Assessment of Sustainable Energy Technology Aboard M/V *Seasteader I*

George L. Petrie[1],

October, 2012

Our Mission: To further the establishment and growth of permanent, autonomous ocean communities, enabling innovation with new political and social systems.

[1] Director of Engineering, The Seasteading Institute

Table of Contents

Assessment of Sustainable Energy Technology

Introduction

As set forth in the Institute's recently completed *Engineering Development Five-year Plan*, the implementation of sustainable energy technology is important to achieving the long-term goals of seasteading. Moreover, the recent acquisition of a 275-foot, four-deck excursion vessel will allow the Institute to evaluate alternative energy conversion and storage technologies within the context of an actual on-board installation.

The vessel, *Seasteader I*, has an expansive, open-air upper-deck layout conducive to installation of a large (roughly 5,000 square-foot or 500 square-meter) solar array. This area could easily accommodate an array of solar panels offering about 60-kilowatts of total rated capacity, which could be mounted on existing steel support structures. In addition, there are open areas on the foredeck and atop the pilothouse that could accommodate (perhaps) four to six wind-powered generators offering as much as 30-kilowatts of additional capacity.

It is proposed to install an array of solar panels, along with horizontal-axis and vertical-axis wind power generators, and to test these devices on Seasteader I. One objective of this project will be to demonstrate the degree to which these sustainable energy sources can reduce the amount of energy that the ship must produce through combustion of fossil fuels.

One of the major complications associated with wind and solar energy systems stems from the fact that energy production is seldom aligned with demand. In a typical solar- or wind-power installation ashore, the problem is easily solved by dumping power onto the grid. However, for a seastead located in the open sea, it will be necessary to have an efficient means of storing energy during times of low demand and recovering that energy during times of high demand.

Accordingly, it is proposed to evaluate a variety of different energy storage technologies as part of this project. Batteries (such as lithium-ion and/or lead-acid) will serve as a baseline for cost and performance, to be compared with one or more of the following alternatives: hydrogen, compressed air, and/or pumped-water reservoirs.

Information obtained from the proposed pier-side tests will provide valuable insight into the expected performance and efficacy of sustainable energy systems in a shipboard installation, while eliminating the logistical complications attendant to testing at sea. Once Seasteader I is placed into service it is anticipated that the most effective elements of these systems will be retained, to reduce the vessel's appetite for diesel fuel and to demonstrate how such systems will perform in actual day-to-day operation.

Purpose

The primary goal of this project will be to demonstrate the degree to which sustainable energy sources can reduce the amount of energy Seasteader I must produce through combustion of fossil fuels. While installation and initial testing will likely take place at the vessel's present berth in Fort Pierce, Florida, it is expected that system testing will continue when Seasteader I is placed in service. This project is intended to support our long-term goal of attaining sustainability and energy independence for future seastead communities.

Scope

This plan focuses on the following engineering activities:

- Energy Conversion
  - ✓ Solar Panels
  - ✓ Wind Power Generators
    - Horizontal Axis
    - Vertical Axis

- Energy Storage
  - ✓ Batteries (Baseline for Comparison)
  - ✓ Hydrogen (H_2) generation and storage
  - ✓ Compressed air energy storage (CAES)
  - ✓ Pumped hydro (using two vertically separated reservoirs)

- Data Acquisition
  - ✓ Environmental Conditions
    - Date and Time of Day
    - Solar Radiation
    - Wind Speed and Direction
  - ✓ Power Produced at each Energy Conversion Device
    - Date and Time of Day
    - Voltage
    - Current
  - ✓ Power Extracted from each Storage Device
    - Date and Time of Day
    - Voltage
    - Current

- Performance Evaluation
  - ✓ Cost per Kilowatt-Hour of Power Produced by each Energy Conversion Device
  - ✓ Efficiency and Losses for Storage Devices, Inverters and other Controllers

Planned Approach and Rationale

Energy Conversion

As sources of sustainable energy, solar panels and wind power generators share one singularly inescapable characteristic: the output of each depends entirely on environmental factors that are beyond our ability to control. Moreover, the capacity (output) rating of these devices is typically based on 'optimum' conditions that will occur during only a limited percentage of the time. Therefore, it is inevitable that the average output from these systems will be significantly less than their rated power.

Solar panels are typically rated for conditions of full sun, directly overhead. It is self-evident that they can produce power only during daylight hours, so at best solar panels will operate only about half the time over the course of a year. Even during daylight hours, their output depends on the angle of the sun relative to the surface of the panel, so output can vary with latitude, time of day, and season of the year. Not to mention reduced output due to clouds, precipitation and other factors.

Wind power generators have similar vagaries influencing their output. The rated power output for most configurations and/or brands is based on a wind speed of 10.0 to 11.0 meters/second (equal to about 20 to 22 knots, or 22 to 24 miles per hour.) There are few locations on earth where the *average* wind speed is that high; more typically, average wind speeds are only about *half* that speed. At those speeds, output is generally only about 20 to 25 percent (or less) of the nominal rated power. Worse yet, most require at least 6 to 7 knots of wind just to produce *any* output at all.

Fortunately for prospective seasteaders, there are plenty of places on the high seas with lots of wind (most of the time) and clear sunny skies. When Seasteader I is not out in the open ocean, she'll be as close as can be while still offering easy pier-side access for logistics. More importantly, data available from nearby buoys will facilitate correlation between measurements onboard and simultaneous conditions in the open waters just offshore.

The following sections provide estimates of the power producing potential of solar panels and wind power generators, assuming installation on Seasteader I docked pier-side at her berth in Fort Pierce, FL. Depending on assumptions, the total cost for solar power is estimated to be between $0.10 and $0.20 per kilowatt-hour. For horizontal-axis wind power units, the total estimated cost is about the same, $0.10 and $0.20 per kilowatt hour, while for vertical-axis units the estimated cost is nearly double, about $0.20 and $0.40 per kilowatt-hour. To put these energy prices in context, the national average residential rate for electricity is just under $0.10 per kilowatt-hour. As a baseline for a seastead using a diesel-fueled generator, the energy cost is estimated to be nearly five times that amount (about $0.50 per kilowatt-hour) assuming a fuel price of $5.00 per gallon delivered offshore.

- *Solar Panels*

Size, weight and ratings from more than a dozen different solar panel manufacturers are compared in Figure 1 below. Although there is some scatter in the data, the variation is rather small. Based on this information, it is assumed that solar panels will typically weigh about 190 pounds per kilowatt of rated output (including the panel frame, but excluding the weight of any supporting structure.) Similarly, the average energy density has an average value of around 75 square feet (about 7.0 square meters) per kilowatt.

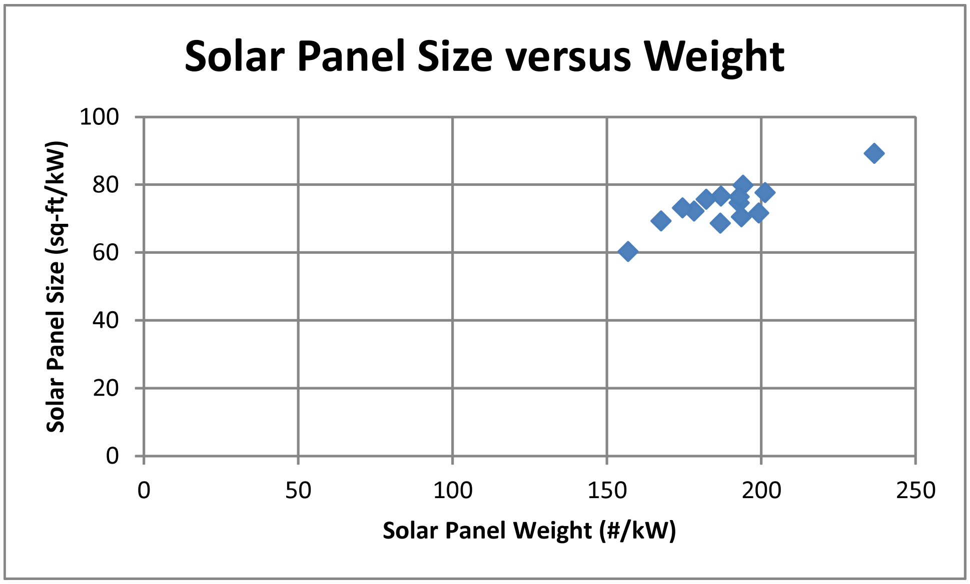

Figure 1 – Comparison of Solar Panel Weight and Size per Kilowatt of Rated Output

The upper deck of Seasteader I is comprised of two sections; the ship's plans indicate a 'center' section (just aft of the pilothouse) that extends about 28.8 meters (94.5 feet) in the fore and aft direction, and an 'aft' section (one deck down) that extends another 8.4 meters (27.6 feet) fore and aft. Above both sections, there is an existing steel framework extending across the full width of the deck, about 10.8 meters (35.4 feet) in the transverse direction.

This existing framework would provide about 4,325 square feet (402 square meters) of area for mounting solar panels. To maximize the available mounting surface, panels could extend beyond the existing framework by about 3 feet on either side without protruding beyond the perimeter of the hull below. This would boost the usable area to about 5,125 square feet (476 square meters).

The solar energy from 'full-sun' shining directly overhead is 1-kilowatt per square meter. However, conversion efficiency of solar panels is typically in the range of 12 to 18 percent, hence our proposal for covering the entire available area on the upper deck of Seasteader I, (some 402 to 476 square meters) would provide an array having about 58 to 68 kilowatts of capacity, rated in the optimum condition of 'full-sun' directly overhead.

However, the sun is rarely (if ever) directly overhead; this occurs momentarily at noon only a few times each year at latitudes within 23.5 degrees of the equator. At higher latitudes, solar panels are usually tilted to match the sun's average angle of elevation, but at best the sun will still be perpendicular to the surface of a fixed panel for just a few moments during the year. While some installations are equipped with solar trackers, it is commonly held that the cost and complexity of such systems is difficult to justify.

For a system mounted on a floating vessel, even the idea of tilting panels at a fixed angle is somewhat problematic, since it would consequently require that the vessel be maintained at a fixed heading. This would require a costly multi-point mooring system or some other means of dynamically controlling the vessel's heading, which would likely consume more energy that would be produced by the increase in solar panel output. Accordingly, it is assumed in this analysis that solar panels are mounted horizontally; although the existing support frames on Seasteader I are inclined at a small angle (about 5^{o}) downward to either side of the centerline, this would have only a small impact in efficiency while offering drainage of rainwater and entrained particulates that may otherwise settle on the panels.

The key question, however, is how much electricity can a notional 58- to 68-kilowatt solar array actually produce? The graph shown in Figure 2, below, illustrates the hourly variation in the fraction of 'full-sun' acting on a horizontal solar panel throughout a 24-hour period on the first day of summer, autumn, winter and spring in Fort Pierce, FL, located at latitude 27.4644^{o} north. Shown in the Appendix, Table A-1, is a spreadsheet indicating this same fraction of 'full-sun' hour-by-hour and week-by-week, year-round.

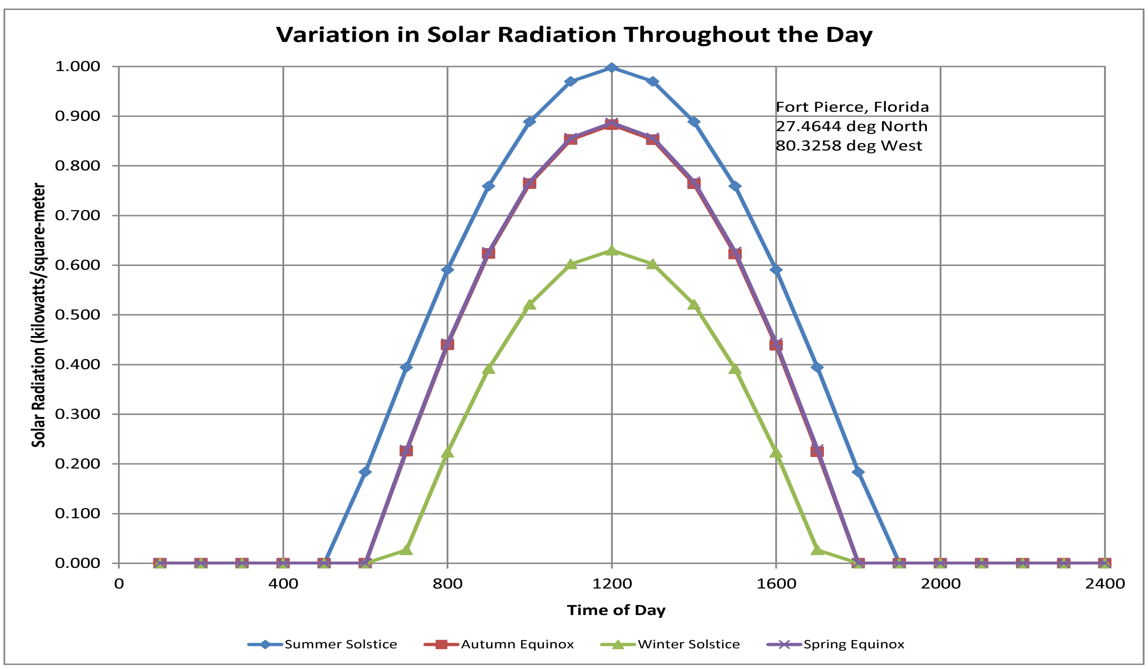

Figure 2 – Hourly Variation in Peak Solar Radiation at Fort Pierce, Florida

From this spreadsheet, which takes into account the hourly variation in the sun's elevation during the year, it has been determined that a solar panel installation of normal efficiency could deliver about 6.5 kilowatt-hours per day (roughly 2,400 kilowatt hours per year) *for each kilowatt* of rated capacity. Other environmental factors associated with each specific installation site will further diminish the effective solar radiation that is actually available to the solar panels.

