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Contract Final Report

Solar Power at the Turkey Lake Service Plaza: A Project Analysis and Best Practices Guide

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16. Abstract

This review of the FDOT Turkey Lake Service Plaza ground-mounted solar power photovoltaic (PV) system reports on lessons learned and suggested best practices to guide future system deployments. The 112.32kW system was completed in October 2012 at a cost of $351,580. System costs have dropped substantially over the past few years; due to these lower costs and newly-obtained in-house experience, FDOT will be able to procure any future installations at significantly lower purchase and operating costs. These future systems could exceed a savings-to-investment ratio of 1.0, making them profitable investments for the FDOT at facilities across the State of Florida.

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Executive Summary

In 2012, the Florida Department of Transportation (FDOT) completed the installation of a ground-mounted photovoltaic (PV) power system at its Turkey Lake Service Plaza facility, located on the northwest side of Orlando, Florida. This PV system bears a nameplate rating of 112.32 kW DC, covers approximately a half-acre at the south end of the service plaza, and offsets energy usage for the DOT Service Plaza buildings, which include the convenience store and restaurants. The PV system annually produces 167,500 kWh/year. This report discusses the PV project, its economics, and the lessons learned. Most importantly, the report presents suggested best practices to guide FDOT and other state departments of transportation through similar procurements to validate the financial viability of these projects from concept to implementation, construction, utilization, and maintenance.

The economics of this system are as follows. For the construction price of $351,580 (after $127,920 utility rebate) and the energy production at 167,500 kWh/year with electricity at $0.082/kWh, the simple payback economic analysis gives a rate of return for the PV system at 3.9% and the payback timeframe is in excess of 25 years. Using a life-cycle cost (LCC) analysis gives different values since the LCC values are dependent on the future economic values selected. Sensitivity values of LCCs are presented in the paper. The LCC calculates the present value of the system cost and then compares this present value cost with the present value of energy saved, accounting for the discount rate (2.53%), potential electric price escalation (3.4%), service life (25 years) power degradation (0.7%/year), maintenance costs ($2,200/year), and inverter replacement at 15 years. For this analysis and the above parameters, the present value of the investment is $426,724 and the present value of the savings is $338,307. This gives a savings-to-investment ratio of 0.79 (a value less than 1.00 indicates that the system is operating at a loss). These LCC values give a payback exceeding 25 years. The analysis also shows a levelized cost of electricity at $0.111/kWh over the project's 25-year lifetime. Future procurements by FDOT are expected to bring a substantially higher rate of return due to incorporation of lessons learned in this effort, drastic price reductions since this system was procured, and the continued decreases in system pricing expected over the coming years.

Figure 1: Site Photo, June 5, 2012 (Arellano)

The FDOT has sponsored various PV projects over the previous decades, focusing mostly on remote power applications such as rural signage lighting. In these installations, PV has long been more viable and cost effective than a generator or new miles-long connection to electric utility power. In 2009, the FDOT Research Center commissioned a study from the University of Florida to examine concepts for the deployment of PV systems at the Turkey Lake Service Plaza. After this study was completed, FDOT made a decision to procure a large ground-mounted PV system at the Service Plaza. One factor in this decision was the availability of a $127,920 rebate from the site's electric utility company. The rebate was funded at 28% of the bid price and was only available for a short time. FDOT applied for the rebate and these funds were successfully awarded.

PV projects are construction projects and best practices for construction generally apply to PV system installations as well. For these types of projects, the project requirements should be clearly scoped, qualified contractors should be hired, sound project management tools should be utilized, routine communication and project inspection should be performed, and a detailed final commissioning event should occur that confirms that requirements have been met. For Turkey Lake Plaza, the end result was a PV system that met the specified performance requirements. The original plans were for a system rating of 100 kW; the final installation totaled 112.32 kW after the winning bidder was able to accommodate a larger system within the project budget.

The system installation and subsequent operation process did not proceed as quickly nor as efficiently as FDOT had initially projected. While the system provided was larger than originally planned, the final costs exceeded the original budget due to other factors and the installation lagged behind the original schedule. The observed delays in both construction and operation of the system were:

1. Large, abandoned underground tanks were discovered in several locations that interfered with the installation for the PV racking system. The design of steel pilings for the PV racking system had to be replaced with concrete footers in this area, causing a system redesign change order.
2. There were some scheduling conflicts, as the PV system installation occurred while a major site renovation was underway. There was no direct cost increase noted from this issue.
3. Once operational, high winds from a severe storm exposed an installation error in the structural support system for the PV modules, which led to failure of some racking and breakage of some modules.
4. A lightning storm in the area caused further damage to the modules as well as the data acquisition equipment that monitored system production.
5. Ongoing construction in the area, and the need to hold funding back to support repair work, altered the plans of designing and building an alternative energy recreational destination park planned to accompany the system and offer information to interested visitors.

In general, new technology projects come with increased risks. For clients that embark on projects which include new technology or new components, it is recommended that a contingency fund be increased to account for this increased risk. The Turkey Plaza project held 10% back for contingency, while a 15% contingency would have proven more appropriate given the challenges faced during the project. A qualified commissioning agent experienced in newer technologies is suggested to perform routine inspections during the project and to provide feedback to the agency contract project manager, site manager, and onsite contractors.

On projects that have large bid documents it is suggested that sufficient time be offered during the bid period, in order to allow interested firms time to review bid documents and review appropriate standards. During contract negotiation, important points should be emphasized to ensure the contractor's familiarity with requirements and improve the likelihood of compliance at project completion. A commissioning agent should be hired and should perform the final inspection and system performance verification in a formal document, such as that detailed in the IEC 62446 standard, "*Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests, and inspection*", most recently updated to Edition 2.0 in 2013 by the International Electrotechnical Commission (IEC). For large projects (250kW or larger), manufacturers may be able to provide on-site representatives to ensure that complicated systems are installed correctly—this would apply to structural as well as electrical systems (notably, the inverters).

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I. Summary

In 2012, the Florida Department of Transportation (FDOT) completed the installation of a ground-mounted photovoltaic (PV) power system at its Turkey Lake Service Plaza facility, located on the northwest side of Orlando, Florida. This 112.32 kW DC PV system covers approximately a half-acre at the south end of the service plaza, and offsets energy usage for the DOT site buildings and plaza convenience store and restaurants. The energy produced by the PV system is 167,500 kWh/year. This report discusses the entire project from start to finish. From the report, lessons learned and the results can be used as a best practices guide to FDOT and other state departments of transportation for similar procurements. The report results will also guide validation of the financial viability of PV projects and provide the step-by-step procedure from concept to implementation, construction, utilization, and maintenance. The economics of this system is that for the construction price of $351,580 (after $127,920 utility rebate) and the energy production at 167,500 kWh/year with electricity at $0.082/kWh, the simple payback economic analysis gives a rate of return for the PV system at 3.9% and its payback in excess of 25 years. Using a life-cycle cost (LCC) analysis, the present value of the investment is $426,724 and the present value of the savings is $338,307. This gives a savings-to-investment ratio of 0.79 (greater than 1 being better and less than 1 operating at a loss). The LCC values give a payback period that exceed 25 years. The analysis also shows a levelized cost of electricity at $0.111/kWh over the project's 25-year lifetime. Future procurements by FDOT are expected to bring a substantially higher rate of return due to incorporation of lessons learned in this effort, drastic price reductions since this system was procured, and the continued decreases in system pricing expected over the coming years.

II. Project Objectives

The purpose of this FDOT project was to evaluate and draw lessons from a 112 kW PV system that was installed at the Florida Turnpike Turkey Lake Service Plaza in Orlando, Florida. The specific project objectives were:

1. Evaluate the PV system performance
2. Evaluate the economics of the PV system
3. Evaluate the feasibility, bidding, construction, and commissioning of the PV system; and develop lessons learned
4. Offer suggested best practices for future PV system procurements.

Each of these objectives is addressed by a specific section in this report.

III. Background Information

Any PV system that is installed to produce power will consist of PV modules wired to produce voltage and current, a structured mounting system to hold panels and to resist wind loads, an inverter to convert the DC power to AC power, and the associated wiring and other components that are required to make the system safe and meet electrical and building codes. Appendix A provides a more detailed discussion of these components, a brief PV manufacturer's review and other PV-related information.

A major issue in any PV system is the correct installation of the system. A poorly-installed system will cause continuing problems for the owner and will inhibit the system performance output. Appendix B presents information on installation credentialing organizations, several textbooks detailing proper installation procedures, and reports on installation and training related organizations. These appendices are intended to provide reference information on a PV system.

With regard to PV, both FDOT and the U.S. Department of Transportation (DOT) have been studying the use of renewable energy systems and their incorporation into the transportation infrastructure for many years. Many reports have been issued including one sponsored by FDOT and authored by Florida International University faculty: *Opportunities on the State Highway System to Generate Revenue or Offset Expenditures for the State of Florida* was published in October 2013. Several chapters of this report are devoted to discussions of PV systems deployed by departments of transportation, with a section dedicated to a "feasibility screening tool" for solar energy deployments (Bayraktar). Two U.S. DOT reports of interest are:

1. *Alternative Uses of Highway Right-of-Way* – This report investigated the use of highway rights-of-way for incorporating alternative fuel facilities and renewable energy technologies. It presents key findings, best practices, and lessons learned from the various projects. Common findings were:

    - Develop strong communications among stakeholders to ensure smooth project progression
    - Develop a risk matrix to identify and resolve potential threats.
    - Develop realistic expectations for cost, schedule, and deliverables.
    - Develop a business model that integrates within the organization.
    - Evaluate different ownership/operation alternatives and select the one that makes fiscal and operational sense for the agency's strategic goals.

2. National Cooperative Highway Research Program's *Renewable Energy Guide for Highway Maintenance Facilities, 2013* – The intent of the guide was to determine best practices for reducing energy costs through either deploying on-site renewable generation or improving energy efficiency at highway maintenance facilities. The 239-page guide provides specific suggestions ranging from selecting the appropriate renewable energy source or energy conservation strategy, to site selection, financing instruments, best practices for pre-design, design, construction, and operation and maintenance. In addition, it provides case studies detailing various renewable energy projects with lessons learned from California, Colorado, Hawaii, and Indiana (NCHRP).

IV. Project Description

In 2008, the FDOT Research Center initiated a feasibility study of the Turkey Lake Service Plaza PV power project with the objective of investigating the options for PV power at the Plaza. After deciding for positive implementation, the FDOT Research Center issued a Request for Proposals (RFP) to procure a ground-mounted, grid-interactive 100 kW PV system for a total budgeted amount of $500,000 ($50,000 was held back as contingency). An architectural and engineering (A&E) consulting firm was hired to assemble the RFP package. The RFP was presented to the public with a non-mandatory pre-proposal conference on August 2, 2011 and a proposal due date of August 23, 2011. An in-house FDOT committee reviewed the submitted proposals using the process specified in the RFP. The A&E firm was also used as a resource to answer questions the review committee members may have had during their review process.

The RFP specified a turnkey PV system with the successful contractor being responsible for all aspects of the project; design, component selection, engineering, permitting, site preparation, construction, installation, and performance verification. A general contractor was selected. (It should be noted that a separate electrical contractor did the electrical installation, which was a major part of the installation). A ground-mount system was specified because the area was available at the site and a ground-mount system was determined to be both less expensive and easier to maintain than a roof-mount system.

That RFP resulted in a contract award for a 112.32 kW size PV system at a cost of $450,000, with the construction schedule starting in January 2012 and completion scheduled for March 2012. The project was completed and connected to the utility grid in August 2012. After completing the FDOT punch list, the project was deemed ready for operation in October 2012 (see Figure 2).

After construction, a post-completion project review was conducted. This review is used by FDOT in project management for improvements and suggestions for future projects (Nicholas, 2010). The method used for this lessons-learned activity was a combination of research and interviews from all parties who had a vested interest in the project, including FDOT personnel on-site and off-site, designers, contractors, and other project-affiliated individuals. Another output of the project review was to produce a “best practices” document that FDOT can use to learn how to construct similar projects in the future, to protect FDOT from unforeseen costs and schedule over-runs and to assist personnel in managing similar projects.

