# II

# RESEARCH ARTICLES

# FEASIBILITY OF AN OFF-GRID RENEWABLE ENERGY SOURCE FOR THE MERCANTILE SECTOR

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## ABSTRACT

*Increased $CO_2$, a Greenhouse Gas (GhG), emission and its accumulation in the atmosphere is a major climatic concern, creating 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 number), at mezzo levels (mercantile stores which are large in numbers and relatively large consumers in scale) and at micro scales (individual dwelling units which are very large in number but relatively small on 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 an off-grid renewable energy source considering a parking lot of a retail outlet was developed. In future work, a proposed physical model 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 $CO_2$ emissions from the grid providers, thus bridging the current grid dependent system and a grid-independent (off grid, or net zero) goal.*

## KEY WORDS

$CO_2$ emissions, energy consumption, mercantile sector, net metering, renewable energy, sustainable development

## INTRODUCTION

Projections of energy consumption as per Annual Energy Outlook, by the Energy Information Administration (EIA, 2009a), for the year 2009 suggest that energy consumption in the commercial sector in United States of America is growing at a high rate and will surpass residential energy consumption by 2030 (EIA, 2009a), (see Figure 1). On analyzing the percentages, the contribution of energy consumption in residential and transportation will remain the same, whereas the industrial energy consumption contribution will drop.

Initiatives by various organizations in promoting sustainable construction in retail have gained momentum. John Lewis Partnership, one of the leading retail giants in the United Kingdom has planned to reduce $CO_2$ emissions as a percentage of 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 for delivering sustainability (energy efficiency) in the mercantile sector exist at different scales. Large power plants are at a macro scale but are relatively few in number; regional malls and retail centers are at the mezzo scale with relatively large numbers; dwelling units exist at a relatively small scale with relatively large numbers; (see Figure 2). We argue that work to reduce energy consumption and emissions generation needs to be done at all scales. Increased $CO_2$, a Greenhouse Gas (GhG), emission and accumulation in the

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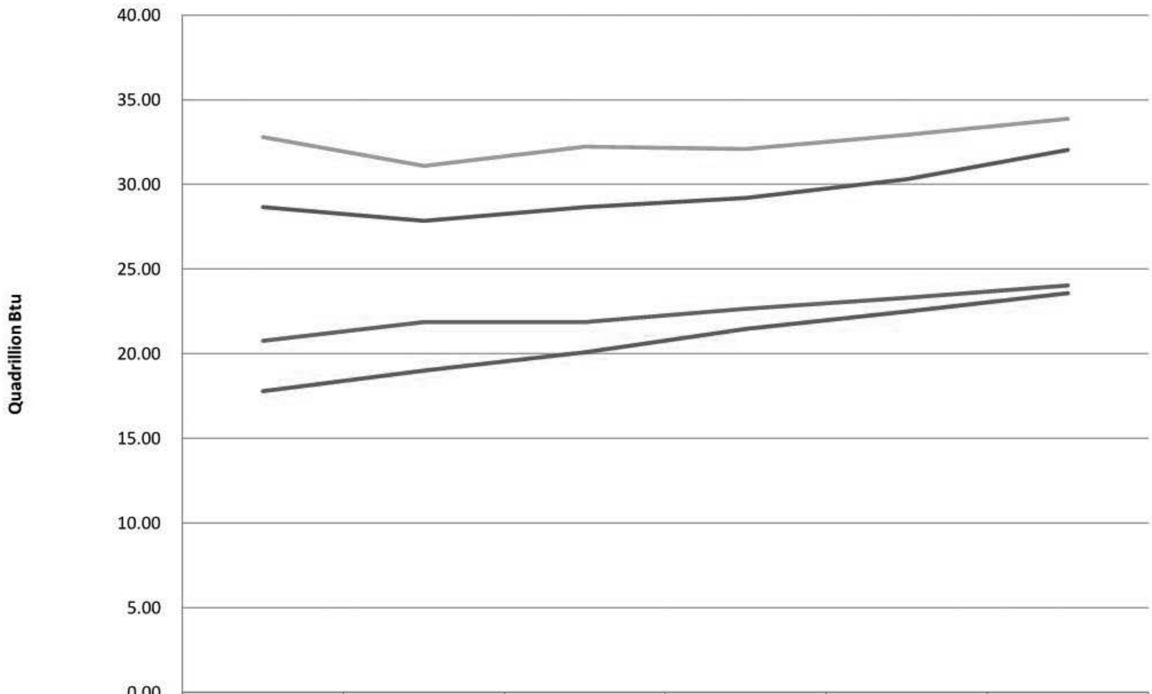
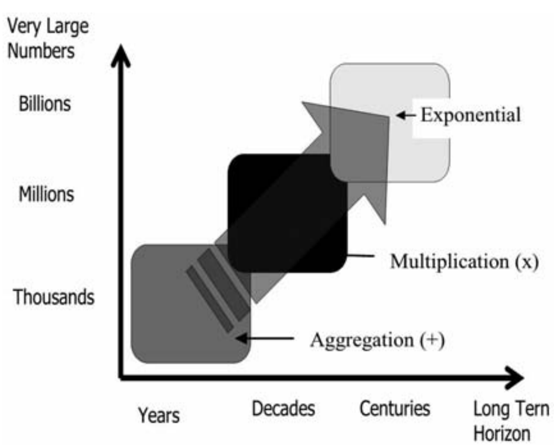
**FIGURE 1.** Energy consumption projections for residential, commercial, industrial and transportation sectors from 2006 to 2030 (EIA, 2009a).