An online calculator at the NREL/PV-Watts website http://www.nrel.gov/rredc/pvwatts/ indicates that the average solar radiation in West Palm Beach, FL (about 60 miles south of Seasteader I in Fort Pierce) is only about 0.719 watts per square meter, as compared to a nominal 1.0 watts per square meter for 'full' solar radiation. Thus, taking into account the reduced solar radiation due to these local environmental effects, annual output would be expected to be about (0.719*2,400=) 1,725 kilowatt hours per year *for each kilowatt* of rated capacity.

Based on the factors presented above, for a solar array of the maximum size that could be accommodated aboard Seasteader I (with a rated output of 58 to 68 kilowatts), the energy produced over the course of the year would be about 100,000 to 117,000 kilowatt-hours. Compared to a hypothetical maximum of (58-kW*24*365 hours/year=) 508,080 kilowatt-hours per year for a system rated at 58 kilowatts, the 100,000 kilowatt-hours of energy that can be achieved means that the utilization factor is about 20-percent. And bear in mind, this utilization factor is separate from (and must be combined with) the conversion efficiency of the solar panel itself; typically about 12 to 18 percent, as previously stated.

Despite the (relatively) low conversion efficiency of solar panels and their inherently low utilization factors (due to rising and setting of the sun) solar panels can be cost effective in some scenarios; they often benefit from government subsidies or tax preferences but those advantages are unlikely to be available to seasteads. Nevertheless, energy produced from solar panels can be cost-competitive when compared to diesel-fueled generators, which are the likely 'default' for a seastead community if alternative energy sources are not utilized.

Several sources suggest that solar cells are presently selling for about $1.00 per watt, with at least one article citing module prices as low as $0.70 per watt. Advertised prices for full solar panels average about $1.50 to $1.60 per watt, including the frame and an inverter, but excluding support structure and energy storage. Using the higher figure ($1.60 per watt), the expected price for a solar array with a rated capacity of 58 to 68 kilowatts would range from $90,000 to $110,000 including an inverter but exclusive of mounting and batteries. For a 20-year life (based on 1,725 kilowatt-hours per year per kilowatt of rated capacity), that translates to about $0.04 to $0.05 per kilowatt-hour excluding installation and (minimal) maintenance. Even with conservative allowances for system installation, energy storage, inverters and the like, the overall cost is in the range of $0.10 to $0.20 per kilowatt-hour, comparing favorably to an estimated $0.50 per kilowatt-hour for a diesel-fueled generator.

- *Wind Power Generators*

Unlike solar panels, which (at best) produce power during only half (or less) of each day, generators powered by wind turbines can generate electricity 24/7 for long as the wind blows. There are, however, a couple of caveats; virtually all wind turbines require at least some minimum wind speed (typically 6 to 7 knots) to generate any power at all, and most require wind speeds of 20 to 22 knots (10 to 11 meters per second, or about 23 to 25mph) to develop their full rated output. Consequently (and not unlike solar panels) wind turbines frequently operate in sub-optimum conditions.

There are two broad categories of wind turbine. Although they vary widely in size, the most common configuration is the horizontal-axis turbine, which has three or more long slender blades that spin in a vertical plane; much like an airplane propeller, but having a generator (instead of a motor) attached to the horizontal shaft. While they can offer relatively good energy conversion efficiency, some find them aesthetically and acoustically challenged; i.e. ugly and noisy. More stylish and less obtrusive alternatives are found amongst the variety of vertical-axis configurations, which are typically designed to have a number of slender blades festooned around a vertical shaft, not unlike the blades on an eggbeater, but with decidedly more aerodynamic shape. While generally quieter, more architecturally pleasing and having a smaller foot-print, vertical-axis wind turbines usually have lower efficiency.

It is our intention to install several wind turbines aboard Seasteader I*,* representing typical horizontal and vertical axis configurations, and to characterize the performance, efficiency and acoustics of both concepts within the constraints imposed by the layout of the vessel. During the proposed performance evaluation, wind speed will be recorded at regular time intervals, to be correlated with the power actually produced and compared to the rated power output of each device at each wind speed.

Summaries in the Appendix, Table A-2, indicate the wind speed frequency of occurrence near the present location of Seasteader I, derived from more than 128,000 measurements taken during an 18-year period (1990 to 2008) at a NOAA National Ocean Service station near Lake Worth, Florida, about 60 miles south of Fort Pierce. Based on these wind speed statistics, the power expected from each type of wind turbine is predicted, as discussed in the following sections of this report. Seasonal and annual wind speed probabilities from this data are shown in Figure 3 on the following page.

Similar wind speed statistics are available from various sources for most coastal areas and open ocean locations throughout the world. Thus the methodology used in this report can be readily applied to any location in which the Seasteader I*,* (or any proposed seastead) is likely to operate. The proposed testing and evaluation activity will allow for calibration of predictions based on wind speed statistics in other location, and based on manufacturer's data for other sizes and types of wind turbines.

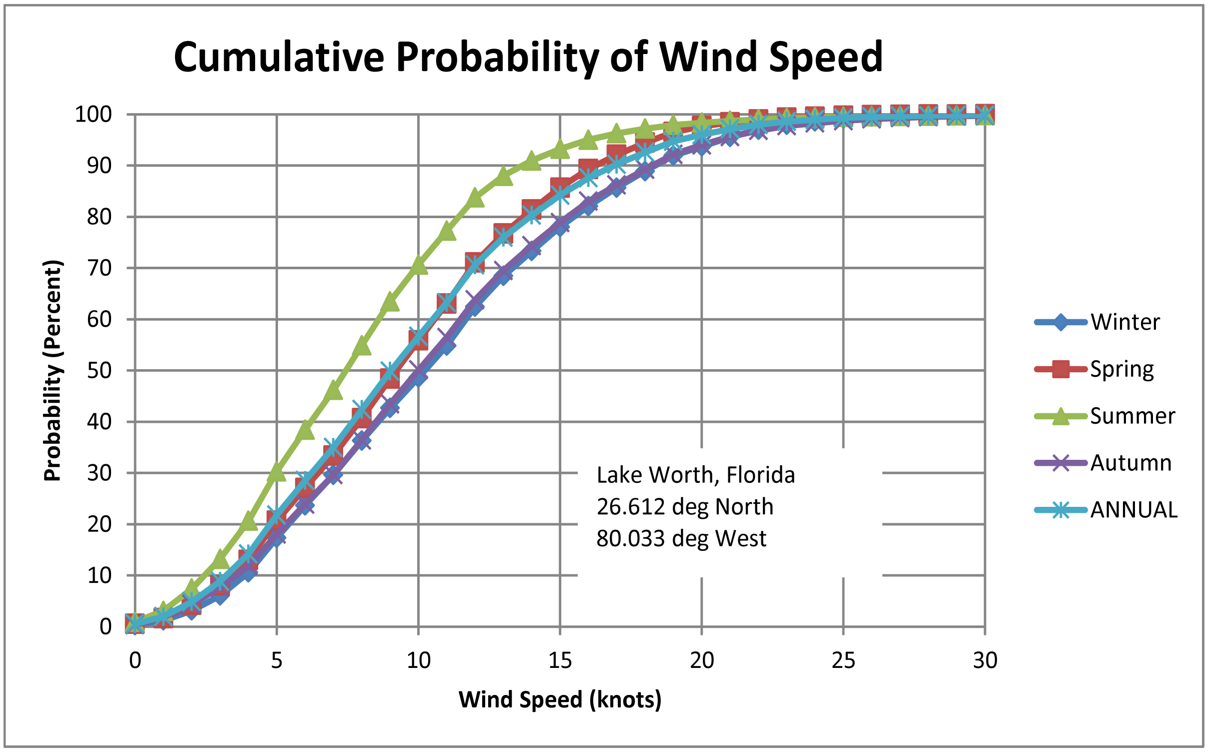

Figure 3 – Seasonal and Annual Wind Speed Probability

Horizontal Axis Wind Turbines

These devices are available in a broad range of sizes, ranging from residential size units that produce just a few hundred watts to utility-scale turbines that generate several mega-watts. For testing aboard Seasteader I, units in the 5.0-kilowatt range are considered to be an appropriate size; the blades on a turbine of this rating would be about 20 feet (6 meters) in diameter. Weighing about 700 to 800 pounds (320 to 360 kg), it is anticipated that two units of this size could be mounted on struts erected at the stern of the vessel in either side.

The rated output characteristics of a typical 5-kw wind turbine are shown in Figure 4 on the following page. Published vendor data for this unit was interpolated to define the output at winds speeds from 5 to 35 knots, in one-knot increments, corresponding to the wind speed intervals in the data for Fort Pierce/Lake Worth, Florida shown in Table A-2. Note that the turbine does not deliver its full rated output until the wind speed reaches 21 knots or more; however, at higher wind speeds it can produce even more than its rated power, although the rate of increase is much more gradual.

Multiplying the number of hours in each month times the probability of occurrence of each wind speed (from Table A-2) gives the expected number of hours per month for each speed; that number times the wind turbine output for that speed yields the kilowatt-hours for each wind speed increment, as summarized in Figure 4 below and detailed in Table A-3.

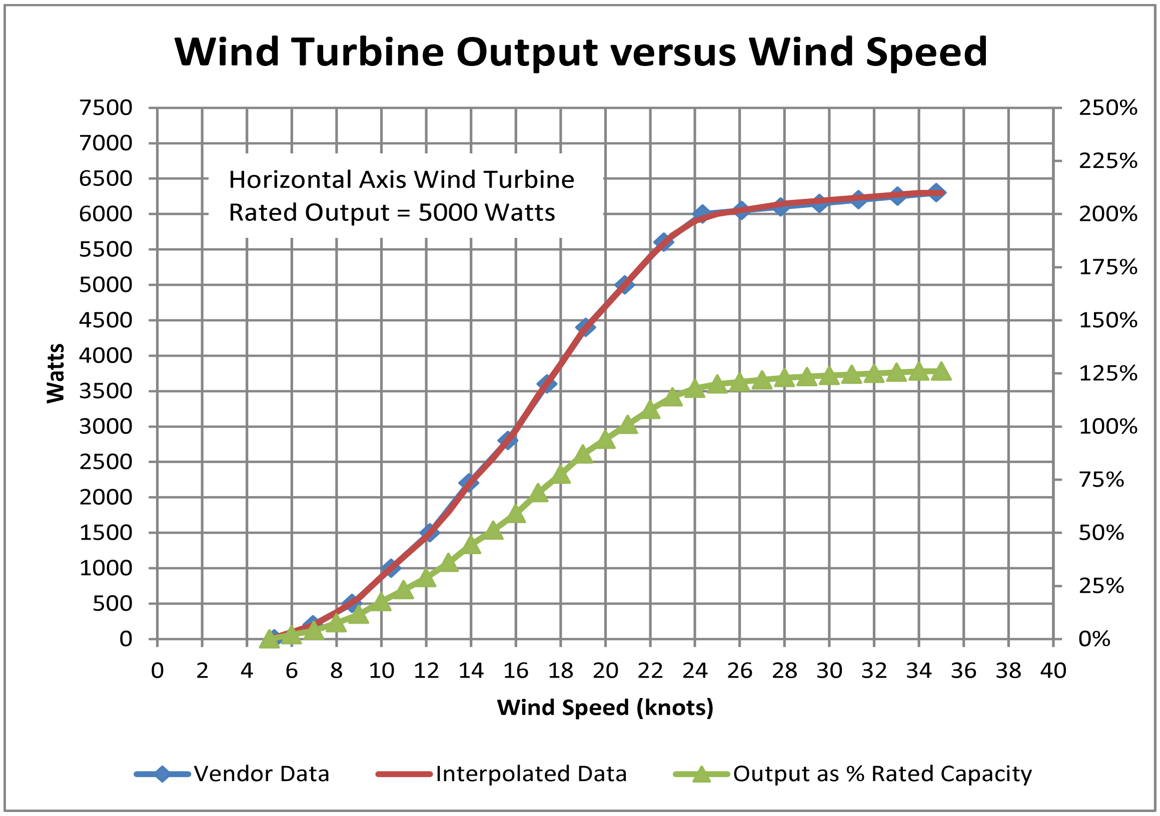

Figure 4 – Output versus Wind Speed for a Typical 5,000-watt Horizontal Axis Wind Turbine

