SEPTA: Midvale Complex Renewable Energy Assessment

PREPARED FOR:

PREPARED BY:

SourceOne, Inc.
A Veolia Energy Company

53 State Street
Boston, MA 02109
Phone: (617) 399-6100
www.sourceone-energy.com

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1. Executive Summary

The Southeastern Pennsylvania Transportation Authority (SEPTA) seeks to evaluate the potential integration of on-site renewable energy systems and energy storage at the Midvale Complex (Complex) in Philadelphia. The specific scope of such a deployment is to cover a base power load of 8-9 MW (8.5 MW for purposes of analysis), in a reliable manner without the need to rely on the utility grid, at the Wayne Junction propulsion power substation and the Complex bus maintenance facility. For the project to move ahead, SEPTA seeks a solution that will be self-funded. SourceOne has been tasked to provide specific metrics that will enable SEPTA to assess the economic feasibility of such a deployment.

The scope of SourceOne's analysis was limited to the following:

- Potential Generation Capacity: An estimate of power (MW) generation capacity from solar and/or wind deployment on SEPTA-owned and operated land at the Midvale Complex. This estimate was performed using a combination of the Systems Advisory Model (SAM) and PV WATTS, ubiquitous tools provided by the National Renewable Energy Laboratory (NREL).
- Logistical Considerations: Mitigating factors in solar and/or wind deployment at the Midvale Complex, such as requirements for battery storage to ensure on-demand generation from the renewable sources.
- Order of Magnitude Costs: An estimate of capital and operating costs associated with the deployment and any ancillary equipment, such as battery storage.

A comprehensive list of criteria was determined so as to be able to evaluate the site for constructability and operability. Based on these criteria, SourceOne was able to provide a preliminary assessment of the site of which three (3) areas were identified to be suitable for PV arrays. These areas are depicted in Figures 3, 6 and 7 of the report. The deployment of wind energy systems was found not to be feasible within the Complex.

After identifying suitable areas, an estimate of power generation was determined for each identified area. These estimates are provided in Table 2 (Page 14). It is worth clarifying that while PV arrays would have the potential to provide instantaneous capacity up to 74% of the power needed (6.26 MW out of 8.5 MW), this would occur only at midday and under ideal conditions. Over the course of the year, the arrays would supply only about 15% (11,200 MWh out of 75,000 MWh) of the energy required by the site. In order to be able to supply uninterrupted power for SEPTA's base load, some form of energy storage is required. To accomplish this objective with PV, SourceOne suggests the deployment of battery storage with a minimum energy capacity of 20 MWh. This would enable the PV system to distribute its output evenly throughout the day, at an annualized around-the-clock average capacity of approximately 1.275 MW (15% of 8.5 MW).

This assessment has concluded that 15% is the maximum levelized load that can be achieved through a combination of on-site renewables energy systems and energy storage at the Complex. The total cost for such a deployment would amount to an initial capital cost of $30-$32 million (without accounting for incentives). As such, the renewable energy/ battery storage scheme cannot accommodate the ability to run SEPTA's base load without an alternative power source, either on-site or utility power. While there may be other on-site technologies that can provide the required capacity, the potential capacity from both wind and solar installations is orders of magnitude too low to provide continuous baseload power supply at the site.

The following table provides a summary of the preliminary renewable energy potential as well as relevant costs.

Table 1: Assessment Summary

System	Effective Capacity	Power Capacity (% of Base load)	Energy Capacity (% of Base load)	Cost w/o Incentives ($ Million)
PV	6.26 MW*	74%	15%	$17
Battery Storage	20 MWh	100%**	15%**	$13-$15

*We note that another 2.08 MW of theoretical capacity at the Bus Maintenance Facility was excluded from our total due to high redevelopment costs that rendered that site economically unfeasible.

**While there is sufficient space to install the battery storage capacity necessary to support native load, approximately 85% of that storage would need to be energized by sources other than PV (i.e., utility power).

2. Site Assessment

SourceOne evaluated the following criteria to determine site suitability for renewable energy integration and operation.

