million British thermal units of produced biogas. (Voegele, 2009)

**The AgSTAR Program:** The AgSTAR Program is a voluntary that encourages the use of methane recovery (biogas) technologies at the confined animal feeding operations that manage manure as liquids or slurries. (USEPA, 2009)

### 4.2 Wind Energy

Wind energy systems have been under development since the early 1980’s and offer clean energy and renewable energy, compared to fossil fuel fired systems (Miles, 2006). There are two types of wind machines (turbines) used today based on the direction of the rotating shaft (axis): horizontal–axis wind machines and vertical-axis wind machines. The size of wind machines varies widely. Small turbines used to power a single home or business may have a capacity of less than 100 kilowatts (EIA:USDOE, 2008).

Recently, there have also been innovations in the design of small turbines that can facilitate their deployment in urban environments. The issues involved with using these systems in urban environments involve noise, aesthetics, integration into architectural systems, and efficient use of the available wind resource. Wind profiles in urban areas tend to be more turbulent and not along a single axis. There are several problems with conventional systems including noise, danger to birds and they do not efficiently convert wind energy that is not parallel to the axis or is turbulent. These systems are also not good at catching the accelerated wind flowing over the building. Below are some recent innovative Wind turbines by various producers (Miles, 2006).

**Aerovironment Wind Energy System:** Aerovironment, the California engineering firm behind the deceased EV1 car, has integrated small wind power into buildings. The forthcoming AVX400 (by Aerovironment) is a small turbine that capitalizes on an urban airflow advantage: the fast-moving current that comes over the parapet of most city buildings. Engineers claim a 40% increase in efficiency as a result. The optional canopy (pictured above) serves as a visual accent and as a potential protective guard for wildlife, although the company does not see a risk for birds or bats. Environmental Building News (EBN) calculates that the cost is a modest $5-$7 per watt of installed capacity, which, they point out, is roughly comparable to photovoltaic systems, and cheaper than building-integrated PVs. (Gordon, 2006).

**Aerotecture Wind Energy System:**These Wind turbines designed for urban settings were invented by University of Illinois industrial design professor, Bill Becker. Aeroturbines are a new development in...
wind turbine technology and can be installed on existing rooftops or built into the architecture of new buildings to provide clean renewable electricity at its site of consumption. This wind turbine can be used in both horizontal and vertical orientations. Figure 11 shows the system mounted horizontally on a building. (Aerotecture.com, 2008).

**Wind Amplified Rotor Platforms (WARPTM):** The Wind Amplified Rotor Platform (WARPTM) system configuration consists of stacked aerodynamic modules about a core lattice tower that draws heavily on the latest technology developments of today’s conventional large diameter, high-efficiency horizontal-axis wind turbines (HAWT), but without their inherent risks and drawbacks. Multiple peer reviews by numerous organizations including the IEEE (Institute of Electrical and Electronics Engineers) have corroborated the veracity of this approach to wind power (WARP:ENECO, 2008).

**4.3 Solar Energy**

In the 1830s, the British astronomer John Herschel used a solar thermal collector box (a device that absorbs sunlight to collect heat) to cook food during an expedition to Africa. Today, people use the sun’s energy for lots of things (EIA, 2007).

Photovoltaic cells convert sunlight directly into electricity and are made of semiconductors such as crystalline silicon or various thin-film materials (USDOE, 2007).

**Figure 13: A Solar Array (SESCI, 1997)**

PV modules generate direct current (DC), the kind of electricity produced by batteries. A device known as an inverter converts DC to AC current. Inverters (Refer to Figure 13) vary in size and in the quality of electricity they supply (SESCI, 1997).

**Sizing a PV system:** To determine the amount of energy to be consumed, the power consumption (watt) of each device using electricity needs to be multiplied by the number of hours a day the device will be used. For example, a 17-watt fluorescent light lit for 18 hours a day uses 306 watt-hours (or 0.306 kilowatt-hours) of electricity. The PV system should supply at least as many kilowatt-hours (under a variety of lighting conditions) as the total electric needs. (SESCI, 1997)

**Third generation photovoltaic: solar cells for 2020 and beyond**

Most solar cells presently in the market are based on silicon wafers, the so-called ‘first generation’ technology. A 1997 study of costs of manufacturing in greatly increased 500 MW/y production volumes suggests material costs in such volumes would account for over 70% of total manufacturing costs. To progress further, conversion efficiency needs to be increased substantially. The Carnot limit on the conversion of sunlight to electricity is 95% as opposed to the theoretical upper limit of 33% for a standard solar cell. Research is in progress on the prospective third generation cells like, tandem cells, multi electron hole pairs, hot carrier cells, multiband cells and thermo photovoltaic and thermo photonic devices (Green, 2002).

**Energy Payback period for Photovoltaic Technologies**

Energy Payback Time (EPBT) is the length of deployment required for a photovoltaic system to generate an amount of energy equal to the total energy that went into its production. Roof-mounted photovoltaic systems have impressively low energy payback times, as documented by recent (year 2004) engineering studies. The value of EPBT is dependent on three factors (USDOE, 2006b):
Recent research has established battery-free, grid-tied EPBT system values for several (year 2004-early 2005) photovoltaic module technologies (refer Table 1). It is seen that, even for the most energy intensive of these four common photovoltaic technologies, the energy required for producing the system does not exceed 10% of the total energy generated by the system during its anticipated operational lifetime. (USDOE, 2006b)

Table 1. System Energy Payback Times for Several Different Photovoltaic Module Technologies (USDOE, 2006b)

<table>
<thead>
<tr>
<th>Cell Technology</th>
<th>Energy Payback Time (EPBT)</th>
<th>Energy Used to Produce System Compared to Total Generated Energy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-crystal silicon</td>
<td>2.7</td>
<td>10.0</td>
</tr>
<tr>
<td>Non-ribbon multicrystalline silicon</td>
<td>2.2</td>
<td>8.1</td>
</tr>
<tr>
<td>Ribbon multicrystalline silicon</td>
<td>1.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Cadmium telluride</td>
<td>1.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Wal-Mart Stores, Inc. purchased solar power from three solar power providers, BP Solar, SunEdison LLC, and PowerLight, a subsidiary of SunPower Corporation, for 22 Wal-Mart stores. The total solar power production from the stores is estimated at 20 million kWh (kilowatt-hours) per year, possibly becoming one of the top-10 solar power initiatives in the U.S. when fully implemented. Wal-Mart will use the power generated by the solar panels onsite at each store and will also keep the Renewable Energy Credits (RECs) (Broehl, 2005).