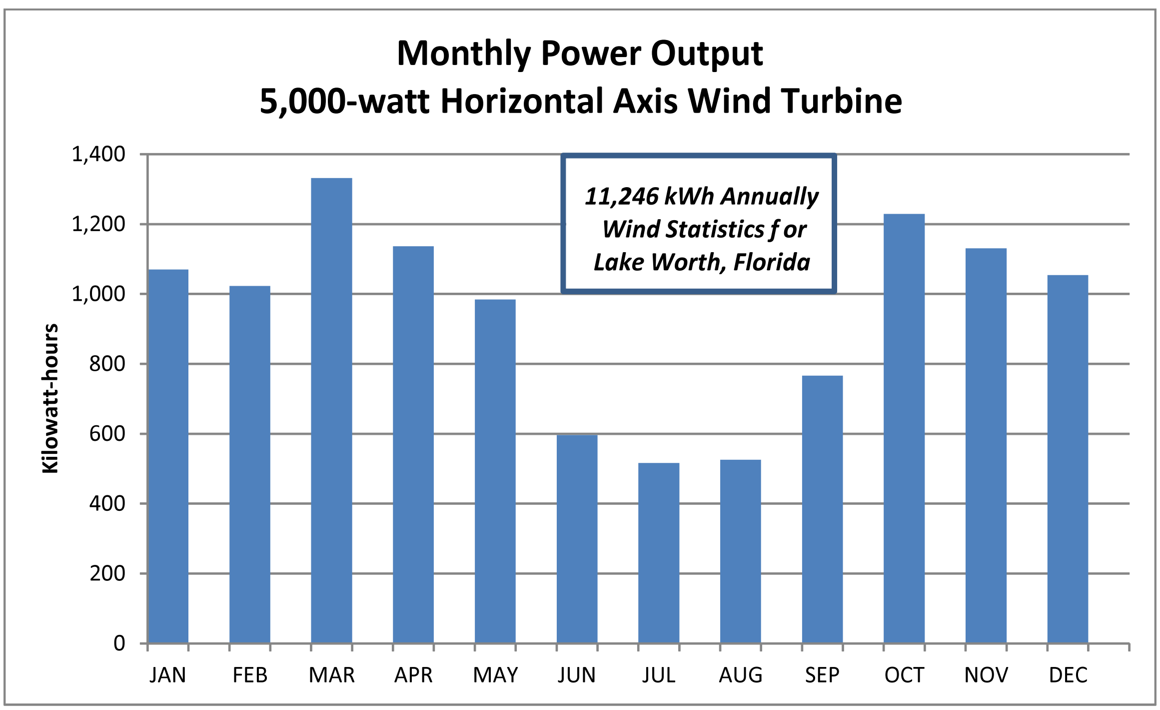

Figure 5 – Monthly Power Output for a Typical 5,000-watt Horizontal Axis Wind Turbine

Vertical Axis Wind Turbines

Although several manufacturers claim to have vertical axis wind turbines offering efficiency equal to or greater than their horizontal axis counterparts, the dominance of horizontal axis turbines in the utility sector would suggest that vertical axis designs still have a ways to go. However, an evaluation of vertical axis wind turbines concluded last year by researchers at CalTech (http://news.cnet.com/8301-11128_3-20079842-54/vertical-axis-wind-turbines-trump-others-on-land-use/) it was found that

> "… *vertical-axis wind turbines have the potential to generate more power per square meter [of land area] than the propeller-like, three-blade wind turbines. The key is that vertical-axis turbines can be placed close together without creating the type of wind disturbances that would sap performance of traditional turbines*."

> *"The tests found that the power density of these vertical-axis wind turbines is about six to nine times that of modern wind farms with horizontal-axis turbines, which need significant spacing among them to prevent causing aerodynamic interference."*

While this conclusion may be of some significance to land-use advocates, it has profound implications for installations on a floating structure such as a seastead. On the assumption that seasteads will generally be located offshore in relatively deep water (more than, say, 100m or 330 feet) it is most likely that wind turbines would be mounted on the seastead platform itself, because installing a separate platform or tower in deep water would almost certainly be cost prohibitive. And because the amount open deck space aboard a seastead is limited by its overall size, maximizing 'kilowatts per square foot of deck area' is likely to be an important consideration.

If it is true that vertical axis wind turbines can produce six to nine times as much power per unit of 'foot print', then that might substantially offset other potential advantages offered by horizontal axis turbines. The performance characteristics of a typical vertical-axis wind turbine rated at 1200 watts is shown in Figures 6 and 7 on the following page, which have been developed using the same methodology as described in the preceding section.

For the 1200 watt turbine used in this example, the rotor diameter is only 4.1 feet (1.2m) in diameter, compared to the blade diameter of 20.2 feet (6.2m) for the 5,000 watt horizontal axis turbine. Accounting for the fact that the horizontal-axis turbine must be free to rotate through a full 360-degrees, it requires a clear footprint at least equal to the blade diameter, excluding the required clearance between units. Thus the 5,000 watt horizontal axis turbine requires a foot print of at least 320 square feet; producing about 15 watts per square foot. On the same basis, the 1200 watt turbine occupies a footprint of only 13.2 square feet, thus producing more than 90 watts per square foot. Of course, these energy densities must be discounted to account for the required clearance between units. One of the objectives of the proposed testing will be to assess how close together wind turbines can be positioned.

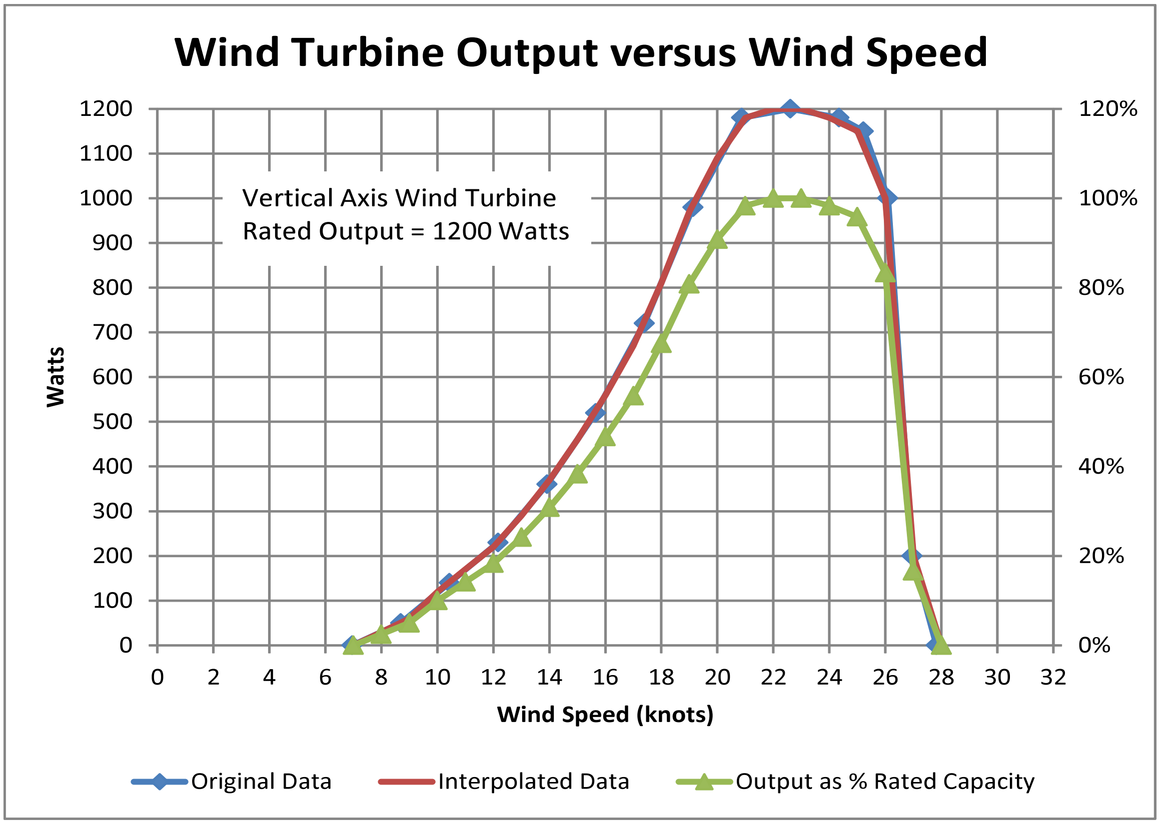

Figure 6 – Output versus Wind Speed for a Typical 1,200-watt Vertical Axis Wind Turbine

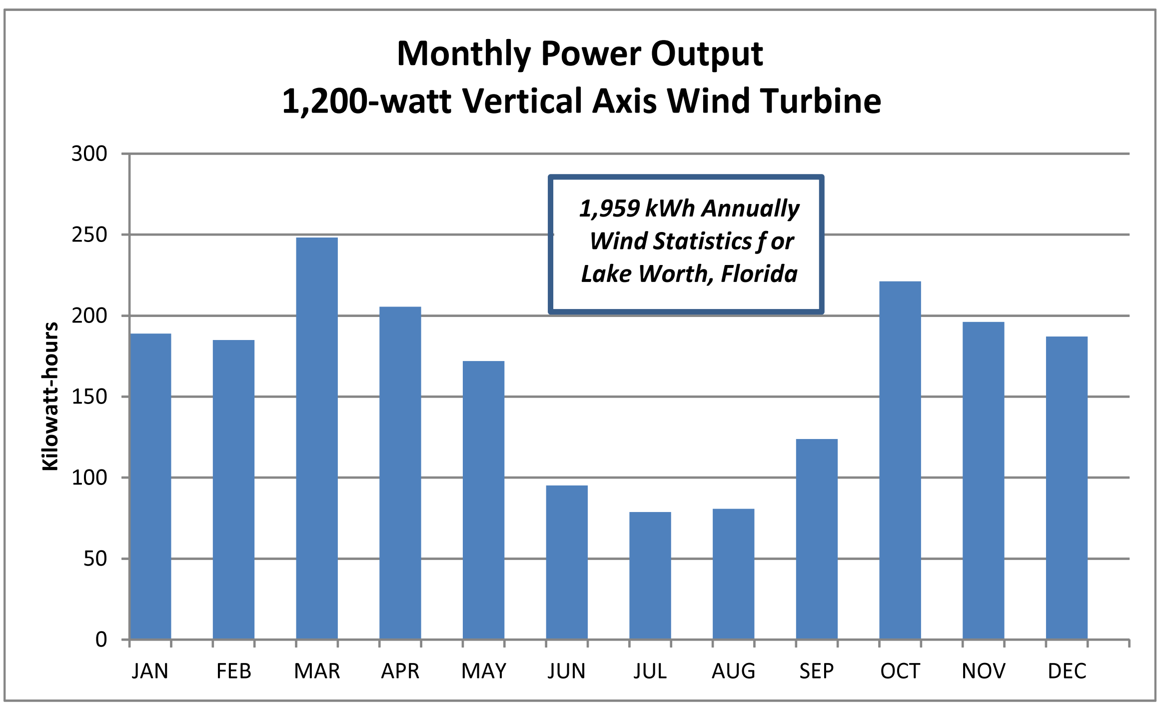

Figure 7 – Monthly Power Output for a Typical 1,200-watt Vertical Axis Wind Turbine

Cost Comparison of Horizontal and Vertical Axis Wind Turbines

Prices posted online (http://turbines.allsmallwindturbines.com/) for horizontal-axis wind turbines are generally in the range of $2 to $4 per watt of rated output. Thus the cost for a model rated to produce 5,000 watts would probably be in the range of $10,000 to $20,000 including an inverter but excluding energy storage, mounting and installation. Based on the annual energy production shown previously in Figure 5 (an estimated 11,246 kWh annually) spreading the initial cost over a period of 20-years yields an equivalent cost of $.05 to $.10 per kilowatt hour. Allowances for mounting, installation and other factors could increase these figures by as much as a factor of two; thus yielding a cost of $.10 to $.20 per kWh.

Published pricing for vertical-axis wind turbines is not as readily available, but inquires have indicated the cost of a typical 1200 watt unit might range from $9,000 to $12,000 *including* installation and an inverter, but excluding energy storage. Based on the energy production shown previously in Figure 7 (an estimated 1,959 kWh annually) spreading the initial cost over a period of 20-years would yield an equivalent cost of $.23 to $.30 per kilowatt hour. While this is significantly higher compared to a horizontal axis turbine, for a seastead with limited deck area it is important to consider that a vertical axis configuration can potentially produce more than six times the amount of energy within a given amount of deck space.

Energy Storage

At present, Seasteader I is fitted with two main diesel generators rated at 250-kW each and an emergency diesel generator rated at 60-kW. Operated as a gaming ship, the nominal load on her electrical system was estimated to be 200-kW in normal circumstances, hence either one of the main diesel generators could provide the full generating capacity required. Without gaming equipment, the power required for lighting and other functions necessary to operate the ship is estimated to be about 60-kW without air conditioning. In her present locale, air conditioning is thought to add an additional 40-kW to her average operating power requirement. Thus, daily energy requirements would be expected to fall within a range from 1,440 kWh to 2,400 kWh.

Based on the analyses presented in the preceding sections, solar panels installed on the ship in its Fort Pierce location would have a utilization factor of about 20%, thus a solar array having a rated capacity of 60-kW should produce about 288 kWh (60-kW x 24-hours x 20%) per day, on average. Likewise, a wind turbine installation rated at 30-kW (having a utilization factor of 25%) should produce about 180 kWh (30-kW x 24-hours x 25%) per day, on average. Thus, the total energy from solar and wind would average about 468 kWh per day, or about 20 to 30 percent of the total energy required to operate the vessel. However, at peak times (from late morning through early afternoon on a windy day) the combined output from the solar panels and wind turbines would approach their full rated output of 90-kW; about 50 percent more than would be required without air conditioning.

For a seastead on the high seas, surplus energy from solar and wind cannot simply be dumped onto the grid. It should be stored during periods of surplus, to be reclaimed when the sun goes down and the wind dies. Of course, economics dictates that the cost of storing surplus energy should not exceed the value of that energy! The remainder of this section sets forth a plan for evaluating several of the myriad technologies considered for energy storage, and comparing them on the basis of cost, size and weight.