Figure 2: The Installed PV System (August 2012)

V. PV System Purchase from Feasibility to Operation and Maintenance

The development of any PV power system will consist of 5 major components: feasibility, design, construction, commissioning, and continuing operations and maintenance. This section covers these five areas related to the FDOT system.

Feasibility

FDOT began investigating the installation of photovoltaic (PV) technology at the Turkey Lake Service Plaza (Florida Turnpike Mile Post 263) in 2009 with the study and report *A Comprehensive Solar Energy Power System for the Turkey Lake Service Plaza* released in January 2010. This feasibility report, produced by a University of Florida research team, provided an extensive review of opportunities and costs of locating PV power systems at various locations at the Turkey Lake Service Plaza.

The feasibility report offered a comprehensive view of the solar technologies available at the time as well as budget numbers for various configurations of those technologies at different locations near the Service Plaza—from building rooftops to open areas to systems mounted high on top of highway “noise walls” that are located alongside the driving lanes of the turnpike. FDOT considered the presented options and selected a ground-mounted system for an open area on the south end of the service plaza for the following reasons:

- It was the lowest unit cost option
- It provided an installation that would be publicly visible so that FDOT could showcase the project
- Concerns about roof membrane penetrations and roof replacement on buildings made roof installation costly
- The noise wall installation was too remote and presented operation and maintenance problems

Note that proper PV system design for a FDOT or state agency organization begins with a feasibility analysis that will evaluate the need, economics, system size, and public exposure desired. The feasibility study should evaluate the goals of the installation, locations such as rights-of-way or at toll-collection areas or service plazas and give consideration to the visual recognition that an organization may be seeking. Once the feasibility study has been completed and the project is given permission to proceed, the actual PV system design begins. Also, it is noted that the local utility company was required by the Florida Public Service Commission to offer PV rebates for large commercial systems each year for a five-year period. This rebate was obtained by FDOT and provided an added economic incentive.

Design

Design is a most critical and important aspect of any project. An improperly designed project will fail before construction begins and will haunt the project during its lifetime. Since PV systems are, in most cases, large and required to be connected to the local utility company, the PV system design must be done by a qualified and licensed engineer. The factors that require evaluation and solutions in the design are:

- Specifics of PV modules, inverter and disconnects
- Proper system grounding, bonding, surge suppression, and lightning protection
- Integration to the site electrical service
- Safeguarding the system from vandalism or contact by unauthorized persons, through fencing or installation in an inaccessible location
- Requirements for meeting the state or local building, electrical, and fire prevention codes
- Interaction with emergency backup generators or other distributed generation technology, if used
- Distance from the system to the utility connection point
- Compliance with utility company interconnection requirements
- Structural mounting systems for PV modules with consideration for wind loads
- Site preparation

At this point in the project, an A&E firm is selected to assist the agency in the preparation of the project RFP.

Request For Proposals (RFP) Preparation

The RFP preparation began in 2010 with the issuance of a 98-page RFP document in 2011. A non-mandatory pre-proposal conference was scheduled for August 2, 2011; questions were due by August 11, with bid opening occurring on August 23, 2011. The RFP evaluation was scored as follows: technical plan (60%), management plan (25%), other (10%), and schedule (5%).

The selected construction contractor was responsible for designing the system given the requirements set forth in the RFP. This project was offered for bid as a design-build project in order to foster competition, rely on the contractor's experience, and leverage the expertise of a quality solar vendor to design and install all project components of a successful installation. For many construction projects, Florida public entities are required to undertake the design and construction phases separately, with the design completed by a selected engineering firm with the construction bid out to a separate, independent contractor. This process may not lend itself well to solar power projects. PV systems differ enough and lack the standardization in some electrical specifications that make such systems more unique. What appears to be a minor difference between two PV systems made by different manufacturers may in fact require major differences in a design such as requiring that different mounting systems be installed using an alternate attachment strategy or the connection of different electrical components (converters or inverters).

The RFP also indicated that the selected contractor may be either an electrical contractor or a solar contractor. (A solar contractor license is a Florida license under which the holder can install PV systems of any size with some limitations.) For example, all alternating current wiring must be subcontracted to an electrical contractor and various aspects of site work often must be subcontracted to a general contractor.

Construction

The selected contractor offered the largest system size, maximizing the use of the allocated space and using high-quality system components. The proposed installation schedule met the Department timeframe to take advantage of the utility rebate offered at the time. The selected contractor held both Florida solar and electrical contractor licenses. The contract was issued on November 8, 2011. Site preparation had begun in 2010, with the solar project being incorporated into an overall construction schedule that included large-scale construction renovations being done at the Service Plaza. The solar system site was cleared and graded prior to the solar contractor beginning work.

An initial problem occurred when the solar contractor's mounting system vendor was conducting soil tests to determine system anchorage requirements. At this time, old abandoned underground gas tanks were discovered approximately four feet below grade. This discovery led to a $32,780 change order being issued to redesign the mounting system such that it did not disturb these buried tanks (FDOT decided to leave the tanks in the ground rather than remove them because footer installation costs were less than the tank removal cost, and in some places, the redesigned PV mounting system is currently in place directly above the tanks).

Originally, the structured system was to use steel galvanized columns driven into the ground as a foundation while the revised system used large concrete footers to avoid disturbing the tanks. The tank problem and the service plaza renovation caused the scheduled start date to be delayed. In addition, the project duration was longer than planned, originally being scheduled to end in March 2012. The construction and commissioning actually ended in October 2012. The PV project's integration into the project schedule for adjacent construction at the main Service Plaza caused some material staging conflicts due to the concurrent renovation and construction of the new Turkey Lake Service Plaza facilities and convenience gas station. Also, some electrical drawing revisions were required for the PV interconnection into the convenience gas station, which was still under construction. A mid-construction photo from the installation is presented as Figure 3 below, with a photo of the completed convenience gas station following in Figure 4.

Figure 3: Construction in Progress - April 30, 2012

Figure 4: Turkey Lake Service Plaza Convenience Store and Gas Station (December, 2014)

Construction was substantially completed in August 2012 with final completion (and payment) in October 2012. Final interconnection after utility approval occurred in October 2012.

Commissioning

A third party performed an acceptance test on August 30, 2012. The acceptance test included a review of the system's compliance with the *National Electrical Code* and verification that all circuitry were operating within the expected performance ranges. Final acceptance of corrections was verified via emailed photos addressing various concerns. System changes were made with the updated acceptance report provided in October 2012. Final interconnection approval by the utility also occurred in October 2012. After the project experienced wind and lightning damage (described in the following pages), another inspection report was commissioned from a separate third party (Matern), with additional findings addressed by the contractor in late 2013.

Although the performance was observed to meet the requirements, a more formal record of performance is recommended. It is standard practice for installation validation to provide a written report that specifies in detail the equipment, design, and system performance. For example, data analysis may be performed on factors including circuit voltages, currents, current-voltage performance curves, and power at various levels of granularity in the system—starting at the DC source circuit level and becoming less granular as appropriate for the test equipment. The IEC 62446 international standard, which has recently seen increased usage in the United States, is an example of such detail that could be provided to the client at the close of the project (the IEC 62446 standard may be purchased at www.iec.org).

Figure 5: Wind-Damaged PV Installation

Figure 6: Mounting System Missing A Securement Wedge

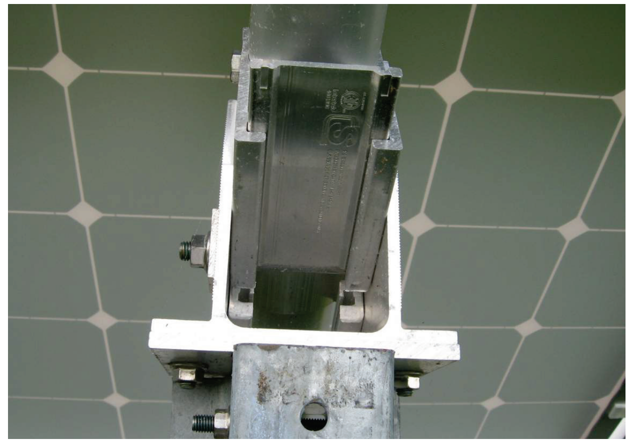

Figure 7: Securement Wedge, Not Fully Installed

System Damage Occurrences after Installation

The first occurrence of system damage was a severe windstorm that occurred at the site on March 24, 2013, and brought wind gusts of 86 mph, as measured at the Orlando International Airport (13 miles from the site, as measured in a straight line in Google Earth). These winds caused several sub-arrays of PV modules to flip over (Figure 5). The ground-mounted mounting structure acted as if the lower attachment points were a hinge. Later examination revealed that a securement wedge was not installed at the upper attachment point on the PV module racking. Fortunately, the storm only caused an issue within a small part of the array, but 20 modules out of 468 modules required replacement. This wedge was a feature of the racking system that was not detected during installation and was not installed until later in 2013. By not installing the upper attachment point, the PV panels acted like a hinge secured only at the bottom. This was an installation error (Figures 6 and 7).

The second weather event that affected the PV system was due to a nearby lightning strike on April 14, 2013, as determined from anecdotal evidence by FDOT personnel. The RFP language required that “the array and inverter(s) shall be protected with a Transient Voltage Surge Suppressor (TVSS). The vendor shall plan to design and install a lightning protection system and surge protection to maximize protection of the solar array” (2. C. 9 of the RFP). Inverters come standard with integrated surge suppression on both the DC and AC sides of the system, but additional TVSS devices were not initially installed. An additional lightning protection system was also not installed, though it is impossible to estimate the additional protection such a system would offer.

Further discussion of the electrical code and lightning protection is presented in Appendix A. As a final note, the data acquisition system was offline for an extended period of time; however, according to the FDOT, the system was operational as of December 2014. These two damage events and repair delays significantly impacted system performance.

Operations & Maintenance

Per the RFP, the contractor provided a 10-year "complete system-level warranty and service contract for the no-cost replacement (inclusive of materials and labor) of any defective component required for safe and as-specified system operation." This warranty covers both parts and labor. The SolarWorld modules have a 10-year product workmanship warranty and a 25-year power production warranty, guaranteeing that after a first-year degradation of 3% (maximum), the modules will degrade by no more than 0.7% annually. The Advanced Energy inverter carries a manufacturer's limited warranty of 20 years. The Schletter mounting hardware carries a 10-year limited warranty. The installer's warranty covered the wind damage repair, however it was agreed that the surge event was not covered by the warranty.

PV systems are not maintenance free, and actual maintenance cost for this system would be an estimated $2,200 annually. FDOT personnel estimated that the additional landscaping maintenance (mowing, trimming, etc.) would cost approximately $900 annually above and beyond the expected maintenance had the PV system not been installed in the field. Additional research would be useful in determining appropriate low-maintenance ground coverage options for FDOT ground-mounted PV systems and other properties. Future PV sites may use crushed shell, xeriscaping, high ground clearances, or other techniques to minimize the need for landscape maintenance. FDOT also contracted for module cleaning for a one-time price of $800. The initial plan is for this to occur every two years, though cost-effectiveness will be analyzed to determine the optimum cleaning frequency. The expected maintenance for the system itself is expected to be approximately $900 per year to cover the cost for a one-day maintenance trip for skilled technicians. Within the economic analysis this number is given at $8/kW/year. This is an estimate and will vary based on system characteristics (size, site accessibility, system complexity, etc.) and the value is best determined by simply bidding out the work. Lower costs may be achieved through either a packaged initial operations and maintenance (O&M) service by the installer or by bidding out O&M services for a fleet of systems should FDOT deploy additional systems.

On future projects, an agency may also be able to ensure proper system performance by enforcing an energy production guarantee. Power Purchase Agreements (see the "Financing Future Systems" section) would offer this inherent protection mechanism—the third-party owner (not FDOT) would be paid only for energy delivered. An unreliable system not producing at expected levels would yield less revenue for that vendor, thereby pushing that vendor to install only the most reliable components in a manner yielding a long system life. A production guarantee with extended warranty service by the installer nevertheless could be integrated into future projects to be owned by FDOT or another State agency.

