Feasibility of an Off-Grid Renewable Energy Source for the Mercantile Sector

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Abstract

An increased CO$_2$, 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) at the mezzo level. A theoretical model for off-grid renewable energy source considering a parking lot of a retail outlet was developed. A proposed physical model, future work, should be able to test the assumptions and hypothesis of the theoretical model presented.

The proposed hybrid system uses two or more alternative renewable energy sources. 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 CO$_2$ emission from the grid providers and 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

1. Introduction

Projections of energy consumptions as per Annual Energy Outlook, by Energy Information Administration (EIA, 2009a), for the year 2009 suggest 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 Figure 1. On analyzing the percentage, the contribution of energy consumption in residential and transportation will remain the same whereas industrial energy consumption contribution will drop.

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 CO$_2$ 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).
These opportunities involved in delivering sustainability (energy efficiency) in the mercantile sector 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 2. We argue that work to reduce energy consumption and emissions generation needs to be done at all scales. 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.

This study makes the argument for the feasibility of a hybrid system using alternative renewable energy, integrated with a local bio gas plant, which treats waste to produce electricity. The proposed hybrid system uses alternative renewable 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. Strategies for Emission Reduction

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). Fernández-Solís (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 3.

![Framework of Assumptions and Facts](image)

**Figure 3: Need for a Common Currency (Fernández-Solis, 2008b)**

2.1 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. Modern technology, using renewable energy sources, has made the financial cost of production relatively constant throughout the world.

2.2 Grid Parity

Grid parity means that the cost of producing solar energy would be comparable to obtaining electricity from fossil fuels (FT, 2008). Refer Figure 4. 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 (Reuters, 2007).

![Path to Grid Parity](image)

**Figure 4: Path to Grid Parity (BP Solar, 2008)**
3. 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 Biomass, Wind Energy, Solar Energy, Geothermal Energy and Hydroelectric.

![Figure 5: Renewable Energy Consumption by Energy Use Sector, 2003-2007 (EIA, 2007)](image)

Figure 5 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. This study analyzes various alternative renewable energy sources (as identified by Energy Information Administration) best suited for the mercantile sector. The renewable energy sources identified and analyzed in this study include Biomass, Wind Energy, Solar Energy and Geothermal Energy.

3.1 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).

3.2 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 (EIA:USDOE, 2008).

![Figure 6: Aerotecture Wind Turbines on roof](image)

![Figure 7: Aerovironment Wind Turbines on Roof Tops (RenewableEnergyAcess, 2007)](image)
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. Recently, there have also been innovations in the design of small turbines that can facilitate their deployment in urban environments. (Miles, 2006).

**AeroVironment Wind Energy System:** The AVX400 (see Figure 7) 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).

**Figure 8: Wind Amplified Rotor Platform** 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 (see Figure 8) 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).

**3.3 Solar Energy**
Photovoltaic cells convert sunlight directly into electricity and are made of semiconductors such as crystalline silicon or various thin-film materials (USDOE, 2007). 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 10) 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. The PV system should supply at least as many kilowatt-hours (under a variety of lighting conditions) as the total electric needs. (SESCI, 1997)
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):

(i) The conversion efficiency of the photovoltaic system;
(ii) The amount of illumination (insulation) that the system receives
(iii) The manufacturing technology that was used to make the photovoltaic (solar) cells.

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) (years)</th>
<th>Energy Used 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>

3.4 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

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 ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration and resource assessment</td>
<td>$ 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>
</tbody>
</table>
Total development cost | $ 4,000

Geothermal electricity production is capital intensive; over 75 percent of the generation costs are fixed costs related to capital investment. 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). 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. 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.

4. 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.

4.1 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).

4.2 New trends and innovation in Parking lot lighting

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). The U.S. Department of Energy and its partners are working to expand market introduction of LED (light emitting diode) parking lot lighting. (USDOE, 2008e). Table 3 compares LED parking lot lighting technology to metal halide (standard parking lot lighting) (USDOE, 2008e):

| Table 3: Comparison of Metal Halide and LED Lights (USDOE, 2008e) |
|---------------------------------|------------------|------------------|
| **Product Feature** | **Metal Halide** | **LED** |
| Life | Limited life (approx 12,000 hours) | Expected long life (50,000+ hours) |
| Maintenance | Potentially high maintenance cost | Very low maintenance expected |
| Environmental | Mercury creates disposal issues | Contains NO mercury |
Cost/Payback

<table>
<thead>
<tr>
<th>Stable</th>
<th>Potentially long payback</th>
</tr>
</thead>
</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. (Energy Star, 2008)

5. Smart Grid

United States of America is increasingly held back by an outdated power delivery infrastructure. The financial consequences of interruptions are growing into an enormous threat. 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 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. 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.

6. 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. 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. The President has called for one million plug-ins by 2015 (Friedman, 2008).

8. Research Method

The study proposes to develop a theoretical off-grid renewable energy model that is sustainable (scalable + has long term horizon) and economically feasible for making a mercantile parking lot partially self sufficient in energy. The research follows a Quantitative Methodology and involves the identification of characteristics and the possible relation of two phenomena, i.e. Sustainability and Economic Feasibility. The Research started with the review of the peer reviewed journal papers regarding the carbon dioxide emissions in United States of America, which also involved studying the emissions data by United States. A theoretical model with the help of literature review was then derived that included the three feasible renewable energy sources identified for the case location Houston, Texas. Out of the four, three feasible energy sources have were used in the theoretical model were biomass, wind energy and solar energy.
Cost and energy production data by various systems was calculated. The payback period was calculated with present energy cost, using the following formula (Hansen, 2004):

| Payback Period = \[
\begin{array}{c}
\text{Initial Investment} \\
\text{Projected Annual Energy Savings at current prices}
\end{array}
\] |

Note that this calculated payback period does not consider the revenue from various available subsidies, tax incentives, rebates and sale of energy. Energy Integration has been done by using flowcharts of the energy models and annual resource availability has been determined by using pie charts, resource maps and line charts. Whereas, Economic feasibility has been determined by using comparative bar charts of payback period of various energy models analyzed. The analysis was followed by determination of significance of the findings in relation to the research problem, hypothesis and literature review. This followed the Conclusion and identification of further research required.