As a common basis for comparison, it is assumed that each storage system has the capacity to store one-half of the total energy that can be produced during an average day, i.e. 50% of the average 468 kWh per day stated above, or (rounding up) about 240 kWh of storage capacity. Arguably the most common method of energy storage, batteries were chosen as the baseline against which other concepts are compared.

In addition to obvious considerations such as size, weight and cost, the primary factors to be considered in selecting an energy storage system the following:

- Discharge time – Over what duration of time is the stored energy to be dissipated? Is the energy to be spent in a quick pulse to meet a sudden surge in demand, or over a longer period of time to bring supply into balance with demand?

- Rated power – Maximum power that the system must produce; not to be confused with energy storage capacity, which is the product of *power* multiplied by *time*.

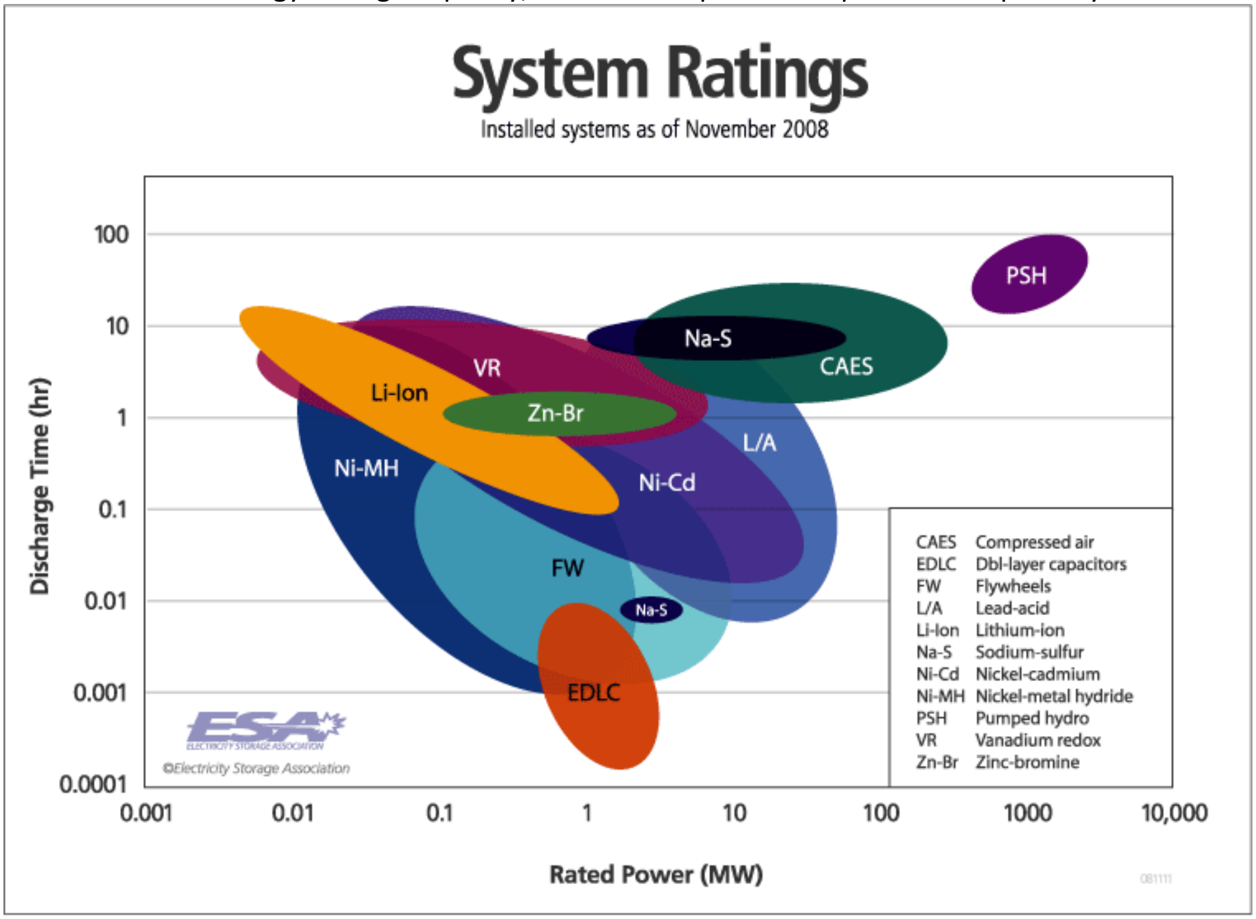

Figure 8 – Comparison of Various Energy Storage Technologies
(http://www.electricitystorage.org/technology/storage_technologies/technology_comparison)

Depictions such as shown in Figure 8, above, illustrate a range of scenarios in which different energy storage systems might be most suitable. For application on Seasteader I, discharge times on the order of 10 hours would be an appropriate time scale; accordingly, the illustration in Figure 8 suggests that any of several types of battery storage could be viable candidates.

However, in looking to the longer term, very large seastead communities would likely have power demands in excess of what could be feasibly met with batteries alone. Thus, it is of interest to consider at least two other options shown on Figure 8, namely compressed air energy storage (CAES) and pumped [static] hydro (PSH) systems, both of which have the capacity to meet very high power demands.

Moreover, taking a long term perspective and recognizing the ongoing research by the US Department of Energy and others to reduce the cost of fuel cells and electrolyzers, it seems warranted in addition to consider hydrogen as a viable future alternative. Implementation of each of these options is discussed in the following sections of this report.

- *Batteries (Baseline for Comparison)*

A comparison of cost and energy density for several common types of batteries is shown below, in Figure 9. Other sources suggest that lithium-polymer batteries can offer superior energy density, in practice this technology has found acceptance only in small hand-held devices. Lithium-ion batteries have found favor in electric car applications because they provide high energy density compared to lead-acid or nickel-zinc batteries. Makers of lithium-polymer batteries have yet to find a way to scale-up that technology to support higher power applications, while nickel-cadmium and nickel-metal-hydride are significantly more expensive.

Battery Type	Cost $ per Wh	Wh/kg	Joules/kg	Wh/liter	Wh per pound	pound per kWh	Wh per cu-ft	cu-ft per kWh	Cost $/kWh
Lead-acid	$0.17	41	146,000	100	18.64	53.66	2,832	0.35	$170
Metal-hydride	$0.99	95	340,000	300	43.18	23.16	8,495	0.12	$990
Nickel-cadmium	$1.50	39	140,000	140	17.73	56.41	3,964	0.25	$1,500
Lithium-ion	$0.47	128	460,000	230	58.18	17.19	6,513	0.15	$470

Figure 9 – Comparison of Various Battery Types
(http://www.allaboutbatteries.com/electric_cars.html)

While energy density is an important consideration for hand-held devices and electric cars, size and weight are not nearly as critical on vessels like Seasteader I, which are typically designed with capacity to carry large volumes of fuel, water ballast and other consumables. In that context, the proven performance, safety and low cost of lead-acid batteries make them an attractive candidate.

Based on the values in Figure 9 and the requirement to provide 240-kWh of energy on Seasteader I, the cost, size and weight of lead-acid and lithium-ion battery systems are estimated as follows:

	Cost (US$)	Size (cubic feet)	Weight (pounds)
Lead-acid batteries	$40,800	84.8	12,878
Lithium-ion batteries	$112,800	36.9	4,125

To put these values in context, the ballast tanks on Seasteader I have a total capacity of some 13,206 cubic feet, which corresponds to about 845,000 pounds of seawater ballast. Clearly, the volume and weight of either type of battery system is negligible in comparison to the vessel itself. Suitability of either battery system is much more likely to be limited by considerations of long term reliability and cycle-life in the context of the charge/discharge cycles that will occur on *Seasteader I*.

Other battery types shown in Figure 8, vanadium redox (VR) and sodium sulfur (Na-S) are both dismissed from consideration. Although VR offers theoretically better performance compared to lithium ion batteries, the potential advantages have yet to be realized in production. And while there are several large scale Na-S installations in existence, that technology is viewed as appropriate only for fixed utility-scale facilities.

- *Compressed air energy storage (CAES)*

  Envisioned as one of the most promising technologies for utility-scale energy storage systems, CAES is thought to be scalable all the way down to residential-size installations. Conceptually, it seems quite simple; use surplus energy to blow air into a large reservoir under pressure, and run the compressed air back through a turbine generator when power is needed. It gets a bit more complicated because compressing the air generates heat and there are several ways to manage the heat that is created.

  For utility-scale systems, it is necessary to provide voluminous storage reservoirs, such as underground caverns or depleted natural gas wells. However, smaller systems might utilize commercially available pressure vessels, similar to existing propane or LNG storage tanks. Storage density is about one-fourth of that achieved by batteries, but as noted above, size and weight are not critical constraints on a vessel like the *Seasteader I*. More important is the efficiency of the storage and recovery process; there are few CAES systems in operation, and their efficiency is thought to be only around 50-percent.

- *Pumped hydro (using two vertically separated reservoirs)*

  Similar in concept to CAES, pumped hydro utilizes two reservoirs at different elevations; electrical energy is used to pump water from the lower to the upper reservoir where it is stored as potential energy. Energy is then recovered by discharging water from the upper reservoir and using the energy to drive a turbo-generator that produces electricity. It works on the same principle as CAES, while eliminating many of the complications because water is incompressible.

  Most existing pumped hydro systems are utility-scale operations that purchase electrical power (from conventional generating facilities) at low rates to pump water into the upper reservoir during periods of weak demand. Then, during periods of peak demand when rates are high, the stored energy is converted back to electricity that can be sold for a profit.

  Like CAES, the primary challenges are related to reservoir size and conversion efficiency. Storage capacity is related to useable reservoir volume and the height differential between the two reservoirs; the potential energy that can be stored is the product of "water mass" times the vertical distance or "head" between the two reservoirs. The rate at which the mass of water moves through that vertical distance determines the power; how much is required to pump water up how much is produced when the water runs back down. Conceptually there is no reason why pumped hydro should not be scalable down to modest size installation, with researchers in Hawaii promoting the feasibility of systems as small as 100 to 1,000-kW or less. With properly configured components (motor, generator, turbine and pump) and sufficient hydrostatic head, efficiencies of 75-percent should be achievable, with utility scale operation capable of attaining conversion efficiencies of 80 to 85-percent.

- *Hydrogen (H_2) generation and storage*

  From a technology standpoint, storing energy in the form of compressed hydrogen (H_2) is certainly an intriguing concept. Hydrogen has the capacity to store about three times as much energy as gasoline, per unit of mass, and on that basis hydrogen offers the highest energy density of any known fuel. However, because the mass density of hydrogen is so low it requires considerably more volume to store the same amount of energy; liquid hydrogen requires almost four times as much volume compared to diesel to store the same amount of energy. As a gas, the volumetric requirement for hydrogen grows substantially higher, in inverse proportion to the storage pressure. And, of course, the favorable energy density based on mass must be discounted to include the weight of the special tankage necessary to store hydrogen. However, as noted in the preceding discussion of battery systems, size and weight are not critical issues for vessels such as Seasteader I.

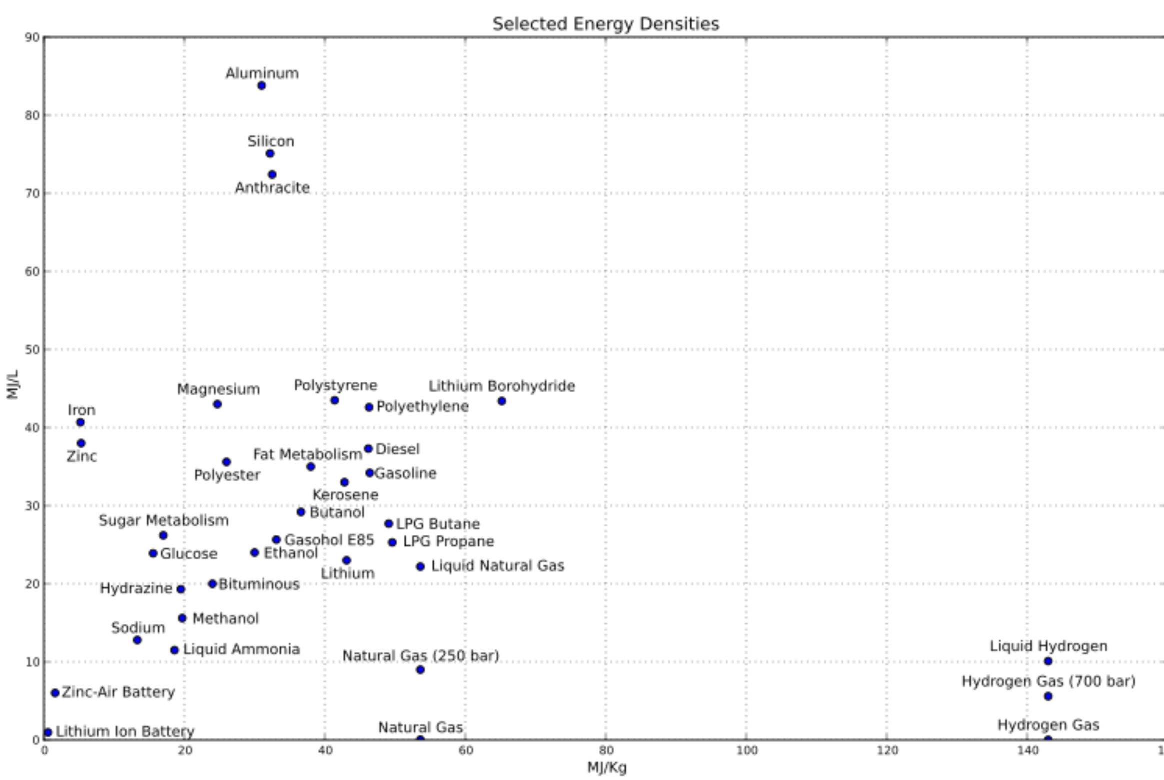

Figure 10 – Comparison of Energy Density by Mass and Volume

(http://en.wikipedia.org/wiki/File:Energy_density.svg)

The advantages of hydrogen for energy storage are well understood, principally that it can power a fuel cell to generate electricity, producing only heat and fresh water as byproducts. The downside is simply cost; presently, fuel cells of the size and type appropriate for testing on *Seasteader I* are likely to cost between $7,000 to $8,000/kW for Solid Oxide (SOFC) or about $11,000/kW for Proton Exchange Membrane (PEM) fuel cells, as shown below in Figure 11.