| | 2006 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|
| Residential | 20.77 | 21.88 | 21.87 | 22.67 | 23.31 | 24.05 |
| Commercial | 17.79 | 19.01 | 20.10 | 21.46 | 22.49 | 23.59 |
| Industrial | 32.81 | 31.10 | 32.24 | 32.09 | 32.93 | 33.87 |
| Transportation | 28.65 | 27.86 | 28.66 | 29.22 | 30.32 | 32.05 |

**FIGURE 2.** Scales of number in a time line (Fernandez-Solis, 2007b).




atmosphere is a major climatic concern, thus creating an urgent need to control its rate of growth with the goal to reduce or reverse the growth.

This study argues 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 excess energy can be sold to the 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. The setting for this study is a commercial facility that requires on-site parking lot illumination (mezzo scale); the aim is to produce a hybrid system that bridges the current grid dependent design and a grid independent (off-grid or net zero) sustainable design target.

## 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), points toward an 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 (e.g. fossil fuels), whereas there is a limited flow of capital from the artificial world (Figure 3).

### *Energy Currency*

Turnbull (1983) argues that energy currency is a concept used in the creation of an energy economy. Energy as a currency in an energy economy works like 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.

### *Grid Parity*

Grid parity means that the cost of producing one form of renewable energy, solar energy, would be comparable to obtaining electricity from fossil fuels (FT, 2008) (see Figure 4). It is being achieved first in areas with abundant sun and high costs for

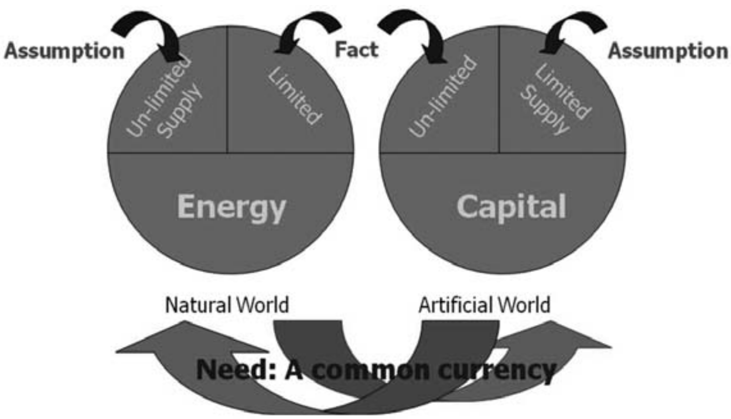



**FIGURE 3.** Need for a common currency (Fernández-Solís , 2008b).

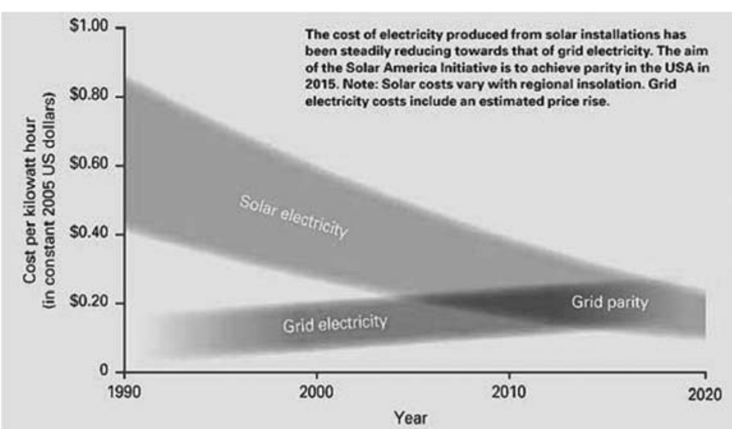



**FIGURE 4.** Path to grid parity (BP Solar, 2008).

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).

## RENEWABLE ENERGY SOURCES

According to the 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 suggests that the consumption of renewable energy in the commercial sector has been nearly constant, whereas there has been growth in the consumption of renewable energy sources in the residential sector. This suggests a need for more efficient systems for the commercial sector. This study analyzes various alternative renewable energy sources (as identified by the Energy Information Administration) best suited for the mercantile sector. This study identifies and analyzes four renewable energy sources, including Biomass, Wind Energy, Solar Energy and Geothermal Energy.

### *Biomass*

Biogas is a clean environment friendly fuel that contains about 55–65% methane (CH4), 30–45% carbon dioxide ($CO_2$), traces of hydrogen sulfide ($H_2S$) 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).

