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Preliminary Design of a Solar Photovoltaic Array for Net-Zero Energy Buildings at NASA Langley

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November 2012

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Abstract

An investigation was conducted to evaluate photovoltaic (solar electric systems) systems for a single building at NASA Langley as a representative case for alternative sustainable power generation. Building 1250 in the Science Directorate is comprised of office and laboratory space, and currently uses approximately 250,000 kW/month of electrical power with a projected use of 200,000 kW/month with additional conservation measures. The installation would be applied towards a goal for having Building 1250 classified as a net-zero energy building as it would produce as much energy as it uses over the course of a year. Based on the facility's electrical demand, a photovoltaic system and associated hardware were characterized to determine the optimal system, and understand the possible impacts from its deployment. The findings of this investigation reveal that the 1.9 MW photovoltaic electrical system provides favorable and robust results. The solar electric system should supply the needed sustainable power solution espically if operation and maintenance of the system will be considered a significant component of the system deployment.

Introduction and Background

Climate change is impacting the NASA Centers. These impacts include rising tidal conditions, changing weather patterns, intensity of weather patterns, increased ambient temperatures and rising energy demand and energy costs. The cumulative effect of these conditions will affect both the near and long term operational posture of NASA Langley Research Center (LaRC) and potentially directly, or indirectly, affect the capability to meet mission requirements. Also it is now clear that burning of fossil fuels increases carbon dioxide in the atmosphere and thus causes increased atmospheric temperatures. The Federal Government has placed emphasis on renewable power generation that will mitigate climate change by reducing carbon emissions.

In particular, LaRC has completed preliminary investigations to ascertain the impacts of the regional climate change on the Center and has identified the need for implementing sustainable solutions to address climate change impacts including electrical power demands.(1) From this, an alternative sustainable power source(s) was identified as one of several significant components to meet the critical need for broadening the base of potential energy supply to LaRC. For land based applications, alternative power sources typically include: geothermal, hydroelectric, biofuels, wind, concentrating solar power, and photovoltaics (solar electric system) which are renewable and sustainable system solutions.

This investigation was initiated to determine the preliminary design requirements for a Net-Zero Energy Building which is defined as a building that produces as much energy as it uses over the course of a year. Net-zero energy buildings are very energy efficient, and the remaining low energy needs are typically met with on-site renewable energy. Much focus is placed on energy efficiency as the most cost-effective way to reduce energy use in commercial buildings. All net-zero energy buildings must reduce energy use through energy efficiency and demand-side renewable energy technologies such as use of skylights, insulation, passive solar heating, high-efficiency heating ventilation and air conditioning equipment (HVAC), natural ventilation, evaporative cooling, ground-source heat pumps, and ocean water cooling. There is a point at which the cost of adding efficiency measures is higher than that of using supply-side renewable energy technologies such as photovoltaics (PV). Supply-side renewable energy technologies must be used for a building to be classified a net-zero energy building.(2)

To assess the potential to support renewable power sources, an investigation was conducted to evaluate solar photovoltaic electric systems for a single building as a representative case for application. The selection of a solar PV system for this investigation was driven based on the familiarity gained by the September 2010 installation at LaRC of a 39.5 kW system for the Badge and Pass Office. In addition, opportunities for use of these PV systems must be investigated routinely as their market cost may make them more attractive. It is noted that a "decline has been indicated in the cost of utility scale solar photovoltaic systems. Current cost benchmarks for utility-sector solar electric systems are generally at the low-end of the range exhibited by the projects sampled for year 2010, with various entities estimating an installed cost of \$3.8/W to \$4.4/W, depending on system size and configuration for utility sector systems installed at the end of 2010 or beginning of 2011."(2)

This investigation is motivated by the 20 year LaRC Master Plan. At the time of the initial plan development it was stated in the Master Plan that: "LaRC's current electricity rates (recently adjusted downward) do not drive a compelling business case for on-site renewable energy sources. This was confirmed through a NASA wide renewable energy assessment. The Master Plan indicates that LaRC is active in renewable energy, and the strategy to address renewable energy goals was identified as: (1) Continue to purchase Renewable Energy Credits (REC's) required to meet goals via the Agency evaluation metric: Increase renewable source energy to 7.5% by 2015 (EO 13514); (2) Leverage other investments and incorporate as much as possible with available funds; and (3) Research other approaches for reduction in energy use." (3)

The use of PV electric systems directly supports the Federal Leadership in Environmental, Energy and Economic Performance Executive Order 13514 (EO) which sets sustainability goals for Federal agencies and focuses on making improvements in their environmental, energy and economic performance. The EO requires Federal agencies to submit a 2020 greenhouse gas pollution reduction target within 90 days, increase energy efficiency, reduce fleet petroleum consumption, conserve water, reduce waste, support sustainable communities, and leverage Federal purchasing power to promote environmentally-responsible products and technologies.