4.4 Geothermal Power

Geothermal energy is heat from within the earth, that uses the steam and hot water produced inside the earth to heat buildings or generate electricity. Geothermal energy is a renewable energy source because the water is replenished by rainfall and the heat is continuously produced inside the earth. Geothermal energy is generated in the earth’s core, about 4,000 miles below the surface. Temperatures hotter than the sun’s surface are continuously produced inside the earth by the slow decay of radioactive particles, a process that happens in all rocks (USDOE:EIA, 2008).

Converting the Earth’s Heat to Electricity

Most power plants - whether fueled by coal, gas, nuclear power, or geothermal energy - have one feature in common: they convert heat to electricity. Geothermal power plants use many of the same components used in traditional power-generating stations, including turbines, generators, heat exchangers, and other standard power generating equipment. (USDOE, 1998). Mile-or-more-deep wells can be drilled into underground reservoirs to tap steam and very hot water that drive turbines that drive electricity generators. (USDOE, 2008d):

The cost of time delays is significant, sometimes adding $10 to $20 or more per MWh or more to the

Development Cost: To get the plant sited, constructed, and put online—are significantly higher than those of fossil-fueled power plants. Development costs of a geothermal facility, in contrast, represent two thirds or more of total costs. The development costs for a typical 20 MW power plant are shown in Table 2. These costs are rules of thumb. Actual costs can vary based on factors such as time delays, geology, environmental restrictions, project size, and transmission access.

Table 2. Typical Geothermal Power Plant Development Costs (USDOE, 2008c)

<table>
<thead>
<tr>
<th>Development Stage</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration and resource assessment</td>
<td>400</td>
</tr>
<tr>
<td>Well field drilling and development</td>
<td>1,000</td>
</tr>
<tr>
<td>Power plant, surface facilities, and transmission</td>
<td>2,000</td>
</tr>
<tr>
<td>Other development costs (fees, working capital, and contingency)</td>
<td>600</td>
</tr>
<tr>
<td>Total development cost</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Development Cost: To get the plant sited, constructed, and put online—are significantly higher than those of fossil-fueled power plants. Development costs of a geothermal facility, in contrast, represent two thirds or more of total costs. The development costs for a typical 20 MW power plant are shown in Table 2. These costs are rules of thumb. Actual costs can vary based on factors such as time delays, geology, environmental restrictions, project size, and transmission access.
are needed to reduce costs from marginal geothermal resources and thus to stimulate geothermal energy development. Significant reduction in power costs would be achieved by reducing well drilling costs, stimulating well flow rates, reducing power plant capital costs, increasing power plant efficiency and utilization, and developing more effective exploration techniques for locating and assessing high-quality resources (Bloomster & Knutsen, 2005). The following are the benefits and limitations of geothermal generation (IPTV, 2001):

Benefits: However geothermal is used, there are many benefits. Geothermal produces no emissions. The resource is naturally renewable. Using this resource can help reduce the demand for fossil fuels – the only outside energy source you would need for heating/cooling air is for energy to run the heat pumps.

Limitations: The biggest limitations of using geothermal to generate electricity is related to geography and geology – there are relatively few places on earth that have magma close enough to the earth’s crust to create the conditions necessary for generating electricity in an economical way. These locations are in regions where there are young volcanoes, crustal shifts, and recent mountain building.

5. Parking Lot Lighting

The primary purpose of adequate lighting in parking structures and parking lots is to permit the safe movement of vehicles and pedestrians. The lighting design must consider the illumination necessary to achieve these objectives balanced against the need to control costs (capital, operational and maintenance costs (ULI, 2000). The Illuminating Engineering Society of North America (IESNA or IES) publishes luminance guidelines for a variety of building types and activities. The guidelines are generally considered the industry standard. IES document RP-20-98 Lighting for Parking Facilities, specifies the design guidelines for lighting surface parking lots and parking structures. The lighting system design should also consider luminaire design, glare, color rendition of light source, maintenance and economics.

5.1 Luminaire

Luminaries are generally classified as cutoff or non-cutoff fixture types. A cutoff luminary is defined by the IES as a fixture that controls emitted light to less than 2 percent above horizontal and less than 10 percent above an 80-degree angle from a vertical line through the light source. On the roof level of the parking structures and in surface parking lots, cutoff luminaries are recommended to minimize light trespass and to hide the light source from the view of adjacent properties (ULI, 2000).

![Cutoff Luminaire](image1)

![Non-Cutoff Luminaire](image2)

Figure 14: Cut-off Luminaire (Left), Non Cutoff Luminaire (Right)

5.2 New trends and innovation in Parking lot lighting

Ami Argand, a Swiss chemist is credited with first developing the principal of using an oil lamp with a hollow circular wick surrounded by a glass chimney in 1783 (Refer to Figure 13). In 1879 Thomas Edison and Joseph Wilson Swan patented the carbon-thread incandescent lamp (Bellis, 2009).