### *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).

There are several problems with conventional systems including noise, danger to birds and the efficient conversion 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

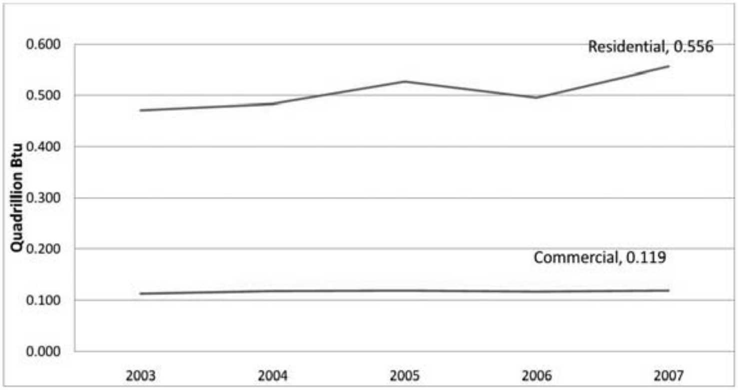
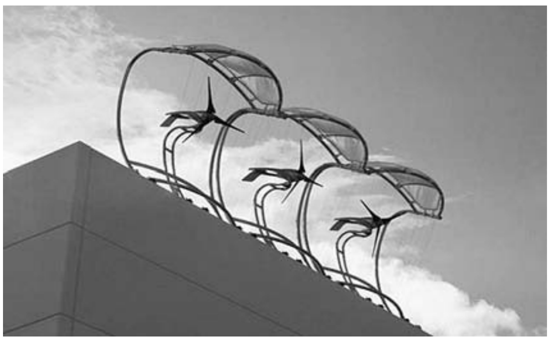



**FIGURE 5.** Renewable energy consumption by energy use sector, 2003–2007 (EIA, 2007).


**FIGURE 6.** Aerotecture wind turbines on roof tops and there integration with Solar Panels (Aerotecture.com, 2008).

**FIGURE 7.** Aerovironment wind turbines on roof tops (RenewableEnergyAcess, 2007).



capacity, which, they point out, is roughly comparable to photovoltaic systems, and cheaper than building-integrated PVs (Gordon, 2006).

***Aerotechture 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 6 shows the system mounted horizontally on a building. (Aerotecture.com, 2008).

***Wind Amplified Rotor Platforms (WARPTM).*** The 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).

### *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 (see 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).

**FIGURE 8.** Wind amplified rotor platform.


***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 engineering studies from 2004. The value of EPBT is dependent on three factors (USDOE, 2006b):

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

Research from 2004–05 has established battery-free, grid-tied EPBT system values for several photovoltaic module technologies (see 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).

### 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. This 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, where temperatures hotter than the sun's surface are continuously produced 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.*** Getting the plant sited, constructed, and put online is significantly more costly than that for fossil-fueled power plants. Development costs of a geothermal facility, in contrast, represent two thirds or more of total costs. The average development costs for a typical 20 MW power plant are shown in Table 2. Actual costs can vary based on factors such as time delays, geology, environmental restrictions, project size, and transmission access.

Geothermal electricity production is capital intensive; over 75 percent of the generation costs

**TABLE 1.** System energy payback times for several different photovoltaic module technologies (USDOE, 2006b).

| Cell Technology | Energy Payback Time (EPBT) (years) | Energy Used Compared to Total Generated Energy (%) |
|---|---|---|
| Single-crystal silicon | 2.7 | 10.0 |
| Non-ribbon multicrystalline silicon | 2.2 | 8.1 |
| Ribbon multicrystalline silicon | 1.7 | 6.3 |
| Cadmium telluride | 1.0 | 3.7 |

**TABLE 2.** Typical geothermal power plant development costs (USDOE, 2008c)

| Development Stage | Cost ($/KW) |
|---|---|
| Exploration and resource assessment | $400 |
| Well field drilling and development | $1,000 |
| Power plant, surface facilities, and transmission | $2,000 |
| Other development costs (fees, working capital, and contingency) | $600 |
| Total development cost | $4,000 |

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 needed 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 with 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.

## 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 capital, operational and maintenance costs (ULI, 2000). The Illuminating Engineering Society of North America (IESNA or IES) publishes luminance guidelines, considered the industry standard, for a variety of building types and activities. 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.

### *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).

### *New Trends and Innovation in Parking Lot Lighting*

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 | Stable | Potentially long payback |

Energy Star has concluded 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).

## SMART GRID

The United States is increasingly held back by an outdated power delivery infrastructure. The financial consequences of interruptions are growing into an enormous threat. One concept getting considerable attention lately, and one intricately entwined with the renewable market, is that of the Smart Grid. 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 wanted to, and utilities have built 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):* This allows customers to decide whether to pay more or not on specific critical days, rather than paying an average cost. It helps balance cost and risk between the consumer and the utility, as well as provide 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.

## ROLLING ENERGY STORAGE UNITS (RESU)

Rolling Energy Storage Units, described by Thomas Friedman in *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 (Friedman, 2008). 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 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 2009 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.

## 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 identifies characteristics and the possible relationship of two phenomena, i.e. Sustainability and Economic Feasibility.

The Research started with a review of peer reviewed journal papers regarding the carbon dioxide emissions in the United States, which also involved studying emissions data. A theoretical model, with the help of the literature review, was then derived that included the three feasible renewable energy sources identified for the case location of Houston, Texas. Out of the four, three feasible energy sources were used in the theoretical model: biomass, wind energy and solar energy. Cost and energy production data by various systems was calculated. The payback period was calculated with present energy costs, using the following formula (Hansen, 2004):

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Projected Annual Energy Savings at Current Prices}}$$

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

## THE PROPOSED SYSTEM

The system of energy delivery has moved from an independent system to the grid system. The consumption of natural resources increased as industries increased and living standards improved, which created a multiplying effect on the consumption of natural resources. It was not until the 1970s that the effects of this development on the environment were realized by many. The growth of energy consumption and delivery has seen four patterns, i.e., Independent (Yesteryear), Grid (Today), Hybrid (Tomorrow) and Net Zero in the Near Future (off the grid, independent again). There is a need for a system that supports the above and also supports a more sustainable environment and produces the fewest hazards to the environment. The hybrid system supports the benefits of both independent and grid. An independent pattern, at a small scale, but with larger numbers, makes the system more sustainable and localized, whereas the grid, at large scale and small numbers, creates economies of scale (see Figure 9).

