A STUDY OF SMALL-SCALE RENEWABLE ENERGY INTEGRATION ON LONG ISLAND, NEW YORK

A Report

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Master of Engineering

By

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ABSTRACT

In an active beach community on Long Island, New York, a local government facility site has installed multiple renewable energy projects, including 128.8 kW of solar and wind generation capacity alone. The administration building for the Department of Conservation and Waterways is located in the middle of this "Energy Park", connected to the grid and solar arrays, and usually uses 15-25 kW throughout the year. Also in the park is a hydrogen and natural gas fueling station which can electrolyze water and compress the hydrogen at around 40 kW, connected to both the grid and 100 kW wind turbine. Energy usage, generation, and cost for the site were modeled using site data to determine how effective the system was working and where it needed improvements. It was found that solar generation meets the administration building load about 25% of all hours, and net cost for the system was around $16,000. Pooling all generation and load under Long Island Power Authority rate 281 would reduce annual expenditures to around $7,300, saving 54% of annual costs. Combined, wind and solar meet load 48% of the time with enough excess generation to run the electrolyzer enough to provide a fuel cell vehicle fleet with 2 kg hydrogen daily, enough to drive 160 km per day. Finally, the Energy Park may be close to grid independence, were it to combine its hydrogen storage system with a stationary fuel cell, since both monthly energy generation and load of the building and fueling stations total approximately 20MWh.

BIOGRAPHICAL SKETCH

Brendan Fogarty is a native of Garden City, New York. His is inspired by biology and passionate about the environment, and he intends to protect it through engineering sustainable solutions to the world's energy needs. He pursued this interest at Cornell University, graduating in May 2015 with a Bachelor of Science in Biological Engineering. He stayed and graduated again in January 2016 with a Master of Engineering. His extracurricular interests also include Irish traditional music and ballroom dancing. Brendan is currently looking to join the energy field professionally in the near future.

ACKNOWLEDGMENTS

Lindsay Anderson for her guidance and generosity; Tara Schneider-Moran, Patrick Shortell, Chris Smith, Rob Longiaru, and Ron Masters for acquainting me with the Energy Park and supplying data; Jean Hunter and the Cornell Graduate School staff for helping me make the most of my Master's program; and finally my ever-supportive parents and uncles.

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1. INTRODUCTION

Point Lookout, New York, is a small beachside hamlet on the south shore of Long Island, 23 miles southeast of midtown Manhattan. Point Lookout has only has about one thousand residents, with sufficent infrastructure to accommodate the other million residents of Nassau County, who flock to the south shore beaches as soon as the weather allows in late spring. As a result of its popularity, the local government of the Town of Hempstead uses the interior portions of the barrier beach as bases for several departments and groups, including Parks, Maintenance, Lifeguards, Police, Bay Constables, Water, and Conservation and Waterways. The Department of Conservation and Waterways supports and regulates recreational water usage, such as boating and fishing, as well as the environmental integrity of Nassau County's few wild places. It's headquarters are located in a small administration building, a few hundred feet west of Point Lookout's quaint village area, along the bay side of the barrier island. The administration building is not only home to Conservation and Waterways, but also the Bay Constables (since recent hurricane activity ruined the nearby building they formerly occupied) and biology labs.

The most remarkable feature of the administration building is not its function, but the projects outside. Since 2005, several renewable energy projects have been completed on the small grounds around the administration building. These projects include several photovoltaic arrays, a hydrogen and natural gas fueling station, two solar-powered electric vehicle charging station, geothermal wells, and two wind turbines. All these projects serve two purposes: firstly, to provide clean energy to the administration building and nearby processes, and secondly, to demonstrate emerging technology to the public. For the second reason, the grounds of the administration building have become officially known as the “Energy Park.” The location has become a popular destination for field trips, offering educational opportunities for local college and high school students. The Town of Hempstead also offers seminars and other public outreach programs to generate interest in renewable energy locally [1,2].

1.1 Site Details

The Energy Park boasts a total of 128.8 kilowatts of rated solar generation; of which 95.7 kilowatts powers the administration building, with the remaining power directed to a few small, independent buildings on site and a floating shellfish nursery. The arrays considered in this report are all within meters of each other and are detailed in Table 1. The only arrays considered are those that are used to power the administration building. The administration building and associated photovoltaic arrays are connected to the local grid and billed under the Long Island Power Authority (LIPA) rate 281. See appendix 5.2 for rate structure details.

Additionally, the output of a 100 kW Northern Power wind turbine is considered. This turbine is connected to the local grid as well as the Energy Park’s alternative energy fueling station. The station dispenses hydrogen, natural gas, and a blend of the two. The hydrogen is produced on-site using an electrolyzer, compressor, and storage tanks. Producing and storing hydrogen requires almost 40 kW, which is assumed to be the vast majority of power required for all fuel station operations. The wind turbine and fueling station system are billed separately from the administration building on LIPA rate 284, which was originally picked for its low off-peak usage costs. [2,3]

Table 1. Summary of photovoltaic units powering administration building.

	Rated Power (kW)	Panels	Panel Model
Administration Rooftop	9.84	80	Sharp ND 208 U1
Bifacial Carport	23.4	120	Sanyo 195 DA3HIT
Ground Mount	57.2	260	Sanyo 220 AONHIT
One-dimensional tracker	1.76	8	Sanyo 220 A
Two-dimensional tracker	3.52	16	Sanyo 220 A

1.2 Site Advantages

The Energy Park has some rather unique features which make it an excellent site for research.

1. *Location*. Point Lookout is only five miles due southeast of John J. Kennedy International Airport (JFK), which is well-equipped with weather instruments. Additionally, the Energy Park sits only a few

hundred feet from a United States Geological Survey (USGS) floating weather station on a buoy in the bay. However, historical information is not as extensive from the USGS buoy.

2. *Site Accessibility*. Although the administration building is closed to the public on the weekends, the site is readily visited. The staff at the Energy Park are enthusiastic to help in any way they can, including discussing the projects and showing people the technology in person.
3. *Data Accessibility*. There are online records of generation data for most of the solar arrays. These are not publically accessible, but the staff are eager to share the data they have collected.
4. *Technology Variety and Layout*. All projects differ, but were constructed within a few hundred feet of each other. This truly allows for side-by-side comparison. When one solar panel is generating electricity, another panel in a different array experiences the same irradiance. Likewise, if a cloud passes over, they are both affected simultaneously. In this way, any photovoltaic array can be compared directly at any given time under nearly identical atmospheric conditions.
5. *Extent of Data*. Although most projects are only about four years old at the time of writing, there are years of data available for each one. This is not a laboratory setting; all projects are operational the entire year. With most meters recording data at hourly or quarter-hourly intervals, there are hundreds of thousands of data points.

6. *Net Metering*. The Energy Park is registered for on-site net metering with the Long Island Power Authority (LIPA). This allows electricity generated on site to be seen by LIPA meters and LIPA only bills for power taken from the grid less the amount generated. New York State allows both remote and on-site net metering for up to 2 megawatts of generation, giving small-scale operations and residences further incentive to install renewable energy generation technology.

1.3 Motivation

The Energy Park installed each project to showcase the feasibility and utility of small-scale renewable energy generation, and more projects are expected in the near future. However each project was installed independently without a unifying power output goal, such as generating enough energy to power all operations at all times, and continuing on to establish a microgrid untethered to the local grid.

However, using solar and wind power means there is inherent intermittency in energy generation. This means that the rated output for any of the given projects outlined above is a likely upper bound for power generation at any given time, and the actual output is difficult to predict exactly but is often significantly lower. While the total generative capacity of the Energy Park is available publicly online, it is not obvious how much energy the site actually consumes. In the area there is a water tower, various inscrutable warehouses, buildings, and machine shops. Furthermore, it is uncommon to see any public intuition of energy or power usage at any scale, so it is not immediately clear if the generation on site might be able to power the town facilities or the entire town of Point Lookout. Even less apparent is frequency of wind and solar generation. The principle behind these projects is very apparent, but the efficacy, in terms of energy generated and cost, is not. I aimed to elucidate the efficacy in this report, which could also guide future projects at the site.