In addition to the cost of the fuel cell itself, a storage system would require an electrolyzer (powered by excess output from the solar panels and wind vanes) to produce the hydrogen. As reported in a 2008 study conducted by the NREL, the cost per kW for a modest size PEM electrolyzer could approach $5,000/kW. On top of that, the cost of piping and storage tanks must be added, so the overall cost could easily be in the neighborhood of $15,000/kW.

Assuming that the hydrogen storage system should be sized to supply 50% of the vessel's operating power (previously stated to be 60 to 100-kW), then installed cost of a 50-kW PEM fuel cell, electrolyzer, and related ancillaries could run to about $750,000. Even if research succeeds in lowering future costs by a factor of ten (in line with DOE targets), batteries still offer a more cost-effective solution for Seasteader I. However, the total energy storage requirements of a much larger seastead could potentially change the balance in favor of hydrogen.

		Carbonate (MCFC)	Solid Oxide (SOFC)	PEM
WHAT	Size range	> 1 MW	5kw - 200kw	~ < 10 kw
	Commercialized	Yes	In process	Yes
	Advantages	High efficiency, CHP, fuel flexible	High efficiency, limited CHP, fuel flexibility varies by type	Load following, low temperature
	Electrical efficiency	40%-50% *or higher using turbine or organic rankine cycle*	45%-60%	25%-40%
WHERE	Typical Application	Large scale baseload power users	Small commercial baseload power users	Transportation, residential - load following
	Markets	Utility grid support, universities, municipal water treatment facilities, industrial operations	Commercial buildings	Buses, forklifts, residential power/heating
	Sales price per kW *(before subsidies)*	FCE: MW class $3,000-$3,500/kW	Bloom Energy: ~$7,000 - $8,000/kW (1)	ClearEdge: ~$11,000/kW (2)

(1) New York Times article, Jan-2011 http://green.blogs.nytimes.com/2011/01/20/an-affordable-way-to-buy-fuel-cell-power/?partner=rss&emc=rss
(2) WSJ article, Aug-2011 http://clearedgepower.com/node/143/

Figure 11 – Comparison of Fuel Cell Capacity, Application and Cost
(http://en.wikipedia.org/wiki/File:Energy_density.svg)

Data Acquisition

To facilitate the assessment of performance and efficiency for each component and system, it will be necessary to collect data on an on-going basis from a variety of sources. Data from a variety of instruments and sensors is to be stored as time histories in digital format, with the ability to generate tabular or graphical summaries and comparisons on a regular, periodic basis or in custom formats on demand.

Central to the data acquisition strategy will be the requirement to monitor the output (voltage and current) from each energy source, the input and output from each storage device, and the input and output from each power conditioning device, i.e., invertors, voltage regulators, etc. Moreover, it considered desirable to have a means of controlling or varying the energy demand (load) on each device so that performance can be assessed in the context of different scenarios.

- *Environmental Conditions*

  Solar radiation on board the vessel will be continuously measured and recorded to establish correlation with power produced by the solar panels. These direct measurements will also be compared to data from nearby weather stations monitoring temperature, precipitation, barometric pressure, cloud cover, solar radiation and the like.

  Wind speed and direction, measured at two locations (bow and stern) on the vessel will be continuously recorded to establish correlation with power produced by each wind turbine generator. An additional wind monitoring station is to be installed high on a nearby tower (to eliminate interference from neighboring structures) so that shielding or other disruption of the wind fields caused by the vessel's deckhouse can be assessed. These measurements will also be compared to data from nearby weather stations.

- *Power Produced by each Energy Conversion Device*

  Solar panels and wind turbines are to be equipped with Maximum Power Point Trackers (MPPT) that will adjust voltage and current output so as to generate maximum power in any particular load scenario. Several different load scenarios (battery charging, variable loads, resistive loads, etc.) will be applied to each device, with the corresponding output voltage and current measured and correlated with the prevailing environmental conditions.

  Power output from solar panels will be correlated with time of day, date and solar radiation measurements, compared to theoretical performance for the device. Similar comparisons will be made between wind speed and power output from each wind turbine configuration.

  As a basis of comparison, comparable load scenarios will be applied to the diesel generator on the vessel. Fuel consumption and power output will be measured for each scenario.

- *Power Delivered to and Extracted from each Storage Device*

  Whenever energy production exceeds demand, the excess power will be delivered to one or more of the storage devices identified in the preceding section of this report. Conversely, when demand exceeds energy production from renewable sources, power will be extracted from the storage devices. Over time, the ratio of energy extracted from each storage device in proportion to the energy delivered to the device represents the efficiency of the storage device.

  To provide a consistent means of comparing different storage devices, their performance will initially be assessed for a range of controlled delivery (charging) rates and for a range of controlled extraction (discharge) rates. For each different device, the power delivered to the device will be measured during a specified period of time relative to some known initial 'state' of the storage device. At the end of each 'charging' interval, power will be extracted from the device at a prescribed rate until the device returns to the same initial 'state', i.e. open-circuit voltage, pressure, etc.

Performance Evaluation

One of the stated objectives of the proposed project is to demonstrate the degree to which sustainable energy sources can reduce the amount of energy that *Seasteader I* must produce through combustion of fossil fuels. An important corollary to the objective is to assess the cost of providing that sustainable energy; that is, what is the total cost per kilowatt-hour of energy produced by sustainable sources, compared to a conventional diesel-fueled generator.

Actual performance data obtained from pier-side testing in Fort Pierce can be extrapolated to any other proposed site (coastal or offshore) based on a comparison between the conditions measured during the tests at Fort Pierce and the expected environmental conditions at any proposed location.

- *Cost per Kilowatt-Hour of Power Produced by each Energy Conversion Device*

  Over the long term, the capital cost of a diesel-fueled generator is small in comparison to the ongoing cost of fuel, which (as stated previously in this report) can approach $0.50/kWh based on present prices for diesel fuel delivered offshore. Conversely, for renewable energy sources, the cost per kWh is heavily dependent on the duration of the anticipated service life. Renewables are economically viable only over the long haul.

  For example, consider a solar array costing $100,000 that produces 100,000-kWh per year; energy cost for a one-year service life would be about $1.00/kWh; very expensive! But if the same solar array had a planned service life of 10 years then the unit cost would be closer to $0.10 per kWh, about the same as present residential rates. And if that same array achieved a 20-year service life, then the unit cost would be reduced to about $0.05/kWh; a bargain!

Admittedly, the preceding analysis is highly simplified, neglecting maintenance costs, and not accounting for the time-value of capital. However, it serves to illustrate the challenge that arises when interpreting the results of the proposed test program. The incremental cost per kilowatt-hour for a diesel generator can be determined by simply dividing fuel cost by the number of kilowatt-hours produced in a certain interval of time; this assumes that the capital cost of the generator is included in the cost of the vessel, and that it is a small component total overall cost.

However, for renewable energy sources, the capital cost is the only significant cost; solar panels can achieve service lives up to 20-years with only minimal maintenance, while maintenance costs for wind turbines can be thought of as being incremental future capital expenses (rather than ongoing operating costs) and treated as a discounted increase in the initial capital outlay. Thus the average cost per kilowatt-hour must be determined based on initial cost divided by the total kilowatt-hours produced over the projected lifetime of the installation.

This is easily done for solar panels or wind turbines installed at a fixed location, where the environmental conditions can be projected with some certainty. However, vessels such as Seasteader I, the total amount of energy produced by solar and wind will be highly dependent on where the vessel is located. Service experience in Fort Pierce must be extrapolated based on the environmental conditions at any other operational site; and the location where the vessel may operate will most likely be dictated by the economics of any proposed operational scenario, not on how conducive the site is to wind and solar energy.

- *Efficiency and Losses for each Storage Device*

  Based on measurements of voltage and current flowing into and out of each storage device, as described in the preceding section, the quotient of energy output divided by energy input will provide a measure of storage efficiency. Because energy storage (charging) and energy extraction (discharging) will occur at different times and over different durations of time, it will be necessary to ensure that measurements are referred to a consistent datum, such as open-circuit voltage (for batteries), pressure (for CAES) or head (for pumped hydro).

- *Efficiency and Losses for Voltage Inverters and other Controllers*

  Based on measurements of voltage and current into and out of each inverter, controller or other device, the quotient of energy output divided by energy input will provide a measure of each device's efficiency. Because these functions take place continually, and because the input can be measured simultaneously, it is possible to assess efficiency on a continuous basis and to identify circumstances or conditions that contribute to an increase or decrease in the efficiency of each device.

Overall Summary and Assessment

This plan anticipates that Seasteder I will be outfitted with about 60-kW of solar panels and about 30-kW of horizontal and/or vertical-axis wind turbines, along with voltage inverters, controllers, and instrumentation necessary to monitor the performance of each device. Based on the vessel's current circumstances, laying pier-side in Fort Pierce, Florida, it is expected that these renewables can provide more than enough power to meet her modest electrical demand; even underway in her present configuration, she requires only about 60-kW of power, which is within the peak capacity of the anticipated renewable sources.

Accordingly, the vessel will be fitted with several different energy storage devices. First we plan to use off-the-shelf lithium-ion batteries or lead-acid batteries, and eventually introduce compressed air energy storage (CASE), and/or pumped hydro storage, and/or a hydrogen generator (electrolyzer) and fuel cell. Each of these storage devices will be sized to accommodate the maximum energy surplus that might be generated during the course of a day. Each device will be evaluated for storage efficiency, and to estimate the corresponding cost per kilowatt-hour of storage capacity.

Equipment installation and initial performance measurements will take place while the vessel is pier-side, providing easy accessibility for installation and monitoring of all equipment. Based on this performance data, the relative cost, performance and efficiency of each technology will be evaluated for the off-grid requirements of the system. When the vessel is placed into active service, the data obtained will be used to predict performance and efficiency of each system in the vessel's anticipated service, as a basis for determining the most beneficial use of sustainable energy sources to reduce the amount of diesel fuel required for generating the ship's electrical power in service.