As an example of how a PV system could power a LaRC building, the Science Directorate (Building 1250) was chosen as a typical installation. The Science Directorate is comprised of office and laboratory space, with supporting cooling/heating HVAC infrastructure and currently uses approximately 250,000 kWH/month electrical power, but with aggressive conservation could experience an electrical power reduction to approximately 200,000 kWH/month. The lower projected electrical demand will be obtained by a detailed energy audit, increased energy conservation, online power use monitoring, and use of intelligent energy control systems. This level of electric energy use is equivalent to the power consumed by about 314 private homes.

The immediate environs of Building 1250 include asphalt paved parking areas with the edges of the developed areas bordered by a dense forest of deciduous trees and intermittent landscaped grassed areas. It is well known that direct rainwater runoff from any development supplies of undesired nutrients and microconstituents to the Chesapeake Bay. These pollutants in rainwater runoff must be mitigated. [4]

Solar photovoltaic systems have been used successfully in extremely harsh environments, [5] [6] and in terrestrial applications where their use is quite common for commercial application as indicated on Table 1.

Table 1
INSTALLED SOLAR POWER SYSTEMS

PV SYSTEM OWNER LOCATION	SYSTEM DESCRIPTION	Characteristics	Date
3.5 MW by Sunpower Corp. Inland Empire Utilities Agency (IEUA), a municipal water agency San Bernardino County, CA	18,210 Panels of the commercial roof & ground system type. PV panels are mounted on the patented single-axis Trackers at 20° of tilt, generating up to 30 % more energy than conventional fixed-tilt solar power systems.	◆ **Offsets** over 10% of the District's total electricity demand ◆ Provides significant **hedge against future rate increases** from Southern Califomia Edison ◆ **Reduces carbon** emissions by over 230 million pounds over the next 30 years, which is equivalent to powering 18,350 homes ◆ **Savings of approximately $500,000 in annual electricity costs** removing more than 19,000 cars from our roads ◆ Contributes to IEUA's increasing commitment to **sustainability** and environmental practices	Dec. 2008
3.5 MW by Solar Power, Inc. Aerojet (Division of GenCorp Inc.) a space & defense contractor Sacramento, California	18,000 Modules consisting of SPI 200-watt unit each mounted atop 12 tracking arrays over 20 acres.	◆ During its first year of use, will offset approximately 4,200 tons of CO_2, 16.7 tons of **SO_2** and approx. 6.5 tons of NO_2. ◆ Is equivalent to planting 976,520 trees or offsets approx. 8,270,000 car miles driven.	Nov. 2009
3.5 MW by CME & DEGERenergie systems Vilanueva de Córdova Province of Andalusia, Spain	3,044 Modules consisting of single-axis TOPtracker 8.5 systems installed with a tilt angle of 30°.	◆ **Maximizes** the yield of solar power plants with an "intelligent" control ◆ MLD tracking is up to **46 % higher yield** than that of rigid systems and this difference is even more pronounced for peaks	Feb. 2011
3.5 MW by Windaerts Energie GmbH Bavaria, Germany	14,208 PV modules by Canadian Solar Inc.	◆ Supplies 3.7 million KWh annually for 1,200 homes	Aug. 2011
2.7 MW by SunDurance Energy William Patterson University Wayne, New Jersey	11,856 panels that cover both rooftops and elevated parking lot canopies.	◆ **Saves** over $3 million in energy costs without any additional capital expenditures. Installed over buildings and parking lots. ◆ SunDurance took a value engineering approach and determined that parking structures over the many existing lots could provide ample solar electricity at a discount to the university's grid rates ◆ Funded and operated by Nautilus Solar. Will cut $4.3 million over 15 Year Purchase Power Agreement. ◆ Reduces air pollution and improve air quality, while creating green jobs in the region.	Aug. 2011

System and Hardware Description

A PV system is made up of many photovoltaic solar panels. An individual panel is usually small, typically producing about 230 watts of power for each panel as direct current (DC). To boost the power output of PV panels, they are connected together to form larger units called modules. Modules, in turn, can be connected to form even larger units called arrays, which are also interconnected. The arrays are then co-located to form a large power system. The modules are mounted on individual or common foundations and oriented to the sun to capture the highest amount of light exposure possible. Spacing of arrays in a commercial system becomes a critical design element as land area must be optimized for panel density, maximum sun exposure, and access for maintenance. These arrays are monitored by computer systems to indicate failure of any one module as well as overall system performance.