1.4 Objective

This report addresses a series of fundamental questions about the operations at the Energy Park, such as:

1. How does yearly solar and wind energy generation compare with the loads of the administration building and fueling station?
2. How frequently is load fully met by generation?
3. Can the system function independently of the grid?
4. Which electric billing rate is most appropriate and most cost-effective for this system?
5. What future work could improve the functionality of the current system?

Further, this report attempts to assimilate data to estimate load, generation, and expenses of the Energy Park to address these questions. The current system is modelled, as are three hypothetical configurations of energy flow which could potentially better utilize energy produced on site and even reduce monthly energy expenses.

2. METHODOLOGY

2.1 Challenges

The particular methodology for manipulating data used was adopted because of issues in data availability and output form.

1. Data Availability Gaps

Despite the thousands of data points, there were occasional gaps in data. These were often due to system maintenance and other unforeseen circumstances (coastal Long Island suffered from Hurricane Sandy in 2012). In one particular case, rodent damage to an inverter caused an entire year's worth of false data points for the administration building rooftop array [4].

2. Data Output Inconsistency

The solar arrays at the Energy Park report to two different online data acquisition systems. The administration building rooftop array and bifacial carport were managed through Sunnyportal, which offers data in the most frequent form of hourly mean-value power output. Text files that show the total power output of a panel can be downloaded individually but not in bulk. The other system, Enlighten from Enphase Energy, handled the ground mounts, both solar trackers, and the independent "Solar House" (which is not connected to the rest of the system). Enlighten generated graphs online that clearly showed that data had been stored at five minute intervals, but there was no obvious way to download this data. Upon discussion with an Enphase Energy representative over the phone, it was determined that these more frequent points were not available for download. Unlike Sunnyportal, individual power outputs from each array were not available; the only power data available was for one week into the past, and it was aggregate over all the arrays reporting to this system. The next best output was actually total energy per individual microinverter per day. Unfortunately, each microinverter was identified by its serial number, not by its array, so nothing could be learned without reorganizing the output.

2.2 Assumptions

In order to show energy generation and load trends, some assumptions were required. These assumptions are basic but could impact results and conclusions, therefore there is a discussion and evidence to validate each one.

1. *Hourly data points are representative.*

Sunnyportal reports data points as "hourly mean-value" power, which is interpreted as average power output over any number of sample measurements in a given hour. This produces a smoothing effect that does not capture any output variability within an hour. For this analysis, the smoothing effect is assumed to be acceptable, not altering results in any significant way. Power usage data for administration building load was given as total energy consumed during quarter-hourly intervals. Since no generation data was available at that frequency, the quarter-hour energy averages reported were assumed to apply for the entire hour and were scaled appropriately; all other data points in the set were not used.

2. *Period is representative.*

In other words, the data points used did not occur during any atypical extended weather conditions that might cause unusual load or generation patterns.

Since the main variability in administration building load over the year would likely be electricity used to run air conditioning units, a useful metric to predict cooling need is the cooling degree-day. This is measured as the difference between the actual environmental temperature and a fixed indoor comfort temperature threshold of 65 degrees Fahrenheit, or in other words, the temperature difference an air conditioning unit has to overcome to achieve indoor comfort.

Inspecting the monthly averages from 2008 through 2013 at JFK airport and comparing them with 2013 (the year picked for modelled generation data) and 2015 (the year picked to represent load data) shows that all values are fairly similar for the first half of the year. The spring of 2013 was cooler by around 40 cooling degree days in May and June, but slightly warmer by 40 cooling degree days in July. 2015 was almost identical to the average, varying by no more than 15 cooling degree days through July.

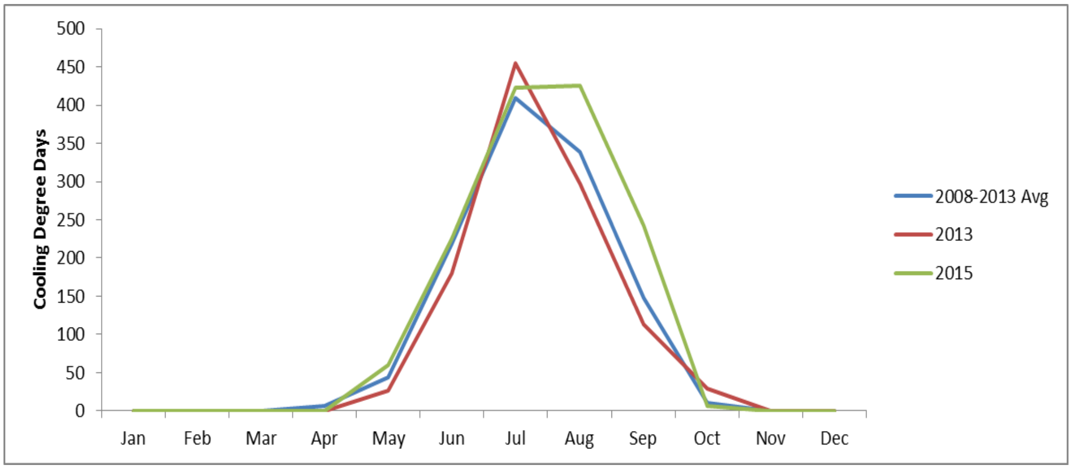

Figure 1. Comparisons between monthly cooling degree days [5].

3. *Annual weather conditions are generally symmetric.*

Specifically, that estimates modelled for the first half of a year could be scaled appropriately to model an entire year. The sun's gradual movements throughout the year cause very even insolation changes monthly, creating pairs of months with similar averages: May and July, April and August, etc. The solstices in June and December cause those months not to have any counterpart.

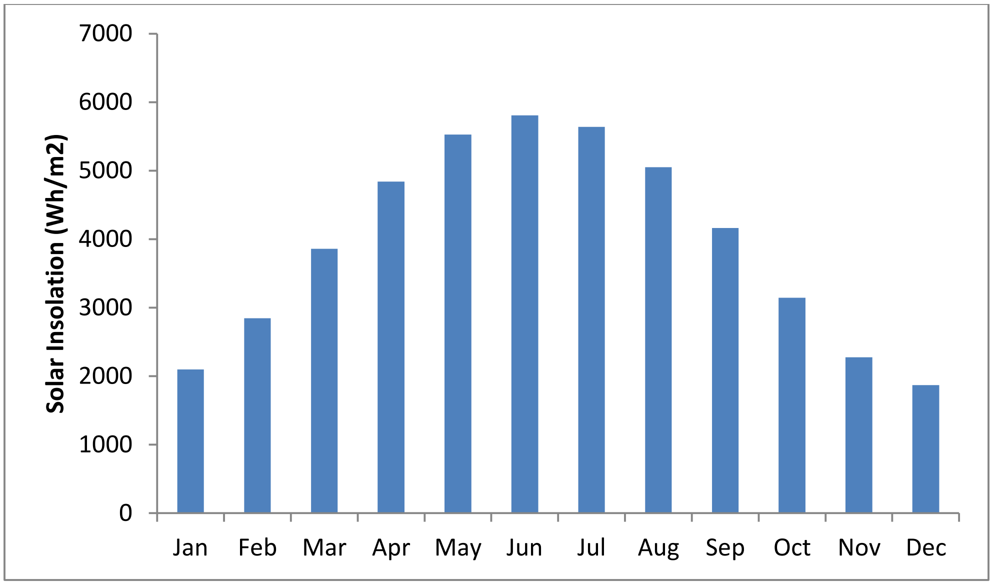

Figure 2. Average daily solar insolation data for JFK Airport, 1990-2010. [6]

4. *There is a correlation between all photovoltaic array outputs.*

In other words, if at any given time a photovoltaic array is producing power, any other photovoltaic array should also be producing a proportional amount of power. This is an assumed result of all solar arrays being located in direct proximity of each other, thus experiencing the same irradiance simultaneously. Even though the proportionality might be estimated by comparing the rated power output of each array, inspection of microinverters reporting to the data acquisition systems shows, in all arrays, individual panels appearing offline for extended periods. For other panels, the power contribution was seen to be below the average for the rest of the array, possibly indicating structural damage or meter error. Essentially, estimating output by rated output proportionality assumed too much about each array's instantaneous output. However, these issues plaguing the arrays tended to be constant over several month's time, and by inspecting daily energy generation for each panel, tight correlations were uncovered.