Appendix A: Tables and Supplementary Information

											Hour of the day - Year Round													
Date	***100***	***200***	***300***	***400***	***500***	***600***	***700***	***800***	***900***	***1000***	***1100***	***1200***	***1300***	***1400***	***1500***	***1600***	***1700***	***1800***	***1900***	***2000***	***2100***	***2200***	***2300***	***240***
6/21/2012	0.000	0.000	0.000	0.000	0.000	0.184	0.394	0.591	0.759	0.889	0.970	0.998	0.970	0.889	0.759	0.591	0.394	0.184	0.000	0.000	0.000	0.000	0.000	0.0
6/28/2012	0.000	0.000	0.000	0.000	0.000	0.182	0.393	0.590	0.759	0.888	0.970	0.997	0.970	0.888	0.759	0.590	0.393	0.182	0.000	0.000	0.000	0.000	0.000	0.0
7/5/2012	0.000	0.000	0.000	0.000	0.000	0.178	0.390	0.588	0.757	0.887	0.969	0.997	0.969	0.887	0.757	0.587	0.390	0.178	0.000	0.000	0.000	0.000	0.000	0.0
7/12/2012	0.000	0.000	0.000	0.000	0.000	0.172	0.385	0.584	0.754	0.885	0.967	0.995	0.967	0.885	0.754	0.583	0.385	0.172	0.000	0.000	0.000	0.000	0.000	0.0
7/19/2012	0.000	0.000	0.000	0.000	0.000	0.163	0.378	0.578	0.750	0.882	0.965	0.993	0.965	0.882	0.750	0.578	0.378	0.163	0.000	0.000	0.000	0.000	0.000	0.0
7/26/2012	0.000	0.000	0.000	0.000	0.000	0.152	0.369	0.571	0.744	0.877	0.961	0.990	0.961	0.877	0.744	0.570	0.368	0.151	0.000	0.000	0.000	0.000	0.000	0.0
8/2/2012	0.000	0.000	0.000	0.000	0.000	0.139	0.358	0.562	0.737	0.871	0.956	0.985	0.956	0.871	0.737	0.561	0.357	0.138	0.000	0.000	0.000	0.000	0.000	0.0
8/9/2012	0.000	0.000	0.000	0.000	0.000	0.123	0.344	0.551	0.728	0.864	0.949	0.978	0.949	0.863	0.727	0.550	0.344	0.122	0.000	0.000	0.000	0.000	0.000	0.0
8/16/2012	0.000	0.000	0.000	0.000	0.000	0.106	0.329	0.537	0.716	0.854	0.940	0.969	0.940	0.853	0.716	0.537	0.328	0.104	0.000	0.000	0.000	0.000	0.000	0.0
8/23/2012	0.000	0.000	0.000	0.000	0.000	0.087	0.312	0.522	0.703	0.841	0.928	0.958	0.928	0.841	0.702	0.522	0.311	0.085	0.000	0.000	0.000	0.000	0.000	0.0
8/30/2012	0.000	0.000	0.000	0.000	0.000	0.066	0.293	0.505	0.687	0.826	0.914	0.944	0.914	0.826	0.686	0.504	0.292	0.065	0.000	0.000	0.000	0.000	0.000	0.0
9/6/2012	0.000	0.000	0.000	0.000	0.000	0.045	0.273	0.486	0.669	0.809	0.897	0.927	0.897	0.809	0.668	0.485	0.272	0.043	0.000	0.000	0.000	0.000	0.000	0.0
9/13/2012	0.000	0.000	0.000	0.000	0.000	0.022	0.252	0.465	0.649	0.789	0.878	0.908	0.878	0.789	0.648	0.464	0.250	0.021	0.000	0.000	0.000	0.000	0.000	0.0
9/20/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.229	0.443	0.627	0.768	0.856	0.886	0.856	0.767	0.626	0.442	0.228	0.000	0.000	0.000	0.000	0.000	0.000	0.0
9/27/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.206	0.420	0.603	0.744	0.832	0.862	0.832	0.743	0.602	0.419	0.205	0.000	0.000	0.000	0.000	0.000	0.000	0.0
10/4/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.183	0.396	0.579	0.719	0.807	0.837	0.807	0.718	0.578	0.395	0.182	0.000	0.000	0.000	0.000	0.000	0.000	0.0
10/11/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.160	0.372	0.553	0.693	0.780	0.810	0.780	0.692	0.553	0.371	0.159	0.000	0.000	0.000	0.000	0.000	0.000	0.0
10/18/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.138	0.348	0.528	0.667	0.753	0.783	0.753	0.666	0.527	0.347	0.137	0.000	0.000	0.000	0.000	0.000	0.000	0.0
10/25/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.117	0.325	0.504	0.641	0.727	0.756	0.727	0.640	0.503	0.324	0.116	0.000	0.000	0.000	0.000	0.000	0.000	0.0
11/1/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.097	0.303	0.480	0.616	0.701	0.730	0.701	0.615	0.479	0.302	0.096	0.000	0.000	0.000	0.000	0.000	0.000	0.0
11/8/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.284	0.459	0.593	0.677	0.706	0.677	0.592	0.458	0.283	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.0
11/15/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.266	0.439	0.572	0.656	0.684	0.656	0.572	0.439	0.265	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.0
11/22/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.051	0.251	0.423	0.555	0.637	0.665	0.637	0.554	0.422	0.250	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.0
11/29/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.041	0.239	0.409	0.540	0.622	0.650	0.622	0.540	0.409	0.239	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.0
12/6/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.230	0.400	0.530	0.611	0.639	0.611	0.529	0.399	0.230	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.0
12/13/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.225	0.394	0.523	0.605	0.632	0.605	0.523	0.394	0.225	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.0
12/20/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.223	0.392	0.521	0.602	0.630	0.602	0.521	0.392	0.223	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.0
12/27/2012	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.225	0.394	0.523	0.605	0.632	0.605	0.523	0.394	0.225	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.0
1/3/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.230	0.400	0.530	0.611	0.639	0.611	0.530	0.400	0.230	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.0
1/10/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.239	0.409	0.540	0.622	0.651	0.623	0.540	0.410	0.239	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.0
1/17/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.051	0.251	0.423	0.554	0.637	0.666	0.638	0.555	0.423	0.251	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.0
1/24/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.266	0.439	0.572	0.656	0.685	0.656	0.573	0.440	0.266	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.0
1/31/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.079	0.283	0.458	0.593	0.677	0.706	0.678	0.593	0.459	0.284	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.0
2/7/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.097	0.303	0.480	0.616	0.701	0.731	0.702	0.616	0.481	0.304	0.098	0.000	0.000	0.000	0.000	0.000	0.000	0.0
2/14/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.116	0.324	0.503	0.641	0.727	0.757	0.727	0.641	0.504	0.325	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.0
2/21/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.137	0.347	0.528	0.666	0.754	0.783	0.754	0.667	0.529	0.348	0.138	0.000	0.000	0.000	0.000	0.000	0.000	0.0
2/28/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.159	0.371	0.553	0.693	0.781	0.811	0.781	0.693	0.554	0.372	0.161	0.000	0.000	0.000	0.000	0.000	0.000	0.0
3/7/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.182	0.395	0.578	0.719	0.807	0.837	0.807	0.719	0.579	0.396	0.183	0.000	0.000	0.000	0.000	0.000	0.000	0.0
3/14/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.205	0.419	0.603	0.744	0.832	0.863	0.833	0.744	0.604	0.420	0.207	0.000	0.000	0.000	0.000	0.000	0.000	0.0
3/21/2013	0.000	0.000	0.000	0.000	0.000	0.000	0.228	0.442	0.626	0.767	0.856	0.887	0.857	0.768	0.627	0.443	0.230	0.000	0.000	0.000	0.000	0.000	0.000	0.0
3/28/2013	0.000	0.000	0.000	0.000	0.000	0.021	0.251	0.465	0.648	0.789	0.878	0.908	0.878	0.790	0.649	0.466	0.252	0.023	0.000	0.000	0.000	0.000	0.000	0.0
4/4/2013	0.000	0.000	0.000	0.000	0.000	0.043	0.272	0.485	0.669	0.809	0.897	0.928	0.898	0.809	0.669	0.486	0.273	0.045	0.000	0.000	0.000	0.000	0.000	0.0
4/11/2013	0.000	0.000	0.000	0.000	0.000	0.065	0.293	0.505	0.687	0.826	0.914	0.944	0.914	0.827	0.687	0.505	0.294	0.067	0.000	0.000	0.000	0.000	0.000	0.0
4/18/2013	0.000	0.000	0.000	0.000	0.000	0.086	0.311	0.522	0.702	0.841	0.928	0.958	0.928	0.841	0.703	0.523	0.312	0.087	0.000	0.000	0.000	0.000	0.000	0.0
4/25/2013	0.000	0.000	0.000	0.000	0.000	0.105	0.329	0.537	0.716	0.853	0.940	0.969	0.940	0.854	0.717	0.538	0.330	0.106	0.000	0.000	0.000	0.000	0.000	0.0
5/2/2013	0.000	0.000	0.000	0.000	0.000	0.122	0.344	0.550	0.728	0.864	0.949	0.978	0.949	0.864	0.728	0.551	0.345	0.123	0.000	0.000	0.000	0.000	0.000	0.0
5/9/2013	0.000	0.000	0.000	0.000	0.000	0.138	0.357	0.561	0.737	0.871	0.956	0.985	0.956	0.872	0.737	0.562	0.358	0.139	0.000	0.000	0.000	0.000	0.000	0.0
5/16/2013	0.000	0.000	0.000	0.000	0.000	0.151	0.368	0.571	0.744	0.877	0.961	0.990	0.961	0.878	0.744	0.571	0.369	0.152	0.000	0.000	0.000	0.000	0.000	0.0
5/23/2013	0.000	0.000	0.000	0.000	0.000	0.163	0.378	0.578	0.750	0.882	0.965	0.993	0.965	0.882	0.750	0.578	0.378	0.163	0.000	0.000	0.000	0.000	0.000	0.0
5/30/2013	0.000	0.000	0.000	0.000	0.000	0.172	0.385	0.584	0.754	0.885	0.967	0.995	0.967	0.885	0.754	0.584	0.385	0.172	0.000	0.000	0.000	0.000	0.000	0.0
6/6/2013	0.000	0.000	0.000	0.000	0.000	0.178	0.390	0.587	0.757	0.887	0.969	0.997	0.969	0.887	0.757	0.588	0.390	0.179	0.000	0.000	0.000	0.000	0.000	0.0
6/13/2013	0.000	0.000	0.000	0.000	0.000	0.182	0.393	0.590	0.759	0.888	0.970	0.997	0.970	0.888	0.759	0.590	0.393	0.182	0.000	0.000	0.000	0.000	0.000	0.0
6/20/2013	0.000	0.000	0.000	0.000	0.000	0.184	0.394	0.591	0.759	0.889	0.970	0.998	0.970	0.889	0.759	0.591	0.394	0.184	0.000	0.000	0.000	0.000	0.000	0.0

Table A-1 – Available Sunlight at Fort Pierce, FL, by Date and Time; Compared to Sun Directly Overhead at Solar Noon

National Data Buoy Center, Station # LKWF1 Coordinates: 26.621 ° N x 80.033 ° W

Monthly and Annual Number of Occurrences and Cumulative Percent Frequency of Occurrence Based on 128,739 Measurements between January 1990 through December 2008

AVERAGE WIND SPEED (KNOTS)