VI. System Performance

PV Energy Production

The PV system consists of 468 SolarWorld SunModule Plus SW240 mono PV modules. These modules are rated at 240 W and have a combined series and parallel configuration DC nameplate rating of 112.32 kW. The array is connected to a single inverter, an Advanced Energy PVP100kW unit bearing an AC nameplate rating of 100 kW. The power ratings can be likened to the horsepower rating of a car—while achievable under rare circumstances, most of the time the system will not be operating at these values, as described in the paragraphs below. As the array output power will rarely be as high as 112.32kW, it is often best practice to size the inverter slightly smaller than the array output. On the rare occasions of exceptionally clear, cool, and breezy Florida weather, if an array is able to produce more power than the inverter can convert, then the inverter simply and safely limits the amount of power produced by the array. The economic value of this unproduced energy is determined to be insignificant when compared to the higher cost of a larger inverter, and this is a judgment call made by the system designer.

The power production of PV systems is primarily influenced by two factors: 1) the amount of sunlight shining on the array at a given time, and 2) the operating temperature of the PV modules. PV arrays produce electricity in proportion to the amount of sunlight on the modules. While modules can produce power any time between dawn and dusk, modules produce the most power during the middle 4-6 hours of the day when the sun shines more directly on the array. However, high sunlight that brings high power production also brings added heat. PV modules are generally cooled by wind and by radiating heat away from the modules. In some roof-mounted systems, there may be only an inch or two between the modules and the building roof, which leads to a PV array experiencing hot operating temperatures, perhaps 150°F or even warmer (SMA). For a ground-mounted system with no such barrier behind the modules, the modules are more likely to operate at up to 130°F (SMA). This cooler operating temperature leads to higher energy production over the life of the system. The nameplate power for a system is measured under very sunny conditions and a module operating temperature of 77°F (SolarWorld). The PV modules in this project will see their power output decrease by approximately 0.25%/°F for operating temperatures above 77°F (SolarWorld); on the rare occasions where the modules operate at cooler temperatures, they will see a corresponding increase in power. Rooftop installations generally will operate at higher temperatures than ground-mounted systems that are better ventilated; therefore configurations that are ground-mounted will generate slightly more energy. “Tracking” mounting systems, configured to move the PV modules throughout the day to better point them towards the sun, can increase the amount of sunlight shining more directly on the modules, and more energy can be produced. Several large systems in Florida have been configured with tracking but, generally speaking, the economics for tracking work better for larger systems (over 1,000kW) due to the higher costs for equipment and maintenance.

PV energy production is variable with time and amount of sunlight (irradiance) on the module, and there are also system efficiencies to calculate. Annual production can generally vary as much as 15% per year as compared to average yearly values, due to weather variability. For comparison purposes, the amount of annual sunlight received for this system is approximately 4.9 kWh/m^2/day; and a similar installation in Yuma, Arizona (perhaps the highest irradiance levels in the US) would receive 6.7 kWh/m^2/day (NREL PVWatts). Irradiance levels are of course higher in the northern parts of the US (see Figure 17 in Appendix A for a visualization). A system can be expected to operate at approximately 75-85% efficiency after power is produced within the modules. Typically, inverters operate at 95-98% efficiency; the inverter in this project has a weighted efficiency of approximately 96%, indicating that 96% of the direct-current power input is converted to alternating-current power. The overall efficiency number includes factors such as array mismatch (where parallel circuits operate at slightly different voltages due to manufacturing tolerances but the parallel connection forces the same voltage back at the array), module soiling, power loss (voltage drop) in wiring throughout the system, and availability issues (e.g., outages).

The SolarWorld modules have a new power rating guarantee that they will operate at a power rating of at least 240W per module. Generally speaking, PV modules experience an initial “light-induced degradation” of 3% over their first few days of solar exposure, with a warrantied degradation rate of no more than 20% over a 25-year period. These modules offer a more specific warranty of 0.7% maximum degradation per year (calculated as a percentage of the original nameplate rating of the module). The results presented below in Table 1 take into account this cumulative degradation.

For PV production, there are many computer programs that provide the PV energy output in terms of kWh/year. The numbers in the following table used the PVWatts estimation software, and the output energy produced for the first year of the 112 kW system was calculated at 167,500 kWh/year. PVWatts was used to derive an initial estimate of annual energy production, to be refined by others after further data collection. As additional points of reference, calculations using Orlando International Airport (MCO) weather data within the System Advisor Model resulted in an energy estimate of 158,600. Simulations using alternate weather data provided slightly different results: 176,100 kWh/year (Ocala International Airport), 164,100 (Orlando Executive Airport), and 178,600 (Sanford International Airport). Given the discrepancies here (largely due to higher-uncertainty irradiance data), the 167,500 kWh/year forecast was used as a mid-range, achievable target.

The energy provided by the PV system will accumulate over the 25-year lifetime of the system. The table shows the yearly decline of 0.7%, giving a 16% decline in 25 years. It is noted that the system may last past the 25-year lifetime. The 2013 year is based upon the beginning of the system utility interconnection (October 2012).

Table 1: FDOT PV Energy Output per Year

Year	Projected Yearly Power Generation (kWh/Yr)	Projected Cumulative Energy Generation (kWh)
2013	167,500	167,500
2018	161,719	821,248
2023	155,044	1,768,065
2028	149,693	2,527,159
2033	144,527	3,260,055
2037	140,523	3,828,116

Over the first 25 months of operation between October 1, 2012 and October 31, 2014, the system produced 288,997 kWh of energy according to the monitoring system. During this time, there were data outages—in some cases, the data monitoring system was not collecting data during times of system operation, at other times, some subset of the PV system had been disabled.

Table 2: Outage Details

Outage Number	Beginning Date	Ending Date	Days Affected	Estimated Energy Lost	Cause
1	3/24/2013	3/29/2013	4.5	2,300 kWh	Wind damage, system offline
2	3/29/2013	4/14/2013	17	1,000 kWh	Wind damage, part of system still disabled
3	4/14/2013	2/11/2014	303	3,000 kWh	Apparent lightning damage to system and data monitoring, no detailed production logged
4	5/12/2014	5/26/2014	13.5	5,700 kWh	Unknown

The “estimated energy lost” column in Table 2 above is calculated using different methods. Outage #1 is calculated based on the average fully-operational day in March 2013 resulting in 513 kWh of energy production per day. Over 4.5 days, this totals approximately 2,300 kWh. For outage #2, approximately 10-20% of the system may have been turned off. The remaining portion of the system was operating and producing an average of 322 kWh per day. Assuming

15% of the system had been disabled, a system producing 322 kWh per day was unable to produce approximately 57 kWh of additional energy per day, for approximately 1,000 kWh total. For outage #3, it is unclear precisely how many days the system was operating and at what capacity during those days due to the damage of the monitoring equipment. FDOT personnel estimated that approximately one-tenth of the system was offline from mid-April until June. Assuming the remainder of the system was online for these two months and that the full system was operational (aside from the data monitoring) from June through February, this would correspond to a loss of approximately 3,000 kWh. This assumes that the complete system would have produced approximately 30,000 kWh during the April 14 – June 13 (inclusive) period. For outage #4, the week preceding and the week following this 13.5 day outage resulted in 422 kWh of average daily production over 14 days, for an expected loss of perhaps 5,700 kWh total (422 x 13.5).

These four outages correspond to approximately 12,000 kWh of lost energy production. During those 25 months, had energy production been at the simulated total of 167,500 kWh/year, this would correspond to a total production of approximately 350,000 kWh. However, 289,000 plus 12,000 is 301,000 kWh for a shortfall of almost 25,000 kWh/year. Some of this difference may be due to the uncertainty around the true energy production total or weather variation. Now that the system is once again fully operational, measurement and verification should continue to confirm that the system is performing according to projections.

VII. System Economics

Project Costs

The project began with a $500,000 budget allocated by the FDOT Research Center. A $50,000 contingency fund was set aside by FDOT to reduce financial risk. The intent of the RFP was to offer it as a $450,000 project. The total estimated cost to FDOT was to be $322,080 ($450,000 - $127,920 rebate). Following the contractor selection, an additional $19,245 was allocated for an added 9.36 kW of installed PV capacity, and $10,255 was allocated for fencing to secure the site. This brings the total capital cost of the project to $351,580, or $3.13/Wdc ($3.13 per watt in DC nameplate rating). Additional detail is provided in Table 3.

Table 3: Project Costs to Date

Item	Item Cost
Original contract amount (102,960 W)	$ 450,000
9,360 W additional installed capacity (39 modules), to total 112,320 W	$ 19,245
Perimeter Fencing	$ 10,255
Additional site work related to underground storage tanks	$ 32,780
Replace and add surge suppression to, monitoring controller	$ 1,461
Replace inverter communication card, PCB, and cable assemblies	$ 750
Replacement of 20 wind damaged PV modules	$ 0
Replacement of 40 surge damaged PV modules	$ 13,500
Future inverter canopy cover (estimate)	$ 4,000
Additional future lightning protection (estimate)	$ 20,000
Utility rebate	**(127,920)**
TOTAL	**$ 424,071**

Simple Payback and Life Cycle Cost Calculations

To economically evaluate the PV system, two methods are used. For all the calculations, a system cost of $351,580 (cost after rebate) and an electricity cost of $0.082/kWh is used. The electricity cost of $0.082/kWh is the expected value of electricity savings under the applicable Duke Energy tariff at the site (GSLM-2, the rate for general service commercial with a demand charge, time-of-use pricing, and utility-controlled backup generation). On-peak energy rates are $0.10822/kWh on weekdays (November through March: 6am – 10am, 6pm – 10pm; April through October: 12pm – 9pm) and off-peak rates (at all other times) are $0.04826/kWh. The calculations follow.

1. Simple Payback: Using a capital cost of $351,580 and a revenue of $13,735 per year (167,500 kWh/year x 0.082 $/kWh) gives a simple rate of return of 3.9% per year. A ratio of 5% return of investment is suitable for a state agency, and this rate of return will increase if electricity prices escalate in the future. The simple yearly payback calculation is $351,580/$13,735 or 25.6 years.

2. Life Cycle Cost: There are many life cycle cost (LCC) models and calculation programs in the literature. Using one developed by the Florida Solar Energy Center (FSEC), this section presents the LCC calculations for this PV system. Life cycle costs consider the PV system cost and income over the lifetime of the system with all costs brought back to present values. For the LCC model, the following values are used:

   System Cost = $351,580
   1st Year Income (PV Output) = $13,735
   Lifetime = 25 Years
   Nominal Discount Rate = 2.53% (0% real discount rate plus 2.53% inflation rate)

PV Output Degradation Rate/Year = 0.7%
Maintenance Costs = $2,200
PV Inverter Replacement after 15 Years
Utility Company First-Year Electricity Cost = $0.082/kWh
Utility Company Escalation Rate/Year = 3.4%
Salvage Value = $20,000 (estimated)
Electric demand reduction = 0 kW (in some cases, the PV production may reduce the peak electric demand of a building, but this is likely only when loads during daylight hours are consistently higher than during nighttime hours)

The maintenance costs above include $8/kW/year for solely electrical maintenance and annual checkups, plus costs of cleaning and landscape maintenance as noted in section V. These costs may vary substantially for other systems as noted in that section, and the unit cost ($/kW/year) will be larger for small systems and smaller for large systems due to economies of scale.

The utility rate escalation is offered as 3.4% per year as this reflects the actual rate change for Florida residential customers between 2002 ($0.0816/kWh) and 2012 ($0.1142/kWh). These values are given in real dollars and include general inflation, which when calculated from the CPI-U (Consumer Price Index for All Urban Customers, as published by the US Department of Labor) data was 2.53% for the same period. Thus, depending on how the term is defined, the electricity "escalation" rate (the rate greater than the general inflation rate) for this period was approximately 3.42% - 2.53% = 0.89%. The analyses below offer escalation rates of either the 3.4% value or 1.7% for a more conservative approach; based upon the Energy Information Administration's actual data for the average price of commercial electricity from 1990 to 2012. It is noted that residential rates and commercial rates are different; however, the commercial rate can vary substantially between customer classes and utility and makes a comparison less straightforward. For future projects, the specific escalation rate could be determined on a site-specific basis.