Arrays are connected to DC to AC (direct current to alternating current) power converters where the required number and size of converters are strategically designed to accommodate the array system voltage and also provide needed redundancy. These DC to AC converters are outdoor installations typically with a 95 percent or greater efficiency, and are connected to metering points at the voltage AC substation. Converters consist of utility-grade multi-megawatt platforms on a reinforced concrete foundation that consists of a unit with power inverters, integrated step-up transformers, disconnect switches, and power use monitoring electronics. Figure 1 shows a schematic of a PV electric system providing power to both the building and the power grid, where it grid is used for power storage.

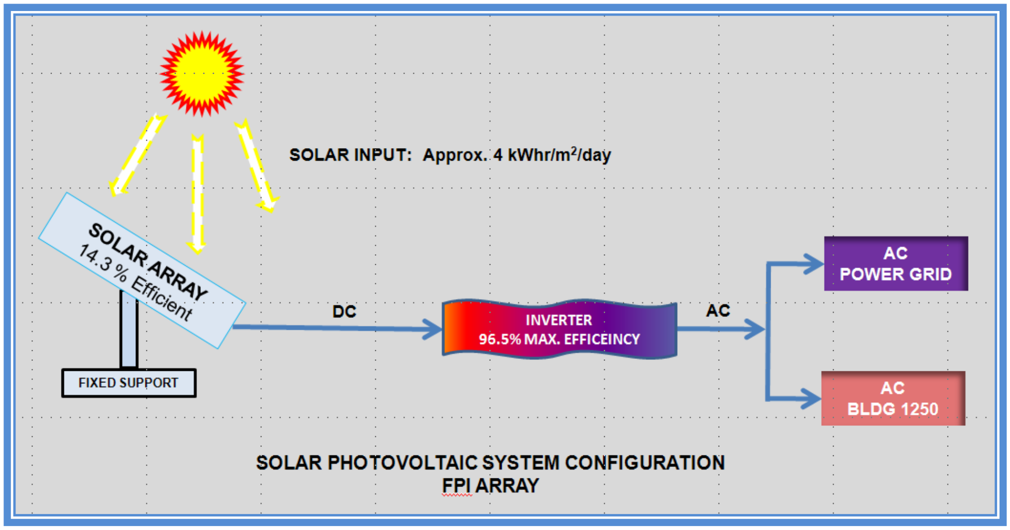

Figure 1. Solar photovoltaic electric system schematic configuration

Mounting the PV arrays for Building 1250 will require substantial land area for the PV array. Mounting PV arrays therefore was designed to optimize the existing land available including clear spaces, parking areas, and building roof tops. The use of PV arrays over parking areas will however provide a unique opportunity for additional environmental and cost benefits such as the capture of rainwater, reduction of heat absorption by the pavement which may contribute to local micro-climate warming, and affording shade and some overhead weather protection to equipment, pedestrians, or automobiles. Electric car charging can be easily accommodated in such structures.

Operation and maintenance (O&M) of the PV system is a necessary and routine requirement. The system must be continuously monitored, and if individual PV panels are found defective they must be replaced. The O&M of the system must be operated and managed by qualified personnel and include a Computerized Maintenance Management System with scheduled services, cleaning, and snow/debris removal. Risk of damage to solar panels could exist from adverse weather including hail or other high winds resulting in airborne debris.

Electrical Demand

Building 1250 electrical demands generally consist of lighting, HVAC, and electrical mechanical systems. Currently, the building has been documented to use approximately 250,000 kWH/month as shown in Figure 2. Energy conservation is expected to reduce this demand to 200,000 kWH/month. The demand would also include charging stations for electric cars.