The proposed system integrates solar energy and biogas energy. The biogas plant uses organic waste coming out of a 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 Units and the owners of these units will be able to buy and sell energy to and 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 the grid during day and will be bought back from the grid at night.

This study proposes a system which produces part of its energy demand out of its own resources (see Figure 10). The renewable energy produced will reduce the load on public utilities, thereby reducing the amount of carbon emissions. 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 (see Figure 11). This system, combined with a biogas plant, would more efficiently generate electricity from the waste produced in the retail outlet.

### *The Theoretical Model*

The theoretical model was developed (see Figure 13), with references from various sources. Assuming a retail shopping center of 50,000 sq. ft., a virtual model was developed. The number of cars (see Figure 12) in the parking lot has been estimated as per Texas Accessibility Standards (TAS, 1999) and Code of Ordinances, City of Houston (City of

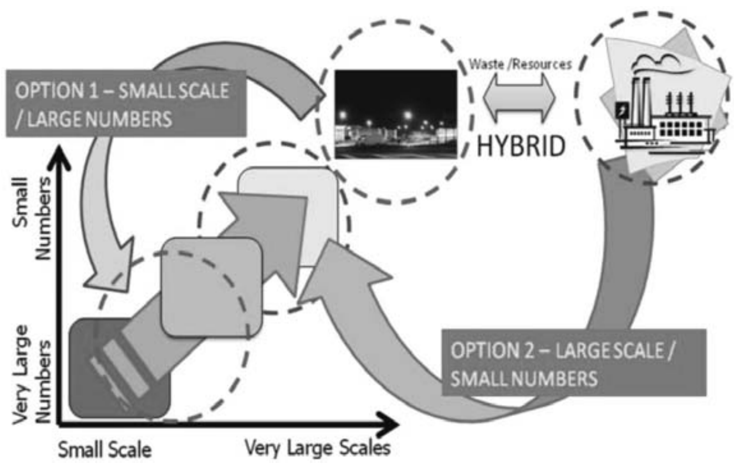



**FIGURE 9.** From independent to grid to hybrid.

**FIGURE 10.** Proposed off-grid renewable energy production system.

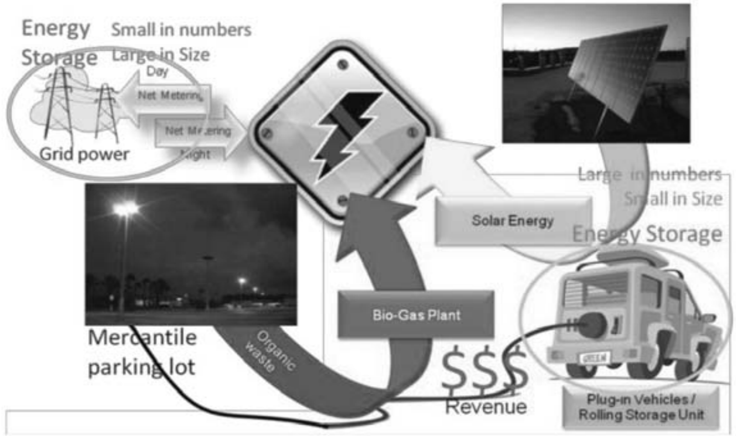



**FIGURE 11.** Proposed system integration with the grid.


**FIGURE 12.** Typical parking lot design used for calculations for 200 cars (area of parking lot for 200 cars as per above model (refer to Figure 21) = 91,945 sq ft).