2.1. Logistical Considerations & Criteria

Several considerations including logistics, safety, environmental and engineering need to be examined. These considerations include structural, spatial, energy availability, human factors, environmental, proximity for interconnection and access for operations and maintenance.

2.1.1. *PV Site Assessment Criteria*

PV systems pose several requirements for successful integration and operation. Primarily, a space with unobstructed direct sunlight, free of shading from nearby structures or trees is required. Shading can significantly reduce the incident solar radiation and hence output. PV systems are subject to accessory use or structure setback requirements in the zoning district in which the system is to be constructed. For installations on roofs, it is very important to have the required structural support for the panels so as to guarantee the roofs can handle the additional load. It is noteworthy that PV array installations in roofs with a poor membrane condition can lead to deficient structural members which will in turn require expensive structural reinforcement. Ideally, the remaining useful life of the roof should also exceed that of the PV system. For ground mount applications, suitable terrain can be classified as smooth, flat (non-anomalous) or slightly sloping to the south which can be easily landscaped. Excessive earthwork can quickly add to the cost of the project. The site also needs to be easily reachable for installation and maintenance purposes as well as near the load or point of interconnection. Long distances from the load or point of interconnection can lead to high costs for trenching and cabling. Finally, the site needs to be assessed for potential flooding.

2.1.2. *Wind Energy Site Assessment Criteria*

Wind energy systems also pose unique requirements for their installation and maintenance. Finding the best site for new wind turbine installations can be a complex task. Initially, it is necessary to obtain wind data. Since wind is a highly localized phenomenon, a site specific study (i.e. meteorological “met” tower) is usually required, although there are various resources available to estimate average regional wind speeds for preliminary purposes. It is then necessary to check for proper structural support to hold the wind turbine in place. Such support can be in terms of some form of foundation such as a concrete pad anchored into the ground or an existing part of a building. A geotechnical survey is required early in the project to determine subsurface conditions. It is important there are no obstacles in the vicinity of the turbine such as buildings, trees and poles which can cause a transition to turbulent airflow and reduce turbine output and useful life. It is important to note that even obstacles that seem to be far away and are much lower in height compared to the turbine can create such a transition. It is important to examine potential noise levels and electromagnetic interference which can affect wireless communications. Similar with PV criteria, the terrain needs to be flat and smooth with proximity to the interconnection point and load.

According to a study[1] by the National Renewable Energy Laboratory (NREL), "*The overall average direct impact area is 0.3 ± 0.3 hectares/MW for permanent impact and 0.7 ± 0.6 hectares/MW for temporary impact, or a total direct surface area disruption of about 1.0 ± 0.7 hectares/MW*." For comparison purposes one hectar is equivalent to 107,639 square feet. The area under examination, around the turbine needs to be cleared for installation as well as maintenance. Wind turbine manufacturers recommend for safety purposes to keep human activities at a specific radius away from the turbines for safety purposes. This radius is normally more than 1,000 feet for large commercial size turbines. In Pennsylvania, local government has the authority to plan and regulate land use including the siting of wind generation facilities. The state has developed a model ordinance for local governments[2] to follow. The model states that wind turbine horizontal distance shall be no less than 1.1x the full turbine height from occupied buildings, property lines and public roads as well as no less than 5x the Hub height from non-participating occupied buildings. Given that Philadelphia is a major urban center it seems reasonable that greater distances than the minimums would apply. A greater setback from structures is beneficial as there are several risks related to large rotating machinery. Moreover, it will result in lower audible noise, added safety and reduced wear on components which results in smaller failure rate. Protection from ice and blade throw stipulate such setbacks. Finally, the FAA needs to be contacted if a height of more than 200 feet is proposed so an obstruction evaluation study can be done.

These factors demonstrate that wind turbines' siting is a complex task and enforces the need for projects to be strategically positioned to mitigate all logistical constraints while maximizing the available wind energy.