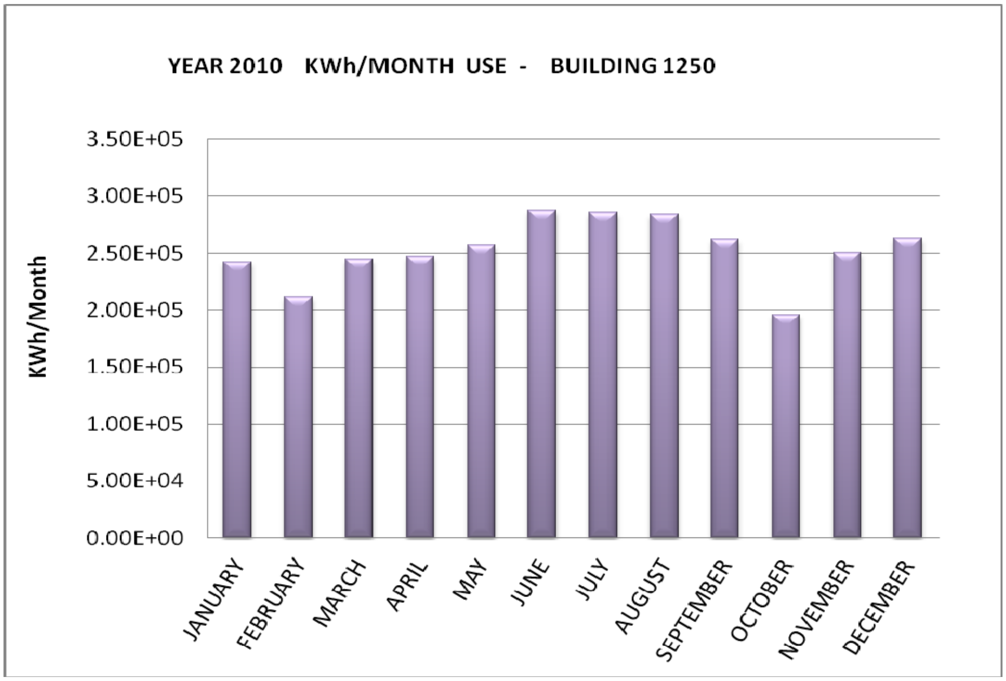

Figure 2. Building 1250 electric energy demand (Year 2010)

System Configuration

The solar electric system configuration consists of PV panels, support structure for the modules, converters, wiring, on-line monitoring system, and the space to install the system. The system is tied to both the Building 1250 electrical supply and to the LaRC substation. During off peak hours and low demand days such as holidays and weekends when the building is unlikely to be occupied, the PV system will supply power to the LaRC electrical grid; thus there is no need for electricity storage usually requiring batteries.

Modules may be fixed or of the type that tracks the sun through the arc of day. Fixed modules are permanently mounted and are pointed in a single direction to obtain the largest exposure of light during the entire day light hours. There is a slight variation of each module direction based on its physical location in the field to optimize the panel exposure to light. Shade from buildings and the tree line must be accounted for in the placement of the modules and the installation location. The specifications for a PV system location and orientation were based on Norfolk, Virginia, as shown in Table 2. In order to generate the required alternating current in kilowatt-hours demand including the de-rating factor of 0.77, a PV system would be sized as a 1.888 Megawatt DC system.

Table 2
Station Identification and System Specifications

City:	Norfolk
State:	Virginia
Latitude:	36.90° N
Longitude:	76.20° W
Elevation (meters):	9
DC Rating:	1,888 kW
DC to AC Derate Factor:	0.77
AC Rating:	1,453 kW
Array Type:	Fixed Tilt
Array Tilt:	36.9°
Array Azimuth:	180.0°

This investigation considered fixed array only based on the perception that it was the least costly. Of these fixed installations, three types of module installation configurations were considered. The first is a basic fixed array that is installed on concrete foundations in open space. The second configuration is a mount on the existing building, and the third is a system mounted on an elevated structure that would support the modules over a parking area for automobiles.

One PV system advantage is the unique opportunity for meeting the environmental goal of collecting valuable rainwater and storing it for beneficial use. These benefits would also include: the reduction or elimination of pollutant runoff from automobile parking areas, runoff volume control, reduction of nutrients in the runoff, supplemental irrigation, supplemental cooling tower water, and aesthetic impoundment features for attracting waterfowl, and supporting other beneficial flora and fauna. The collection of this valuable rain and runoff water as resource would be by construction of an impoundment comprised of an earthen detention pond with a spillway, and an outfall weir to control the volume of water. Panels would be equipped with a gutter edge material to collect rainwater. Figure 3 provides a schematic and photo of an array installation for a parking area where panels collect rain water.