Salvage value is offered as $20,000 at the end of the 25-year expected life of the system. Dunlop notes that some analyses use a salvage value of 20% of the original purchase price for the equipment only, with the caveat that "the salvage value assigned to the system is subjective and difficult to quantify, but must not be ignored since it can be significant." (Dunlop, p. 435). This $20,000 value is less than this 20% rule of thumb and can be viewed as a conservative estimate.

Conducting the LCC calculations gives a present value of the investment cost of $426,724 (system cost plus inverter replacement at 15 years) and a present value of the system revenue or savings of $338,307. These numbers give a savings-to-investment ratio (SIR) of 0.79. Greater than 1.00 is a gain and less than 1.00 is a loss. These numbers also show that the payback period exceeds 25 years and that a levelized electricity cost from the PV system is $0.111/kWh over the payment life. Figure 8 shows key indicators for capital cost and energy savings in present value dollars along with PV system and utility electric cost in future dollars. Detailed calculations are shown in Appendix C.

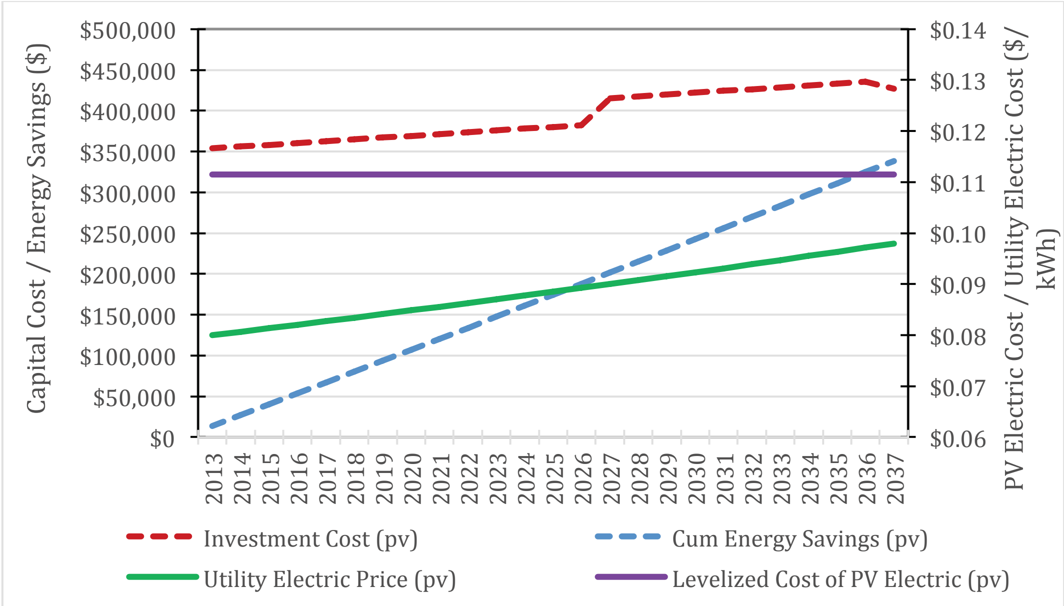

Figure 8: Life Cycle Cost Analysis

Since the LCC calculations are very dependent upon the economic parameters selected, the following calculations were made to give a sensitivity analysis. The following sensitivity analysis tables indicate savings-to-investment values with the initial investment cost fixed at $351,580.

When a PV system offsets higher prices from the electric utility, the better the investment becomes as noted in Table 4:

Table 4: Effect of Electric Price on Savings/Investment Ratio

Electricity Prices	Savings/Investment
$0.08	0.84
$0.10	1.05
$0.12	1.26

The effect of borrowing the initial cost (through a bond) in place of paying 100% is described in Table 5:

Table 5: SIR For Various Interest Rates and Borrowing Percentages

Interest Rate	Borrowing Percentage		
	100%	80%	50%
1%	1.12	1.09	1.04
2%	1.01	1.00	0.99
3%	0.92	0.92	0.94
4%	0.83	0.85	0.89
5%	0.76	0.79	0.85

The above result shows that the greater the amount of money borrowed, the better the savings/investment value, as long as the borrowed interest rate is lower than the life cycle analysis discount rate.

Looking to the future, utility rebates are unlikely to persist in Florida beyond the year 2015; rates are expected to stay stable and system costs will continue to fall much lower than historical prices. The following table illustrates the Savings/Investment Ratio (SIR), the Internal Rate of Return (IRR, in %), and Levelized Cost of Energy (LCOE, in cents per kWh). SIR and IRR are presented for varying offset utility rates (8c, 9c, and 10c/kWh). LCOE is the life-cycle investment divided by the total energy produced, and it provides the cost of energy provided by the PV system. This number could be compared with LCOE of competing approaches. Calculations were made for escalating utility costs of 1.7%/year as well as 3.4%/year. These calculations assume a 25-year service life for the system, an inflation rate of 2.53%, and a maintenance cost of $2,200/year (in Appendix C, this is calculated at $19.58/kW solely to maintain input compatibility with the spreadsheet) plus an inverter replacement cost of $0.40/Wdc.

Table 6: Comparison of SIR and IRR at Varying Discount Rates and Costs

Electricity Cost Escalation (%/Yr)	System Cost ($/Wdc)	Nominal Discount Rate (%/Yr)	SIR			IRR (%)			LCOE
			8c/kWh	9c/kWh	10c/kWh	8c/kWh	9c/kWh	10c/kWh	c/kWh
1.7	$1.50	2	1.19	1.34	1.48	4.1	5.6	7.1	6.5
		3	1.09	1.23	1.37	4.1	5.6	7.1	6.3
		4	1.01	1.14	1.26	4.1	5.6	7.1	6.1
	$1.75	2	1.07	1.20	1.33	2.7	4.1	5.5	7.2
		3	0.98	1.10	1.22	2.7	4.1	5.5	7.0
		4	0.90	1.01	1.12	2.7	4.1	5.5	6.8
	$2.00	2	0.97	1.09	1.21	1.6	3.0	4.2	8.0
		3	0.89	1.00	1.11	1.6	3.0	4.2	7.7
		4	0.81	0.91	1.01	1.6	3.0	4.2	7.5
	$2.25	2	0.89	1.00	1.11	0.7	2.0	3.1	8.7
		3	0.81	0.91	1.01	0.7	2.0	3.1	8.5
		4	0.74	0.83	0.92	0.7	2.0	3.1	8.3
3.4	$1.50	2	1.47	1.65	1.84	6.4	7.9	9.3	6.5
		3	1.34	1.51	1.68	6.4	7.9	9.3	6.3
		4	1.23	1.38	1.54	6.4	7.9	9.3	6.1
	$1.75	2	1.32	1.49	1.65	5.0	6.4	7.7	7.2
		3	1.20	1.35	1.50	5.0	6.4	7.7	7.0
		4	1.10	1.23	1.37	5.0	6.4	7.7	6.8
	$2.00	2	1.20	1.35	1.50	3.9	5.2	6.4	8.0
		3	1.09	1.22	1.36	3.9	5.2	6.4	7.7
		4	0.99	1.11	1.24	3.9	5.2	6.4	7.5
	$2.25	2	1.10	1.24	1.37	2.9	4.1	5.3	8.7
		3	0.99	1.12	1.24	2.9	4.1	5.3	8.5
		4	0.90	1.01	1.13	2.9	4.1	5.3	8.3