Figure 15: Ami Argand Lamp (Left) and Edison’s Incandescent Lamp (Right) (MathewBoulton, 2008) (SmithsonianInstitution, 2008)

European leaders, green pundits and the widely reported light bulb provisions of the U.S. Energy Independence and Security Act of 2007 all urgently push the abandonment of incandescent bulbs. The plan appears to be to convince everyone to switch to compact fluorescent lights (CFL), a technology that was introduced in the 1930s and perfected when rock was young and computers used vacuum tubes (Bellis, 2009).

The Semiconductor light emitting diodes (LEDs) are finally on the verge of having the capability to radically alter the entire lighting landscape with staggering improvements in both lighting efficiency and efficacy (Mill, 2008). LEDs are small light
sources that become illuminated by the movement of electrons through a semiconductor material. (EnergyStar, 2008)

About 12 billion electric lights on the planet use Edison bulbs; a third are in the U.S. So, lighting up the world consumes about 2 trillion kilowatt-hours annually, or one-eighth of all electric power. This takes a lot of fuel: the equivalent of nearly a billion tons of coal annually. In the U.S., half of that is in fact coal. Or, in oil-equivalent terms, U.S. lighting uses the equivalent of 50% of the energy used by all cars on American roads (Mill, 2008).

The U.S. Department of Energy and its partners are working to expand market introduction of LED (light emitting diode) parking lot lighting. Under the Commercial Building Energy Alliances (CBEAs), a new working group is focused on making reliable, energy efficient, and competitively priced outdoor LED luminaries more widely available in the marketplace. In April 2008, a working group formed to accelerate the market availability of parking lot lighting using LED luminaries. Initiated by the Retailer Energy Alliance, this working group has begun a collaborative project (USDOE, 2008):

The following table compares LED parking lot lighting technology to metal halide (standard parking lot lighting) (USDOE, 2008):

<table>
<thead>
<tr>
<th>Product Feature</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color Quality and Stability</td>
<td>Good white initial color but with unpredictable color shift over time</td>
<td>Good white initial color and modest color shift over time</td>
</tr>
<tr>
<td>Life</td>
<td>Limited life (approx 12,000 hours)</td>
<td>Expected long life (50,000+ hours) but actual end of life performance not completely understood</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Potentially high maintenance cost due to short life and labor needs for lamp replacement</td>
<td>Very low maintenance expected due to long life and durability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment (Mercury)</th>
<th>Contains mercury, creating disposal issues</th>
<th>Contains NO mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Pollution</td>
<td>Can be shaded for improved light pollution capability</td>
<td>Easy to reduce light pollution effects due to inherent directionality of source</td>
</tr>
<tr>
<td>Cost/Payback</td>
<td>Stable</td>
<td>Potentially long payback due to high initial cost, but maintenance savings are substantial; costs are rapidly decreasing</td>
</tr>
</tbody>
</table>

Energy Star has qualified that LED lighting uses at least 75 percent less energy than incandescent lighting, is at least as efficient as fluorescent lighting and provides a clear and consistent shade of white light throughout the lifetime of the fixture.

Table 4: Annual Operating Cost Comparison for Recessed Down Lighting (Energy Star, 2008)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Lifetime (hours)</th>
<th>Annual Operating cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent bulb</td>
<td>1000</td>
<td>$8.87</td>
</tr>
<tr>
<td>Compact fluorescent light bulb (CFL)</td>
<td>10,000</td>
<td>$2.37</td>
</tr>
<tr>
<td>Energy Star qualified LED lighting</td>
<td>25,000 or 35,000</td>
<td>$1.95</td>
</tr>
</tbody>
</table>

6. Smart Grid

United States of America is increasingly held back by an outdated power delivery infrastructure. Designed in the 1960s or earlier, much of this critical national asset is well beyond its design life. The financial consequences of interruptions are growing into an enormous threat. Consider some of the economic consequences of power losses [USDOE, 2008a]:

- Power interruptions and disturbances cost the U.S. electricity consumer at least $79 billion per year
- When the Chicago Board of Trade lost power for an hour during the summer of 2000, trades worth $20 trillion could not be executed

Name of Journal: Renewable and Sustainable Energy Reviews
Published by Elsevier
One of the concept that has been getting a lot of attention lately – and one intricately entwined with the renewable market – is that of the Smart Grid. The electrical grid today is largely dumb. To ‘educate’ the grid requires an intelligent networking infrastructure – perhaps the most sophisticated and intricate network of our time. The US energy grid is the source of one-third of America’s atmospheric CO₂. The economic stimulus package President Obama signed into law in 2009 includes $11 billion to build a bigger and more efficient electricity grid, with "smart" meters that help consumers track and manage their energy use (Burnham, 2009). The following are some components of the smart grid (Miller, 2009):

- **Advanced metering infrastructure (AMI):** AMI systems capture data, typically at the meter, to provide information to utilities and transparency to consumers.
- **Demand response (DR):** To date, consumers have used energy whenever they want to, and utilities have built the power plants and delivery infrastructure to support it, no matter what the cost or environmental impacts. If some electricity-consuming devices can be deferred to nonpeak time, everyone wins.
- **Critical peak pricing (CPP):** It allows customers to decide whether to pay more or not on the specific critical days, rather than paying an average cost. It helps balance cost and risk between the consumer and the utility, as well as providing a further incentive for consumers to reduce energy consumption.
- **Time-of-Use Pricing (TOU):** TOU is similar to CPP, except extrapolated across every hour for every day.

### 7. Rolling Energy Storage Units (RESU)

Rolling energy storage Units as has been described by Thomas Friedman in his book ‘Hot, Flat, and Crowded: Why We Need a Green Revolution and How It Can Renew America’ are plug-in hybrid cars that could store and sell energy back to the grid when necessary. He goes on to say that cars will not be called ‘cars’ in future, they would be called “Rolling Energy Storage Units”.