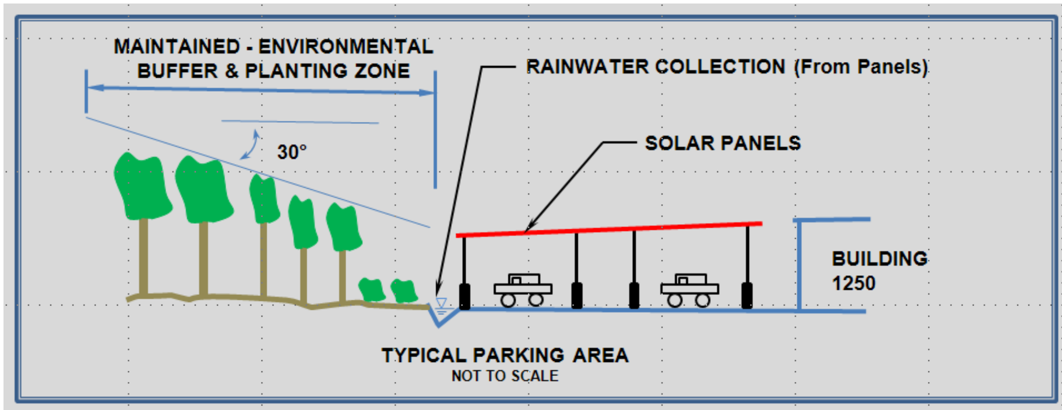

Figure 3. Typical Solar panel installation for parking areas.

The installation of arrays could be mounted in areas where the land is subject to 100 year flooding or is otherwise unsuitable for other heavy building construction. The relatively lightweight arrays can be installed on fixed pier type screw type anchors which readily allow the installation in soft and unstable soils and thereby maximize land use.

Panel Hardware

Solar panels are manufactured worldwide and improvements to their output performance and efficiency vary. For convenience, a single manufacturer, UNICOR FPI (a U.S. company) was selected from multiple panel manufacturers to characterize panel performance. Based on UNICOR's manufacturing data (2011), the following performance data is given in Table 3.

Table 3
PV PANEL PERFORMANCE - UNICOR PV (2011)

Panel Efficiency	14.3%
Number of Panels for a 1.9 MW Array	Approximately 7,826
Watts per Panel	230 W
Guaranteed Life Expectancy	25 Years
Actual Panel Life Expectancy	40 Years
Approx. Panel Cost, Each	$368
Operating Module Temperature	-40 to 85ºC
Maximum Series Fuse Rating	15 A
Nominal Voltage	24 V
Limiting Reverse Current	15 A
Power output Tolerance	-0 /+4.999 watts
Current Temperature Coefficient	0.04 to 0.08 %/ºC
Voltage Temperature Coefficient	-0.45 to -0.36 %/ºC
Power Temperature Coefficient	-0.68 to -0.52 %/ºC

Electrical Power Supply

A monthly load projection of 200,000 kWh would require a system output of 2,400,000 kWh annually. Figure 4 shows the monthly AC energy production per month for the example Building 1250, and Figure 5 shows the corresponding solar radiation received per month for the Norfolk and Hampton, Virginia region. In order to generate the requirement for 200,000 kWh per month including the de-rating factor, a PV electric system would be sized at approximately 1.9 MW. It is important to note that the system utilized to produce these results assumes a DC to AC de-rating factor of 0.77. This de-rating factor represents the loss in energy and inefficiencies when converted from DC to AC. Furthermore, the array could produce more kWh depending on the efficiency and performance capabilities of the module provider. Thus the total kWh indicated to be required at 1.9 MW is a conservative estimate.