Wind	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANNUAL	
Speed (knots)	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct	# Occ.	Pct
54	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	100.0	0	100.0	0	100.0	0	100.0	1	100.0
53	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	99.9	0	100.0	0	100.0	0	100.0	0	99.9
52	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	2	99.9	0	100.0	0	100.0	0	100.0	2	99.9
51	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	99.9	0	100.0	0	100.0	0	100.0	0	99.9
50	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.9	0	100.0	0	100.0	0	100.0	1	99.9
49	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	2	99.9	0	100.0	0	100.0	0	100.0	2	99.9
48	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	99.9	0	100.0	0	100.0	0	100.0	0	99.9
47	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	99.9	0	100.0	0	100.0	0	100.0	0	99.9
46	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.9	0	100.0	0	100.0	0	100.0	1	99.9
45	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.9	0	100.0	0	100.0	0	100.0	1	99.9
44	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	3	99.9	1	100.0	0	100.0	1	100.0	5	99.9
43	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	3	99.9	0	100.0	0	100.0	0	100.0	3	99.9
42	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.9	0	100.0	0	100.0	0	100.0	1	99.9
41	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.9	0	100.0	1	100.0	0	100.0	2	99.9
40	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	2	99.9	0	100.0	0	99.9	0	100.0	2	99.9
39	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	99.8	2	99.9	1	99.9	1	99.9	4	99.9
38	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	2	99.8	0	99.9	2	99.9	2	99.9	6	99.9
37	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	2	100.0	3	99.8	1	99.9	4	99.9	2	99.9	12	99.9
36	0	100.0	2	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.8	0	99.9	6	99.9	3	99.9	12	99.9
35	2	100.0	1	99.9	0	100.0	0	100.0	0	100.0	1	100.0	0	100.0	0	100.0	5	99.8	1	99.9	3	99.8	0	99.9	13	99.9
34	1	99.9	4	99.9	0	100.0	0	100.0	0	100.0	0	100.0	0	100.0	1	99.9	2	99.7	0	99.9	4	99.8	3	99.9	15	99.9
33	4	99.9	2	99.9	1	100.0	0	100.0	0	100.0	0	100.0	0	100.0	2	99.9	8	99.7	1	99.9	10	99.8	3	99.9	31	99.9
32	7	99.9	7	99.9	1	99.9	0	100.0	3	100.0	0	100.0	0	100.0	1	99.9	6	99.6	2	99.9	15	99.7	0	99.9	42	99.9
31	5	99.9	4	99.8	3	99.9	0	100.0	0	99.9	0	100.0	0	100.0	0	99.9	11	99.6	7	99.9	14	99.5	0	99.9	44	99.9
30	6	99.8	4	99.8	2	99.9	1	100.0	2	99.9	1	99.9	0	100.0	4	99.9	8	99.5	11	99.9	15	99.4	1	99.9	55	99.8
29	9	99.8	3	99.8	3	99.9	9	99.9	3	99.9	2	99.9	0	100.0	5	99.9	13	99.4	22	99.8	16	99.2	2	99.8	87	99.8
28	13	99.7	9	99.7	8	99.9	2	99.9	5	99.9	5	99.9	1	100.0	12	99.9	9	99.3	21	99.6	27	99.0	7	99.8	119	99.7
27	18	99.6	15	99.6	16	99.8	8	99.9	7	99.9	6	99.9	1	99.9	7	99.8	13	99.2	34	99.4	25	98.8	12	99.8	162	99.6
26	35	99.4	22	99.5	42	99.7	36	99.8	11	99.8	3	99.9	1	99.9	14	99.7	29	99.1	60	99.1	28	98.5	19	99.7	300	99.5
25	47	99.1	59	99.3	74	99.3	31	99.5	8	99.7	10	99.8	3	99.9	14	99.6	14	98.8	76	98.5	48	98.2	19	99.5	403	99.3
24	49	98.6	68	98.6	96	98.6	43	99.2	20	99.6	4	99.7	4	99.9	14	99.5	29	98.7	80	97.8	51	97.7	30	99.3	488	99.0
23	80	98.2	89	97.9	130	97.7	65	98.7	22	99.5	19	99.7	8	99.9	12	99.4	63	98.4	128	97.1	92	97.1	63	99.0	771	98.6
22	121	97.5	138	97.0	184	96.4	102	98.1	65	99.3	21	99.5	13	99.8	23	99.3	66	97.9	146	95.9	127	96.2	101	98.4	1107	98.0
21	169	96.3	147	95.6	253	94.7	142	97.1	74	98.7	21	99.3	16	99.7	37	99.1	69	97.3	210	94.6	154	94.8	145	97.5	1437	97.1
20	163	94.8	166	94.1	231	92.3	178	95.8	144	98.0	54	99.1	25	99.6	41	98.8	83	96.6	218	92.6	182	93.2	160	96.1	1645	96.0
19	266	93.3	265	92.4	418	90.1	319	94.0	251	96.7	93	98.7	43	99.4	80	98.4	123	95.9	375	90.6	279	91.3	265	94.6	2777	94.7
18	284	90.8	332	89.7	388	86.1	361	91.0	294	94.4	118	97.8	71	99.0	81	97.7	158	94.7	369	87.2	273	88.3	281	92.1	3010	92.6
17	320	88.2	365	86.3	424	82.4	371	87.5	366	91.8	158	96.7	88	98.4	121	97.1	222	93.3	370	83.8	275	85.4	349	89.5	3429	90.2
16	387	85.3	382	82.5	500	78.4	495	83.9	451	88.5	228	95.3	143	97.6	170	96.1	295	91.3	467	80.4	352	82.5	467	86.2	4337	87.6
15	493	81.7	423	78.6	551	73.7	540	79.1	555	84.4	295	93.2	247	96.3	210	94.6	327	88.6	474	76.1	411	78.8	508	81.8	5034	84.2
14	536	77.2	444	74.3	542	68.4	619	73.9	558	79.4	335	90.5	315	94.2	291	92.9	418	85.6	545	71.8	442	74.4	522	77.0	5567	80.3
13	655	72.3	549	69.7	659	63.3	674	67.9	711	74.4	437	87.4	517	91.4	409	90.4	518	81.8	577	66.8	575	69.8	618	72.1	6899	76.0
12	856	66.2	733	64.1	786	57.0	859	61.4	928	68.0	812	83.4	789	86.8	684	87.0	753	77.0	719	61.5	699	63.7	857	66.3	9475	70.6
11	702	58.4	579	56.6	649	49.6	775	53.1	835	59.6	725	76.0	814	79.9	749	81.3	698	70.2	638	54.9	595	56.3	742	58.2	8501	63.3
10	682	51.9	542	50.7	630	43.4	719	45.6	846	52.0	845	69.4	856	72.7	829	75.0	768	63.8	691	49.0	624	50.0	723	51.3	8755	56.7
9	781	45.6	612	45.1	604	37.4	686	38.7	868	44.4	947	61.7	987	65.2	1050	68.0	904	56.8	773	42.7	672	43.4	740	44.5	9624	49.9
8	745	38.4	657	38.8	672	31.7	697	32.1	709	36.6	951	53.0	1002	56.5	1091	59.2	884	48.5	732	35.6	619	36.3	747	37.5	9506	42.4
7	688	31.6	585	32.1	586	25.3	589	25.3	598	30.2	854	44.3	912	47.7	970	50.1	783	40.4	622	28.9	496	29.7	662	30.5	8345	35.0
6	722	25.3	636	26.1	604	19.7	521	19.6	705	24.8	856	36.5	917	39.7	1005	42.0	861	33.3	627	23.2	513	24.5	680	24.2	8647	28.5
5	745	18.6	724	19.6	636	14.0	621	14.6	797	18.4	1051	28.7	1079	31.6	1302	33.5	916	25.4	637	17.4	540	19.0	726	17.8	9774	21.8
4	525	11.8	504	12.1	381	8.0	368	8.6	517	11.2	728	19.1	847	22.1	988	22.6	715	17.0	470	11.6	397	13.3	438	11.0	6878	14.2
3	344	6.9	334	7.0	231	4.4	263	5.1	377	6.6	590	12.4	689	14.6	738	14.3	561	10.5	367	7.2	343	9.1	313	6.9	5150	8.9
2	260	3.8	203	3.5	137	2.2	182	2.5	211	3.2	443	7.0	548	8.6	570	8.2	370	5.4	274	3.9	285	5.5	213	4.0	3696	4.9
1	111	1.4	105	1.5	72	0.9	56	0.8	101	1.2	211	3.0	276	3.8	296	3.4	160	2.0	116	1.4	195	2.5	165	1.9	1864	2.0
0	39	0.4	37	0.4	19	0.2	23	0.2	37	0.3	113	1.0	151	1.3	108	0.9	59	0.5	32	0.3	37	0.4	42	0.4	697	0.5
TOTAL	10870		9751		10533		10355		11079		10937		11363		11931		10945		10896		9447		10632		128739	
MAX	35.2		35.8		32.7		29.9		32.1		34.6		27.8		36.7		53.7		43.7		41.2		43.5		53.7	knots
75th %	14.0		14.6		15.7		14.8		13.6		11.3		10.7		10.5		12.2		15.2		14.6		14.2		13.4	knots
50th %	9.9		10.3		11.5		11.1		10.1		8.2		7.8		7.4		8.6		10.5		10.5		10.3		9.5	knots
25th %	6.4		6.4		7.4		7.4		6.6		5.1		4.7		4.7		5.4		6.8		6.6		6.6		6.0	knots
MEAN	10.6		10.8		11.8		11.2		10.3		8.4		7.9		7.9		9.3		11.3		11.0		10.6		10.1	knots
St.Dev.	5.4		5.6		5.6		5.1		4.8		4.4		4.1		4.4		5.4		5.9		6.0		5.2		5.3	knots

Table A-2 – Monthly and Annual Wind Speed Frequency of Occurrence

National Data Buoy Center, Station #		LKWF1						Bergey Excel 5-kW Horizontal Axis Wind Turbine																			
												Rated Capacity	5,000	Watts													
Monthly and Annual																											
Produced kW-hr =		**1,070**		**1,023**		**1,332**		**1,137**		**984**		**596**		**516**		**526**		**767**		**1,229**		**1,131**		**1,054**		**11,246**	
Days per Month =		31		28		31		30		31		30		31		31		30		31		30		31		365	
Wind	Production	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
Speed	as % Rated		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.
(knots)	Capacity	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr
54	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.43
53	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
52	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.83	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.86
51	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
50	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.43
49	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.83	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.86
48	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
47	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
46	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.43
45	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.43
44	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.027	1.24	0.009	0.43	0.000	0.00	0.009	0.44	0.004	2.14
43	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.027	1.24	0.000	0.00	0.000	0.00	0.000	0.00	0.002	1.29
42	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.43
41	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.011	0.48	0.000	0.00	0.002	0.86
40	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.83	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.86
39	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.86	0.011	0.48	0.009	0.44	0.003	1.71
38	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.83	0.000	0.00	0.021	0.96	0.019	0.88	0.005	2.57
37	126%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.017	0.79	0.027	1.24	0.009	0.43	0.042	1.92	0.019	0.88	0.009	5.14
36	126%	0.000	0.00	0.021	0.87	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.064	2.88	0.028	1.32	0.009	5.14
35	126%	0.018	0.86	0.010	0.43	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.41	0.000	0.00	0.000	0.00	0.046	2.07	0.009	0.43	0.032	1.44	0.000	0.00	0.010	5.57
34	126%	0.009	0.43	0.041	1.74	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.008	0.39	0.018	0.83	0.000	0.00	0.042	1.92	0.028	1.32	0.012	6.43
33	126%	0.037	1.72	0.021	0.86	0.009	0.44	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.017	0.78	0.073	3.30	0.009	0.43	0.106	4.78	0.028	1.32	0.024	13.24
32	125%	0.064	2.99	0.072	3.02	0.009	0.44	0.000	0.00	0.027	1.26	0.000	0.00	0.000	0.00	0.008	0.39	0.055	2.47	0.018	0.85	0.159	7.15	0.000	0.00	0.033	17.86
31	125%	0.046	2.13	0.041	1.72	0.028	1.32	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.101	4.50	0.064	2.98	0.148	6.64	0.000	0.00	0.034	18.64
30	124%	0.055	2.55	0.041	1.71	0.019	0.88	0.010	0.43	0.018	0.83	0.009	0.41	0.000	0.00	0.034	1.55	0.073	3.26	0.101	4.66	0.159	7.09	0.009	0.43	0.043	23.20
29	124%	0.083	3.80	0.031	1.28	0.028	1.31	0.087	3.86	0.027	1.24	0.018	0.81	0.000	0.00	0.042	1.93	0.119	5.28	0.202	9.28	0.169	7.53	0.019	0.86	0.068	36.56
28	123%	0.120	5.47	0.092	3.81	0.076	3.48	0.019	0.86	0.045	2.06	0.046	2.02	0.009	0.40	0.101	4.60	0.082	3.64	0.193	8.82	0.286	12.66	0.066	3.01	0.092	49.80
27	122%	0.166	7.52	0.154	6.31	0.152	6.89	0.077	3.39	0.063	2.87	0.055	2.41	0.009	0.40	0.059	2.66	0.119	5.22	0.312	14.16	0.265	11.62	0.113	5.12	0.126	67.24
26	121%	0.322	14.49	0.226	9.17	0.399	17.95	0.348	15.14	0.099	4.47	0.027	1.19	0.009	0.40	0.117	5.28	0.265	11.54	0.551	24.79	0.296	12.91	0.179	8.04	0.233	123.50
25	120%	0.432	19.30	0.605	24.40	0.703	31.36	0.299	12.93	0.072	3.22	0.091	3.95	0.026	1.18	0.117	5.24	0.128	5.53	0.698	31.14	0.508	21.95	0.179	7.98	0.313	164.53
24	118%	0.451	19.79	0.697	27.65	0.911	40.01	0.415	17.64	0.181	7.92	0.037	1.55	0.035	1.55	0.117	5.15	0.265	11.26	0.734	32.23	0.540	22.93	0.282	12.39	0.379	195.91
23	114%	0.736	31.21	0.913	34.96	1.234	52.34	0.628	25.76	0.199	8.42	0.174	7.13	0.070	2.99	0.101	4.27	0.576	23.62	1.175	49.82	0.974	39.97	0.593	25.13	0.599	299.04
22	108%	1.113	44.72	1.415	51.36	1.747	70.18	0.985	38.30	0.587	23.57	0.192	7.47	0.114	4.60	0.193	7.74	0.603	23.45	1.340	53.83	1.344	52.27	0.950	38.17	0.860	406.76
21	101%	1.555	58.41	1.508	51.16	2.402	90.25	1.371	49.86	0.668	25.10	0.192	6.98	0.141	5.29	0.310	11.65	0.630	22.92	1.927	72.41	1.630	59.27	1.364	51.24	1.116	493.79
20	94%	1.500	52.44	1.702	53.77	2.193	76.69	1.719	58.17	1.300	45.45	0.494	16.71	0.220	7.69	0.344	12.02	0.758	25.66	2.001	69.96	1.927	65.19	1.505	52.62	1.278	526.09
19	87%	2.447	79.20	2.718	79.44	3.968	128.44	3.081	96.49	2.266	73.32	0.850	26.63	0.378	12.25	0.671	21.70	1.124	35.20	3.442	111.38	2.953	92.50	2.492	80.67	2.157	821.98
18	78%	2.613	75.42	3.405	88.77	3.684	106.34	3.486	97.39	2.654	76.60	1.079	30.14	0.625	18.04	0.679	19.60	1.444	40.33	3.387	97.76	2.890	80.73	2.643	76.29	2.338	794.68
17	69%	2.944	75.34	3.743	86.53	4.025	103.03	3.583	88.74	3.304	84.55	1.445	35.78	0.774	19.82	1.014	25.96	2.028	50.24	3.396	86.91	2.911	72.10	3.283	84.01	2.664	802.64
16	59%	3.560	78.14	3.918	77.66	4.747	104.19	4.780	101.53	4.071	89.35	2.085	44.28	1.258	27.62	1.425	31.27	2.695	57.25	4.286	94.07	3.726	79.14	4.392	96.40	3.369	870.57
15	51%	4.535	86.38	4.338	74.63	5.231	99.64	5.215	96.12	5.009	95.41	2.697	49.72	2.174	41.40	1.760	33.52	2.988	55.07	4.350	82.86	4.351	80.19	4.778	91.00	3.910	876.89
14	44%	4.931	81.44	4.553	67.93	5.146	84.99	5.978	95.55	5.037	83.19	3.063	48.96	2.772	45.79	2.439	40.28	3.819	61.04	5.002	82.61	4.679	74.78	4.910	81.09	4.324	840.95
13	36%	6.026	80.70	5.630	68.10	6.257	83.79	6.509	84.36	6.418	85.94	3.996	51.78	4.550	60.93	3.428	45.91	4.733	61.34	5.296	70.92	6.087	78.88	5.813	77.84	5.359	844.99
12	29%	7.875	84.37	7.517	72.74	7.462	79.95	8.296	86.01	8.376	89.74	7.424	76.98	6.944	74.39	5.733	61.42	6.880	71.33	6.599	70.70	7.399	76.71	8.061	86.36	7.360	928.40
11	23%	6.458	55.74	5.938	46.29	6.162	53.18	7.484	62.51	7.537	65.05	6.629	55.36	7.164	61.82	6.278	54.18	6.377	53.26	5.855	50.53	6.298	52.60	6.979	60.23	6.603	671.00
10	18%	6.274	41.08	5.558	32.87	5.981	39.16	6.944	43.99	7.636	49.99	7.726	48.95	7.533	49.32	6.948	45.49	7.017	44.46	6.342	41.52	6.605	41.85	6.800	44.52	6.801	524.24
9	12%	7.185	31.00	6.276	24.46	5.734	24.74	6.625	27.67	7.835	33.81	8.659	36.16	8.686	37.48	8.801	37.98	8.259	34.49	7.094	30.61	7.113	29.71	6.960	30.03	7.476	379.82
8	8%	6.854	19.38	6.738	17.21	6.380	18.04	6.731	18.42	6.399	18.09	8.695	23.79	8.818	24.93	9.144	25.85	8.077	22.10	6.718	18.99	6.552	17.93	7.026	19.86	7.384	245.80
7	4%	6.329	9.42	5.999	8.06	5.563	8.28	5.688	8.19	5.398	8.03	7.808	11.24	8.026	11.94	8.130	12.10	7.154	10.30	5.709	8.49	5.250	7.56	6.226	9.27	6.482	113.57
6	2%	6.642	4.94	6.522	4.38	5.734	4.27	5.031	3.62	6.363	4.73	7.827	5.64	8.070	6.00	8.423	6.27	7.867	5.66	5.754	4.28	5.430	3.91	6.396	4.76	6.717	58.84
5	0%	6.854	0.00	7.425	0.00	6.038	0.00	5.997	0.00	7.194	0.00	9.610	0.00	9.496	0.00	10.913	0.00	8.369	0.00	5.846	0.00	5.716	0.00	6.828	0.00	7.592	0.00
4	0%	4.830	0.00	5.169	0.00	3.617	0.00	3.554	0.00	4.666	0.00	6.656	0.00	7.454	0.00	8.281	0.00	6.533	0.00	4.314	0.00	4.202	0.00	4.120	0.00	5.343	0.00
3	0%	3.165	0.00	3.425	0.00	2.193	0.00	2.540	0.00	3.403	0.00	5.395	0.00	6.064	0.00	6.186	0.00	5.126	0.00	3.368	0.00	3.631	0.00	2.944	0.00	4.000	0.00
2	0%	2.392	0.00	2.082	0.00	1.301	0.00	1.758	0.00	1.905	0.00	4.050	0.00	4.823	0.00	4.777	0.00	3.381	0.00	2.515	0.00	3.017	0.00	2.003	0.00	2.871	0.00
1	0%	1.021	0.00	1.077	0.00	0.684	0.00	0.541	0.00	0.912	0.00	1.929	0.00	2.429	0.00	2.481	0.00	1.462	0.00	1.065	0.00	2.064	0.00	1.552	0.00	1.448	0.00
0	0%	0.359	0.00	0.379	0.00	0.180	0.00	0.222	0.00	0.334	0.00	1.033	0.00	1.329	0.00	0.905	0.00	0.539	0.00	0.294	0.00	0.392	0.00	0.395	0.00	0.541	0.00