Since there were no periods in which data was available for every solar array under consideration, correlations between pairs of solar arrays (or in the case of the ground mounts and solar trackers, a combination of several arrays acting as a unit) were made when there was actual data for each. For the period that was eventually modelled, the administration building rooftop array was used for its actual data and all other points were estimated using the correlations found. In figure 3, a scatterplot showing the energy output of the rooftop array versus the sum of all other arrays reveals a clean, linear correlation, making the rooftop array a sufficient predictor of the entire photovoltaic energy output of the Energy Park. Figure 3 was produced through comparing the energy outputs of the various arrays and discovering their proportionalities; the process is described in appendix 6.1.

There is a slight but distinct deviation from the trend for very low daily energy outputs. This is assumed to be caused by an inherent issue of the inverters that convert the direct current from the panels to alternating current for use. In general, inverters have a very high conversion efficiency (over 95%), but these are known to drop dramatically when they are inverting a small amperage of current [7]. The trend deviation can be seen begin around 7 kilowatt-hours of energy produced in a day, which would translate to less than a 1 kilowatt of power during the short days of February. The deviation increases toward the origin, where there is less energy than expected coming from the rooftop mount compared to the other arrays.

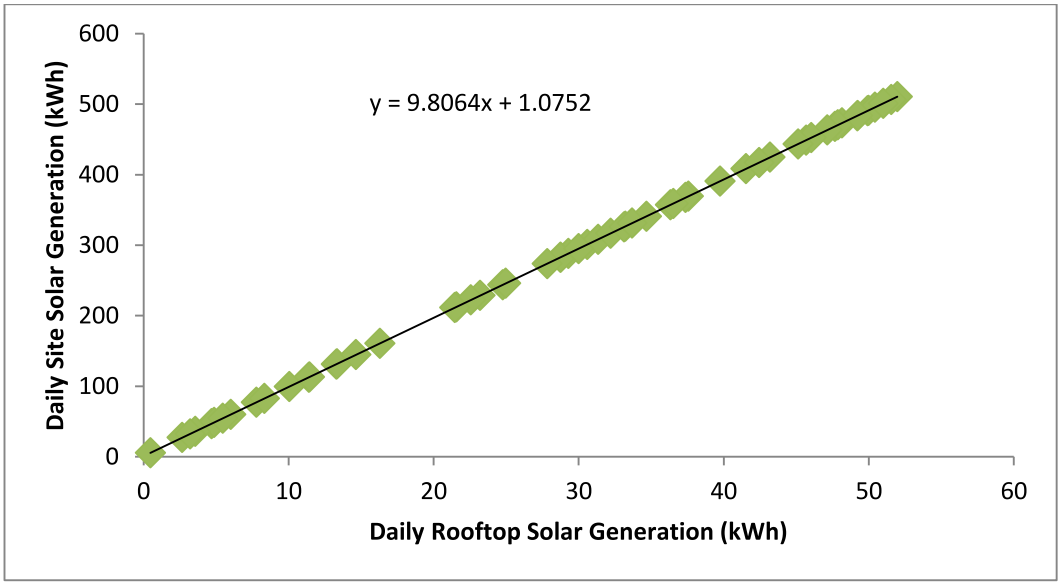

Figure 3. Correlation between rooftop solar array generation with all other array generation for all hours from February to July 2013.

5. *The load profile of the building assumes a stationary pattern.*

Since the only load data available was two years more recent than the best generation data, it was important to show that the load followed a regular and predictable pattern, so that it could be assumed to be similar across all recent years. In figure 4, it is apparent that on most days, hourly power load is quite close to the median value. This is more pronounced at night, when fewer people are using the building and when outside temperature is more comfortable, requiring less air conditioning power draw.

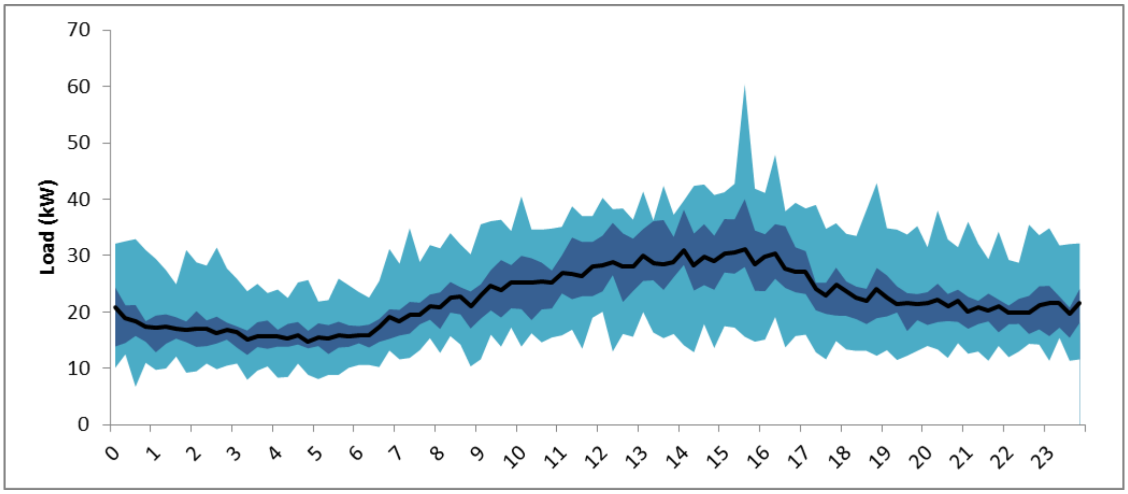

Figure 4. Weekday load profile for the administration building for June 2015. The median hourly power draw is denoted as a black line, dark blue shows the interquartile range, and light blue shows hourly maxima and minima.

The weekday load profiles vary across the year, ostensibly in response to the extra power needed to cool the building in the warmer months. In general, power consumption is stable throughout the night, increasing in the morning as employees begin arriving at work, increasing with the outside temperature through the mid-afternoon, and falling sharply as many employees leave around 1700 hrs. This trend is apparent in figure 4. In figure 5, the main difference visible between months is the peak afternoon load, reaffirming the idea that the cooling system is the main variable in power requirements. In general, afternoon load follows two trends: one for winter, one for summer. The overnight load during

February more closely resembles summer overnight load; it is not clear if this is due to heating (either the built-in system or personal space-heaters) or some unknown factor. Repeated perturbations in March and April 2015 at night are of unknown origin, as are the brief midday load spikes in July.