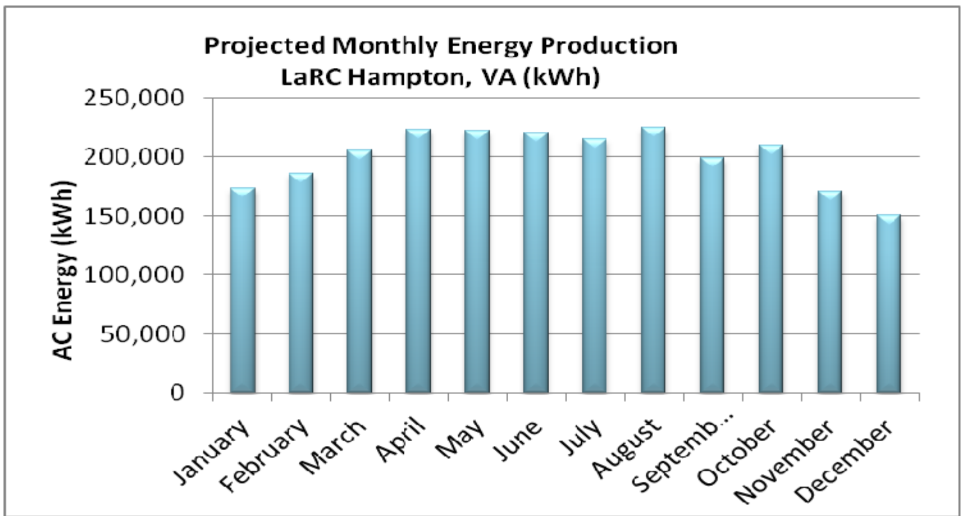

Figure 4. Projected electric energy supply per month for Building 1250
(Courtesy Rae Sullivan, UNICOR FPI)

SUMMARY TOTAL ENERGY PRODUCTION IN ONE YEAR		
Month	**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**
January	3.84	173560
February	4.53	185493
March	4.69	205580
April	5.47	222830
May	5.40	222490
June	5.69	220219
July	5.44	215125
August	5.61	224918
September	5.02	199136
October	4.95	210019
November	4.04	170351
December	3.37	150474
Total Year	**4.84**	**2,400,194**

Figure 5. Summary of incident solar radiation and AC power production.
(Courtesy Rae Sullivan, UNICOR FPI)

Land Use Requirements

Land use within the environs of Building 1250 is a critical system constraint. In consideration of this constraint, the arrays would be located contiguous to Building 1250 in open spaces not designated for development and above existing parking areas. Based on preliminary sizing calculations, a 1.9 MW ground mount system would require about 8 acres of total space, or 348,480 square feet. This is based on the average watts per square foot expected to be generated with an array tilt of 37 degrees. A conceptual layout of this array is shown in Figure 6 where red boxes indicate the PV array area. As seen in the figure part of the total PV array is a large array field and part is designed for use on a car port structure. The final determination of how much space would be required would also be accomplished during the final design, as the parking lot layout heavily impacts the amount of PV ground area needed. Preliminary estimate for the total area required for parking areas would increase total the area by about 1 acre, or 43,560 square feet.

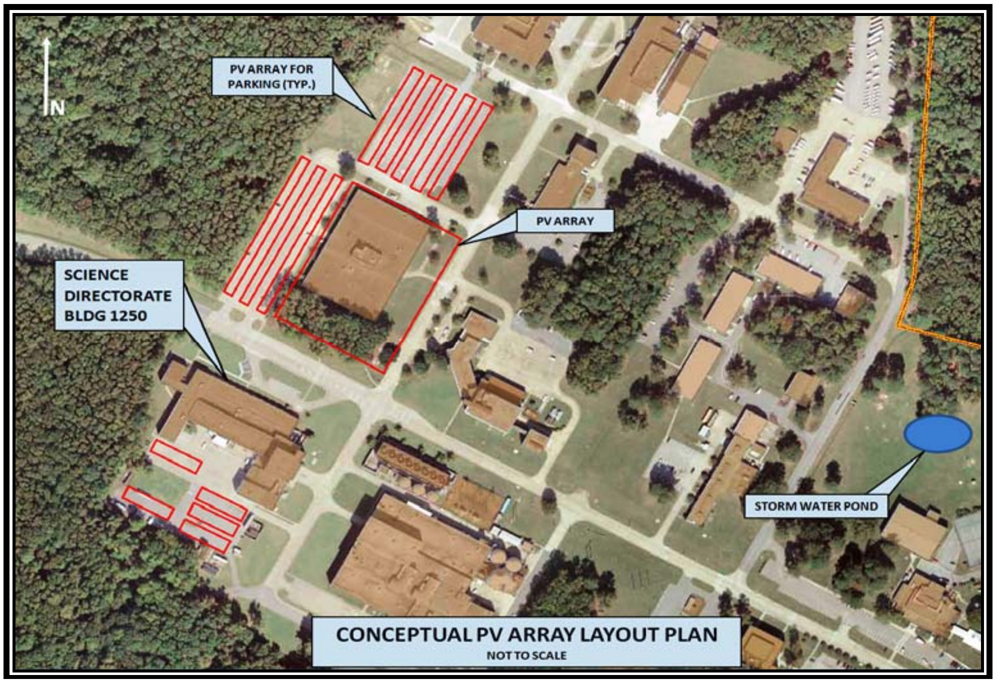

Figure 6. Conceptual layout showing area for a 1.9MW PV array.