2.1.3. *Other Site Assessment Criteria*

It is also important to examine site specific considerations related to its use and requirements for continuation of normal operations as well as access to areas for operations and maintenance, safety of personnel and future projects. It is noteworthy that the Complex is operated by SEPTA except for a specific building that is highlighted in Figure 1. SourceOne has been informed by SEPTA that their nature of operations require 365 day, 24/7 access to all parts of the Complex. SourceOne has not been informed by SEPTA of any new planned structures in the Complex that would preclude an area for renewable energy systems installation.

[1] Denholm, P., M. Hand, M. **Jackson, and S. Ong. "Land Use Requirements** of Modern Wind Power Plants in the United States." *NREL/TP-6A2-45834* (2009): 1-46. Print.

[2] "Model Ordinance for Wind Energy Facilities in Pennsylvania." (2006): 1-10. Web.

2.2. Site Assessment

In order to evaluate the Complex, SourceOne first subdivided the site into areas for ease of visualization. The following Figure is a map of the Complex, displaying the fence line as well as the key areas identified. The entire site can be approximated to be 1900 long by 1500 feet wide. Each of the areas identified in Figure 1 will be examined separately.

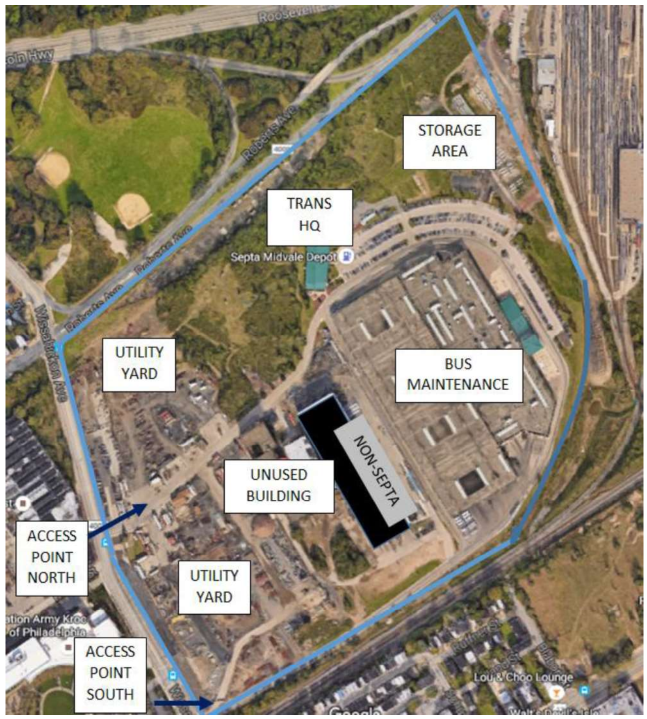

Figure 1: Midvale Complex Key Areas

2.2.1. *Bus Maintenance Facility*

The roof of the Bus Maintenance Facility (Figure 2) provides flat terrain and unobstructed solar radiation at all times of day.

However, SEPTA has indicated that the roof of the Bus Maintenance Facility is in poor state and that to hold a PV array, it would need to be replaced and reinforced at a cost of approximately $28 per square foot. Additionally, due to the presence of HVAC equipment, maintenance access requirements, and skylights at the East end of the roof (Left side as shown in Figure 2), we believe that only the West end of the roof is viable for siting purposes.

At the West part of the roof, accounting for the skylights, there is a usable area of approximately 200,000 square feet. This area can potentially be suitable for an installation of a PV array with an AC capacity, after losses, of 2.08 MW. However, the cost of roof replacement diminishes the economic feasibility of this option and therefore, we do not include it in our subtotal of available capacity.

Figure 2: Bus Maintenance Facility Roof

SourceOne has identified an area to the East of the bus maintenance facility which is approximately 21,500 square feet (Area A). This area can potentially be suitable for an installation of a PV array with an AC capacity, after losses, of 0.225 MW. This area is flat and provides unobstructed sunlight and is currently not used by SEPTA.