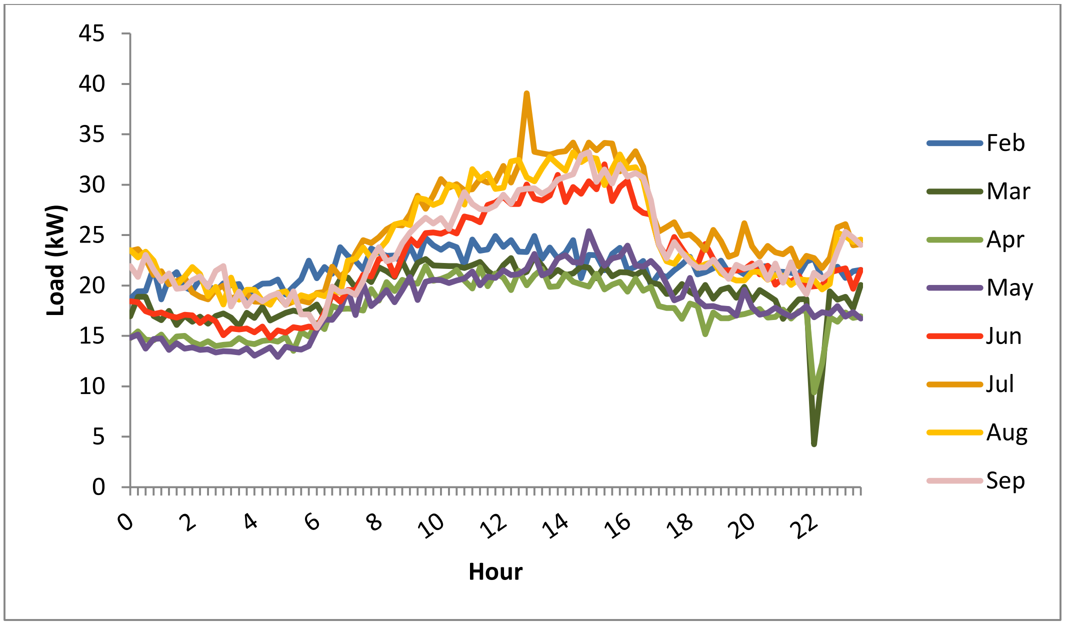

Figure 5. Average load profile for administration building for months of 2015, only considering weekdays.

All weekdays throughout the year experience a similar and predictable flow of employees, but weekends are far more variable. On weekends there are always Bay Constables, usually conservation workers, sometimes students using the biology lab, and sometimes extra safety officers if there is a special event happening nearby. Partially for the above reasons and partially due to the smaller sample size of weekends, the load trends are faintly reminiscent of the weekday pattern but tend not to form the obviously different summer and winter patterns.

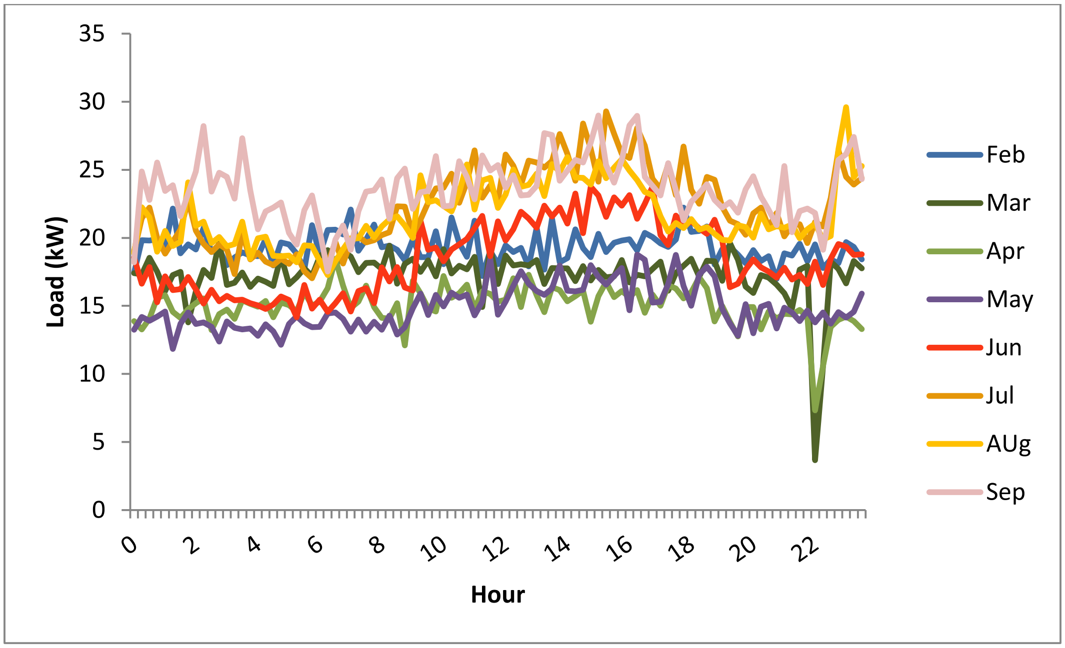

Figure 6. Average load profile for administration building for months of 2015, only considering weekends.

Inspecting all these load profiles shows that the load is fairly consistent. A load duration curve (figure 7) from February through June 2015 shows that the load of the building is between 15 and 25 kilowatts for 70% of all nighttime and daytime hours in that period. This shows that the load of the administration building is indeed usually around 20 kilowatts, with relatively few hours with higher demand. These hours are only seen in the afternoons of the warmer months.

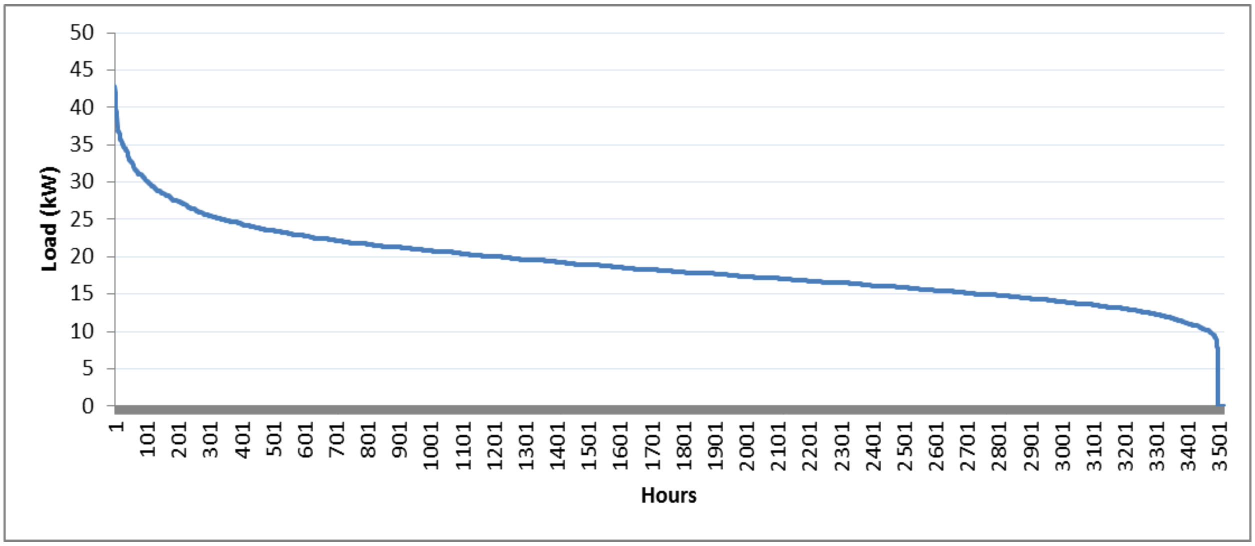

Figure 7. Load duration curve for administration building.

6. *Wind turbine output could be estimated from local wind speed alone.*

Wind turbines have well-known correlations between the perpendicular wind speed their blades are experiencing and instantaneous power they are producing. The available wind data was sampled at a strange frequency, approximately once per two days, offering sparse glimpses into its daily power production. For this reason, wind energy had to be estimated using wind readings from JFK airport, five miles to the northeast. Although farther from open water, the airport is positioned similarly on the edge of a large estuary, and is reasonable to assume that even if the wind speed is not identical at both JFK and the leeward, bay side of Point Lookout at a given time, they likely follow very similar distributions.

What was more certain was the power produced for any given wind speed affecting the turbine, as seen in Figure 8. Power produced while the nacelle of the turbine rotates into the direction of the wind is not considered separately; all predicted power follows the fifth order polynomial fit to the data points in Figure 8. Lower-order order polynomials also fit this distribution well, but have erroneously high power for wind speed values under 5 miles per hour. The fifth-order polynomial produces negative power values in this region, which are easily discarded in further data analysis.