The estimated ground area needed for installation of the solar electric system is therefore about nine acres. This space need not be contiguous, however long electric lines tying sub-arrays together do increase project cost. The optimization of the array spacing was not performed in this investigation. Space utilization for the arrays, however, was assumed to take existing large open spaces and encompassing areas near sensitive waterways and adjacent to wetlands. These sensitive areas most likely will never be developed as they are presently used as buffers.

The environmental impact of the array installation on trees was considered. Cutting of large stands of trees or tracts of foliage was not recommended. Where parking areas were found distinctly attractive for application of the arrays, adjacent or perimeter trees could be selectively cut trimmed or topped as identified by a professional arborist's strategic objective for improved tree management, and thus help to improve the direct exposure to panels. See Figure 3 for a schematic of the concept and Figure 7 photo for the parking lot PV installation.

Figure 7. Typical Solar panel installation for parking areas.
(Photo Courtesy of Andrew T. Nekus P.E., SunDurance Energy, anekus@SunDuranceEnergy.com, www.SunDuranceEnergy.com, A Conti Group Company)

Estimated Cost

PV power generation cannot compete directly with current utility power generation cost. While cost is continuing to lower for PV arrays, it will be a considerable time before cost is comparable to central station utility power cost. An approximate cost is projected here with the assistance of UNICOR FPI for the assumptions above and is given in Table 4.

Table 4
SOLAR ELECTRIC SYSTEM COST - BUILDING 1250

PV Panel and Installation Costs	$8 to $9 Million
AC/DC Inverters	$3 to $4 Million
O&M (5 Years)	$1 Million
TOTAL	$12 to $14 Million

The use of PV power generation does allow for other cost reduction scenarios to be accomplished which include:

1. Rent car parking spaces with electric car charging hook up
2. Water runoff and reuse
3. Black out and brown out protection
4. Power agreement with Dominion Virginia Power for sale of excess power generation
5. Dominion Virginia Power cost sharing to meet renewable energy portfolio energy requirements
6. No need for Center to buy renewable energy certificates

A report by Ernest Tucker, U.S. DOE, Office of Energy Efficiency and Renewable Energy on September 23, 2011 stated, "Installed Cost of Solar PV Systems in the U.S. Declined. The installed cost of solar photovoltaic power systems in the United States fell substantially in 2010 and into the first half of 2011." Tucker also cited a report released on September 15 by DOE's Lawrence Berkeley National Laboratory where the average installed cost of residential and commercial PV systems completed in 2010 fell by roughly 17 percent from 2009, and by an additional 11 percent within the first six months of 2011."(8) This gives hope that PV cost will eventually be lowered to the point that it can be used for utility scale electric generation.

A study by Lawrence Berkeley National Laboratory shown by Figure 8 revealed that the cost of commercial PV systems is in a downward trend, and the cost of these systems makes them more attractive for deployment. Strategies should be developed to look for opportunities to install PV systems from commercial vendors as an alternative power system at reasonable cost for Building 1250.

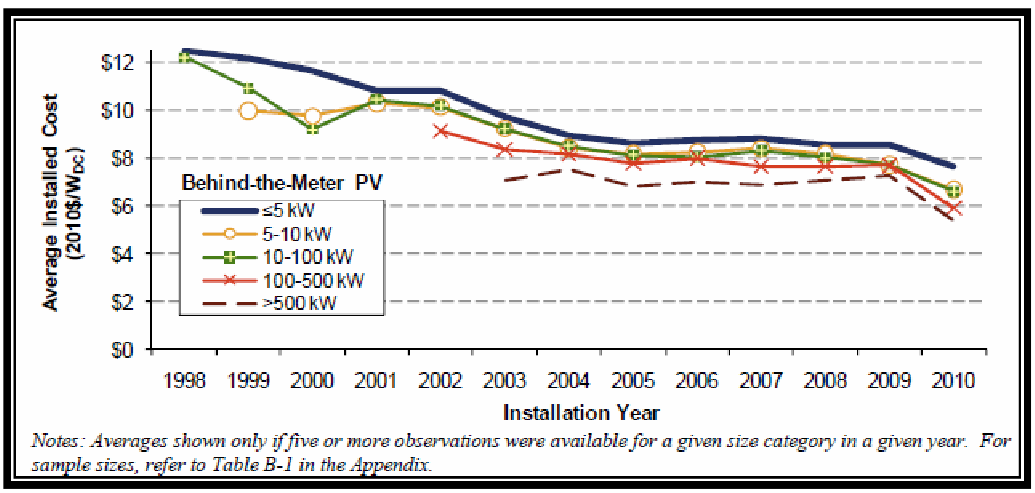

Figure 8. Installed cost trends over time for behind the meter PV, by PV system size (5)