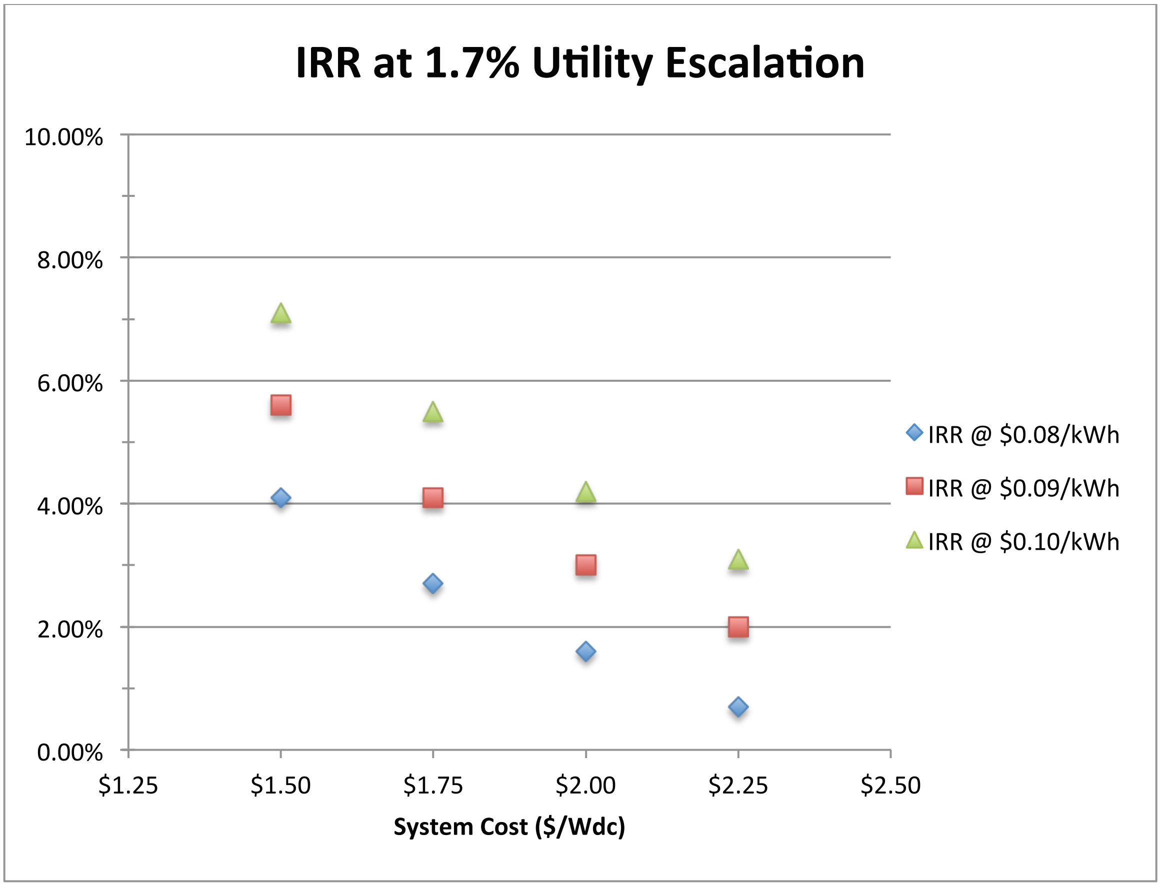

Figure 9: IRR for Various System Costs, Assuming 1.7% Utility Escalation

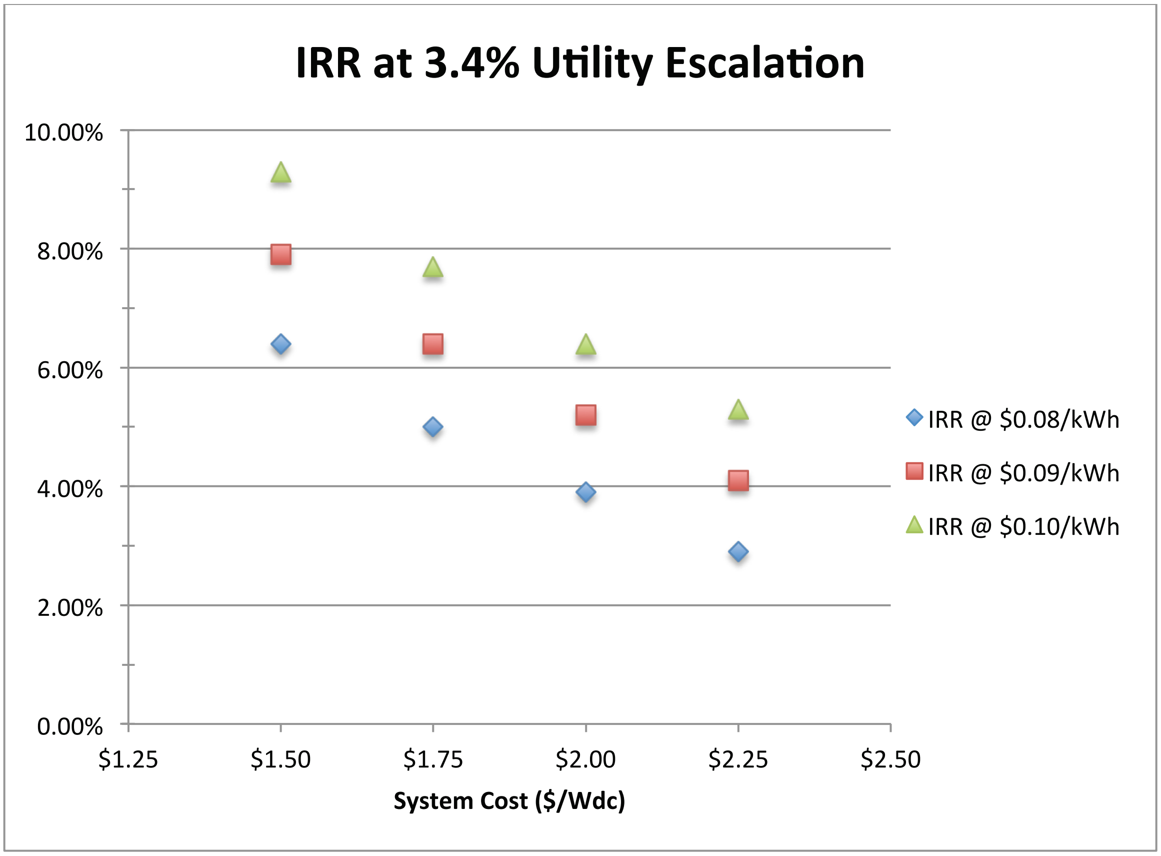

Figure 10: IRR for Various System Costs, Assuming 3.4% Utility Escalation

Higher SIR and IRR values result from lower-cost PV systems offsetting higher-cost energy delivered by an electric utility. An important caveat is that the results of cost analyses will be different for each system due to differences in utility policies, customer risk tolerance, system pricing, site weather conditions, product reliability, and operation and maintenance costs. For some system owners, another factor that comes into play is valuing the pollution reductions achieved through installation of PV or other renewable fuels or consideration of externality costs. Also, some system owners may place a higher value on the ability to hedge against the variability of electric utility costs.

The above analysis was performed as if the FDOT owned the system with FDOT also receiving the financial benefits of system operation: lowered electricity bills. However, in this case FDOT owns the system and the financial benefits of the system are passed to the operator of the convenience station and gas station, who is responsible for paying the electric bill. In this case, the annual revenue is simply the agreed-upon lease value ($15,000 per year as a ten-year contract) incorporating the expected energy savings.

Externality Costs

Historically, the cost of energy produced by PV systems has been higher than energy produced from conventional fossil fuel-fired utility plants. Utility-owned generators do not generally pay a dollar amount in exchange for pollution they produce, either at the source of the fuel extraction or the location where the power is produced. Thus, if a customer pays $0.10/kWh for electricity from a fossil fuel-fired power plant, then the value of an offsetting kWh produced by a PV system is $0.10/kWh plus some externality value of the benefits the PV system provides. This value is currently undefined, as it includes a number of intangible benefits difficult to quantify such as: the value of local energy production, benefits of cleaner air through reduced sulfur dioxide, nitrogen oxides, airborne mercury, and carbon dioxide and monoxide emissions, acid rain costs on buildings, and lung disease costs from air pollutants. Many studies have been conducted on externality costs, and these references are not cited herein. The most difficult factors to evaluate are the effects of acid deposition on buildings and within aquatic environments, as well as polluted air on lung diseases. Since these numbers cannot be quantified as easily or accurately as other costs associated with this project, no attempt will be made here to evaluate these effects. However, the numbers and effect are real and a PV system has the benefits of offering positive values, versus fossil fuel based electrical generating sources that offer varyingly negative health values. Additional details on pollution factors and externalities are presented in Appendix A.

Financing Future Systems

Although not part of the economic analysis due to current availability of FDOT funds, several options exist for the FDOT and other entities to finance future PV construction projects and their options are reviewed here. The most straightforward method for financing solar projects may be *direct ownership* of the PV systems via either direct budget allocation or bond issuance. However, this comes with substantial risk in the area of quality assurance, as outright ownership does not necessarily obligate an installer to long-term performance. If a bidder is selected based on lowest cost alone, with no long-term, bankable performance guarantee, then system reliability and durability may not be as predicted. Retaining a portion of the payment until the end of the 25-year project, pending satisfactory performance, is not applicable for today's bidders. Also, there are federal tax incentives in place through the end of 2016 that can reduce the cost of a system by approximately 40%. Though FDOT may have access to lower-interest financing than a taxable entity (this would be verified on a case-by-case basis), the FDOT cannot claim the substantial federal tax incentives for itself. Therefore, a direct ownership plan would likely not achieve the lowest cost possible for future projects.

The alternative to direct ownership of the PV systems is *third-party ownership*, either on a temporary or permanent basis. One way to accomplish this is for a third-party developer to build and own the system, selling the produced energy to FDOT over a long-term contract, generally 15 to 30 years. This arrangement, called a "power purchase agreement," or PPA, puts performance risk on the developer if a system is unreliable and underperforms, then FDOT only pays for the energy that was delivered. This is a popular solution for both governmental and private entities to deploy solar projects as it pushes most risk onto the system developer and inherently includes a performance guarantee. As one example, the PV developer SolarCity of California recently deployed eight PV projects across four Hawaiian islands for the Hawaii DOT.

Unfortunately for FDOT and other interested entities, a decision made by the Florida Public Service Commission (PSC) in 1987 makes “third-party sale” of electricity on a per-kWh basis illegal in Florida. It is noted that 22 states, as well as Washington, DC and Puerto Rico have legal third-party sales and these agreements have been instrumental in creating some of the largest solar markets in the country (e.g., California, New Jersey, Massachusetts, New York, and the southwest US). (DSIRE)

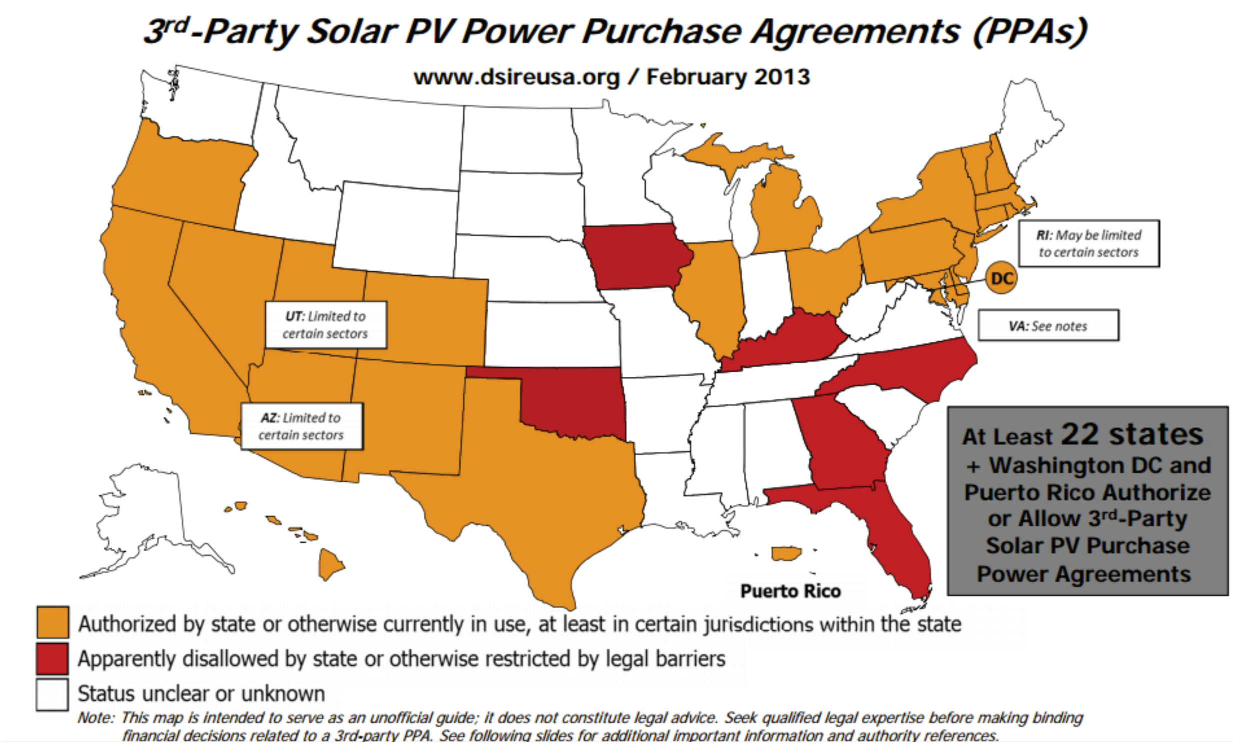

Figure 11: Legality of 3rd-Party Power Purchase Agreements Across the US

The alternative to third party sales is a solar leasing model. Under a solar lease, a third-party developer still builds, owns, operates, and maintains the system over the contract term. FDOT would then pay a prescribed lease payment, either periodically or as a lump pre-payment upon installation. At the end of the lease period, ownership of the system could be transferred to FDOT. This could occur as early as six years after the system is brought online (to allow the federal tax credits to fully vest) or as late as 25 or 30 years after construction completion. Regardless of length, the contract should include language to ensure long-term performance and responsive repairs when the system experiences downtimes. Performance guarantees are typically in terms of generated kilowatt-hours, with a baseline sometimes correlated to the unique site weather conditions in each year. At the same time, this language may need to be written carefully to avoid triggering the PSC definition of “retail sale of electricity.” It is possible that the restriction on PPAs will be lifted in the future.

The actual arrangement of the Turkey Lake PV system is that the system is owned and operated by FDOT and the financial savings from production benefit the operator of the convenience store. If this is the financial model for future projects, FDOT simply would set the lease payments such that the value exceeded the costs of operating and maintaining the system. Until FDOT or another agency gains in-house expertise in this area, it is suggested that these maintenance costs be subcontracted out to the industry.

VIII. Lessons Learned

As with almost all construction projects, there were change orders or site design modifications as construction progressed. This was expected for this project as well, given that it was a large PV system procurement unfamiliar to FDOT. These types of modifications carry a higher risk with new technologies. A second issue involves new technology design. Good design and considerations for all aspect of the project is a must. Thorough oversight through a construction process can mitigate but not eliminate risks. The following section offers a list of project considerations.

IX. Best Practices

Some “best practices” for FDOT and other organizations planning solar deployments are:

1. Determine project criteria and conduct feasibility study:
    a. Determine rationale for deploying solar power systems. These may include one or more of the following: achieving financial savings, offsetting a certain percentage of the energy consumption of an organization or facility, decreasing pollution emissions associated with organizational operations, meeting a statewide solar procurement goal, promoting energy efficiency, or demonstrating locally-sited distributed generation.
    b. Determine financial constraints. These constraints will include minimum rate of return, payback years, tax considerations, utility tariffs, energy savings, rebates, utility policies related to customer-sited energy generation projects, organizational budget constraints, and project financial risk.
    c. Select financial instrument to fund the project. These options are power purchase agreement, lease-back, or owner-operator. Each instrument has its own advantages and disadvantages and should align with the long-term strategy of the organization.
    d. Conduct feasibility study. A feasibility study provided by a third-party can assist in determining what barriers exist and how (or whether) they can best be addressed.