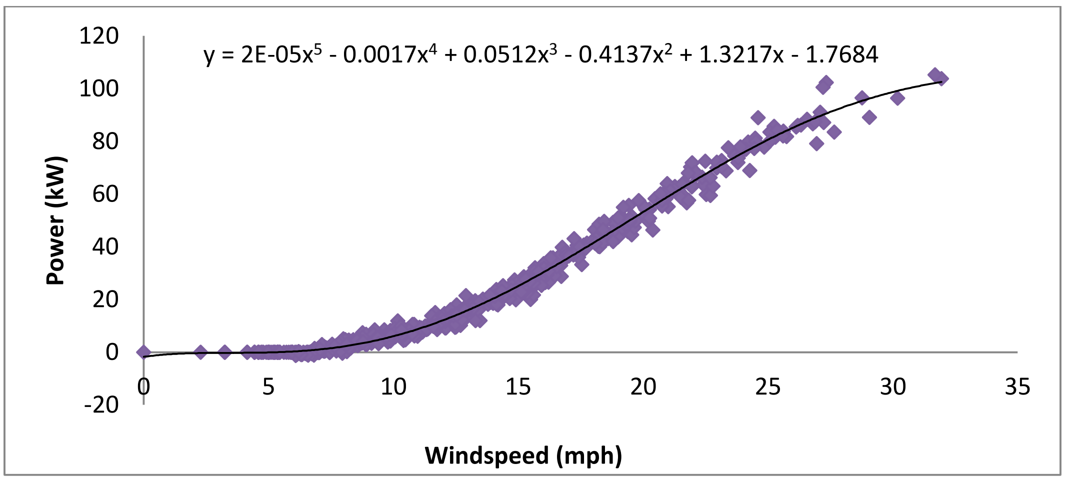

Figure 8. Wind speed and power correlation for January through October 2013.

2.3 Data Selection

Considering the above challenges and assumptions, the year 2013 was selected to model energy generation at the Energy Park. February through July 2013 had the most available data for daily solar generation and wind generation. Load data was only available for 2015.

2.4 Data Organization

The various output data files were usually comma-delimited text files. These were converted to Excel spreadsheet files in Excel then reorganized by one of several MATLAB scripts which read daily data files for a given month, identified microinverters to their arrays in necessary, combined the data, and printed the monthly data into a new Excel spreadsheet.

2.5 Financial Calculations

To determine the cost of energy of both the administration building and the turbine-fueling station subsystems, 2013 Long Island Power Authority (LIPA) rate structure values were used in conjunction with the modelled net load values. 2014 LIPA net financial reconciliation for the wind turbine's excess production was factored in to the 2013 financial model for the site under the current system configuration; reconciliation for hypothetical scenarios with other configurations was assumed to be $0. Annual energy charge from LIPA was calculated under four configurations:

1. The actual configuration in 2013, with all solar offsetting administration building load on rate 281 and all wind offsetting electrolyzer load for the fueling station load on rate 285.

2. Solar and wind primarily offsetting administration building load, but using excess generation to power the electrolyzer at the fueling station on rate 281.
3. The same as configuration 2 but on rate 284.
4. The same as configuration 2 but on rate 285.

Generally, charges calculated as seen below. For specific charges, see appendix 6.2.

1. Energy charge per kilowatt-hour. For most rates, the charges vary between peak, intermediate, and off-peak usage hours. They average a few cents per kilowatt-hour.
2. Demand charge per kilowatt of expected system load. This price averages from a few dollars per kilowatt to nearly $100, again depending on time of use.
3. Service charge, which is generally a few dollars per day per meter.
4. Minimum Demand Charge, which operates as a lower bound for combined energy and power for large systems which do take energy from the grid frequently. This charge is assumed for the current wind turbine and fueling station subsystem, which is used infrequently.
5. Reconciliation. At the end of each year LIPA reimburses Conservation and Waterways for the electricity produced by the wind turbine that is seen by the grid meter. The value from 2012, which was approximately $10,300, was used in calculations [8]. All wind turbine energy is expected to be used on-site in the hypothetical system setup scenarios, therefore no

significant reconciliation is expected and it is omitted from these scenarios.

6. New York State tax, which in 2013 was 4.5%.

Avoided cost of gasoline for fuel cell vehicles is not factored in to these equations since all scenarios are all equally capable of producing free hydrogen. Additionally, any demand ratchet effect, which provides a recurring penalty charge for extreme load peaks for several months after they occur, are not expected and ignored.

3. RESULTS

3.1 Load

On average, the administrative building uses 13,400 kWh of energy per month. For the warm months showing the trend for heavy afternoon load (June through September), the average monthly energy load is slightly higher at 14,000 kWh. For the trend of moderate afternoon load, seen in the months of February through May, average monthly energy load is 12,600 kWh. See figures 4 and 5 to see how the load profile varies throughout the day and year.

3.2 Solar Generation

Average estimated monthly solar generation was 8.800 kWh over all months of 2013. The total generation was lowest in February at 6,000 kWh and highest in July at 11,600 kWh. In February, solar generation alone met or exceeded administrative building load for 16% of all hours in the month. In June and July, it met or exceeded load 27% of all hours. In May, generation met or exceeded load 31% of all hours.

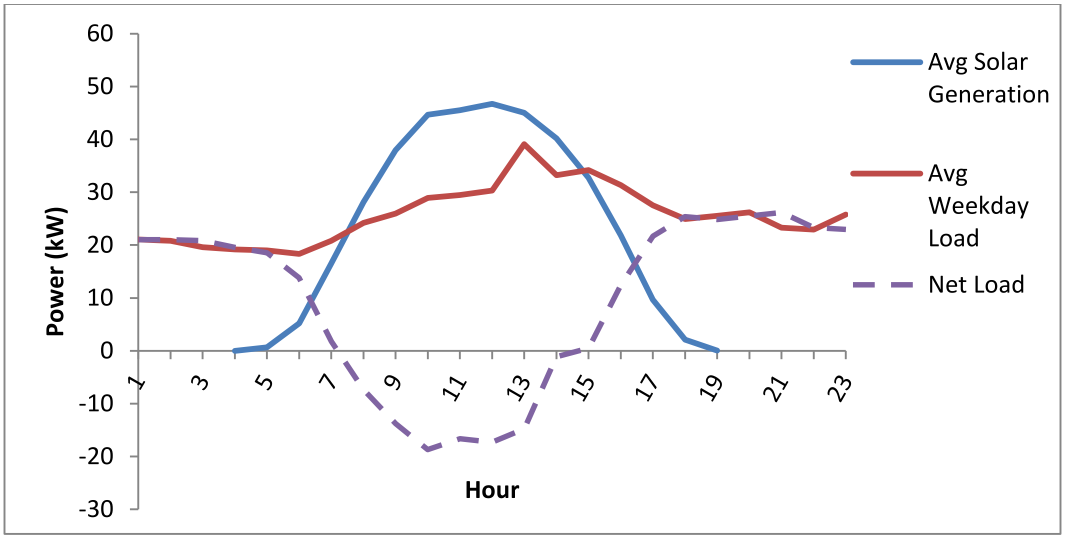

Figure 9. Total generation, load, and net load in July 2013.

