FEASIBILITY STUDY OF CITY-SCALE SOLAR POWER PLANTS USING PUBLIC BUILDINGS

Case Studies of Newark and Wilmington Delaware with Early Investigations of Bifacial Solar Modules and Dual Orientation Racking as Tools for City-Scale Solar Development

Third Year Report Revised June 2019


Rooftop Distributed PV System for Newark (Trabant University Center at the University of Delaware) and Wilmington (Public Works Yard)

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BOS	Balance of Systems
CBI	Capacity Based Incentive
CEEP	Center for Energy and Environmental Policy
CESP	Community Energy Strategic Planning
DC/AC	Direct Current / Alternating Current
DEMEC	Delaware Municipal Electric Corporation
DOE	U.S. Department of Energy
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
FREE	Foundation for Renewable Energy and Environment
G	Gigawatt
GWh	Gigawatt-hour
IEC	Institute of Energy Conversion
kWh	Kilowatt-hour
LCOE	Levelized Cost of Energy
LiDAR-GIS	Light Detection and Ranging and Geographic Information System
MACRS	Modified Accelerated Cost Recovery System
MUSH	Municipalities, universities, schools and hospitals
MWh	Megawatt-hour
MWp	Megawatt-peak
NREL	National Renewable Energy Laboratory
NSCP-1	Phase 1 of Newark Solar City Plant
O&M	Operation and maintenance costs
PBI	Performance Based Incentives
PII	Permitting, Inspection and Interconnection
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PV	Photovoltaic(s)
R&D	Research and Development
SAM	System Advisor Model
SCP	Solar City Plant
SET	Science, Engineering and Technology Services Program
SEU	Sustainable Energy Utility
SREC	Solar Renewable Energy Credits
STAR	Sustainability Tools for Assessing and Rating
UHI	Urban Heat Island
US$	U.S. Dollars
WPA	Wilmington Parking Authority
WSCP-1	Phase 1 of Wilmington Solar City Plant

EXECUTIVE SUMMARY

This report describes our findings for research conducted with the support of the 2018-19 Science, Engineering and Technology (SET) Services Program. This research builds upon two previous studies: "Measuring Urban Sustainability Through Common Indicators and Peer City Benchmarking in Delaware" (Byrne et al., 2017); and "Urban Solar Rooftop Potential: Technical and Economic Analysis of Rooftop Solar Generation in Wilmington and Newark Delaware" (Byrne et al., 2018).

In the third-year of the research program organized by CEEP, the electricity generation has been estimated for flat rooftop buildings in Wilmington and Newark. The city-wide technical and economic potential of solar energy that is deemed suitable for photovoltaics (PV) system deployment in Wilmington was estimated in the second-year study, at approximately 194 MWp (Byrne et al., 2018). Using the same methodology, the estimated city-wide solar electricity-generation capacity for the City of Newark yielded 83 MWp for its flat rooftops.

The analytical approach of this project follows the U.S. Department of Energy's (DOE's) *Guide to Community Energy Strategic Planning (CESP)* which provides a detailed step-by-step process for developing a robust strategic energy plan for cities (U.S. Department of Energy, 2013a).

Our analysis for the Wilmington 'Solar City' Plant (SCP)[1] identified a priority pool of public buildings, for phase 1 development with a total of nearly 7.9 MWp. It includes four city parking garages, four warehouses at the Port of Wilmington, one public building in the Riverfront district (the Chase Convention Center), and twenty one city-owned buildings. The total estimated potential for priority Wilmington rooftops accounts for approximately 3.0 MWp of the city's potential.

[1] This third-year study builds off of the second-year study of Wilmington and Newark that employed a remote sensing database using Light Detection and Ranging (LiDAR) and geographic information system (GIS) tools to provide a 3-D model of all buildings. This study analyzes the LiDAR-GIS database using HelioScope software (a solar system design tool created by Folsom Labs) and SAM (System Advisor Model, a software created by the National Renewable Energy Laboratory for the evaluation of solar economics) (National Renewable Energy Laboratory, 2018).

The capital cost for phase 1 of the Wilmington SCP (WSCP-1) is approximately US$14.5 million. The WSCP-1 is based on the following three main principles:

- The SCP is owned by the city but day-to-day operations and management of the solar power plant is performed by a third-party, either a utility or a private developer through a lease for an agreed duration with the city;
- The city update its building codes to enable and accommodate using its public buildings for solar power development;
- The project is revenue-neutral to the city. That is, the revenues received from the sale of output of the SCP must be equal to or greater than all capital, operating and maintenance costs to create and operate the SCP.