Figure 3: Area A

2.2.2. *Unused Buildings*

Similar to the bus maintenance facility, the state of the roofs of the unused buildings, as shown in Figure 4, are very poor and would require a significant investment to bring them up to standard. SourceOne was not able to identify any suitable area for PV array installation in the vicinity of the unused buildings. If the buildings are repurposed and repaired in the future they may pose an opportunity for a PV array installation.

Figure 4: Unused Buildings

2.2.3. *Utility Yard*

Figure 5: Utility Yard

As is visible in Figure 5, the Utility Yard features a significant amount of stored equipment, materials as well as machinery and vehicles, containers and miscellaneous structures. SourceOne has identified the area (Area B) starting to the North of the Utility Yard until the East end of the Complex as a candidate for the deployment of PV. Area B as shown in Figure 6 seems suitable but will require moderate landscaping to bring it up to standard. Several trees will need to be removed in the process. This area represents approximately 560,820 square feet of usable space and can feature an AC capacity, after losses, of 5.87MW.

Figure 6: Area B

2.2.4. *Transportation Headquarters*

The transportation headquarters building has a slanted roof (approximately 18,000 square feet of surface area) and seems to provide some potential for PV installations pending structural evaluation. Nonetheless, the panels probably need to be installed in a 90 degree surface azimuth angle and flat on the roof (approximately 15 degree tilt) as to minimize weight. Pending structural evaluation, the roof of the building (Area C) depicted in, can feature an AC capacity, after losses, of 0.165 MW.

Figure 7: Transportation Headquarters (Area C: Roof)

2.2.5. *Storage Area*

The storage area shown in the right hand side of Figure 8 features several access roads to the railroad tracks which are at the Northeast corner of the Complex. This area is unsuitable for an installation of a PV array given that these access roads are routinely used and there is stored equipment in the area including several buses. SEPTA has indicated that there is little space to store equipment elsewhere. Area B is marked on Figure 8 and visible to the West of the storage area.

Figure 8: Storage Area

3. Generation Capacity Estimation

Each of the areas described above was considered separately to determine the PV system capacity of the Complex. SourceOne utilized the System Advisory Model (SAM) coupled with PV WATTS, tools provide by the NREL. These tools are ubiquitous in the industry for initial estimation of PV capacity. The inputs used for the analysis through PV Watts are as follows:

- TMY 3 solar data from the Philadelphia International Airport
- Fixed open rack type system: 30 degree tilt for Areas A and B, 15 degrees for Area C
- DC to AC ratio of 1.1
- Inverter efficiency of 96%
- Ground coverage ratio of 0.4
- System losses of 14%.

3.1. PV Generation Capacity Summary

A summary of the potential generation from PV deployment is presented in Table 2 presented on the next page. It is worth noting that the nameplate capacity of the PV arrays does not account for losses. Accounting for the expected losses an actual power capacity of 6.26 MW[3] is predicted. Although 74% of the required power can be provided with PV (6.26MW out of 8.5MW), this is possible during only a couple hours in the day when the sun is at its highest point, assuming perfect conditions in the summer without any clouds. As such it is important to stress that capacity only refers to the maximum possible power generation and does apply to the entire day. Finally, the potential energy production of approximately 11,197 MWh per year represents only about 15% of the required energy at the site. This assumes a base load energy requirement of 75,000 MWh per year for a base load of 8.5MW.

[3] If the West end of the Bus Maintenance Facility was considered as per Section 2.2.1, an additional nameplate capacity of 2.775 MW DC, an AC power capacity of 2.08 MW and energy generated of 3,749,236 kWh per year could be expected. SourceOne found this area to be unsuitable for a PV array deployment as explained in Section 4.1.

Table 2: PV Generation Capacity Summary

	Area A	Area B	Area C	Total
Surface Area (sq ft)	21,500	560,800	18,000	**600,300**
Name Plate Power Capacity (MW DC)	0.300	7.815	0.220	**8.405**
AC Power Capacity (MW)	0.225	5.866	0.165	**6.256**
Energy Generated per Year (kWh)	390,000	10,557,000	250,000	**11,197,000**

The following table provides a breakdown for the AC Energy Output of each Area using the SAM and PV WATTS software. The energy output refers to the first year after installation only. For analysis purposes a degradation rate of 0.5% per year[4] can be used.