9. The Proposed System

9.1 Introduction

The system of energy delivery has 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. The growth of energy consumption and delivery has seen three kinds of patterns, i.e., Independent (Yesteryears), Grid (Today), Hybrid (Tomorrow) and Net Zero in Near Future (off the grid, independent again).

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. The 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 9.

![Figure 9: From Independent to Grid to Hybrid](image)

The proposed system integrates solar energy and biogas energy. The Biogas plant uses 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. 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. This system uses two energy storage systems, grid and plug-in vehicles. The energy produced by this system will be sold to grid during day and will be bought back from grid during night time, which makes grid as a Storage of Energy.

Figure 10: Proposed Off-Grid Renewable Energy Production System

This study proposes a system which produces a part of its energy demand out of its own resources, refer to Figure 10. 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 (Refer Figure 11). This system when combined with bio gas plant, where the waste produced in the retail outlet could be processed to generate electricity.

Figure 11: Proposed System Integration with the Grid

9.2 The Theoretical Model

The theoretical model was developed (Refer Figure 13), with references from various sources. Assuming a retail shopping center of 50,000 sqft, a virtual model was developed. The number of cars (Refer Figure
12) 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).

![Figure 12: Typical Parking Lot design used for calculations for 200 cars](Image)

(Area of Parking Lot for 200 cars as per above model (Refer to Figure 21) = 91,945 sq ft)

**9.3 Lighting Energy Requirements**

For the calculations of energy, only lighting energy has been considered, which is the major source of energy consumption in the parking lot. For the calculations of the system design we consider 1 fc as the minimum value of luminance. As per uniformity standard of 15:1 for enhanced security (Refer Table 5), the minimum to maximum range of lighting intensity will be in the range of 1 to 15 fc as per IESNA. Considering an average 7.5 fc for calculations the following calculations have been arrived for the lighting requirements of parking lot The power of light required will be 689,588 Lumens, i.e. 91,945 sq ft X 7.5 fc. Refer Table 4 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>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>
Figure 13: Theoretical Model

- DC Loads
- PV Charge Controller
  - Over-current Protection/ System Disconnect
  - Solar Panels on Light Poles
- Biogas Generator
- DC-AC Inverter
- Utility Meter
- Biogas Plant
- Wind Turbines on Parapet walls on Shopping Center
9.4 Sources of 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, 2006). As per calculations from the data available from CIWMB 93.42 and 87 kWh of energy per day will be generated at anchor malls and other malls areas respectively. 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, which will need to produce the of energy per year as in Table 5:

<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 6. 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>
<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 monthly performance of each panel calculated for the city of Houston and the monthly generation as per the PV watts calculator follow the same profile (Refer to the Monthly performance of 6kW Solar panel in Figure 14). 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.

**Figure 14:** Monthly performance of 6 kW Solar panel (DC Rating) calculated as per PV Watts (NREL, 2008)

Considering REC SCM 215 module (area per panel =17.77 sq ft) the number of panels of 212kW have been calculated (Refer Table 7):
Table 7: 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>

Each 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 per Figure 8.

Table 8: 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 9.

Table 9: 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 8 & 9 do not consider:

- Available Subsidies and Rebates
- 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 (Aerovironment, 2009), Aerotec 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 Figure 13). However, further investigation is required in indentifying the best turbine out of these three.

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 quiet 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 in Table 10:

Table 10: 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 $140,000, therefore the approximate cost of
one wind turbine is 7000$. Assuming this rate, the cost of total wind turbine system (including, turbines, inverter, charger and installation) will be as per Table 11:

<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>

Under wind power classification Houston comes under class 1 which is the lowest. Class 4 and above are considered good resources. (SECO, 2008). Therefore, it would be advisable to opt for combination of Solar-Wind or Biogas-Wind systems in areas of Class 1 if wind energy has to be taken up for the projects here.

**Geothermal Energy:** Geothermal Power plant cost has been calculated as per the literature review. Assuming that we replace solar and wind energy systems with geothermal energy systems, the power production requirement will be as per Table 8 above. As per the geothermal resource map available at SECO (2008) we require a depth of geothermal resource is 13,000 feet @ 300-450 degree Fahrenheit. We will require three wells, Exploratory Well, Injection Well and Production Well (USDOE, 2008c). As per cost data from Bloomfield & Laney (2005) representative of geothermal wells completed between 1997 and 2000 in Central America and the Azores, drilling costs can be calculated. The drilling cost will be around $3 to 4 million per well. And three wells will cost in a range of 9 to 12 million US 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.

10. **Financial Support Systems**

The financial support systems is a term which has been used in various journal papers and books in different contexts, but, here the term refers to a set of financial programs that are intended to raise funds for or financially support the proposed system. This can include Carbon trading, Net metering, and Renewable energy incentives

**Carbon Trading:** 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. 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.

**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, that include 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).
11. Conclusions 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 be 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 increase in various states 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 the 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 also (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 the United States. Although, there are technologies available, further research is 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.
References


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