The Newark SCP analysis has identified a priority pool of buildings with a total of nearly 3.9 MWp of rooftop PV potential, including 0.7 MWp of solar generation capacity hosted by 7 city-owned buildings and 3.2 MWp hosted by 12 University of Delaware-owned buildings.[2] The initial economic assessment finds that a capital investment of approximately US$7.1 million (combining city- and university-owned buildings) would be needed to construct phase 1 of the Newark SCP (NSCP-1). The NSCP-1 is based on the following three main principles:

- The project is owned and operated by the city's municipal utility with all PV systems installed within its administrative boundary;
- The city would maintain current contractual obligations with Delaware Municipal Electric Corporation (DEMEC) (and may choose to ask DEMEC to operate the plant on its behalf);
- The project must be revenue-neutral to the city – that is, the city must receive revenues from the SCP that are equal to or greater than the capital, operating and maintenance costs incurred to create and operate the SCP.

[2] Criteria for the priority pool in both cities include: large, flat, unshaded roof area (> ~ 1,000 ft^2); selected buildings are planned for continued use of 5-10 years or more; roofing surfaces are in good order (based on inspection of Google Earth images for each building).

A list of potential co-benefits[3] of investing in the WSCP-1 and NSCP-1 and related catalytic opportunities to the two cities includes:

- Both Wilmington and Newark could obtain city-located electricity from clean, renewable and sustainable sources to further their sustainability planning;
- Both cities would meet their share of all state policy targets for solar and renewable electricity through 2030;[4]
- Newark and its largest electricity consumer, the University of Delaware, could present themselves as low-carbon prosumers and improve electricity choices for their customers (Nyangon and Byrne, 2018), including advertising Newark as a "solar city" realized by 'town-and-gown' co-operation;
- To ensure full participation of all of Wilmington's and Newark's residents, a solar lifeline program could be added which sets aside a share of SCP generation to be credited to qualifying moderate income families at a reduced rate (for example, the initial 250 kWh of monthly household electricity consumption of families eligible for the State's Weatherization Assistance Program might be priced at a solar lifeline rate);
- The SCP can be designed to invite participation by real estate developers, business owners, and residents who would benefit from lower technology costs due to city-anchored large procurements;
- Participants could be offered long-term fixed price electricity contracts, or equivalent incentives, for the share of generation hosted on their roof, thereby attracting new businesses and residents and incentivizing building owners to expand their involvement.

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[3] Co-benefits refer to added benefits that would be derived from the SCPs, above and beyond the direct benefits such as providing residents with clean, affordable and renewable electricity.

[4] Assumes that Delaware pursues 30% renewable electricity use and 6% solar electricity use by 2030. Both are above the existing requirement of 25% renewable electricity use and 3.5% solar electricity use by 2026. Higher state targets can be accommodated.

The analysis for both WSCP-1 and NSCP-1 has identified a priority buildingscape with significant solar technical potential. The results of a direct purchase option analysis assuming a commercial-scale opportunity, show feasible PV system deployment at 9.68 cents/kWh for both cities. Current average retail costs for electricity in the two cities are greater than 14 cents/kWh.

1. INTRODUCTION

Installed rooftop solar PV generation in the U.S. has grown rapidly to meet the increasing electricity demand, reduce reliance on expensive fossil fuel, while reducing greenhouse gas emissions. According to Wood Mackenzie Power & Renewables and the Solar Energy Industries Association (SEIA), the U.S. topped 2 million solar PV installations in 2019, hitting a milestone previously reached only by two countries—Australia in 2018 and Japan in 2014 (Wood Mackenzie and SEIA, 2019). Delaware, for example, average solar electricity consumption increased at a compound growth rate of 138% from 2010-2016[5]. Some of the factors contributing to this dramatic growth of solar power include the declining cost of solar equipment, installation, and operation and maintenance (O&M)[6] which make investment in rooftop PV attractive for municipal and state buildings, universities, colleges, K-12 schools, and hospitals (often abbreviated as MUSH). Although investment opportunities in urban rooftop PV in privately-owned residential and commercial buildings have also grown significantly in Delaware, as consumers seek greater control of their energy use, MUSH buildings may provide the most attractive PV investment potential due to their public function and better institutional capacity.