The recent stimulus bill passed by President Barack Obama is a major boost to plug-in vehicles. The $787-billion stimulus bill (HR 1, the American Recovery and Reinvestment Act) provides funds for a large range of transportation-related projects. It also made significant changes in the current plug-in vehicle tax credit program, including increasing the limit from a program total of 250,000 vehicles to a maximum of 200,000 plug-ins per manufacturer. The legislation that President Obama signed on February 17th invests more than $5 billion in plug-in vehicles and will increase the numbers and kinds of plug-in electric vehicles on the road. Eight major auto companies have announced (with delivery dates) the manufacture of highway-capable all-electric or plug-in hybrid vehicles. Therefore, the historic bill, which has a tax credit of up to $7,500 per vehicle, has the potential to stimulate the sale of more than one-and-a-half million plug-in vehicles. The President has called for one million plug-ins by 2015 (Friedman, 2008).

### 8. The Proposed System

#### 8.1 Introduction

Resource consumption and the delivery of energy have come a long way through various developments. Before the Industrial revolution, resources were assumed to be unlimited and were directly used to convert them to energy for household usage. Post-industrial revolution saw the increase in the consumption of natural resources and changed the pattern of human development. More centralized options were created for the delivery of the energy to the industries and human habitat. The system of energy delivery moved from an independent system to the grid system. The consumption of natural resources increased as the industries increased and so the living standards improved which created a multiplying effect on the consumption of natural resources. And it was not until 1970s that the affects of this development on environment were realized by many.

In the minds of many, 1970 marked the birth of the modern environmental movement, symbolized by the first observance of "Earth Day" in April of that year. As the second green generation begins, it seems wise to measure the environmental changes since 1970 (Jesse, Victor & Vernick., 1995). As explained above, the growth of energy consumption and delivery has seen three kinds of patterns, Refer to Figure 18:

- Yesteryears: Independent
- Today: Grid
- Tomorrow: Hybrid
- Near Future: Net Zero (off the grid, independent again)

Now, as we realize that natural resources are not unlimited and if compared to the present rate of consumption, there is a need for a system to be
developed which supports this fact and also supports a more sustainable environment and produces least hazards to the environment. There is a need to develop a hybrid system, which supports the benefits of both independent and grid. Independent, at a small scale but with larger numbers makes the system more sustainable and localized, whereas, Grid at large scale and small numbers creates economies of scale, Refer to Figure 20.

**Figure 20: From Independent to Grid to Hybrid**

During peak seasons of energy requirement, this stored hydrogen was converted into energy using Fuel cells. In this system hydrogen was used as a storage of energy. But, the problem faced by this system was that the amount of energy consumed by Fuel cell and electrolyzer was more than that produced by this system. The storage of energy was required for seasons when solar energy is less (for example, during winter season), Refer to Figure 21 & 22. Therefore this system was discarded, but this system has been included as an analysis.

**Figure 21: Comparison of AC Energy Requirement and Production for a 6 kW solar module in Houston (NREL, 2008)**

The next system that was studied integrated solar energy and biogas energy. The Biogas plant used organic waste coming out of retail center to produce energy. This has been integrated with solar energy to reduce the overall cost of solar energy and bring down the payback period of the system. Also, a new dimension has been added to this system and that is transportation. The excess energy produced by this system could be sold to plug-in electrical vehicles. The electric vehicles will act as Rolling Energy Storage Unit and the owners of these units will be able to buy and sell energy to & from the retail center. As we know, the goal of present administration of president Obama is to bring in 1 million plug-in vehicles on road by 2015 (CNN, 2009), which is a step forward to make all vehicles fossil fuel free. Therefore this system uses two energy storage systems, grid and plug-in vehicles. As has been used in our earlier system, energy will be sold to grid during Day time and will be bought back from Grid during night time, which makes grid as a Storage of Energy produced by this system.

**Figure 22: Off Grid Renewable Energy Production System using Hydrogen Storage**

**Figure 23: Proposed Off-Grid Renewable Energy Production System**
As has been realized earlier in this study, the rate of increase in energy consumption has been highest in the commercial sector. Realizing the impacts by mercantile sector on energy consumption, it is proposed to develop a prototype hybrid model (explained above) for a retail parking lot to observe the affects and identify strategies and challenges of adopting an off-grid renewable energy source for the mercantile sector, refer to Figure 23.

**Figure 24: Proposed System Integration with the Grid**

This study proposes a system which produces a part of its energy demand out of its own resources, refer to Figure 24. The renewable energy produced will reduce the load on public utilities, thereby reducing the amount of carbon emissions too. The proposed hybrid system that produces renewable energy treats the waste, additionally earning revenue by net metering or selling the excess energy to plug-in vehicles. This system when combined with bio gas plant, where the waste produced in the retail outlet could be processed to generate electricity. The system will absorb alternative renewable energy during the day and sell the excess energy to grid, whereas, during night, the retail center will buy back the energy from the grid. The excess energy can be sold to grid using net metering or dual metering or sold to charge plug-in vehicles to earn revenue.

<table>
<thead>
<tr>
<th>Table 5: Recommendations are for minimum maintained foot candle levels from curbline to curbline (IESNA, 1998)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Horizontal Illuminance (foot candles (fc))</td>
</tr>
<tr>
<td>Basic</td>
</tr>
<tr>
<td>Enhanced Security</td>
</tr>
</tbody>
</table>

8.2 The Theoretical Model

The theoretical model has been developed, with references from various sources. Assuming a retail shopping center of 50,000 sq ft, a virtual model has been developed. The number of cars in the parking lot have been considered as per Texas Accessibility Standards (TAS, 1999) & Code of Ordinances, City of Houston (CityofHouston, 2009) and the Lighting has been considered as per Illuminating engineering society of North Americas guidelines, Lighting for parking Facilities (IESNA, 1998). The following are the assumptions for the parking lot:

- Location of Shopping Center: Houston
- Store Size: 50,000 sq ft
- Parking Requirements: 4 parking spaces per 1000 sq ft of Gross Floor Area (GFA) of Commercial space
- Total Parking Requirement: 200 Cars

**Texas Accessibility Standards**

A model was developed for 200 Cars and the total area of parking lot calculated. The following were the dimensions that were referred from Texas Accessibility Standards (TAS, 1999).