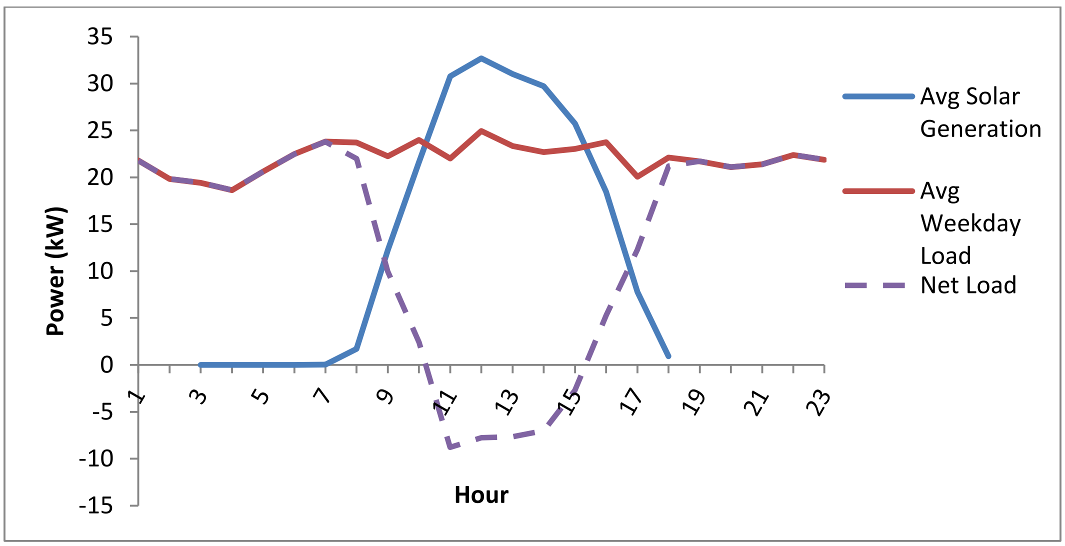

Figure 10. Total generation, load, and net load in February 2013. Note that February 2013 suffered many days of inclement weather, which has disrupted the typical Gaussian distribution of solar generation.

3.3 Wind Generation

Average estimated monthly wind generation was 12,600 kWh. Average wind generation followed a trend inverse to the solar trend, with peak values in February with 17,100 kWh generated. July saw the lowest generation, with only 8,000 kWh of generation.

It can be seen that wind generation is more significant at night in Figure 11, but consider that 62% of the month illustrated, February, is night. High wind (and/or low load) situations where wind generation alone can power the administration building occurred in 43% of all hours in February 2013, with only a slight majority of those points occurring at night.

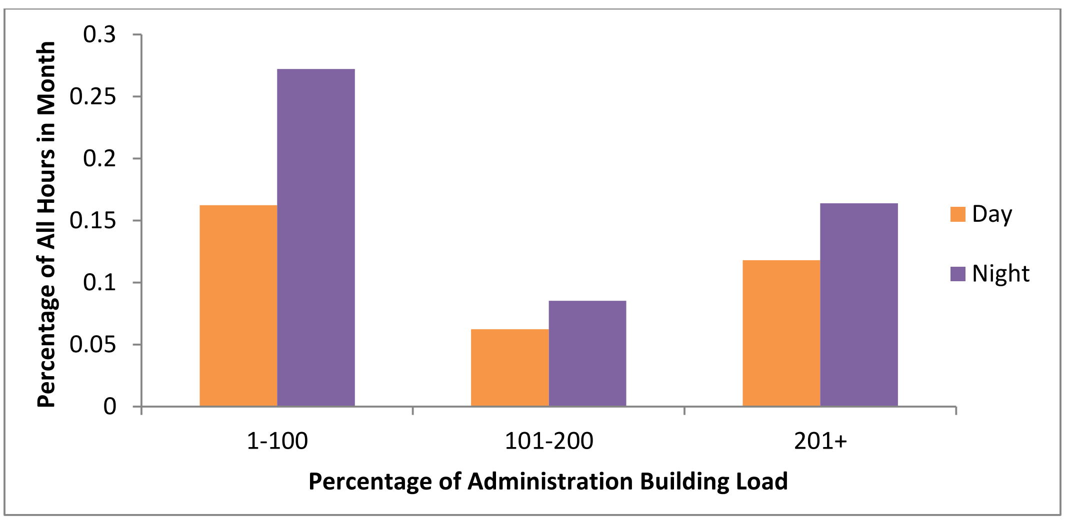

Figure 11. Comparison of daytime and nighttime wind generation meeting load in February 2013. Only hours producing at least 1 kW of power are considered.

3.4 Combined Wind and Solar Generation

When considered together, adding the wind turbine to the administrative building subsystem, combined wind and solar generate enough power to meet or exceed load for around 48% of most of the year, dropping to a minimum of 41% in July. Combined generation produces a stable average of 21,900 kWh per month, varying by only about 2,000 kWh with the maximum in winter and minimum in summer. Combined solar and wind was seen to be producing less than 1 kilowatt of power on an average of 16% of all hours sampled. This spiked to 21% in May, but was lowest in February and June, both at 14%.

Monthly solar generation approximately doubles from February to July, while monthly wind generation halves over that same period. Wind produces slightly more energy in most months, but the combination of both solar and wind power produces a very constant sum of around 22,000 kWh per month. This syzygy of the two types of power matches administrative building load almost twice as often as the current system configuration while still allowing for ample hydrogen production.

On average, solar generation alone brings system load down to net zero in the middle of the day, in both winter and summer (see figures 9 and 10), which is doubly important in that it offsets power draw from the grid during peak electricity hours. The complementarity of wind to solar generation can be seen in figure 11, which shows greater potential for wind alone to meet building load at night, when load is lightest.

3.5 Hydrogen Fueling Station

This combination of both solar and wind power together was seen to meet or exceed the combined load of both administrative building and the electrolyzer on average 18% of the time, allowing for production of hydrogen while meeting all electrical needs of the administrative building. Around 2 kilograms of hydrogen can be produced daily, which could provide around 160 kilometers of travel for new fuel cell vehicles with a fuel economy of 80 kilometers per kilogram of hydrogen. In a month, this would offset an average of $360 of avoided fuel cost (at the current, low average gasoline price of $2.35) and 1,380 kilograms of carbon dioxide emissions. This amount of regular production would require about 5,400 kWh monthly, bringing the total energy requirements of the station and administrative building to around 20,000 kWh per month.

3.6 Financial

The total cost of energy and power is the sum of many different charges. Estimated expenses for the month of February 2013 are detailed in table 2, illustrating relative contributions of individuals costs.

Table 2. Components of estimated LIPA energy bills for February, 2013.

Charge Type	Current System (Base Case)	All Rate 281	All Rate 284	All Rate 285
Intermediate Energy Charge	$177.39	$105.45	$27.25	$108.99
Off-peak Energy Charge	$227.52	$75.79	$137.09	$137.09
Demand	$330.02	$330.02	$236.08	$691.40
Service Charge	$711.20	$39.20	$672.00	$672.00
Reconciliation	-$790.14	N/A	N/A	N/A
Minimum Charge	$635.60	N/A	N/A	N/A
Total Before Tax	$1,291.59	$550.46	$1,072.42	$1,609.48
Total After tax	**$1,349.71**	**$575.23**	**$1,120.68**	**$1,681.91**

Over all months of the year, the following energy expenses are expected for the Energy Park, outlined in table 3 and broken down monthly in figure 12.

Table 3. Estimated annual savings from different configurations and billing structures.