2. Procurement of a PV power system:
    a. Barriers that may prevent/delay the PV system from meeting goals are lacking support from within the organization or from other stakeholders (local citizenry, neighbors, peer organizations), or an electric utility that does not permit or encourage renewable generation. Barriers may also be technical; for example, organizations may not have sufficient space available for a PV system of the size required. In many cases, the feasibility analysis can provide a greater amount of certainty as to the suitability of a specific location.
    b. Systems concerns for ground-mounted systems include the investigation of underground surveys, proper low-maintenance ground cover, and soil studies; for systems mounted on existing structures, an independent structural engineering analysis will verify the suitability of the structure and its roof to withstand additional PV loads. These analyses may reduce the project risk for the customer (with respect to both schedule and budget) later in the project and it also gives greater certainty to the bidders when preparing their bids.
    c. Determine risk allocation through performance guarantees or other incentives to ensure that high-quality equipment is installed in a manner as to promote operation. Minimizing the perceived risk for a bidder should lead to lower-priced construction projects. Alternatively, a project schedule could be lengthened to allow for discovery events after project award and kickoff.

d. Determine minimum project requirements to guide the installer through what may be complicated policies set by the host organization.
e. Develop Request for Proposal.
f. Obtain bids for work from multiple contractors, ensuring that project contractual and technical requirements are understood and that organizational goals for the project will be exceeded through implementation of proposed systems. Ensure that scopes of work are clear. A suggestion is to interview and hire a contractor who has performed similar types of PV installations and is a certified NABCEP (North American Board of Certified Energy Practitioners) PV Installation Professional (see Appendix B). PV installations on large flat rooftops require a different set of experiences and expertise than large ground-mount arrays. Likewise, a contractor who has installed thirty 5 kW systems may not have the expertise required to install a 150 kW system. Objective evidence for the contractor should be offered as to previous accomplishments.
g. Investigate long-term operations and maintenance considerations by determining whether internal organizational resources can be allocated to assure long-term operation or external resources will be relied upon.
h. After project completion, hire an agent to commission the project.

3. Construction:
    a. To minimize risk, contractors should have a methodology in place to manage their component selection. The design and component selection need to meet the client requirements but they also need to be vetted for compatibility, durability, ease of installation, and availability. When contractors take on a new product line, they should ensure that they have evaluated the risk with using the new equipment.
    b. Determine need for an agent(s) to verify satisfactory completion of tasks throughout the construction process. Agent(s) may be manufacturer representatives or independent commissioning agents. They must also ensure that building inspectors conduct inspections and give approvals. Local building inspectors can supply strong expertise because of their experience with local contractors and their understanding of code needs and their relationship with members of the local construction workforce. If possible, the independent agent should be hired directly by the organization rather than the contractor.

4. Operation and Maintenance:
    a. Assign responsibilities and authority within the organization to an individual to monitor and maintain adequate system health and performance.
    b. Set minimum standards for the long term performance of the system.
    c. Benchmark future projects against past systems' performance to ensure that goals are reasonable and that procurement processes are optimized.
    d. Ensure that the operations and maintenance of the power system and the monitoring system is accounted for in future budgets.

X. Conclusions

In 2012, the Florida Department of Transportation (FDOT) completed the installation of a ground-mounted photovoltaic power system at its Turkey Lake Service Plaza facility, located on the northwest side of Orlando. This 112.32 kW DC PV system covers approximately a half-acre at the south end of the Service Plaza, and offsets the electric demand at the Plaza convenience store and gas station. The PV system is expected to initially deliver approximately 167,500 kWh/year of energy to the store.

The main focus of this report is to evaluate this PV installation at the Service Plaza and evaluate its economic performance as well as provide a lessons-learned and best practices guide. The lessons learned and suggested best practices can be used as a best practices guide to FDOT and other government agencies within the State of Florida for similar procurements. Using a simple payback analysis, the rate of return for this PV system is 3.9% and the payback is in excess of 25 years. Rates of return are expected to be substantially higher for future projects, as the FDOT incorporates the lessons learned within this report and procures systems at substantially lower prices due to industry-wide cost reductions.

The Turkey Lake Service Plaza project achieved the major stated goals that FDOT set in 2009. This installation marked the FDOT's first major foray into larger PV systems after installing many small PV systems for remote power applications. While the project encountered several obstacles throughout the construction and early operation phases, successfully overcoming these issues has better prepared the FDOT for potential PV construction projects in the future. This experience initiated FDOT into PV technology. Lessons learned from this project should improve the performance of future PV projects that FDOT may undertake and while the sizable rebate that this project received is no longer available, the decrease in system costs over the past three years has more than made up for the rebate.

XI. Acknowledgements

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APPENDIX A: PV Systems, Components, Solar Resource

A PV system has several major components described as follows:

- PV modules ("solar panels") convert sunlight into direct current electricity. PV modules are generally made from a semiconductor material, sealed under a glass layer for protection and installed within an aluminum frame. Power generated within the module is carried out of the unit on included wires and these wires are connected to other modules to comprise a complete PV array.

Figure 12: PV modules, installed

Figure 13: PV modules, rear view showing wiring

- Mounting systems provide structural support for the PV modules. Generally fabricated by a variety of manufacturers from aluminum or galvanized steel, these systems allow PV arrays to be installed on building roofs or walls or as a self-supporting ground-mounted structure. These structures can range from large covered parking structures to lower-profile systems in a field. Ground-mounted systems are generally built up from a foundation, with vertical supports stabilized using concrete, driven piles, or ground screws.

Figure 14: Mounting system, showing columns, rails, and attachment points

- Inverters and associated power electronics maximize the direct current electricity produced by the PV modules and convert it into alternating current appropriate for the site.

Figure 15: Inverter and Interconnection Point (within the building in background)

Commercial-scale facilities typically have a three-phase electric service at 480 volts (V) or 208V. Large PV systems generally will interconnect near the utility service entrance at the utility service voltage. Standard building wiring methods, such as large conductors in conduits or raceways, are used to bring power from the PV array to the inverter(s) and then to the utility interconnection point. This interconnection point is the location in the existing building electrical distribution where a new breaker or fused disconnect is installed to connect the PV system.

- Monitoring systems are typically included with systems as a means for the owner, operator, customer, and other interested parties to observe energy production and where applicable, react to system warnings or alarms. These systems are sometimes used to promote solar projects through public viewing of the production data on a website. These systems are critical to ongoing Operations & Maintenance (O&M) activities at the site, allowing personnel to learn quickly of system performance issues before a regularly-scheduled visit to the site.

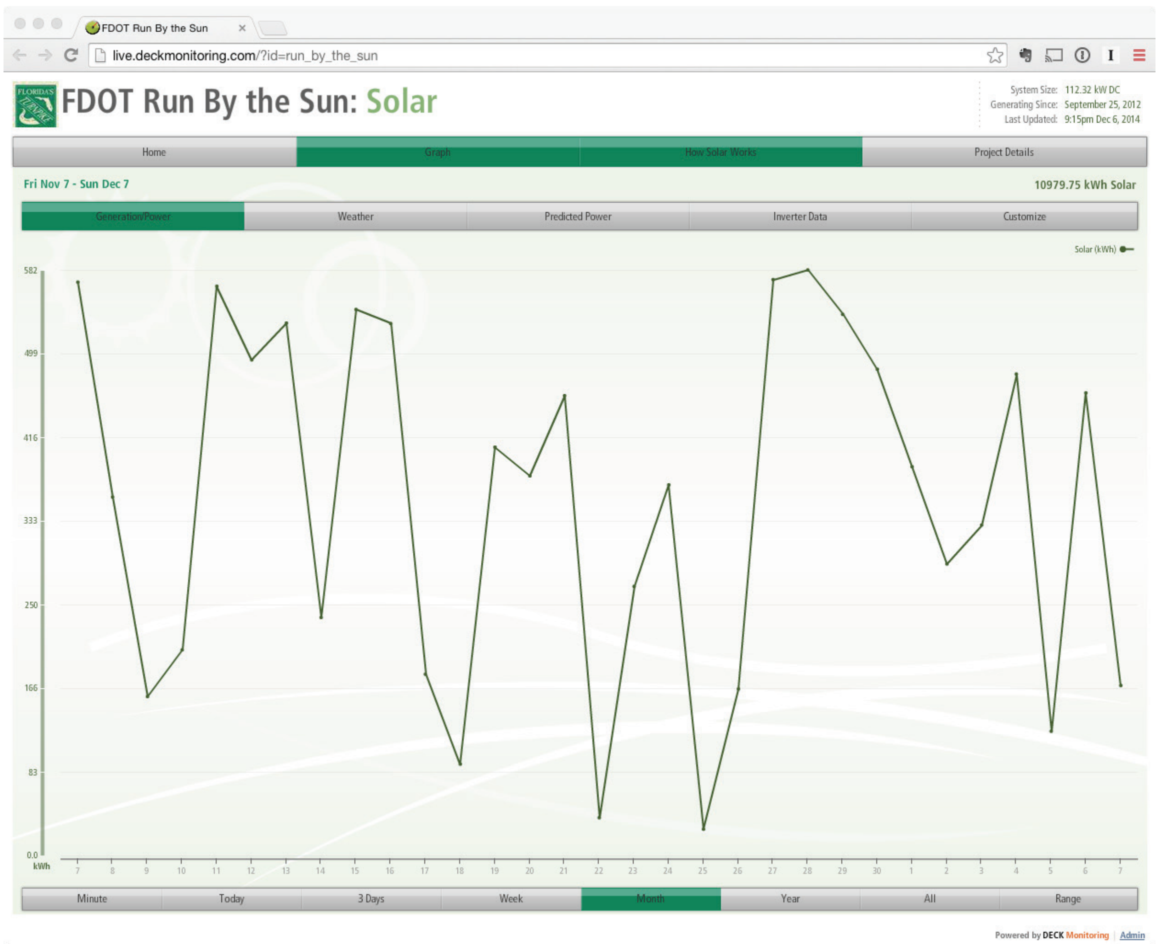

Figure 16: Monitoring System View, Displaying Production From Previous 30 Days

- Other components include electrical disconnects, panelboards, circuit breakers and fuses, surge arrestors, lightning protection systems, wiring, conduit, placards, a monitoring system, fencing around ground-mounted systems, and other minor items.

A PV system's power production depends upon the solar resource at the local site. A map of the U.S. solar resources is presented below.

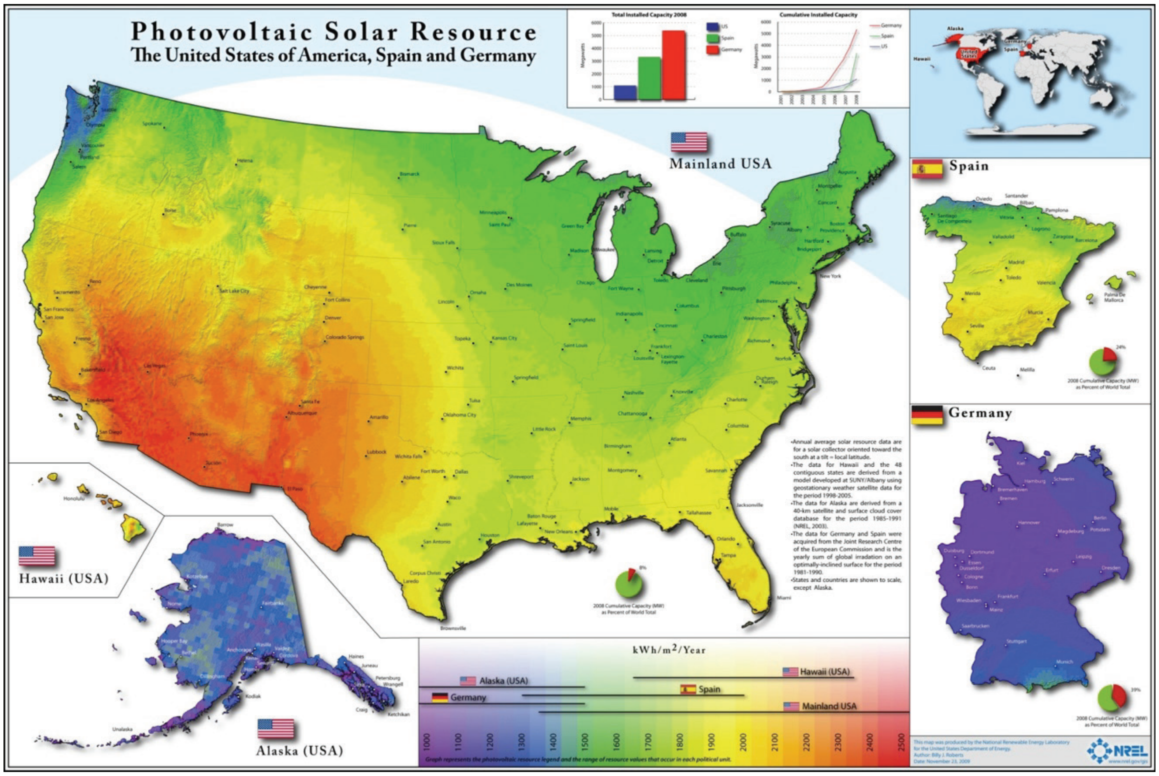

Figure 17: Photovoltaic Solar Resource of the USA, Spain, and Germany (NREL)

PV Manufacturers

The PV industry is very dynamic, with manufacturers continually improving their products to reduce cost, improve efficiency and simplify installation methods. While recent declines in system pricing has been driven largely by reduction in module prices, system price reductions are also coming from lower-cost equipment (due in part to increased volume) and improved installation techniques.