**Code of Ordinances, City of Houston**

For the purpose of Parking lot dimensions, Chapter 26 (Section VIII, Division 2) has been referred for requirements of parking lot spaces.

**Figure 27: Typical Parking Lot design used for calculations for 200 cars**

(Area of Parking Lot for 200 cars as per above model (Refer to Figure 19) = 91,945 sq ft)

*Illuminating engineering society of North Americas guidelines, Lighting for parking Facilities (IESNA, 1998).* The dimensions in Figure 27 have been considered as per Texas Accessibility Standards.

For minimum maintained foot candles (fc) at the parking lot from curb line to curb line IESNA RP-20-
98 (Refer Table 5) have been considered. However, as per IESNA, if personal security or vandalism is likely and/or severe problem, a significant increase of the basic level may be appropriate.

**Required Lighting**

With a specification of 1 foot candles (fc) as the minimum value as per IESNA RP-20-98, many retailers prefer higher levels of illumination. Therefore, for the calculations of the system design we consider 1 fc as the minimum value of luminance or light intensity. As per uniformity standard of 15:1 for enhanced security, the minimum to maximum range of lighting intensity will be in the range of 1 to 15 fc as required by IESNA. Considering an average 7.5 fc for calculations the following calculations have been arrived for the lighting requirements of parking lot:

- Area of Parking Lot for 200 cars as per above model (Refer to Figure 19) = 91,945 sq ft
- 1 Foot Candle = 1 Lumen per sq. feet (sq ft)
- Power of light required (Lumens) = 91,945 sq ft X 7.5 fc = 689,588 Lumens

Refer the following table for calculations:

<table>
<thead>
<tr>
<th>Lamps</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp Make</td>
<td>GE</td>
<td>IQLED</td>
</tr>
<tr>
<td>Model</td>
<td>MH250W/H 75/PS</td>
<td>IQLED 01455</td>
</tr>
<tr>
<td>Lighting power per Lamp (Watt)</td>
<td>250</td>
<td>168.00</td>
</tr>
<tr>
<td>Lumens per Watt</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>Number of Lamps that will be required</td>
<td>46.00</td>
<td>55.00</td>
</tr>
<tr>
<td>Total Power Required (Kilo-Watt)</td>
<td>11.50</td>
<td>9.24</td>
</tr>
<tr>
<td>Energy Consumption (kWh/day)</td>
<td>138.00</td>
<td>110.88</td>
</tr>
<tr>
<td>Add 2.5% for other amenities (kWh))</td>
<td>3.450</td>
<td>2.772</td>
</tr>
<tr>
<td>Energy Consumption (kWh/day)</td>
<td>141.450</td>
<td>113.652</td>
</tr>
<tr>
<td><strong>Energy Consumption (kWh/year)</strong></td>
<td><strong>51629.250</strong></td>
<td><strong>41482.980</strong></td>
</tr>
</tbody>
</table>

**Sources of Energy**

There are four sources of energy being used by the system: Biomass, Solar Energy, Wind Energy and Geothermal Energy

**Biogas Plant**

Bio gas plant is considered for production of energy, using organic waste produced from the respective retail store. The data for the solid wastes coming out of retail centers have been taken from the survey commissioned by California Integrated Waste Management Board (CIWMB). This was study of waste disposal and diversion practices by key types of commercial establishment. A total of 371 commercial sites belonging to 14 industry groups participated from heavily urbanized areas of Los Angeles, Sacramento, San Diego, and San Francisco.

Diversion was documented through interviews with employees at the businesses and inspection of recycling and diversion systems during on-site visits. Disposal was quantified through measurement of waste accumulation in dumpsters or through interviews and examination of waste disposal records. Both disposal and diversion rates were determined, either on a per-employee basis (pounds per employee per year), or per room, per thousand square feet, or per visitor, as appropriate to the nature of the business.

**Table 7: Number of business sites included in the study (CIWMB, 2006)**

<table>
<thead>
<tr>
<th>Industry Group</th>
<th>Number of Participating Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast-Food Restaurants</td>
<td>24</td>
</tr>
<tr>
<td>Full-Service Restaurants</td>
<td>27</td>
</tr>
<tr>
<td>Food Stores</td>
<td>34</td>
</tr>
<tr>
<td>Durable Goods (Wholesale)</td>
<td>33</td>
</tr>
<tr>
<td>Non-Durable Goods (Wholesale)</td>
<td>30</td>
</tr>
<tr>
<td>Large Hotels</td>
<td>35</td>
</tr>
<tr>
<td>Building Material &amp; Garden</td>
<td>49</td>
</tr>
<tr>
<td>Retail, Big Box Stores</td>
<td>27</td>
</tr>
<tr>
<td>Retail, Other Stores</td>
<td>25</td>
</tr>
<tr>
<td>Anchor Stores at Shopping Malls</td>
<td>8</td>
</tr>
<tr>
<td>Other Parts of Shopping Malls</td>
<td>25</td>
</tr>
<tr>
<td>Public Venues &amp; Events</td>
<td>32</td>
</tr>
<tr>
<td>Large Office Buildings</td>
<td>29</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>378</strong></td>
</tr>
</tbody>
</table>
Figure 28: The Proposed Theoretical Model and its Integration