Table 3: SAM (PV WATTS) Energy Output Breakdown

Month	AC Energy Output (kWh)			
	Area A	Area B	Area C	Total
January	23,293	691,049	11,545	725,887
February	25,014	711,889	13,743	750,646
March	34,018	928,994	20,553	983,565
April	36,800	969,333	24,946	1,031,079
May	41,245	1,060,303	28,808	1,130,356
June	41,880	1,065,174	30,772	1,137,826
July	39,511	1,010,798	28,597	1,078,906
August	41,264	1,080,978	28,591	1,150,833
September	33,864	913,423	22,104	969,391
October	30,478	860,846	17,626	908,950
November	22,650	661,618	11,600	695,868
December	20,166	602,758	9,692	632,616
Annual	**390,183**	**10,557,163**	**248,577**	**11,195,923**

[4] Jordan, D. C., and S. Kurtz R. "Photovoltaic Degradation Rates-an Analytical Review." *Prog. Photovolt: Res. Appl. Progress in Photovoltaics: Research and Applications* 21.1 (2011): 12-29. Web.

3.2. Wind Energy System Capacity

SourceOne did not identify any areas as potential candidates for wind energy system deployment. In order to fulfill the capacity or a fraction of the capacity required to satisfy base load, a high tower(s) (more than 100 feet) would be required. Furthermore, required setback area is not available due to limited space in the Complex. Small scale wind turbines are not an effective means of power generation since output is proportional to the square of the diameter of the turbine (or area swept) and to the cube of the wind velocity, which normally increases with elevation. Small wind turbines mounted on buildings have not proved successful given their small size, low elevation and inbound turbulent airflow due to building structure interference. Additionally, they can often create vibrations and noise that can be transmitted into the building. In order to fulfill a fraction of the base load with small wind turbines, several units would be required. As such, for physical- and site specific purposes, wind energy does not seem to be a reasonable alternative and is unlikely to be able to provide meaningful capacity at the site.

3.3. Energy Storage Required Capacity

Figure 9 portrays a typical solar radiation profile (direct solar irradiance on a horizontal collector) for a sunny summer day. The data was obtained from Philadelphia International Airport measurements and portrays incident radiation. Due to the intermittent nature of renewable energy, a storage medium is required to provide consistent base load power.

Figure 9: Sample Direct Normal Irradiation for Philadelphia

SourceOne has contemplated two of the most popular storage options used in industry. First, it is possible to export the power produced by the system to the utility grid during the day and then import energy during the night, or when the system cannot generate power. Essentially, this method uses the utility grid as a battery but the project itself is not a base load power source. Although this option can be very attractive given net metering regulations and other incentives, it does not conform to SEPTA's scope to evaluate onsite base load sources of energy that can fuel its operations without the need to rely on the grid.

Another option is battery storage. Storing surplus energy and using it when the PV arrays cannot generate power can maintain a constant level of power, as to fulfill SEPTA's need for consistent base load power. Battery storage in Figure 10 would provide constant power for the entire day. The batteries would charge during times for high power output and discharge below a set point. Although there are several technologies for energy storage including mechanical devices such as flywheels, for this particular application, batteries such as lithium ion or sodium sulfur (NAS) seem to be the most applicable technology.