SolarPro magazine (available at http://solarprofessional.com) profiles companies and the products they offer the US PV market. These profiles have covered the major components of PV systems: modules (900 models from 40 manufacturers), inverter manufacturers (111 models from 16 manufacturers), ground mount racking systems (34 manufacturers), combiners (148 products from 11 manufacturers), and monitoring systems. The vast array of choices increases the potential risk on projects, as installers and other construction personnel may not be familiar with the final equipment selected.

PV Costs

The cost of PV-produced energy has dropped substantially over time, as shown in Figure 18, with decreases especially significant over the past five years. Figure 19 shows the costs for commercial-scale systems have dropped from approximately $0.28/kWh to $0.17/kWh from 2010-2013. These unsubsidized costs assume a typical large system size greater than 100 kW, which is similar to what FDOT would expect to pay as an owner-operator of such a system. The 30% federal tax credit is used in the figure and is not available to non-taxable entities. The installed costs for PV systems installed in 2014 have fallen under $3/W; systems of 500kW and larger may carry costs under $2/W (SEIA/GTM). System prices are expected to continue to fall.

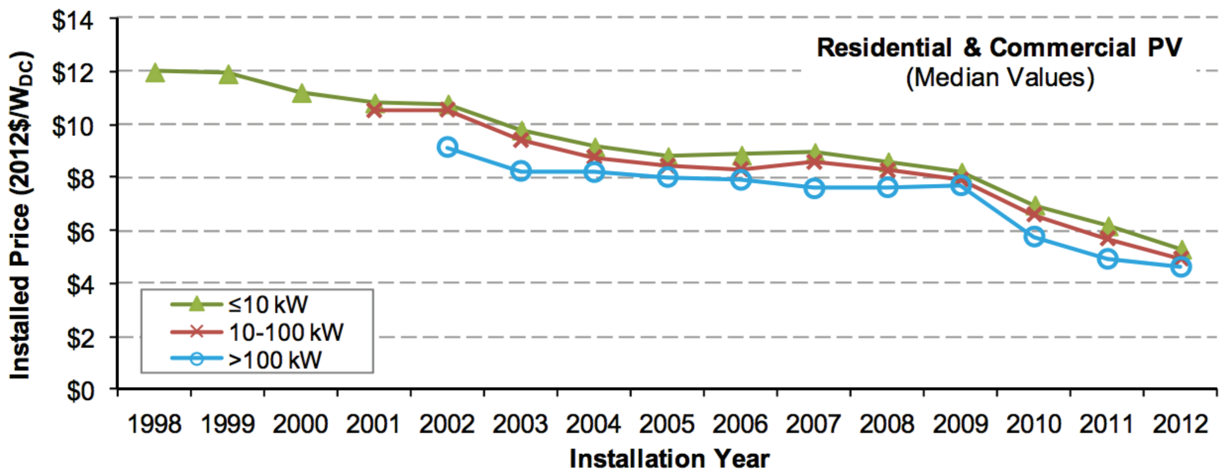

Figure 18: Median Costs ($/Wdc) For Sampled Systems From 1998-2012 (Barbose, Fig. 7)

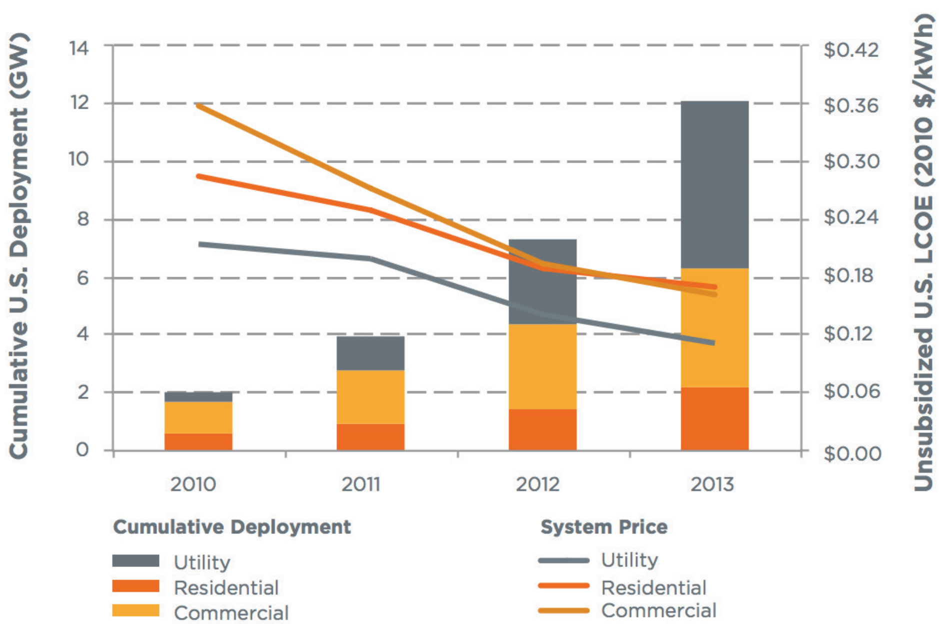

Figure 19: The Nationwide Decrease in PV-Generated Electricity Cost, 2010-2013 (SEIA/GTM)

Even if no consideration is given to the lower pollution emitted by PV systems, PV systems can make economic sense under many circumstances when competing directly against fossil fuel-fired generation. The specific economic analysis will vary based upon the installation location. There is a variety of incentives available to subsets of the country, with different incentives offered by neighboring states or even neighboring utilities or cities. The DSIRE (Database of State Incentives for Renewables and Efficiency) website (http://www.dsireusa.org) presently maintains a comprehensive database of financial incentives for solar projects. Other useful resources include PVWatts (http://pvwatts.nrel.gov) or System Advisor Model (https://sam.nrel.gov) for energy production estimates, the Solar Energy Industries Association website (http://www.seia.org) for industry perspectives, and in-house resources to determine the financial boundary conditions of the project.

An additional value provided by the PV system is that it acts as a hedge against fluctuations in utility bills—an additional benefit will be received if utility bills rise with time. This cost certainty has a value to any organization, public or private with budget constraints.

Clean Energy Values

The value of onsite generation includes not only the savings of reduced electric bills, but also that of clean energy that reduces or produces no air pollution. Utility electricity generated in Florida are fueled mostly by natural gas (65%), coal (20%), and nuclear (8%). According to the Environmental Protection Agency Power Profiler, electric utilities provide electrical energy to Florida and the FDOT site with an emissions profile of 0.98 lbs/MWh nitrogen oxide, 1.89 lbs/MWh sulfur dioxide, and 1,177 lbs/MWh carbon dioxide (EPA). One megawatt-hour (MWh) is equivalent to 1,000 kWh. Other pollutants would also be offset through a PV system deployment, including: airborne mercury, carbon monoxide, methane and other hydrocarbons, nitrogen oxides, and sulfur oxides (EPA, UCS). Specific information on pollution offsets will be site-specific (dictated by the utility generation mix) and may be determined for future projects through an information request to the serving electric utility.

Pollution control is generally discussed as it relates to carbon dioxide emissions which are considered by most scientists to be accelerating sea level rise. Federal or state programs do not currently assess a value upon carbon dioxide emissions, expected to be applied either as a cap-and-trade program of allowances or as a carbon tax. A recent effort by the U.S. Congressman Henry Waxman and others considered three options as a starting point for discussion of a potential carbon tax: $15, $25, and $35 per metric ton of carbon emissions with annual escalation of 2-8%. In 2013, a US interagency working group updated a 2010 estimate of $21 for 2013, a value of $36 is more appropriate (Interagency Working Group on Social Cost of Carbon, 2013, p.18). These working group estimates were based on the 2007 value of the dollar; $36 in 2007$ equates to roughly $41 in 2014$. Johnson and Hope's 2012 analysis concluded that the social cost of carbon falls in a range from $55 to $266 depending on discount rates (Johnson 2012). This report calculates the value of offset carbon emissions under two scenarios—$15 with a 3% escalation and $41 with a 3% escalation. These calculations are presented in Table 7.

CO2 offsets assume that the emissions rate from the utility generation mix remains at a steady 1,177 lbs/MWh over the period of the analysis.

Table 7: Value of Expected Utility Savings and CO2 Offsets Under Two Scenarios

Year	Annual utility savings ($0.082/kWh)	Offset CO2 (tons)	CO2 offset value ($15+/ton)	CO2 offset value ($41+/ton)
2013	$13,700	89	$1,300	$3,700
2014	$13,600	89	$1,400	$3,700
2015	$13,500	88	$1,400	$3,800
2016	$13,400	88	$1,400	$3,900
2017	$13,300	87	$1,500	$4,000
2018	$13,200	86	$1,500	$4,000
2019	$13,100	86	$1,500	$4,100
2020	$13,000	85	$1,600	$4,200
2021	$12,900	84	$1,600	$4,200
2022	$12,800	84	$1,600	$4,300
2023	$12,700	83	$1,700	$4,300
2024	$12,600	82	$1,700	$4,400
2025	$12,500	82	$1,700	$4,500
2026	$12,400	81	$1,800	$4,500
2027	$12,300	80	$1,800	$4,500
2028	$12,300	80	$1,900	$4,500
2029	$12,200	79	$1,900	$4,600
2030	$12,100	79	$1,900	$4,600
2031	$11,900	78	$2,000	$4,700
2032	$11,800	77	$2,000	$4,700
2033	$11,800	77	$2,100	$4,800
2034	$11,700	76	$2,100	$4,800
2035	$11,600	75	$2,200	$4,900
2036	$11,500	75	$2,200	$4,900
2037	$11,400	74	$2,300	$5,000
Totals:	**$313,300**	**2043**	**$44,100**	**$109,600**

Lightning Protection

Lightning protection systems are a somewhat controversial topic, especially when installed to protect PV systems. The relevant document published by the National Fire Protection Association, *NFPA 780: Standard for the Installation of Lightning Protection Systems* is updated every few years with the first edition dating from 1994 and the recently revised 2014 edition approved in June 2013. This document is considered an American National Standard rather than a building code. In most areas of the country, its requirements are only applied to public buildings though it contains information that could be applied to residential construction. The first NFPA 780 edition that includes specific guidance for PV systems was the 2014 edition in its new Chapter 12. It is noted that this situation was not in place until after the lightning damage had already occurred.