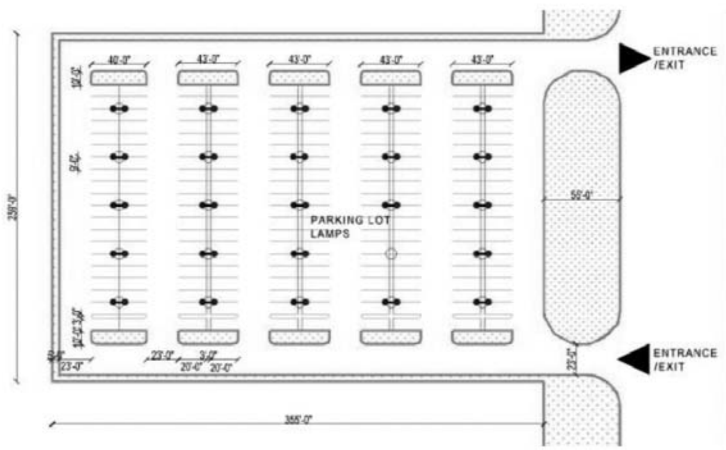
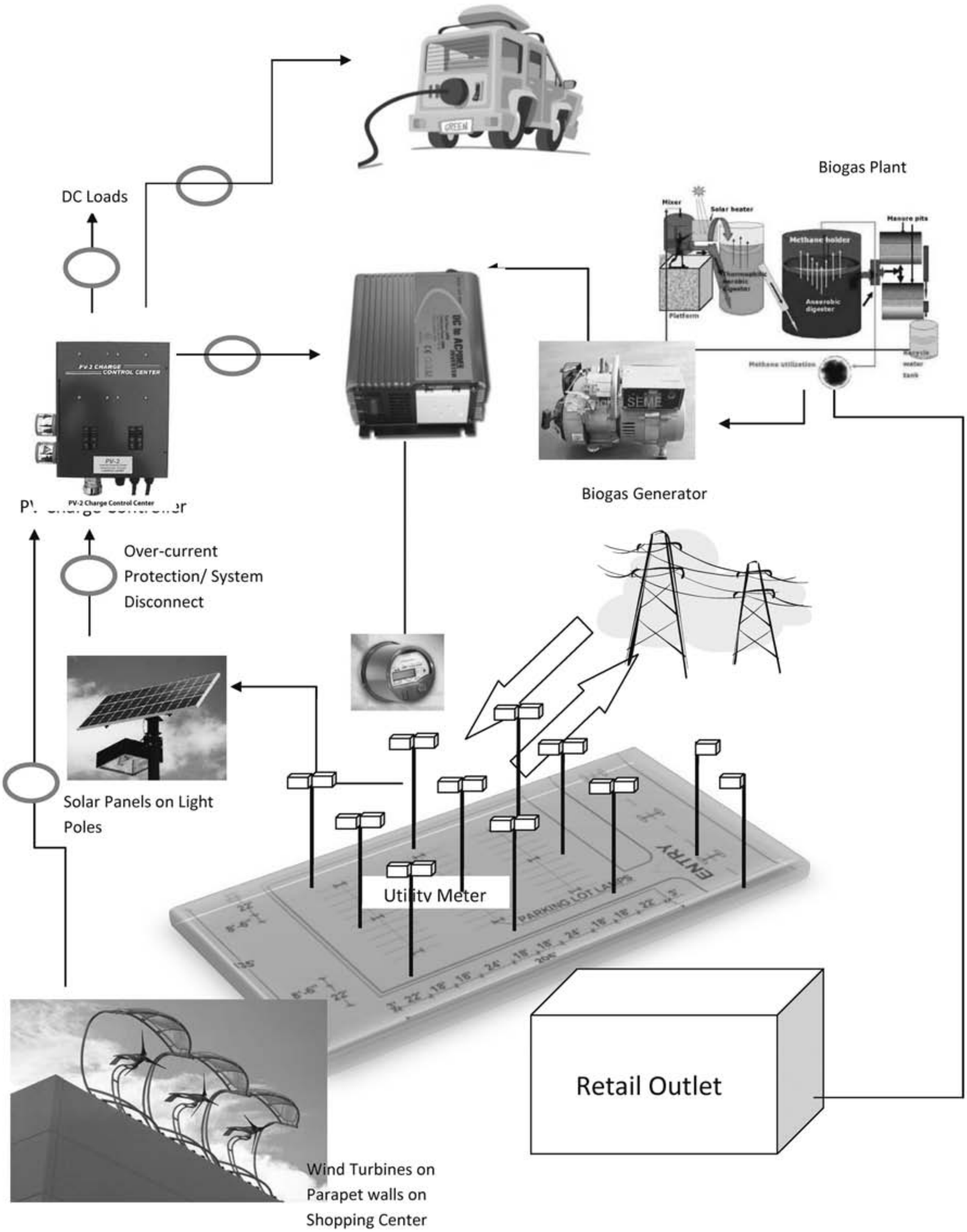


**FIGURE 13.** Theoretical model.



Houston, 2009) and the lighting has been calculated per the Illuminating Engineering Society of North America's guidelines, Lighting for Parking Facilities (IESNA, 1998).

### Lighting Energy Requirements

For the energy calculations, only lighting energy has been considered, which is the major source of energy consumption in the parking lot. For the system design calculations, we consider 1 fc as the minimum value of luminance. As per uniformity standard of 15:1 for enhanced security (see 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 determined for the lighting requirements of the parking lot. The power of light required will be 689,588 Lumens, i.e. 91,945 sq ft × 7.5 fc. Refer to Table 4 for calculations:

**TABLE 4.** Lighting calculations for the proposed system.

| Lamps | Metal Halide | LED |
|---|---|---|
| Lamp Make | GE | IQLED |
| Lighting power per Lamp (Watt) | 250 | 168.00 |
| Lumens per Watt | 60 | 75 |
| Number of Lamps that will be required | 46.00 | 55.00 |
| Total Power Required (Kilo-Watt) | 11.50 | 9.24 |
| Energy Consumption (kWh/day) | 138.00 | 110.88 |
| Add 2.5% for other amenities (kWh) | 3.450 | 2.772 |
| Energy Consumption (kWh/day) | 141.450 | 113.652 |
| Energy Consumption (kWh/year) | 51629.250 | 41482.980 |

### Sources of Energy

***Biogas Plant.*** The biogas plant would produce energy, using organic waste produced from the respective retail store. The data for solid wastes coming out of retail centers have been taken from a 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 cases; therefore we need to integrate an alternate renewable energy source with the system. It could be Solar, Wind or Geothermal energy, which will need to produce the amount of energy needed per year as in Table 5:

**TABLE 5.** Energy to be produced by solar, wind or geothermal sources of energy.

| Lamp | Anchor Store Malls | Other Parts of Shopping Mall |
|---|---|---|
| LED | 7385 kWh/year | 9710 kWh/year |
| Metal Halide | 17531 kWh/year | 19856 kWh/year |

### *Solar Energy System*

The total production requirement as per the above calculation for the solar energy system is represented in Table 6. The solar calculations have been done with the help of PV Watts (version 1), a performance calculator for grid connected PV Systems (developed by National Renewable Energy Laboratory, United States). As per PV Watts (version 1) the following is the sizing of solar panels:

**TABLE 6.** Solar panel sizing (DC Rating).

| Stores | Metal Halide | LED |
|---|---|---|
| Anchor Store Malls | 14.5 kW | 6 kW |
| Other parts of Mall | 16.5 kW | 8 kW |

It is assumed that the monthly performance of each panel calculated for the city of Houston and the monthly generation as per the PV Watts calculator will 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.