Risks

Project risks are complex and difficult to quantify, but the following are potential risk that must be considered when incorporating PV systems. The first is the risk of potential damage to the facility within the 40 years potential lifespan due to inclement weather. Hampton Roads is subject to hurricanes, tornados, and other adverse weather, and such weather could damage some PV panels. The advantage of PV arrays is that damaged panels can be isolated and quickly replaced thus preventing the entire system from being decommissioned. The second project risk is component malfunction and single point failure. This risk can be minimized by having adequate redundancy. If redundancy is not provided for the DC/AC inverters, then the replacement period for either repair or re-manufacture of an individual inverter can be 12 to 16 months. The loss of a sole inverter will cause the entire solar electric system to be off line. Another risk is that advancing PV technology may create breakthroughs that significantly improve performance over the current installed PV system. While this may happen a unique advantage of PV power generation is the component nature of the technology. For instance newer higher efficiency panels can be interchanged with the older panels over time without a major new system cost. The component nature of PV system makes it relatively insensitive to technology maturation.

Conclusions

Climate change will impact NASA installations, requiring them to reduce energy cost and carbon footprint. These impacts will affect both the near and long term operational posture of the center and influence the capability to meet mission requirements. LaRC has completed preliminary investigations to ascertain the impacts of localized changing environmental conditions and has identified the need for improving solutions to address electrical power demands. An investigation was conducted to evaluate solar photovoltaic systems for a single building (Building 1240) as a representative case for a sustainable power source application. The PV system would achieve the goal of having Building 1250 classified as a net-zero energy building as it would produce as much energy as it uses over the course of a year.

Based on the facility's electrical demand of 200,000 kWh per month, a PV system of 1.9 MW would provide sufficient power. While current PV installation cost is high, the cost for large PV system is decreasing. The PV system would supply the needed solution for sustainability given that operation and maintenance is a significant component of the overall system deployment.

The project will provide a robust system for supply of alternative power. A 1.9 MW solar electric power system will be required. The project will provide the desired net-zero supply using on-site renewable energy as a solar PV system. Operation and maintenance of the system must be included with the installation.

The following benefits will be incurred by implementation of a PV system:

- Sustainability goals established by Executive Order may be achieved
- Environmental benefits by removal of pollutants from rainwater/parking area runoff and beneficial reuse of rainwater
- Use of electrical powered transportation will be encouraged by charging stations
- Beneficial use of lands not available for other uses
- An alternative electric power system provides a strategic additional level of redundancy to the existing electric power system
- Sale of unused electricity output
- Reduced carbon footprint

Nomenclature

A	Amps
AC	alternating current
DC	direct current
DOE	Department of Energy
EO	Executive Order
HVAC	heating ventilation and air conditioning equipment
kW	kilowatt
kWH	kilowatt hours
LaRC	Langley Research Center
MW	megawatt
NASA	National Aeronatic and Space Administration
O&M	operation and maintenance
PV	photovoltaics
REC	Renewable Energy Credits
V	Volts
W	Watt

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14. ABSTRACT
An investigation was conducted to evaluate photovoltaic (solar electric systems) systems for a single building at NASA Langley as a representative case for alternative sustainable power generation. Building 1250 in the Science Directorate is comprised of office and laboratory space, and currently uses approximately 250,000 kW/month of electrical power with a projected use of 200,000 kW/month with additional conservation measures. The installation would be applied towards a goal for having Building 1250 classified as a net-zero energy building as it would produce as much energy as it uses over the course of a year. Based on the facility’s electrical demand, a photovoltaic system and associated hardware were characterized to determine the optimal system, and understand the possible impacts from its deployment. The findings of this investigation reveal that the 1.9 MW photovoltaic electrical system provides favorable and robust results. The solar electric system should supply the needed sustainable power solution especially if operation and maintenance of the system will be considered a significant component of the system deployment.

15. SUBJECT TERMS
Photovolatics; Power; Solar array

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