1. Biogas Plant
2. Biogas Generator
3. Utility Meter
4. Wind Turbines on Parapet walls on Shopping Center
5. Solar Panels on Light Poles
6. DC-AC Inverter
7. DC Loads
8. Over-current Protection/ System Disconnect
9. PV Charge Controller
10. DC Loads

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Published by Elsevier
Disposed waste was characterized by obtaining into 74 material categories, broadly divided into lumber, food, leaves and grass, pruning and trimmings, concrete, carpet, recyclable papers, gypsum board, flat glass, cardboard, ferrous metal and plastic bottles and containers, tin/steel cans, aluminum cans. Out of the 14 industry (Refer table 7) types surveyed by CIWMB, two relevant industry types, i.e. Anchor stores at shopping malls and other parts of shopping malls (Refer table 8) were selected for calculations. Also, as the data of waste was available in weight, it was easy for calculations and analysis of the data, because the energy conversions use weight of the waste material for energy production calculations.

As per the above data, 44 tons of paper and organic waste is generated by Anchor stores at shopping malls, 83% of which consist of paper waste (Refer table 8). Whereas 42 tons of paper and organic waste is generated in other parts of shopping malls (not including anchor stores), which has an approximate ratio of 60:40 for paper and organic waste. This means that per day waste generated by these two 50,000 sq ft stores will be in the range of 0.11 to 0.12 tons/day.

Each ton of dry material produces 465 m3 of bio gas. Some digesters even produce up to 20-800 m3 of bio gas per ton waste. (Zhang, El-Mashad et al., 2007). Therefore, considering 0.12 and 0.11 tons/day of waste for Anchor Malls and Other Mall areas, the bio gas produced per day would be 56 m3 and 52m3 approximately. 0.6 m3 of biogas produces 1.0 kWh of electricity (GEDA, 2008). Therefore, 93.42 and 87 kWh of energy per day will be generated at anchor malls and other malls areas respectively.

For the case model, the following are the energy consumption calculated for LED (Light Emitting Diode) and Metal halide lamps:

- LED Lights: 113 kWh/day
- Metal Halide: 141.45kWh/day

Energy production by Biogas will not be sufficient in both the cases, therefore we need integrate an alternate renewable energy source to the system. It could be Solar, Wind or Geothermal energy, that will need to produce the following amounts of energy per year:

Table 9: Energy to be produced by Solar, Wind or Geothermal sources of energy

<table>
<thead>
<tr>
<th>Lamp</th>
<th>Anchor Store Malls</th>
<th>Other Parts of Shopping Mall</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td>7385 kWh/year</td>
<td>9710 kWh/year</td>
</tr>
<tr>
<td>Metal Halide</td>
<td>17531 kWh/year</td>
<td>19856 kWh/year</td>
</tr>
</tbody>
</table>

Solar Energy System

The total production requirement as per the above calculation for the solar energy system is as per Table 9. The solar calculations have been done with the help of PV Watts (version 1), a performance calculator for grid connected PV Systems (a calculator has been developed by National Renewable Energy Laboratory, United States of America). As per PV Watts (version 1) the following is the sizing of solar panels:

Table 10: Solar Panel Sizing (DC Rating)

<table>
<thead>
<tr>
<th>Stores</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Store Malls</td>
<td>14.5 kW</td>
<td>6 kW</td>
</tr>
<tr>
<td>Other parts of Mall</td>
<td>16.5 kW</td>
<td>8 kW</td>
</tr>
</tbody>
</table>

Assuming the following, monthly performance of each panel has been calculated:

- Station Identification: Houston, Texas
- PV System Specifications
  - DC to AC factor: 0.77
  - Array Type: Fixed Tilt

The monthly generation as per the PV watts calculator follow the same profile (Refer to the Monthly performance of 6kW Solar panel in Figure 30)

Figure 30: Monthly performance of 6 kW Solar panel (DC Rating) calculated as per PV Watts (NREL, 2008)

As per figure 30, there will be deficiency during the months of January, February, November and December, but the system will produce excess energy
during other months. The excess energy could be sold to grid, which will earn extra revenue for the store.

Considering REC SCM 215 module produced by REC, that has a minimum output of 212 kW per panel and the area per panel is 17.77 sqft. As per this we will require following number of panels of 212kW each:

Table 11: Number of Solar Panels required  
<table>
<thead>
<tr>
<th>Stores</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Store Malls</td>
<td>67</td>
<td>28</td>
</tr>
<tr>
<td>Other parts of Mall</td>
<td>76</td>
<td>37</td>
</tr>
</tbody>
</table>

The weight of each panel is 44 pounds. Lamp posts which can take this weight plus the weight of the lamps need to be used. Available number of lamp posts are (assuming 2 light fixture per lamp post, Refer Table 6 for lamp fixture calculation) 23 and 28 for Metal Halide and LED Lamps.

Each of the above panel costs approx $1000 after discount and the approx total cost of the above system (including the module, inverter, installation and battery cost) is as follows:

Table 12: System Cost of Solar Energy required  
<table>
<thead>
<tr>
<th>Stores</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Store Malls</td>
<td>$102,127</td>
<td>$43,020</td>
</tr>
<tr>
<td>Other parts of Mall</td>
<td>$115,672</td>
<td>$56,564</td>
</tr>
</tbody>
</table>

Assuming grid electricity rate in 2008 were 10.65 cents/kWh for commercial (EIA, 2009). The annual total energy requirement for metal halide and LED lamps is 51,629 kWh and 41,483 kWh. If costed as per present rate, the electricity consumption cost/year will be $5498/year for Metal Halide and $4418/year for LED Lights. As per this the payback period for commercial will be as per Table 13,

Table 13: Payback Period for various Lamps  
<table>
<thead>
<tr>
<th>Stores</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Store Malls</td>
<td>22 years</td>
<td>14 years</td>
</tr>
<tr>
<td>Other parts of Mall</td>
<td>24 years</td>
<td>17 years</td>
</tr>
</tbody>
</table>

Whereas, Tables 12 & 13 do not consider:
- Subsidies and Rebates available for renewable energy sources
- Financial support systems such as carbon trading and net metering
- Revenue from excess energy sold to Rolling Energy Storage Units
- Price escalation of electricity per year.