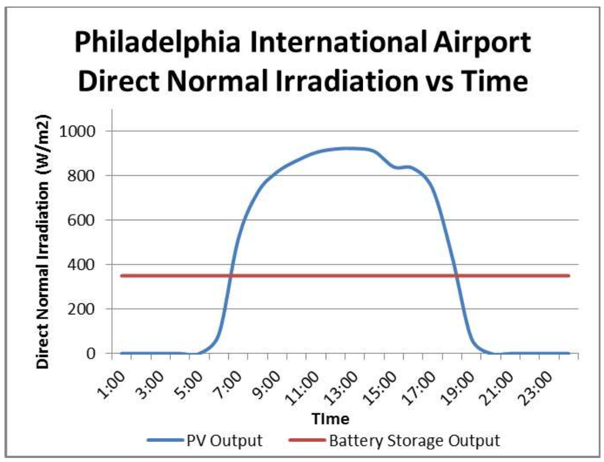

Figure 10: Sample Direct Normal Irradiation for Philadelphia with Battery Storage

Based on SEPTA's desire to provide base load power to the extent of available PV capacity, and to not lean on the grid for supplemental power, the battery storage system needs to be sized for the highest energy production in the year. As seen in Table 3, in August the system can produce approximately 1150 MWh, which on average is 37 MWh per day. This energy would have to be distributed evenly throughout the day. For purposes of this high level analysis, SourceOne assumed that approximately half the energy would be used during the day and the other half would be stored and released at night. To maintain constant power throughout the day it is reasonable to use a battery with a capacity half that of the production of the PV array for the day. Given that most manufacturers quote the size of battery storage systems after 10 years of deep cycle operation[5], 20 MWh of batteries would be needed. However, as to account for days without sun, a few days of extra storage might be required. This would enable the

[5] Manufacturers like GE will quote the size of the batteries based on the minimum amount of energy they can store after 10 years of operation. Depending on the depth of discharge, batteries will lose a percentage of capacity after a specific amount of cycles. As such, in most cases the nameplate capacity accounts for the loss of storage capacity due to operation after 10 years of storage. If battery capacity is quoted at Year 1, manufacturer documentation should be consulted to adjust the required capacity.

6.26 MW PV capacity to distribute around-the-clock based load of approximately 15%, or 1.275 MW on average, over the course of the year.

In terms of physical footprint, batteries come in 20, 40 or 60 foot containers depending on size. For example, a 2MWh battery (capacity after 10 years of operation) would require a 40 foot container. For a 2MWh battery size including ancillary equipment such as the power conversion system and transformer an area of 60 by 24 feet would be required (1440 square feet). The area in and around the Complex has ample space for the 20 MWh storage scenario, which would require approximately 17,000 square feet after accounting for clearance between the storage units.

4. Order of Magnitude Costs

SourceOne developed the following preliminary and order of magnitude costs.

4.1. PV Costs

SourceOne presents a summary from the Distributed Generation Renewable Energy Estimate of Costs[6] report, updated in February 2016 by NREL. An excerpt from Table 1 of this report is presented in Table 4 below.

Table 4: NREL PV Cost Summary

Technology Type	Mean Installed Cost	Installed Cost Std. Dev	Fixed O&M	Fixed O&M Std. dev.	Lifetime	Lifetime Std. Dev.
	($/kW)		($/kW-year)		(years)	
PV 100-1,000 kW	$ 2,943	$ 774	$ 19	$ 15	33	11
PV 1-10 MW	$ 2,025	$ 694	$ 16	$ 9	33	9

The total capital (installed) cost associated with the PV array would then be approximately $17 million with a fixed operation and maintenance cost of $75,000 per year. This excludes development of the West end of the Bus Maintenance Facility.[7]

4.2. Battery Storage Costs

SourceOne has recently obtained pricing for outdoor battery storage units. The capital cost SourceOne was provided was in the range of $660 to $760 per installed kWh of batteries[8], in 1 MWh increments. The Inspection and Maintenance cost was quoted around $14,500 per MWh of installed capacity. The capital costs include transportation, inspection and commissioning but are exclusive of transformers, switchgear and cables, and site preparation.

The capital cost associated with battery storage would then be approximately $13-15 million with a fixed operation and maintenance cost of $290,000 per year.

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6 "Distributed Generation Renewable Energy Estimate of Costs." NREL: Energy Analysis. N.p., Feb. 2016. Web. 19 Sept. 2016.