1.1. Project Context and Purpose

The third-year study assesses the technical and economic dimensions of urban rooftop solar energy potential in Newark and Wilmington. As the concept of "solar city" continues to drive actions at municipal levels in and beyond the U.S., the CEEP-led research team have pioneered a solar city assessment model which provides a comprehensive, accurate estimation of technical and economic potential of rooftop solar development for a wide range of cities, enabling objective decision-making on the economic practicality of solar projects. We

[5] Comprehensive state-level estimates of energy production, consumption, prices, and expenditures by source and sector. U.S. Energy Information Administration. (2018).

[6] Examples of PV O&M expenses include: operations administration (planned), inverter replacement reserve (corrective), module replacement reserve (corrective), component parts replacement (planned), system inspection and monitoring (planned), module cleaning and vegetation management (planned).

recognize that assessing the technical and economic potential of rooftop PV is time consuming and laborious, especially for resource-constrained medium-sized cities, which often need to prioritize the most beneficial economic development with minimal resource investment.[7]

An important innovation of this year's study involves using a building-level performance analysis software (HelioScope) to estimate municipal rooftop 'real estate'. HelioScope is a web-based, industry leading-edge software for estimating solar PV output that accounts for system losses due to panel mismatches, temperature and climate, irradiance, shading, reflection, soiling and provides recommendations for PV panel and array layout. HelioScope software is applied to conduct a complete building-level assessment and system design estimation for buildings that were identified as a 'priority' in Wilmington and Newark.

1.2. Overview of Research Approach

The following three research questions informed our analysis:

- What is the potential for rooftop solar energy development for flat rooftops of 'priority' public agencies and other properties in Wilmington and Newark?

- What are technical innovations in rooftop PV markets that could enhance solar electricity development in Delaware, specifically, bifacial PV modules design and dual east-west panel facing orientation?

- Can the "solar city" strategy help Wilmington and Newark meet their state's renewable portfolio standard targets?

[7] Examples of municipalities that have conducted comprehensive energy strategic plans and achieved significant energy savings include: Frederick County, Maryland ($358,000); Arlington County, Virginia; Rochester, New York, ($231,000); Boise, Idaho; City of Denton, Texas. Additionally, in New York, the NY State Energy Research and Development Authority (NYSERDA) announced in December 2018 nine community solar projects targeting 10,000 low-income communities (NYSERDA, 2018). CEEP-led research team recently designed a version of its model to measure solar rooftop potential for four cities, namely Philadelphia (Pennsylvania), Tempe (Arizona), Newark (Delaware), and Wilmington (Delaware), addressing variations in climate, solar irradiance, and applicable policy incentives.

To address these questions, we used a three-stage approach that is discussed in detail in Byrne et al (2018). The approach which has been applied in evaluating technical, economic, and policy potentials of major cities, including New York City, Seoul, Tokyo, London, Amsterdam, and Munich, deploys several research and analytical methods in each module (Byrne et al., 2015). Figure 1 shows the three-stage approach.