	Current System	All 281	All 284	All 285
Annual Cost	$15,935	$7,361	$21,814	$25,037
Annual Savings	N/A	$8,304	-$5,879	$9,102
Percent Cost Reduction	N/A	54	-37	-57

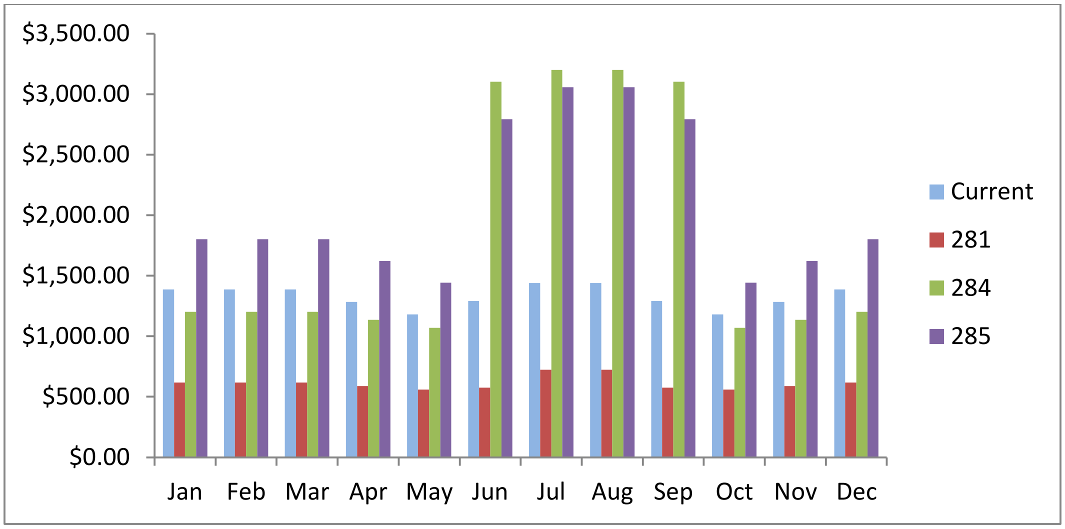

Figure 12. Monthly breakdown of estimated LIPA bills for the Energy Park.

Rates 284 and 285 are attractive in that they offer very inexpensive energy charges [9]. However, daily service charges are very low for rate 281 and account for most of the difference between rates in winter. As solar generation increases through spring, total cost begins to decrease, but then demand charges for both rates 284 and 285 increase dramatically during peak hours in the summer while rate 281 demand charges remain low. This makes rate 281 the most attractive electrical rate structure for this system. The current Energy Park configuration also suffers from its rate division by an extra $720 per month in service charges for the second meter on the wind turbine-fueling station subsystem. Further, infrequent grid power draw from this subsystem incurs a hefty minimum demand charge, meaning that the wind turbine primarily offsets costs through reconciliation. It is much more economical to run the fueling station only during times of excess generation for now, since actual hydrogen usage is currently very small. Even if the total mileage seen by a fuel cell fleet per day requires more than the predicted 2 kilograms per day in the combined rate 281 scenario, the electrolyzer could be run in evenings using grid power for minimized cost. Lastly, reductions in energy expenses are limited in the long run by minimum demand charges and the demand ratchet. LIPA does not give an exact figure for its minimum demand rate for rate 281, so it is impossible to say what the lower limit is. Combining both systems under rate 281 today would save over $8,500 annually, minus any one-time charges to changing the system.

4. CONCLUSIONS

4.1 Summary

The Energy Park produces renewable power through a wind turbine and photovoltaics and uses it for powering its multi-use administration building and fueling station. Currently the photovoltaics meet the load of the administration building around 25% of the time in summer, but this estimate decreases markedly during the winter. The wind turbine tends to produce more power in winter and at night, but little of the power is actually utilized for work in the current configuration. Comparing net load with the LIPA billing structure shows that the energy costs of the system are not minimized on the current combination of rates 281 and 284. Further, around 18% of the time neither wind nor solar is generating power, introducing power gaps that cannot be overcome by simply adding more wind or solar generation. Fortunately, these issues can be addressed simultaneously with some improvements to the current system.

4.2 Recommendations

Considering the current patterns of load and generation, there are a few ways for the Energy Park to improve its own energy usage and reduce annual costs.

1. *Combine all generation and load under one rate structure.*

Switching the power production of the wind turbine from the fueling station to the administration building and billing it under rate 281 would be the first step in system optimization. Not only would it save around $8,300 annually (before expenses to reconfigure the system), but the combined wind and solar system would also cover administrative building load for around 48% of the time.

2. *Produce hydrogen only during times of excess generation.*

Only running the electrolyzer during times of generation excess (considering both wind and solar) would produce enough hydrogen to drive a fuel cell fleet 160 kilometers daily. This would only be possible with a control system that would run the electrolyzer under appropriate conditions. The cost of such a system is not clear.

3. *Diversify generation sources.*

Currently the generation of the system is over twice that of all fueling station and administrative building operations, and increasing solar and wind capacity further will only produce more power during the times of nonzero generation, and will not affect the other half of the time when no power is being produced. With the current low demand for hydrogen, there is little need to install additional generative capacity unless the generating source generates out of synchronization with the current turbine and photovoltaics. Tidal power may be effective in filling this gap; further study would be needed. Conservation and Waterways has already experienced delays in working with LIPA since rate 284 is an uncommon rate structure, so immediate action is recommended to enact any changes.

4. *Expand storage system.*

Current estimations for total energy needed for administrative building and the hypothetical increased energy load for the fueling station actually closely matches the total amount of energy generated at the Energy Park. This suggests that if efficient energy storage were available, the Energy Park would be generating all the energy it needs. The Energy Park is already halfway to using hydrogen fuel as a form of storage since it produces and stores it on site. The last step to proper energy storage would be to add a stationary fuel cell which could be called upon to supply the Energy Park with power. Currently fuel cell systems, such as those used in vehicles, might have an expected round-trip electrical conversion efficiency of around 40%, a power output of up to 100 kW, and a price of around $60/kW [10,11,12]. A small fuel cell would be affordable with the money saved from switching systems and could power the administrative building. With the current hydrogen storage capacity of 42 kilograms, approximately 1400 kWh can be stored at any one time [13]. However, the inherent round-trip losses would vastly reduce available capacity and require more generation capacity on site for a fully independent system.

Increasing generation might be addressed by fixing the considerable number of non-communicating panels already installed, or adding an additional solar array, since photovoltaics are becoming increasingly affordable, and there is still space in the Energy Park to install more.

5. Transition to a microgrid.

This report does not serve as a microgrid feasibility assessment; more study would be needed. However, there is clear potential at this site. If a proper storage system were implemented on site with sufficient generation and storage capacity as needed, the Energy Park would be well on its way to grid independence. However, such an endeavor would require system upgrades to connect all components to a smart control panel which could rapidly divert generation between the building and electrolyzer, as well as instantly call the fuel cell online when needed [14,15]. This governing system is critical and potentially costly.

5. APPENDIX

5.1 Solar Estimation

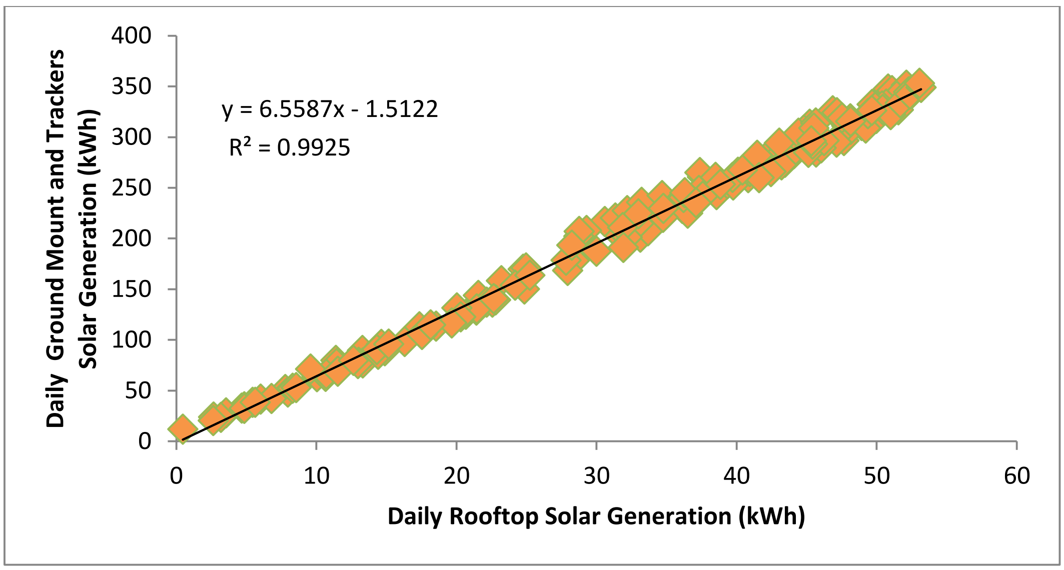

Figure A1. Scatterplot of rooftop solar generation and generation of both ground-mounted arrays and solar trackers for February to July 2013. Each point represents the sum of energy produced over a single day in the given period. Note that for the ground mounts and trackers, data is reported as daily energy accumulations. For the rooftop array, data is reported as power averages for each hour, which can be directly summed to estimate daily energy generated. A slight deviation from the trend can be seen near zero generation, when the rooftop inverter is likely experiencing reduced efficiency due to low current.