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

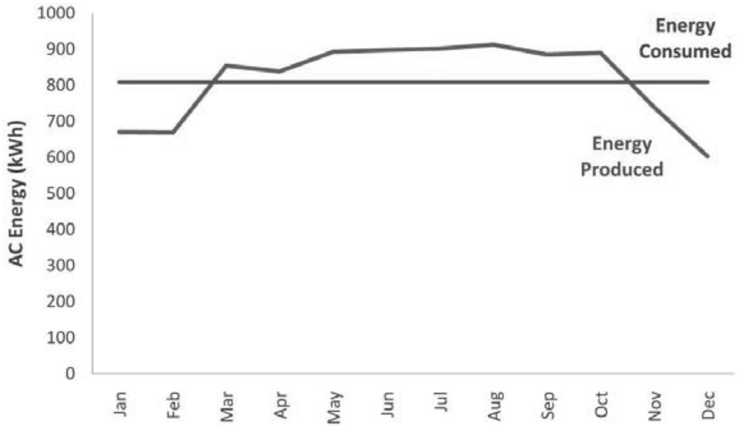



**FIGURE 14.** Monthly performance of 6 kW solar panel (DC Rating) calculated as per PV Watts (NREL, 2008).

**TABLE 7.** Number of solar panels required.

| Stores | Metal Halide | LED |
|---|---|---|
| Anchor Store Malls | 67 | 28 |
| Other parts of Mall | 76 | 37 |

Each panel costs approx $1000 after discount and the approx total cost of the above system (including the module, inverter, installation and battery) is shown in Figure 8.

**TABLE 8.** System cost of solar energy required.

| Stores | Metal Halide | LED |
|---|---|---|
| Anchor Store Malls | $102,127 | $43,020 |
| Other parts of Mall | $115,672 | $56,564 |

The calculations assume a grid electricity rate in 2008 of 10.65 cents/kWh for commercial use (EIA, 2009). The annual total energy requirement for metal halide and LED lamps is 51,629 kWh and 41,483 kWh. If costed at the present rate, the electricity consumption cost/year will be $5498/year for Metal Halide and $4418/year for LED Lights. Consequently, the payback period for commercial will be as per Table 9.

**TABLE 9.** Payback Period for various Lamps.

| Stores | Metal Halide | LED |
|---|---|---|
| Anchor Store Malls | 22 years | 14 years |
| Other parts of Mall | 24 years | 17 years |

However, Tables 8 and 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 items are further considered, the payback period could be reduced significantly. As of today, the payback period for solar energy may extend up to 30 years (Fu & Ding, 2009). Considering this, the proposed system will considerably help reach grid parity at a much earlier stage and will be profitable for end users.

### *Wind Energy*

The calculations in this section are based on replacing the above solar panels with wind turbines. The three wind turbine models from Aerovironment (Aerovironment, 2009), 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 (see Figure 13). However, further investigation is required to identify the best turbine out of these three.

In 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 low. Wind energy was calculated 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.

| Stores | Metal Halide | LED |
|---|---|---|
| Anchor Store Malls | 41 | 17 |
| Other parts of Mall | 46 | 22 |

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). Each turbine costs $7000, so the set of 20 units costs $140,000. Assuming this rate, the cost of the total wind turbine system (including turbines, inverter, charger and installation) will be as per Table 11:

**TABLE 11.** Approximate total system cost of wind turbines.

| Stores | Metal Halide | LED |
|---|---|---|
| Anchor Store Malls | $326,363 | $135,321 |
| Other parts of Mall | $366,163 | $175,122 |

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 a combination of Solar-Wind or Biogas-Wind systems in Class 1 areas if wind energy is to be used for the projects here.

### *Geothermal Energy*

Geothermal power plant costs were 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 noted in the geothermal resource map available at SECO (2008), we require a depth of geothermal resource of 13,000 feet @ 300–450 degrees Fahrenheit. We will require three wells, Exploratory Well, Injection Well and Production Well (USDOE, 2008c). Given cost data from Bloomfield & Laney's (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 $3–4 million per well. Three wells will cost in the range of $9–12 million USD, which is approximately 25 to 200 times the cost of the total wind turbine and solar energy systems. Clearly, geothermal energy is not feasible for small scale plants.

## FINANCIAL SUPPORT SYSTEMS

The financial support system is a term that has been used in various journal papers and books and in different contexts, but here, the term refers to a set of financial programs 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 $CO_2$ emissions in the atmosphere. Carbon trading markets 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 $CO_2$ 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 low carbon development in the 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 certain states of the United States. These 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).