If the above is further considered, the payback period could be reduced significantly. As of today the payback period of Solar Energy may extend to up to 30 years (Fu & Ding, 2009). Considering this, the proposed system will considerably help in reaching Grid parity at a very earlier stage and will be a profitable for end users.

Wind Energy

The calculations in this section have been done based on the assumption that the above solar panels are replaced with wind turbines.

The three wind turbine models from Aerovironment, Aerotecture and WARP were compared to choose the wind turbine to be used for the model. On preliminary comparison based on the specifications sheets of the above turbines, it was found that AVX 1000 was a better choice for the proposed theoretical model (Refer to Table 14). However, further investigation is required in indentifying the best turbine out of these three.

Table 14: Comparison of the three turbine models discussed in the literature review section  
<table>
<thead>
<tr>
<th></th>
<th>Aerovironment (AVX 1000)</th>
<th>Aerotecture (610V Aeroturbine)</th>
<th>WARP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>1kW</td>
<td>1kW</td>
<td>upto 4000 kW</td>
</tr>
<tr>
<td>Horizontal Axis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertical Axis</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Width</td>
<td>6 feet</td>
<td>6 feet</td>
<td>3 feet to 10 feet</td>
</tr>
<tr>
<td>Height</td>
<td>8.5 feet</td>
<td>10 feet</td>
<td>varies</td>
</tr>
<tr>
<td>Start up speed</td>
<td>5 mph</td>
<td>6.3 mph</td>
<td>Not Available</td>
</tr>
<tr>
<td>Survival Wind Speed</td>
<td>120 mph</td>
<td>90+ mph</td>
<td>Not Available</td>
</tr>
</tbody>
</table>
Considering the lowest annual average wind speeds, the total wind energy production can be calculated. The power curve of a wind turbine (Refer to Figure 31) is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds. If we consider Houston which has an average wind speed of 7.6 miles per hour, the power out of this wind turbine would be less than or around 50 watts, which seems to be quite less. Wind energy calculations have been done using windcad performance models developed by Bergey wind power (Bergey, 2008). As per above, the number of wind turbines that will be required are as follows:

**Table 16: Number of AVX1000 rooftop wind turbines required**

<table>
<thead>
<tr>
<th>Stores</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Store Malls</td>
<td>41</td>
<td>17</td>
</tr>
<tr>
<td>Other parts of Mall</td>
<td>46</td>
<td>22</td>
</tr>
</tbody>
</table>

Aerovironment has installed 20 units of its AVX 1000 rooftop turbines on a building at Boston's Logan International Airport (Boston has an average wind speed of 12.4 mph (NCDC, 2008). 20 units costed $140,000 (Refer to Figure 32), therefore the approximate cost of one wind turbine is 7000$. Assuming this rate, the cost of total wind turbine system (including, turbines, inverter, charger and installation) will be:

**Table 17: Approximate total system cost of wind turbines**

<table>
<thead>
<tr>
<th>Stores</th>
<th>Metal Halide</th>
<th>LED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Store Malls</td>
<td>$326,363</td>
<td>$135,321</td>
</tr>
<tr>
<td>Other parts of Mall</td>
<td>$366,163</td>
<td>$175,122</td>
</tr>
</tbody>
</table>

As per Figure 33, Houston comes under class 1 which is the lowest. Class 4 and above are considered good resources. In general, at 50 meters, wind power class 4 or higher can be useful for generating wind power with large turbines. Sites in class 3 are candidates for wind farm development, although, given the advances in technology, a number of locations in the class 3 areas may become suitable for utility-scale wind development. (SECO, 2008)

Therefore, it would be advisable to opt for combination of Solar-Wind or Biogas-Wind systems in these areas if wind energy has to be taken up for the projects here. Since this area gets the lowest wind speeds, it would be advisable to evaluate this option in detail and if required wind energy can be opted out and a Solar-Biogas option could also be worked out if found feasible.

**Geothermal Energy**

Geothermal Power plant cost has been calculated as per the literature review. Assuming we replace solar and wind energy systems with geothermal energy systems, the power production requirement would be as per table 9 above.
As per the geothermal resource map (Refer to Figure 34) we require a depth of geothermal resource is 13,000 feet @ 300-450 degree Fahrenheit. We will require three wells, each for (Refer to Figure 35):

- Exploratory Well
- Injection Well
- Production Well

Figure 34: Geothermal Resource Map (SECO, 2008)

Figure 35: Development Sequence of Geothermal Plant (USDOE, 2008c)

Figure 34 summarizes depth and cost data representative of geothermal wells completed between 1997 and 2000 in Central America and the Azores (Lovekin et al. 2004). To escalate these prices to account for inflation, the costs of all wells have been escalated to equivalent U.S. dollars as of 1 July 2003, using the Producer Price Index. Figure 36 is a curve fit to the data in Figure 35 (Bloomfield & Laney, 2005)

<table>
<thead>
<tr>
<th>Depth Interval (ft)</th>
<th>Number of Wells</th>
<th>Total Footage</th>
<th>Total Cost (SK)</th>
<th>Average Depth (ft)</th>
<th>Average Cost/Well (SK)</th>
<th>Median Cost/Well (SK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4,249</td>
<td>1</td>
<td>679</td>
<td>280</td>
<td>679</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>1,250-2,499</td>
<td>8</td>
<td>15,692</td>
<td>10,415</td>
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Figure 36: Geothermal Drilling Costs from 1997 to 2000 for Central America and the Azores (Bloomfield & Laney, 2005)

Drilling costs (Bloomfield & Laney, 2005) in Texas can be calculated from the graph below:

Figure 37: Geothermal Drilling costs in Texas (Bloomfield & Laney, 2005)

As per the above graph, the drilling cost would be around $3,000,000-4,000,000 per well (Refer to Figure 35). And three wells will cost in a range of 9,000,000 to 12,000,000 dollars which is approximately 25 to 200 times the cost of the total wind turbine and solar energy systems. It could be inferred that Geothermal is not feasible for small scale plants.