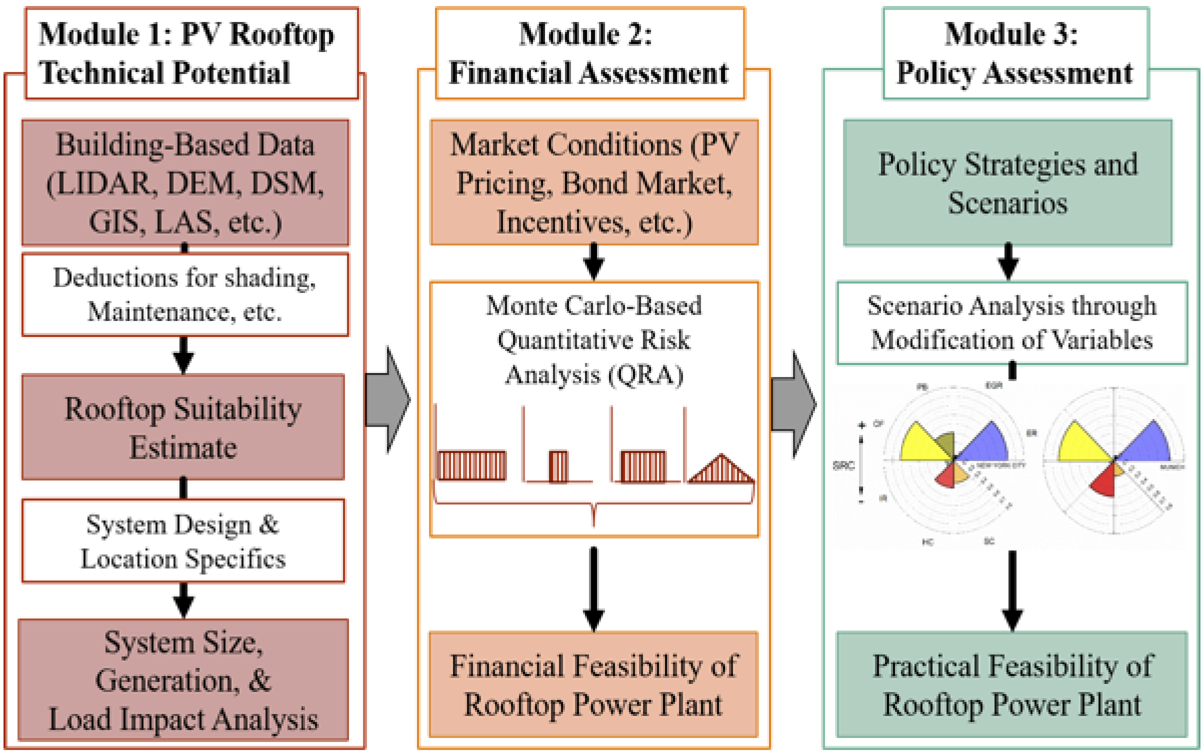


Figure 1. A three-stage research approach detailing solar PV opportunity

This study focusses on the first stage of the research approach and, unlike Year 2 study which evaluated city-wide solar electricity-generating potential of all existing rooftops, it concentrates on building-level assessments.[8] The assessment of priority buildings in Wilmington and Newark was based on a remote sensing database which uses Light Detection and Ranging (LIDAR) and geographic information system (GIS) tools to provide a 3-D model of all buildings. The LIDAR-GIS database was then analyzed using HelioScope software (a solar system design tool created by Folsom Labs) and SAM (System Advisor Model, a

[8] For a detailed discussion of the three-stage research approach in Figure 1 above, see Byrne et al. (2018).

software created by the National Renewable Energy Laboratory for the evaluation of solar economics). SAM integrates a detailed system performance model with a financial model and provides cost analysis solutions. SAM was used to assess economic performance of the estimated solar PV generation capacity for the two cities. For example, we assessed the investment profiles of the two cities considering the following cost parameters: system costs and other financial parameters i.e., direct costs of components (module and inverter types, balance of system equipment, installer margin and overhead, and installation labor costs); indirect costs (permitting, engineering, and land-related costs); O&Ms (for labor, equipment, and other costs associated with operating the project); and financial parameters (inflation rate, project timeline, incentives such as tax credits and direct cash incentives).[9]

Analysis of the rooftop PV system modeling and performance simulation is described in Section 2. Criteria for the priority pool of buildingscape includes: large, flat, unshaded roof area (> ~ 1,000 ft2). We assume the selected buildings will be in use for 5-10 years or more and roofing surfaces are in good condition (based on Google Earth inspections conducted for each building).

[9] We classified PV O&M costs into five main categories: administration, operations, design, preventive, corrective, and decommission. Examples of PV component include: AC wiring, related asset management, cleaning, DC wiring, electrical, inverter, mechanical, meter, PV array, PV module, tracker transformer.

2. SYSTEM MODELING AND DESIGN OPTIMIZATION OF ROOFTOP PV

2.1. Data and Design Assumptions

2.1.1. PV Module Analysis for Efficiency, Material and Voltage

The rapid deployment of rooftop solar PV systems in urban environments can be attributed to their competitive electricity cost with shorter payback periods as a result of the dropping installation costs as well as improved PV module efficiency (Calcabrini et al., 2019; Byrne and Lund, 2017; Nyangon, 2017; Hegedus, 2013). PV solar panels absorb sunlight to produce energy in the form of direct current (DC) electricity which is converted to alternating current (AC) electricity by a standard device called an inverter as required for self-consumption within the building while excess is exported to the grid. They must have relatively unshaded access to the sun from 9 am to 4 pm for maximum value.