Table A-3 – Performance of Horizontal-axis Wind Turbine, Lake Worth, Florida

National Data Buoy Center, Station #		LKWF1						Windspire 1200 Vertical Axis Wind Turbine																			
										Rated Capacity	1,200 Watts																
Monthly and Annual																											
Produced kW-hr =		**189**		**185**		**248**		**206**		**172**		**95**		**79**		**81**		**124**		**221**		**196**		**187**		**1,959**	
Days per Month =		31		28		31		30		31		30		31		31		30		31		30		31		365	
Wind	Production	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC		ANN	
Speed	as % Rated		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.		Prod.
(knots)	Capacity	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr	(%occ)	kW-hr
54	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.00
53	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
52	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.00
51	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
50	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.00
49	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.00
48	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
47	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
46	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.00
45	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.00
44	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.027	0.00	0.009	0.00	0.000	0.00	0.009	0.00	0.004	0.00
43	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.027	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.00
42	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.001	0.00
41	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.011	0.00	0.000	0.00	0.002	0.00
40	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.002	0.00
39	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.011	0.00	0.009	0.00	0.003	0.00
38	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.018	0.00	0.000	0.00	0.021	0.00	0.019	0.00	0.005	0.00
37	0%	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.017	0.00	0.027	0.00	0.009	0.00	0.042	0.00	0.019	0.00	0.009	0.00
36	0%	0.000	0.00	0.021	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.064	0.00	0.028	0.00	0.009	0.00
35	0%	0.018	0.00	0.010	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.046	0.00	0.009	0.00	0.032	0.00	0.000	0.00	0.010	0.00
34	0%	0.009	0.00	0.041	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.008	0.00	0.018	0.00	0.000	0.00	0.042	0.00	0.028	0.00	0.012	0.00
33	0%	0.037	0.00	0.021	0.00	0.009	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.017	0.00	0.073	0.00	0.009	0.00	0.106	0.00	0.028	0.00	0.024	0.00
32	0%	0.064	0.00	0.072	0.00	0.009	0.00	0.000	0.00	0.027	0.00	0.000	0.00	0.000	0.00	0.008	0.00	0.055	0.00	0.018	0.00	0.159	0.00	0.000	0.00	0.033	0.00
31	0%	0.046	0.00	0.041	0.00	0.028	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.101	0.00	0.064	0.00	0.148	0.00	0.000	0.00	0.034	0.00
30	0%	0.055	0.00	0.041	0.00	0.019	0.00	0.010	0.00	0.018	0.00	0.009	0.00	0.000	0.00	0.034	0.00	0.073	0.00	0.101	0.00	0.159	0.00	0.009	0.00	0.043	0.00
29	0%	0.083	0.00	0.031	0.00	0.028	0.00	0.087	0.00	0.027	0.00	0.018	0.00	0.000	0.00	0.042	0.00	0.119	0.00	0.202	0.00	0.169	0.00	0.019	0.00	0.068	0.00
28	0%	0.120	0.00	0.092	0.00	0.076	0.00	0.019	0.00	0.045	0.00	0.046	0.00	0.009	0.00	0.101	0.00	0.082	0.00	0.193	0.00	0.286	0.00	0.066	0.00	0.092	0.00
27	17%	0.166	0.25	0.154	0.21	0.152	0.23	0.077	0.11	0.063	0.09	0.055	0.08	0.009	0.01	0.059	0.09	0.119	0.17	0.312	0.46	0.265	0.38	0.113	0.17	0.126	2.20
26	83%	0.322	2.40	0.226	1.52	0.399	2.97	0.348	2.50	0.099	0.74	0.027	0.20	0.009	0.07	0.117	0.87	0.265	1.91	0.551	4.10	0.296	2.13	0.179	1.33	0.233	20.41
25	96%	0.432	3.70	0.605	4.68	0.703	6.01	0.299	2.48	0.072	0.62	0.091	0.76	0.026	0.23	0.117	1.00	0.128	1.06	0.698	5.97	0.508	4.21	0.179	1.53	0.313	31.54
24	98%	0.451	3.96	0.697	5.53	0.911	8.00	0.415	3.53	0.181	1.58	0.037	0.31	0.035	0.31	0.117	1.03	0.265	2.25	0.734	6.45	0.540	4.59	0.282	2.48	0.379	39.18
23	100%	0.736	6.57	0.913	7.36	1.234	11.02	0.628	5.42	0.199	1.77	0.174	1.50	0.070	0.63	0.101	0.90	0.576	4.97	1.175	10.49	0.974	8.41	0.593	5.29	0.599	62.95
22	100%	1.113	9.94	1.415	11.41	1.747	15.60	0.985	8.51	0.587	5.24	0.192	1.66	0.114	1.02	0.193	1.72	0.603	5.21	1.340	11.96	1.344	11.62	0.950	8.48	0.860	90.39
21	98%	1.555	13.65	1.508	11.95	2.402	21.09	1.371	11.65	0.668	5.86	0.192	1.63	0.141	1.24	0.310	2.72	0.630	5.36	1.927	16.92	1.630	13.85	1.364	11.97	1.116	115.38
20	91%	1.500	12.16	1.702	12.47	2.193	17.79	1.719	13.49	1.300	10.54	0.494	3.87	0.220	1.78	0.344	2.79	0.758	5.95	2.001	16.23	1.927	15.12	1.505	12.20	1.278	122.01
19	81%	2.447	17.66	2.718	17.71	3.968	28.64	3.081	21.52	2.266	16.35	0.850	5.94	0.378	2.73	0.671	4.84	1.124	7.85	3.442	24.84	2.953	20.63	2.492	17.99	2.157	183.29
18	68%	2.613	15.75	3.405	18.53	3.684	22.20	3.486	20.33	2.654	15.99	1.079	6.29	0.625	3.77	0.679	4.09	1.444	8.42	3.387	20.41	2.890	16.85	2.643	15.93	2.338	165.90
17	56%	2.944	14.67	3.743	16.85	4.025	20.07	3.583	17.28	3.304	16.47	1.445	6.97	0.774	3.86	1.014	5.06	2.028	9.78	3.396	16.93	2.911	14.04	3.283	16.36	2.664	156.33
16	47%	3.560	14.83	3.918	14.74	4.747	19.78	4.780	19.27	4.071	16.96	2.085	8.41	1.258	5.24	1.425	5.94	2.695	10.87	4.286	17.86	3.726	15.02	4.392	18.30	3.369	165.26
15	38%	4.535	15.52	4.338	13.41	5.231	17.90	5.215	17.27	5.009	17.14	2.697	8.93	2.174	7.44	1.760	6.02	2.988	9.90	4.350	14.89	4.351	14.41	4.778	16.35	3.910	157.57
14	31%	4.931	13.57	4.553	11.32	5.146	14.17	5.978	15.92	5.037	13.86	3.063	8.16	2.772	7.63	2.439	6.71	3.819	10.17	5.002	13.77	4.679	12.46	4.910	13.52	4.324	140.16
13	24%	6.026	13.00	5.630	10.97	6.257	13.50	6.509	13.59	6.418	13.85	3.996	8.34	4.550	9.82	3.428	7.40	4.733	9.88	5.296	11.43	6.087	12.71	5.813	12.54	5.359	136.14
12	18%	7.875	12.89	7.517	11.11	7.462	12.21	8.296	13.14	8.376	13.71	7.424	11.76	6.944	11.37	5.733	9.38	6.880	10.90	6.599	10.80	7.399	11.72	8.061	13.19	7.360	141.84
11	14%	6.458	8.17	5.938	6.78	6.162	7.79	7.484	9.16	7.537	9.53	6.629	8.11	7.164	9.06	6.278	7.94	6.377	7.81	5.855	7.41	6.298	7.71	6.979	8.83	6.603	98.34
10	10%	6.274	5.60	5.558	4.48	5.981	5.34	6.944	6.00	7.636	6.82	7.726	6.68	7.533	6.73	6.948	6.20	7.017	6.06	6.342	5.66	6.605	5.71	6.800	6.07	6.801	71.49
9	5%	7.185	3.21	6.276	2.53	5.734	2.56	6.625	2.86	7.835	3.50	8.659	3.74	8.686	3.88	8.801	3.93	8.259	3.57	7.094	3.17	7.113	3.07	6.960	3.11	7.476	39.29
8	3%	6.854	1.53	6.738	1.36	6.380	1.42	6.731	1.45	6.399	1.43	8.695	1.88	8.818	1.97	9.144	2.04	8.077	1.74	6.718	1.50	6.552	1.42	7.026	1.57	7.384	19.40
7	0%	6.329	0.00	5.999	0.00	5.563	0.00	5.688	0.00	5.398	0.00	7.808	0.00	8.026	0.00	8.130	0.00	7.154	0.00	5.709	0.00	5.250	0.00	6.226	0.00	6.482	0.00
6	0%	6.642	0.00	6.522	0.00	5.734	0.00	5.031	0.00	6.363	0.00	7.827	0.00	8.070	0.00	8.423	0.00	7.867	0.00	5.754	0.00	5.430	0.00	6.396	0.00	6.717	0.00
5	0%	6.854	0.00	7.425	0.00	6.038	0.00	5.997	0.00	7.194	0.00	9.610	0.00	9.496	0.00	10.913	0.00	8.369	0.00	5.846	0.00	5.716	0.00	6.828	0.00	7.592	0.00
4	0%	4.830	0.00	5.169	0.00	3.617	0.00	3.554	0.00	4.666	0.00	6.656	0.00	7.454	0.00	8.281	0.00	6.533	0.00	4.314	0.00	4.202	0.00	4.120	0.00	5.343	0.00
3	0%	3.165	0.00	3.425	0.00	2.193	0.00	2.540	0.00	3.403	0.00	5.395	0.00	6.064	0.00	6.186	0.00	5.126	0.00	3.368	0.00	3.631	0.00	2.944	0.00	4.000	0.00
2	0%	2.392	0.00	2.082	0.00	1.301	0.00	1.758	0.00	1.905	0.00	4.050	0.00	4.823	0.00	4.777	0.00	3.381	0.00	2.515	0.00	3.017	0.00	2.003	0.00	2.871	0.00
1	0%	1.021	0.00	1.077	0.00	0.684	0.00	0.541	0.00	0.912	0.00	1.929	0.00	2.429	0.00	2.481	0.00	1.462	0.00	1.065	0.00	2.064	0.00	1.552	0.00	1.448	0.00
0	0%	0.359	0.00	0.379	0.00	0.180	0.00	0.222	0.00	0.334	0.00	1.033	0.00	1.329	0.00	0.905	0.00	0.539	0.00	0.294	0.00	0.392	0.00	0.395	0.00	0.541	0.00

Table A-4 – Performance of Vertical-axis Wind Turbine, Lake Worth, Florida