7 The added capital (installed) cost to incorporate the West end of the roof of the Bus Maintenance Facility would be $5.62 million for the PV array and ancillary systems with an O&M cost per year of $44,400. However, in order to repair the 240,000 square foot roof, at $28 per square foot, an additional $6.72 million would be required. This would amount to $12.34 million, yielding the average cost per installed kW to be more than double that of Areas A, B and C. As such, the deployment of PV on the roof of the Bus Maintenance Facility would be disproportionally capital extensive. For this reason, SourceOne determined that this site should not contribute to Midvale's available capacity unless the repair of the roof is undertaken under the umbrella of another project.

8 Industry capital costs associated with battery storage range between $500 to $1100 per kWh of installed capacity. In our analysis we used commercial quotes from vendors, as outlined above.

A useful life of 5-15 years is typical for a battery storage system, depending on the depth of discharge. With proper care, including temperature monitoring and manufacturer maintenance, a useful life of around 5,000 deep cycles is feasible (~14 years). While this is consistent with the mature life of the PV system, it is likely that an additional CAPEX would be required to replenish and extend the life of the battery storage system beyond 14 years. This would likely entail the purchase of new capacity rather than replenishment of existing capacity. Due to the declining cost trend of the technology, we believe this CAPEX to be relatively small and not central to the analysis.

4.3. Incentives

SourceOne has identified some incentive schemes that are applicable to PV installations.

- Renewable Energy Credits (REC's) can be sold in MWh increments and vary according to market conditions. Pennsylvania's solar RECs have traded between $12-20/MWh over the past year and represent a substantial recurring revenue stream.
- Through the U.S Department of Energy Loan Guarantee Program, financing can be guaranteed.
- The solar Investment Tax Credit (ITC) allows owners to deduct 30% of the installed cost of PV system from their federal taxes. Accelerated depreciation can also significantly improve project payback. SEPTA would need a private partner and to potentially sign a lease agreement in order to access these benefits.
- The project would not likely qualify for standard Net Metering of excess generation because the program's regulatory cap is currently 3MW and the site's load is considerably larger. However, PA's virtual net metering law may provide a means to bypass this restriction by siting projects behind separate interconnections with the utility.

5. Key Takeaways

This section provides a brief summary of key takeaways. It also provides insight on additional renewable energy schemes for solar future projects.

- Wind energy systems deployment does not seem feasible at this point in time due to physical/safety limitations.

- With PV arrays at three (3) areas identified approximately 74% of the base load power can be supplied, but only during limited hours in a day and during optimal weather conditions. Throughout the year, the PV arrays can produce up to 15% of the energy needed to supply the base load but with significant production gaps unless they are supplemented with on-site storage.

- The total capital cost associated with the PV array is estimated to $17 million with a fixed operation and maintenance cost of $75,000 per year. This is without incentives or other financing structures.

- Since the Complex hosts many of the ongoing maintenance operations and SEPTA employees need access to all parts of the site, it might be preferable to limit deployment of PV arrays, if economically viable, to a portion of the areas highlighted in this report.

- Energy storage is required in order to have an on-site reliable power supply, without relying on the grid. Due to high capital costs and limited rate volatility, energy storage in medium sized commercial applications in terms of batteries, flywheels or other technology is currently economically viable for demand response and power conditioning scenarios, but not for base load power supply in urban areas.

- The initial capital cost associated with battery storage is estimated at $13-15 million with a fixed operation and maintenance cost of $290,000 per year.

- Taken together, a baseload PV system with storage would have a CAPEX of approximately $30-32 million. It would produce approximately 15% of the site's baseload, or 1.275 MW, on average throughout the year.

- For future projects under a different scope, not subject to constraints of base load supply and with more optimal siting options, solar may provide an economic solution for on-site supplemental or peak shaving power supply. There may be opportunities to reduce project cost by taking advantage of various financing and virtual net metering provisions with a more holistic approach across SEPTA's portfolio. SEPTA could also evaluate financial transactions with offsite solar or wind developers (i.e., via power purchase agreements or "PPAs") to further leverage economies of scale and improve production efficiency.