With dramatic growth in rooftop solar industry in the United States—roughly 50% annually since 2012, the cost of PV deployment has steadily fallen driven by new technology, expanding renewable energy market, and policy innovations (Sunter et al., 2019; Nyangon and Byrne, 2018; Byrne and Taminiau, 2018; Nyangon et al., 2017; Byrne and Lund, 2017; Byrne and Taminiau, 2016). For example, the falling cost profile of solar PV remains a key driver to observed market trend. Commercial PV system prices experienced a compound annual price drop of 12.7% per year or a total price decline of over 65% between 2010 (US$5.36/Wp adjusted for 2017 US$) and 2018 (US$1.83/Wp adjusted for 2018 US$) (Fu et al. 2018).

Table 1 summarizes the PV module and inverter types used in our HelioScope assessment, detailing their efficiencies, dimensioning, and power ratings. A detailed summary of the PV modules assessed in our study based on the IHS

Markit's *PV Integrated Market Tracker* ranking is provided in Appendix 1.[10] In this study, we assumed LG365Q1C-A5 module type with a conversion efficiency of 21.1% for our PV system design estimation and analysis using the HelioScope software. Although Trina Solar (TSL) is one of the foremost solar companies having strong partnerships with leading utilities, installers, distributors, and developers in most PV markets, the LG module selected for this study has better conversion efficiency.

Table 1: Solar PV module and inverter specifications

Product Name: PV Module	Power Rating	Panel Dimensions (W / L) (mm)	Conversion Efficiency	Warranty (years)
LG: LG365Q1C-A5	365W	1016 / 1700	21.10%	25 for combined power and product warranty
Product Name: Inverter	**AC Power Output**	**Dimensioning (W / H / D) (mm)**	**Peak Efficiency**	**Warranty (years)**
SMA Solar Technology: Sunny Tripower	12-30 kW	780 / 790 / 380	98.60%	10

2.1.2. Solar PV Optimizing Inverter

An inverter converts the direct current (DC) power generated by the module into functional alternating (AC) power for grid and off-grid use. Therefore, for the DC/AC conversion process to be efficient, the inverter must have the same voltage and frequency as the electric grid system (Doulop, 2012; Renewable Insight-Energy Industry, 2011).

At present, inverters have very high peak conversion efficiency, typically ranging from 95%-99% (Mertens, 2018). The inverter efficiency linearly affects the solar system performance and production capacity. High inverter efficiency yields

[10] IHS Markit's PV Module Intelligence Service consistently provides forecasts and analysis for installed PV capacity in more than 30 countries. This includes PV installations tracker, PV module supply chain tracker, PV suppliers tracker, PV systems price tracker, PV manufacturing & equipment spending tracker, market surveys, trends and industry outlook (IHS Markit, 2018).

proportionally higher electricity production and, therefore, higher revenue yields for the PV investor. As a result, inverter efficiency has become an effective and appropriate identifier for rating the top companies in the inverter industry. Appendix 2 summarizes the latest in utility-scale, commercial, industrial, and residential inverters, including those offered by SMA Solar Technology, ABB, Enphase, SolarEdge, TMEIC, and Huawei companies. The average inverter efficiency of these products is about 98%. In our HelioScope assessment, we selected Sunny Tripower inverters manufactured by SMA Solar Technology with a conversion efficiency of 98.6%, as shown in Table 1. Note that standard inverter warranties are a little less than half that of the modules (10 vs 25 years).

2.1.3. Balance of Systems (BOS) Components

Solar balance-of-system, or BOS, refers to all the components and equipment that are necessary to install and safely operate a PV system exclusive of the modules and inverters. BOS equipment transports the electricity generated by the PV system for grid and off-grid use, and/or to battery storage for later use. For grid-connected systems, additional equipment is needed to comply with grid-connection regulations and power provider's requirements.

The specific equipment included in the BOS is as follows:

AC and DC disconnects: switches that are used to shut-down the system in case of emergency or while performing maintenance.

Metering and monitoring equipment: components that record the amount of energy produced, as well as evaluate the PV system’s performance to alert the owner of potential issues. This equipment is typically web-based for remote monitoring and provides the record of energy production used to determine Solar Renewable Energy Credits (SREC) credits.

Switchgear: electrical disconnect switches, fuses and circuit breakers used to control, protect and isolate electrical equipment. It is used to stop electrical flow in the system to allow for work to be done, and to clear faults downstream.

Transformers: larger grid-tied PV systems may include a main power transformer to “step up” the voltage. This allows for energy to be transferred back to the utility grid at a suitably high voltage to avoid losses.