Perhaps as this new NFPA 780 language has only recently been published, and with minimal input from the PV industry, there are several major issues preventing enforcement of the language as it applies to PV systems. First, the new requirements have inconsistencies in the language. NFPA 780 section 12.2.2 suggests that PV systems can be protected from lightning by “direct mounting of strike termination devices to the solar panel,” or “direct mounting of strike termination devices to the solar panel framing,” or by placing the PV system in a “zone of protection.” Of these three options, only the third is practical for installations, as the first two options typically void the solar module manufacturer warranty (a fact acknowledged in Section 12.3.6, which then states that “strike termination devices shall not be secured directly to the panels or panel frames of photovoltaic panels and arrays”.) Without carefully reading the standard, personnel working on projects may apply the wrong sections and void the warranty on the PV modules—this, of course, is a major issue for O&M providers or system owners.

A second issue is that the standard overprescribes the installation of surge arrestors on these systems. For traditional PV systems, many PV modules are wired via series and parallel connections onto a large inverter. Series connections are made by simply connecting a module with perhaps 14 of its neighbors in an end-to-end configuration. Parallel connections are made within “combiner boxes” which can combine up to several dozen circuits. These connections are all made to reduce the amount of wire needed for these systems without sacrificing protection or reliability. Had this new NFPA 780 language been enforced on this project retroactively, the installer would have been required to install surge arrestors at the output of every module, at each combiner box, at the inverter DC input, and again at the inverter output. Though the specific costs would vary depending on the specifics of the system, the cost of these arrestors could easily exceed the value of the equipment they are intended to protect.

In place of a system that strictly follows the language of NFPA 780, something consistent with the intent of NFPA is more reasonable. Surge arrestors could be installed at locations where circuits are combined on either side of an inverter, within either a direct-current combiner box or a typical alternating-current electrical panelboard.

APPENDIX B: Installation Organizations and Reference Material

General Information

The North American Board of Certified Energy Practitioners (NABCEP) was established in 2000 to provide certification credentials for those installing renewable energy systems and equipment (SolarPro, 2013). The organization provides detailed resource guides for the installation of both PV systems and solar water heating systems. The guides are not intended to be the definitive resource for installation—they are general guides with strong background information to educate the reader of the details associated with these renewable energy systems. The 160 page *NABCEP: PV Installation Professional Resource Guide* provides the reader with sufficient information to understand many aspects of PV systems and their installation (Brooks, 2013). The guide covers:

- Introduction to the PV systems and components
- System design verification
- Project management
- Electrical component installation
- Mechanical component installation
- System installation completion
- Maintenance and troubleshooting

The end of the guide provides a detailed reference list correlated to the various chapters covered in the guide. Overall, this is an excellent guide for anyone who needs to understand the details of a PV system and installation requirements. It is meant as a guide for practitioners of the PV trade but is equally valuable to persons who would like to learn more about PV systems.

In addition to the freely-available NABCEP resource guide, several textbooks are available for the interested student—among them are *Photovoltaic Systems* by James P. Dunlop, PE and *Solar Electric Handbook, Photovoltaic Fundamentals and Applications* by Solar Energy International.

There is a wide variety of training opportunities available for the hands-on learner, with several hundred providers nationwide offering a course linked to the NABCEP Entry Level Exam. This exam, not to be confused with the NABCEP PV Installation Professional exam, is designed as "a way for candidates to demonstrate that they have achieved a basic knowledge of the fundamental principles of the application, design, installation and operation of PV and Solar Heating systems" (NABCEP).

Another resource available for PV system project managers is the IEC 62446 *Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests, and inspection*. This international standard provides guidance on the documentation package and information that should be handed over to a customer after a PV system is installed. It contains attestation statements from the commissioning agent confirming design review, installation quality, and initial system performance metrics. This standard is a formal mechanism that can be used to complete a system installation.

The Sandia National Laboratories photovoltaics research group has several reference reports that are available at their website http://www.sandia.gov/index.html. A search using 'PV Guide' returns over 400 reports from top scientists, engineers, and practitioners involved in the design, installation, modeling, and performance measurement of PV systems. Depending on the project, these reports can provide useful information.

The National Electrical Code (NEC) and other building code standards (e.g., the International Building Code) are invaluable resources to query, as the rules within them define what makes a code-compliant design. A large industry is in place providing comprehensive training opportunities in the NEC alone. These resources are not intended for the layperson; interpreting these comprehensive and complex documents requires years of experience and study.

APPENDIX C: Life Cycle Cost Assessment

Table 8: Life Cycle Cost Assessment Using $351,580 ($3.13/W) PV Purchase Price

PV Size	112.32	kWp	Nominal Discount Rate	2.53%	per year
PV Cost	$479,500	$	Service Life	25	years
Utility Rebate	$127,920	$	LC Investment	$426,724	$
Actual PV Cost	$351,580	$	LC Savings	$338,307	$
Energy Cost	$0.079	$/kWh	SIR	0.793	
Inverter Replacement	$0.40	$/PVwatt	LCOE	0.111	$
PV Degradation	0.70%	per year	Net Present Value	-$99,122	$
Utility Escalation Rate	3.40%	per year	Total Energy Produced	3,827,776	kWh
Maintenance Cost (annual)	$19.58	per kWp	Internal Rate of Return	0.06%	%
General Inflation Rate	2.53%	per year	Payback Period	N/A	years

Year	Date	Capital Cost (fv)($)	Annual Energy (kWh)	Utility Electric Cost ($/kWh)	Annual Energy Savings (fv)	Inverter Replacement (fv)	Inverter Salvage (fv)	Maintenance (fv)	Cash Flow (fv)
2012	31-Dec-12	-479,500			$0	$0	$0	$0	-$479,500
2012	31-Dec-12	127,920		0.0793	$0	$0	$0	$0	$127,920
2013	31-Dec-13		167,485	0.0820	$13,734	$0	$0	-$2,255	$11,479
2014	31-Dec-14		165,149	0.0848	$14,003	$0	$0	-$2,312	$11,691
2015	31-Dec-15		163,992	0.0877	$14,377	$0	$0	-$2,370	$12,007
2016	31-Dec-16		162,845	0.0907	$14,762	$0	$0	-$2,430	$12,332
2017	31-Dec-17		161,705	0.0937	$15,157	$0	$0	-$2,492	$12,665
2018	31-Dec-18		160,573	0.0969	$15,563	$0	$0	-$2,555	$13,008
2019	31-Dec-19		159,449	0.1002	$15,979	$0	$0	-$2,620	$13,360
2020	31-Dec-20		158,333	0.1036	$16,407	$0	$0	-$2,686	$13,721
2021	31-Dec-21		157,224	0.1071	$16,846	$0	$0	-$2,754	$14,092
2022	31-Dec-22		156,124	0.1108	$17,297	$0	$0	-$2,823	$14,473
2023	31-Dec-23		155,031	0.1146	$17,760	$0	$0	-$2,895	$14,865
2024	31-Dec-24		153,946	0.1185	$18,235	$0	$0	-$2,968	$15,267
2025	31-Dec-25		152,868	0.1225	$18,723	$0	$0	-$3,043	$15,680
2026	31-Dec-26		151,798	0.1266	$19,224	$0	$0	-$3,120	$16,104
2027	31-Dec-27		150,735	0.1309	$19,739	-$44,928	$0	-$3,199	-$28,389
2028	31-Dec-28		149,680	0.1354	$20,267	$0	$0	-$3,280	$16,987
2029	31-Dec-29		148,632	0.1400	$20,809	$0	$0	-$3,363	$17,446
2030	31-Dec-30		147,592	0.1448	$21,366	$0	$0	-$3,448	$17,918
2031	31-Dec-31		146,559	0.1497	$21,938	$0	$0	-$3,535	$18,403
2032	31-Dec-32		145,533	0.1548	$22,525	$0	$0	-$3,625	$18,900
2033	31-Dec-33		144,514	0.1600	$23,128	$0	$0	-$3,717	$19,411
2034	31-Dec-34		143,503	0.1655	$23,747	$0	$0	-$3,811	$19,936
2035	31-Dec-35		142,498	0.1711	$24,382	$0	$0	-$3,907	$20,475
2036	31-Dec-36		141,501	0.1769	$25,035	$0	$0	-$4,006	$21,029
2037	31-Dec-37		140,510	0.1829	$25,705	$0	$20,000	-$4,107	$21,598

Table 9: Life Cycle Cost Assessment Using $2/W PV Purchase Price

PV Size	112.32	kWp	Nominal Discount Rate	2.53%	per year
PV Cost	$224,640	$	Service Life	25	years
Utility Rebate	$0	$	LC Investment	$299,784	$
Actual PV Cost	$224,640	$	LC Savings	$338,307	$
Energy Cost	$0.079	$/kWh	SIR	1.129	
Inverter Replacement	$0.40	$/PVwatt	LCOE	$0.078	$
PV Degradation	0.70%	per year	Net Present Value	$38,523	$
Utility Escalation Rate	3.40%	per year	Total Energy Produced	3,827,776	kWh
Maintenance Cost (annual)	$19.58	per kWp	Internal Rate of Return	3.79%	%
General Inflation Rate	2.53%	per year	Payback Period	23	years

Year	Date	Capital Cost (fv)($)	Annual Energy (kWh)	Utility Electric Cost ($/kWh)	Annual Energy Savings (fv)	Inverter Replacement (fv)	Inverter Salvage (fv)	Maintenance (fv)	Cash Flow (fv)
2012	31-Dec-12	-224,640			$0	$0	$0	$0	-$224,640
2012	31-Dec-12	0		0.0793	$0	$0	$0	$0	$0
2013	31-Dec-13		167,485	0.0820	$13,734	$0	$0	-$2,255	$11,479
2014	31-Dec-14		165,149	0.0848	$14,003	$0	$0	-$2,312	$11,691
2015	31-Dec-15		163,992	0.0877	$14,377	$0	$0	-$2,370	$12,007
2016	31-Dec-16		162,845	0.0907	$14,762	$0	$0	-$2,430	$12,332
2017	31-Dec-17		161,705	0.0937	$15,157	$0	$0	-$2,492	$12,665
2018	31-Dec-18		160,573	0.0969	$15,563	$0	$0	-$2,555	$13,008
2019	31-Dec-19		159,449	0.1002	$15,979	$0	$0	-$2,620	$13,360
2020	31-Dec-20		158,333	0.1036	$16,407	$0	$0	-$2,686	$13,721
2021	31-Dec-21		157,224	0.1071	$16,846	$0	$0	-$2,754	$14,092
2022	31-Dec-22		156,124	0.1108	$17,297	$0	$0	-$2,823	$14,473
2023	31-Dec-23		155,031	0.1146	$17,760	$0	$0	-$2,895	$14,865
2024	31-Dec-24		153,946	0.1185	$18,235	$0	$0	-$2,968	$15,267
2025	31-Dec-25		152,868	0.1225	$18,723	$0	$0	-$3,043	$15,680
2026	31-Dec-26		151,798	0.1266	$19,224	$0	$0	-$3,120	$16,104
2027	31-Dec-27		150,735	0.1309	$19,739	-$44,928	$0	-$3,199	-$28,389
2028	31-Dec-28		149,680	0.1354	$20,267	$0	$0	-$3,280	$16,987
2029	31-Dec-29		148,632	0.1400	$20,809	$0	$0	-$3,363	$17,446
2030	31-Dec-30		147,592	0.1448	$21,366	$0	$0	-$3,448	$17,918
2031	31-Dec-31		146,559	0.1497	$21,938	$0	$0	-$3,535	$18,403
2032	31-Dec-32		145,533	0.1548	$22,525	$0	$0	-$3,625	$18,900
2033	31-Dec-33		144,514	0.1600	$23,128	$0	$0	-$3,717	$19,411
2034	31-Dec-34		143,503	0.1655	$23,747	$0	$0	-$3,811	$19,936
2035	31-Dec-35		142,498	0.1711	$24,382	$0	$0	-$3,907	$20,475
2036	31-Dec-36		141,501	0.1769	$25,035	$0	$0	-$4,006	$21,029
2037	31-Dec-37		140,510	0.1829	$25,705	$0	$20,000	-$4,107	$41,598