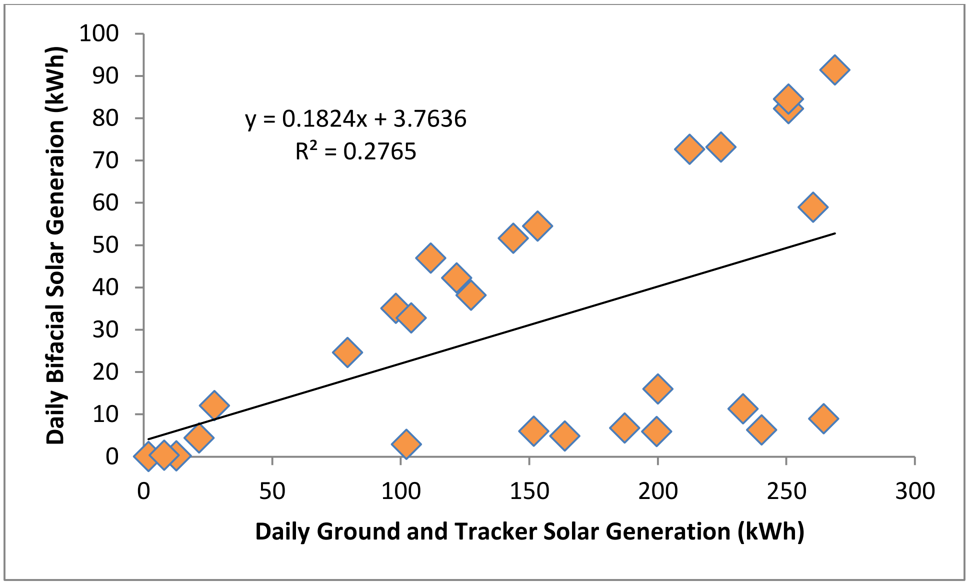

Figure A2. Scatterplot of ground-mounted and tracker array energy output versus bifacial array, February 2014. On many days, which did not show an obvious pattern throughout the month, the bifacial array produced unusually poor outputs. The cause of this inconsistency is unknown. Weather would have affected all arrays equally and maintenance should have shown a more consistent pattern week to week. This error was attributed to metering issues and was not considered to affect long-term energy output.

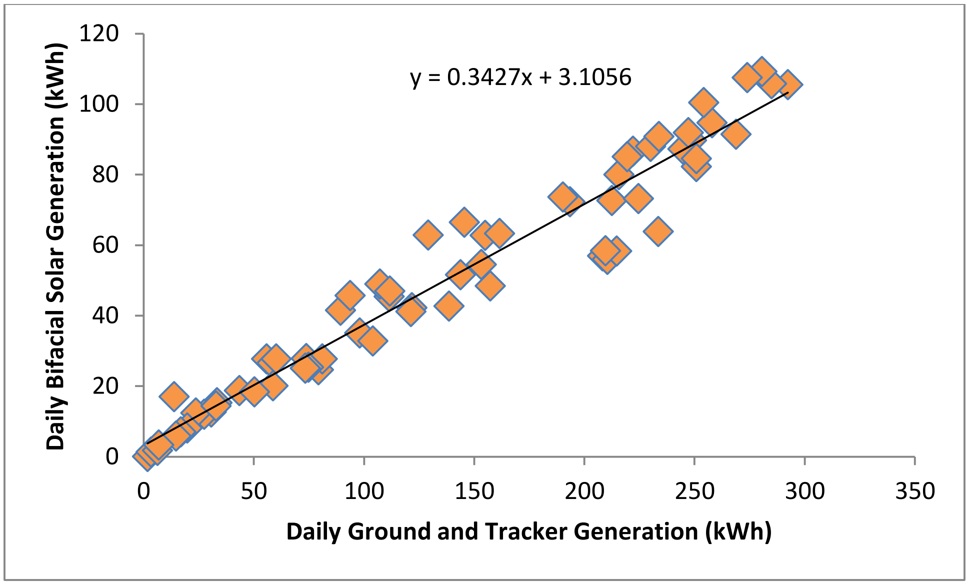

Figure A3. Scatterplot of ground-mounted and tracker array energy output versus bifacial array, February to June 2014, corrected. Removing the most clearly erroneous data points from February to April, the only months in which any bifacial array data was available, produced a scatterplot which could be used for more accurate predictions. Although the new trendline may still be slightly conservative, it was used to estimate the bifacial array's contribution.

In this way, the rooftop solar array output, which has good data for February through July 2013, can be used to estimate the ground and tracker arrays, which in turn can precisely estimate the bifacial energy output. Furthermore, since for any given day all solar panels produce energy for the same amount of time, proportionality between instantaneous power output of all arrays can be inferred. For instance, on a given day the rooftop array produces just under 9.9% of all energy generated. Therefore at any given time, the rooftop array will be producing 9.9% of all power generated. Via the linear proportionalities between array energy produced, the total power of the site at any time can be inferred with only power data for the rooftop solar array.

5.2 Rate Structures

Table A1. LIPA Rate 281 for secondary voltage service, in which LIPA supplies the system transformer (which is the case at the Energy Park) [4,9].

Hour Class	June1-Sep30	Oct1-May31
Service Charge (per day)	$1.4	$1.4
Demand (per kW per mo.)	$10.84	$9.63
Energy (per /kWh per mo.)	$0.0536	$0.0387

Rate 281 is the recommended structure for systems that use between 7 and 145 kW of electricity, making it optimal for the Energy Park. Rates 284 and 285 are recommended for load over 145 kW, which is not expected at the Energy Park. Other rates are intended for seasonally-inactive systems and do not apply. For rates 284 and 285, secondary and transmission voltages are calculated, since the transformer used to procure grid power was supplied by LIPA.

Table A2. Comparison of LIPA Rates 284 and 285. Note that both also charge a $7.50 service charge per day for primary, secondary, and transmission voltage, and a meter charge of $2.50 per day for secondary voltage, $6.50 otherwise [9].

		285 (Standard)			**284 (Alternative)**		
	Hour Class	Off Peak	Peak	Intermed.	Off Peak	Peak	Intermed.
	Time	All Year 11PM -7AM	June 1-Sept30, weekdays, 12PM-8PM	All Remaining Hours	All Year 11PM -7AM	June 1-Sept30, weekdays, 12PM-8PM	All Remaining Hours
Demand Charge (per kW)	Secondary Voltage	None	$22.09	$5.26	None	$42.83	$4.28
	Primary Voltage	None	$18.96	$4.65	None	$38.45	$3.84
	Trans. Voltage	None	$15.68	$15.68	None	$28.74	$2.87
Energy Charge (per kWh)	Secondary sVoltage	$0.02	$0.05	$0.04	$0.01	$0.04	$0.04
	Primary Voltage	$0.02	$0.04	$0.04	$0.00	$0.04	$0.03
	Trans. Voltage	$0.02	$0.04	$0.03	$0.00	$0.03	$0.03
Min Demand Charge (per kW, per rate period, per meter)	Secondary Voltage	None	$33.50	$9.21	None	$54.99	$7.25
	Primary Voltage	None	$28.76	$8.13	None	$49.57	$6.68
	Trans. Voltage	None	$23.79	$6.68	None	$36.88	$5.06

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