Junction boxes: connects PV strings electrically in series or parallel to create an array.

Conduit: a protective cover, tube or piping system for electric cables.

Wiring: the interconnection cables used to electrically connect the PV system.

Racking: structural components (rails) on which the modules are mounted on long rows. The racks must be mounted or ballasted on the roof without damaging its waterproof or structural integrity.

Grounding and surge protection equipment: protects the system against power surges from lightning strikes or equipment malfunctions.

Table 2 and Figure 2 summarize NREL PV benchmarks of module, inverter, BOS, and soft costs for a commercial-scale flat-roof solar system, and a detailed schematic relationship of the commercial-scale system cost model, respectively.

Table 2: Commercial solar PV price benchmark historical trends

2010 US$/Wdc	2010	2011	2012	2013	2014	2015	2016	2017	2018
Module (US$)	2.23	1.89	0.98	0.59	0.64	0.62	0.57	0.31	0.47
Inverter (US$)	0.32	0.37	0.27	0.24	0.15	0.12	0.12	0.09	0.08
Hardware BOS (Structural and electrical components), (US$)	0.63	0.64	0.60	0.59	0.38	0.33	0.29	0.26	0.26
Soft Costs (install labor), (US$)	0.28	0.28	0.27	0.26	0.19	0.17	0.17	0.15	0.16
Soft Costs (others (permitting, inspection, and interconnection—PII, sales tax, overhead, and net profit), (US$)	1.25	1.18	0.88	0.75	1.06	0.76	0.76	0.81	0.81
Total (adjusted for inflation, 2017 US$)	**4.71**	**4.36**	**3.00**	**2.44**	**2.42**	**1.99**	**1.90**	**1.62**	
Total (adjusted for inflation, 2018 US$)	**5.43**	**5.04**	**3.47**	**2.82**	**2.80**	**2.30**	**2.20**	**1.88**	**1.83**
Total inverter replacement price (US$/W)	0.22	0.19	0.17	0.15	0.13	0.11	0.10	0.09	0.09
O&M expenses (US$/kW-yr)	24	22	20	18	16	14	14	14	14

Source: Modified from Fu et al. (2017). Unless specified otherwise, all costs in Table 2 are inflation adjusted (2017 US$), and assumes a 200-kW, 1,000 volts DC, commercial-scale flat-roof solar system. The total installed cost in Q1 2018 is US$1.83/W, assuming a 1) system lifetime of 30 years; 2) federal tax rate of 35% from 2010–2017, changing to 21% in 2018; 3) state tax rate of 7%; 4) MACRS depreciation schedule; 5) no state or local subsidies; 6) a working capital and debt service reserve account for 6 months of operating costs and debt payments (earning an interest of 1.75%); 7) a 6-month construction loan, with an interest rate of 4% and a fee of 1% of the cost of the system; 8) a system size of 200 kW; 9) an inverter lifetime of 15 years; 10) a module tilt angle of 10 degrees and an azimuth of 180 degrees; 11) debt with a term of 18 years; and 12) US$1.1 million of upfront financial transaction costs for a US$100 million TPO transaction of a pool of commercial projects.