## 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 sources; however, there are challenges involved in implementing this model. The challenges can be summarized as follows:

- **Grid parity:** Although this system will help in reaching grid parity at an earlier stage, the cost of alternative renewable energy sources still need to be further reduced to bring it to grid parity.
- **System efficiency:** System efficiencies need to be increased, through additional solar cells, biogas plants, and batteries used in vehicles.
- **Hybrid systems:** Systems need to be made hybrid to bridge the current grid dependent system and a grid-independent (off grid, or net zero) goal. This will further help with 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 retail centers in that region, but the use of biogas plant can further bring down the cost of solar energy.
- **Available technologies:** There are renewable technologies available and the use of these technologies needs to be enhanced.
- **Awareness:** Under federal law, utilities must purchase any excess electricity they generate. There is an awareness needed among utilities to recognize the benefits of net metering (USDOE, 2006).

Various support systems 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 on 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 in order to reach 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 $CO_2$ emissions reduction will be analyzed on a global scale and the challenges involved will create further studies to be taken up.

## REFERENCES


Aerotecture.com. (2008). *Aerotecture Products*. Retrieved March 7, 2009, from Aerotecture: http://www.aerotecture.com/products.html.

Appropedia (2008): *The Sustainability Wiki*, Retrieved on 25 July 2008 from the web site www.appropedia.org.

Aerovironment (2009). *AVX1000*. Monrovia: Aerovironment.

Bergey. (2008). *WindCAD Performance Models*. Retrieved February 10, 2009, from Bergey Windpower: http://www.bergey.com/Technical.htm.

Bloomster, C., & Knutsen, C. (2005). *Economics of geothermal electricity generation from hydrothermal resources*. Retrieved February 18, 2009, from USDOE: Office of Scientific & Technical Information: http://www.osti.gov/servlets/purl/7194293-sLSqhX/.

BP Solar (2008): *Going for Grid Parity*. Retrieved on 8 June 2008 from www.bp.com.

Carbon Trading (2008); *Welcome to Carbon Trading: A primer for forest landowners*, Retrieved on 25 July 2008 from the web site www.carbon.sref.info).

City of Houston. (2009, March 4). *Code of Ordinances*. Retrieved April 5, 2009, from City of Houston: http://www.municode.com/Resources/gateway.asp?pid=10123&sid=43.

CIWMB. (2006, June). Waste Disposal and Diversion Findings for Selected Industry Groups. Retrieved March 20, 2009, from California Integrated Waste Management Board (CIWMB): http://www.ciwmb.ca.gov/Publications/LocalAsst/Extracts/34106006/ExecSummary.pdf.

DSIRE, 2008. Database for state incentives for renewables and efficiency (DSIRE), 2008 Last Updated on 07/28/2008, Retrieved on July 28, 2008 from web site www.dsireusa.org).

EIA. (2007, November). *Solar Energy: Energy from the Sun*. Retrieved December 24, 2008, from U.S. Department of Energy: Energy Information Administration (EIA): http://www.eia.doe.gov/kids/energyfacts/sources/renewable/solar.html.

EIA:USDOE. (2008, July). *Energy Kids Page : Wind Energy, Energy from Moving Air*. Retrieved February 15, 2009, from U.S. Department of Energy: Energy Information Adminis-