The financial support systems is a term which has been used in various journal papers and Books in different contexts, but, here the term means a set of financial programs that are intended to raise funds for or financially support the proposed system. This can include the following:

- Emissions Trading
- Net Metering
- Renewable Energy Incentives

The above financial support systems have been explained below for details.
Emissions Trading
As discussed, there is an urgent need to control atmospheric CO2 emissions, primarily resulting from the burning of fossil fuels. Carbon Trading is a market-based mechanism for helping mitigate the increase of CO2 emissions in the atmosphere. Carbon trading markets are developed that bring buyers and sellers of carbon credits together with standardized rules of trade (Carbon Trading, 2008). A challenge faced by Carbon Trading is the fall in CO2 price which is a risk to ‘green’ investment. Recently, the price of carbon dioxide in the European Union fell down so low that it no longer provides an incentive to low carbon development. As has the price of oil fallen drastically so has the carbon price, which has again compounded by recession as companies produce less, they need fewer permits (FT, 2009). Such challenges need to be tackled and a framework needs to be developed so that such instances do not challenge the low carbon development in future.

Net Metering
As per the U.S. Department of Energy (USDOE), net metering is a policy that allows homeowners to receive the full value of the electricity that their solar energy system produces. Under federal law, utilities must allow independent power producers to be interconnected with the utility grid, and utilities must purchase any excess electricity they generate.

The excess electricity is then fed into the utility grid and sold to the utility at the retail rate (US DOE 2006). At the end of the month, if the customer uses more electricity than the PV system generates, the customer pays the difference. The billing period for net metering may be either monthly or annually (USDOE, 2006). Some utilities are opposed to net metering because they believe it may have a negative financial impact on them. However, a number of studies have shown that net metering can benefit utilities. These benefits include reductions in meter hardware and interconnection costs, as well as in meter reading and billing costs. Grid-connected PV systems can also help utilities avoid the cost of additional power generation, increase the reliability and quality of electricity in the grid, and produce power at times of peak usage, when utility generation costs are higher and they often need the extra power (USDOE, 2006).

Renewable Energy Incentives and Grants by Federal and State Governments
As per the Database of State Incentives for Renewable Energy (DSIRE), presently there are various rebate and grant programs being provided in various states of the United States. There are financial incentives available in various states of the United States including tax credits like personal tax, corporate tax, sales tax, property tax, rebates, grants, loans, industry support programs, bonds and production incentives available from both federal and state governments (DSIRE, 2008 and Golove, 2004).

10. Conclusion and Further Research
This paper develops a theoretical model and identifies strategies and challenges of adopting an off-grid renewable energy source for the mercantile sector at the defined meso level. Various strategies in the developed theoretical model have been analyzed for off-grid renewable energy source, however there are various challenges involved in implementing this model. The challenges have been summarized as follows:

- **Grid Parity:** Although this system will help in reaching grid parity at an earlier stage, still, the cost of alternative renewable energy sources need to further reduced to bring it to Grid Parity.
- **System Efficiency:** System efficiencies need to be increased, like solar cells, biogas plant, batteries used in vehicles need to be increased.
- **Hybrid Systems:** Systems need to be made hybrid that bridges the current grid dependent system and a grid-independent (off grid, or net zero) goal. This will further help in energy storage and bring down the cost of renewable energy storage.
- **Integrated Systems:** More Integrated systems using two or more renewable energy sources, that can work together depending on the available resources bring down the cost of renewable energy. The proposed system uses Biogas and Solar Energy sources. The Biogas energy will vary in a particular region depending on the organic waste produced by different retail centers in that region, but the use of biogas plant has further brought down the cost of Solar energy.
- **Available Technologies:** There are renewable technologies available and the use of these technologies needs to be enhanced.
- **Awareness:** Awareness of benefits for the acceptance of alternative renewable energy sources need to increased. Individual system size limit need to be increased in various states.

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to make the systems more beneficial to the consumers and utilities. Although, 10 states (including Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont) in United States have begun Carbon trading since September 2008 in the power sector, it needs to be implemented on a large scale in other sectors too (WRI, 2008). There are number of challenges to the personal carbon trading in cost effective and desirable policy option (Defra, 2008). Although, under federal law, utilities must purchase any excess electricity they generate, some utilities are opposed to net metering because they believe it may have benefit utilities. There is an awareness required to be generated among utilities of the benefits of net metering (USDOE, 2006)

There have been various support systems that have already been developed or are in a developing stage in the United States for the use of alternative renewable energy sources. However, there are still significant challenges involved in implementing off-grid renewable energy sources at a large scale in United States. Although, there are technologies available, further research is also required to increase the efficiency of the available technologies to make them more cost efficient to reach the Grid Parity. The study gives an in depth analysis of the strategies and challenges of adopting an off-grid renewable energy source. A multiplying effect of CO₂ emissions reduction will be analyzed on a global scale and the challenges involved will create further studies to be taken up.
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           United States of America,