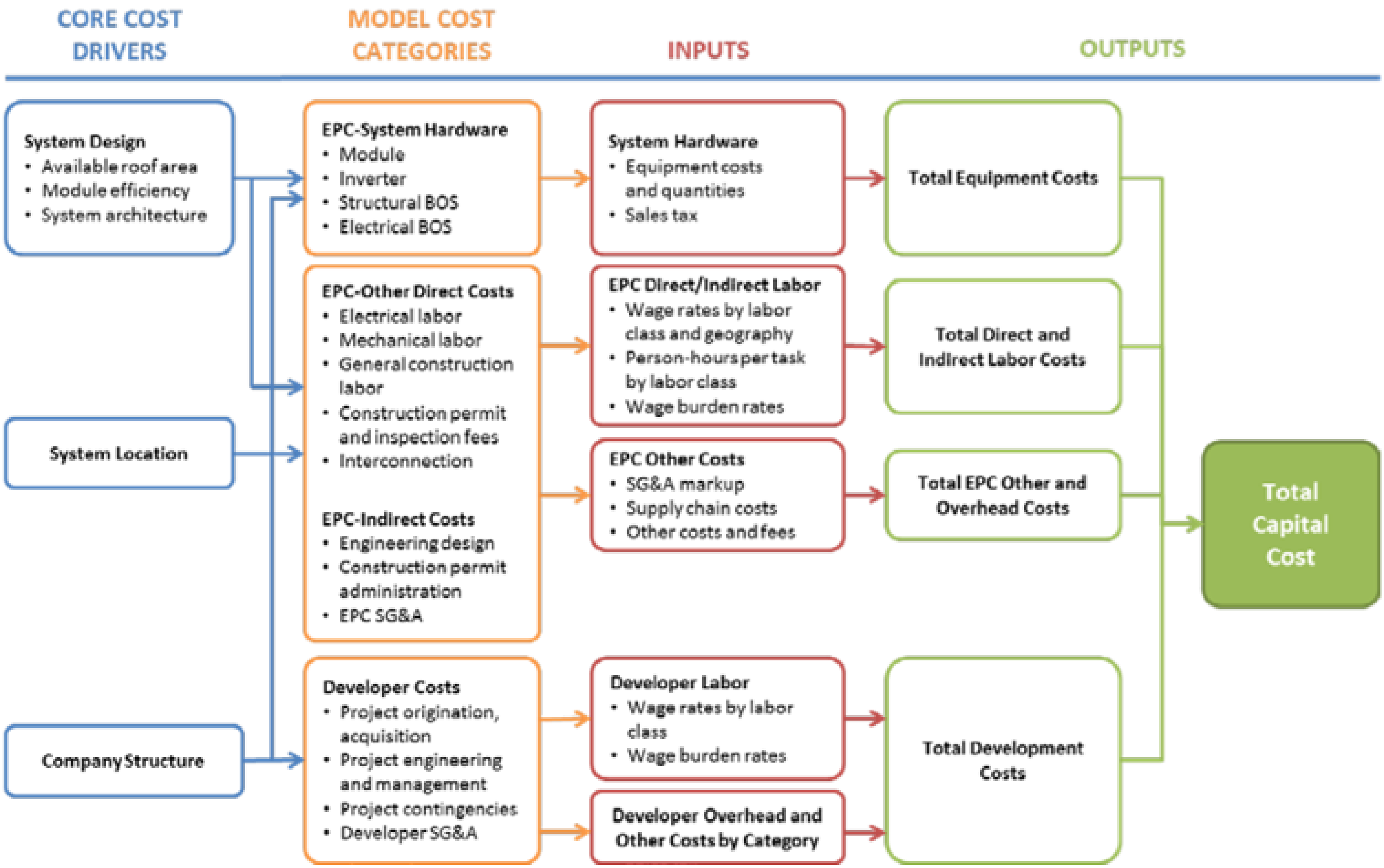


Figure 2. A schematic relationship of core cost drivers, cost categories, inputs, and outputs for PV system cost model

Source: Fu et al. (2017).

2.2. Methodology

2.2.1 Design Optimization Using HelioScope PV Modeling Software

Modeling the built area, analyzing the insolation incident, and estimating the suitable rooftop area is a vital step in assessing the potential of the building for city-scale solar deployment. To estimate the rooftop solar PV technical potential in Wilmington and Newark, we used HelioScope PV modeling software. HelioScope supports the PV system design and installation process with bankable performance modeling tools. The tool provides solar developers with CAD-caliber layouts and remote shade analysis that is fast enough to assess a location's solar potential without time-intensive and costly site visits (National Renewable Energy Laboratory, 2018). These cost savings in on-site data assessments directly benefits solar PV developers and installers. NREL estimates that costs related to on-site assessment of rooftop PV potential constitute 55% of customer acquisition and engineering design costs. By using bid preparation and performance monitoring software tied with integrated shading-modeling analysis such as HelioScope, developers can save approximately US$0.17 per watt on a 5 kW PV solar system (Ardani et al., 2013).

Using HelioScope software, Google Earth visual inspection, and LiDAR-GIS methods, our study assessed a total of 97 and 28 rooftops of municipally-owned or controlled buildings in Wilmington and Newark, respectively. Out of these, a total of 30 and 8 rooftops were prioritized as "shovel-ready" projects for the first phase of development in Wilmington and Newark, respectively, considering factors such as suitability of rooftop space and economies of scale. Our assessment focused only on flat rooftops with slope tilts of less than 9.5 degrees. We also modelled shading simulations and spacing restrictions to account for rooftop obstructions, including mechanical equipment, surrounding trees, and other factors. Table 3 summarizes design assumptions used in the HelioScope modeling and analysis. The LG365Q1C-A5 module, with a power rating of 365 W and conversion efficiency of 21.1%, is assumed to provide optimal power matching and a DC/AC ratio of approximately 1.2.