tration (EIA): http://www.eia.doe.gov/kids/energyfacts/sources/renewable/wind.html.
EIA. (2009, February 13). *Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State*. Retrieved March 14, 2009, from Energy Information Administration (EIA): http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html.
EIA (2009a), *"Annual Energy Outlook 2009,"* Energy Information Administration. Retrieved April 2009, from Energy Information Administration (EIA): www.eia.doe.gov/oiaf/aeo/excel/aeotab_2.xls.
EnergyStar (2008, November). *U.S. Department of Energy and Energy Star Qualified LED Lighting: 2008 Partner Resource Guide.* Retrieved March 24, 2009, from Energy Star: www.energystar.gov/ia/partners/manuf_res/downloads/2008_LED_PRG.pd.
Fernández-Solís, J. L. 2007b, *"Sustainability as the Force that Tames an Exponentialoid,"* Proceedings, CIB World Building Congress 2007, Cape Town, South Africa, Proceedings CIB-460.
Fernández-Solís, J. L. (2008), *"Is Building Construction Approaching the Threshold of Becoming Unsustainable? A System Theoretic Exploration Towards a Post-Forrester Model for Taming Unsustainable Exponentialoids,"* VDM & Co. Saarbruecken, Germany. Retrieved on 08 August 2008 from http://archone.tamu.edu/faculty/jsolis.
Fernández-Solís, J. L., (2008b), "*The Challenges of Unsustainable Growth,"* ACEC Proceedings, 2008 Denver, CO, Retrieved on 08 August 2008 from http://archone.tamu.edu/faculty/jsolis.
Friedman, T. L. (2008). *Hot, Flat, and Crowded: Why We Need a Green Revolution—and How It Can Renew America.* New York: Farrar, Straus and Giroux.
FT (2008); "*Squeeze is on as interest grows in Solar Sector*," Financial Times, June 2, 2008, p. 19.
Golove, W. (2004); *State Renewable Energy Incentive Programs for Federal Customer,* FEMP: Meeting Federal Renewable Energy Goals, Seattle WA; April 29, 2004. Retrieved on 24 July 2008 from www1.eere.energy.gov.
Gordon, J. (2006, August 11). *Wind Turbines on the Edge: Small Wind Power Could be Moving in Next Door*. Retrieved March 8, 2009, from Treehugger: http://www.treehugger.com/files/2006/08/wind_turbines_on_the_edge.php.
Hamson's, Stuar S., (2007, February); *Sustainable Construction Framework*, Retrieved May 02, 2008, from www.johnlewispartnership.co.uk.
Hansen, S. J. (2004). *Manual for Intelligent Energy Services.* Fairmont.
IESNA, (1998), *IESNA-RP-20-98: Lighting for Parking Facilities*. Illuminating Engineering Society of North America (IESNA): American National Standards Institute (ANSI).
Kapdi, S., Vijay, V., Rajesh, S., & Prasad, R. (2005). Biogas scrubbing, compression and storage: Perspective and Prospectus in Indian context. *Renewable Energy, Volume 30, Issue 8* , 1195–1202 .
Miles, C. (2006, October). *Sustainability and the Built Environment.* Retrieved March 22, 2009, from UC Davis Extension: http://extension.ucdavis.edu/unit/green_building_and_sustainability/pdf/resources/arch_wind_power.pdf.
Mill, M. P. (2008, February 27). *Energy Intelligence: The LED Illumination Revolution*. Retrieved March 08, 2009, from Forbes.com: http://www.forbes.com/2008/02/27/incandescent-led-cfl-pf-guru_in_mm_0227energy_inl.html.
Miller, E. (March-April, 2009). Renewables and the Smart Grid. *Renewable Energy Focus, Vol 10, Issue 2*, 67–69.
NCDC. (2008, August 20). *Average Wind Speed: Data Through 2002*. Retrieved February 10, 2009, from National Climatic Data Center (NCDC): http://lwf.ncdc.noaa.gov/oa/climate/online/ccd/avgwind.html.
NREL (2008) *PV Watts: Performance Calculator for Grid Connected PV Systems.* National renewable energy laboratory (NREL), U.S.A. Retrieved on 10 September 2008 from the web site http://rredc.nrel.gov/solar/codes_algs/PVWATTS/.
RenewableEnergyAccess.com. (2007, October 29). *AeroVironment Installs Wind Turbines on Roof of Potato Chip Factory* . Retrieved March 27, 2009, from RenewableEnergyAccess.com: http://www.renewableenergyworld.com/rea/news/article/2007/10/aerovironment-installs-wind-turbines-on-roof-of-potato-chip-factory-50403.
Reuters (2007); *Solar Power edges towards boom time*: Reuters: Fri Oct 19, 2007, Retrieved on July 25, 2008 from the web site in.reuters.com.
SECO. (2008). *Wind Energy Maps*. Retrieved March 20, 2009, from State Energy Conservation Office (SECO): http://www.seco.cpa.state.tx.us/re_wind_maps.htm.
SESCI. (1997, November 25). *PhotoVoltaic Solar Energy*. Retrieved January 10, 2009, from Ontario Ministry of Environment and Energy: Solar Energy Society of Canada Inc (SESCI): http://www.newenergy.org/sesci/publications/pamphlets/photovoltaic.html.
TAS, (1999). *Parking and Passenger Loading Zones (4.6).* Texas Accessibility Standards (TAS) Retrieved on 10 September 2008 from the web site http://www.license.state.tx.us/ab/tas/abtas4a.htm#4.6.
Turnbull, Shann (1983); *Selecting a Community Currency,* Retrieved on 22 July 2008 from the website http://cog.kent.edu/lib/TurnbullSelectingACommunityCurrency.htm.
ULI, (2000). *Dimensions of Parking, 4th Ed.* NPA-the National Parking Association and the Urban Land Institute (ULI).
USDOE 2006; *PV Systems and Net Metering,* Last Updated: 01/05/2006, Retrieved on 25 July 2008 from United States Department of Energy (USDOE). the website / http://www1.eere.energy.gov/solar/net_metering.html.
USDOE. (2006b, October 04). *Solar Energy Technologies Program*. Retrieved January 12, 2009, from US Department of Energy (USDOE): Energy Efficiency and Renewable Energy: http://www1.eere.energy.gov/solar/pv_basics.html.
USDOE. (2007, October 19). *Solar*. Retrieved January 10, 2009, from United States Department of Energy (USDOE).: http://www.energy.gov/energysources/solar.htm.

USDOE. (2008c, September). *Geothermal Technologies Program.* Retrieved February 25, 2009, from United States Department of Energy (USDOE).: http://www.nrel.gov/docs/fy08osti/43504.pdf.

USDOE. (2008e, October). *LED Parking Lot Lighting Technology Procurement Project.* Retrieved March 15, 2009, from United States Department of Energy (USDOE).: apps1.eere.energy.gov/buildings/publications/pdfs/alliances/led_parking_lot_lighting.pdf.

USDOE:EIA. (2008, July). *Geothermal Energy — Energy from the Earth's Core*. Retrieved March 20, 2009, from Energy Information Administration (United States Department of Energy): http://www.eia.doe.gov/kids/energyfacts/sources/renewable/geothermal.html.

WARP:ENECO. (2008). *Mass Customization of WARP Wind Power Plants: The Next generation of Wind Power Plant.* Retrieved March 7, 2009, from WARP ENECO: http://www.warp-eneco.com/documents.php.