Table 3: HelioScope data design assumptions

System Metrics & Components	Assumptions
Solar PV System Metrics and Components	
Module (LG brand)	LG365Q1C-A5 (365 W)
Inverter (SMA brand)	Sunny Tripower 24000TL-US (12-30 kW)
String wiring	10 AWG (Copper)
Performance ratio	82-89%
Solar PV Production	
Irradiance	kWh/m^2
Energy	kWh
Design Segment	
Racking	Fixed tilt
Module azimuth	180° due south
Modules per string	Target Range: 5 - 19 modules
Module Spacing	0.041 ft
Setback and Row Spacing	2 ft each, both sides totaling 4 ft each
DC/AC Ratio	1.1-1.2
Temperature Metrics / Condition Set	
Weather Dataset	TMY3, Wilmington New Castle County, NSRDB
Solar Angle Location	Meteo Latitude/Longitude
Transposition Model	Perez Model
Temperature Model	Sandia Model
Soiling (%)	2
Irradiation Variance (%)	5
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%
Types of System Losses	
AC system, shading, reflection, soiling, irradiance, temperature, mismatch, wiring, clipping, and inverters.	

2.2.3 Economic Analysis Using System Advisor Model

The following section highlights our economic analysis based on the SAM (System Advisor Model) version 2018.11.11 r3, SSC 207 provided by NREL. SAM is a performance and financial model software that is capable of running hourly or sub-hourly simulations to calculate a solar power system's electrical output as well as a project's cash flow over the analysis period. The financial models represent two principal types of projects: (a) residential and commercial projects that buy and sell solar electricity at retail rates thereby displacing purchases of power from the electric grid and are financed through either a loan or cash payment i.e., 0% debt percent; and (b) power purchase agreement (PPA) projects that sell electricity at a wholesale rate to meet a set of equity returns requirements. The sum of the hourly or sub-hourly simulations is the total annual output that the financial model uses to determine the financial metrics and annual cash flows.

The inputs for the PV commercial financial model include the location and solar resource weather file, module and inverter types, system design, shading and layout, irradiance, DC/AC and transmission losses, lifetime, system costs, financial parameters, time of delivery factors (uniform dispatch, generic summer peak, etc.), incentives, depreciation, electricity rates, and electric load. SAM uses these parameters to create an annual project cash flow detailing hosts costs and savings (electricity bill with and without system, energy value in each year, host agreement cost, host after-tax cash flow), developer revenues (PPA price, PPA revenue, salvage value and total revenue), developer operating expenses (O&M fixed expenses, O&M production-based and capacity-based expenses, property tax and insurance expenses), EBITDA (earnings before interest, taxes, depreciation, and amortization), state and federal taxes, depreciation and solar investment tax credit (ITC), and its net present value (NPV).

We tested three possible economic scenarios: (a) outright purchase whereby city governments of Wilmington and Newark each finance their SCP from their balance sheets; (b) municipal bond financing whereby the municipalities raise funds through the municipal bond market once a sufficient scale of technical potential is reached; and (c) low-cost sustainable energy loan available through the Delaware Sustainable Energy Utility (DE SEU) program for clean energy projects. We model the system's economic performance using a 20-year, 2% loan from the DE SEU and we assume that an equity investor[11] takes advantage of the federal tax provisions—a MACRS 5-yr (Modified Accelerated Cost Recovery System) depreciation and the solar ITC.

Table 4 summarizes SAM inputs for location and resource, module, inverter, system design, system cost and financial parameters. Both Wilmington and Newark share climatic conditions hence the weather file used was from "USA DE Wilmington New Castle County AP (TMY3)" provided by NREL National Solar Radiation Database (NSRDB) based on 30-year historical data. Also, the system cost data was obtained from NREL, in particular, the most recent benchmark reports for the region.

The estimated total installed cost in Table 4 (US$1.83/W) is consistent with NREL's commercial PV levelized cost of energy benchmarks for Q1 2018, as detailed in Fu et al. (2018) and Fu et al. (2017), adjusted for inflation (see Table 2). According to Fu et al. (2018), commercial PV system prices for a 200 kW system unit stood at US$1.83/Wp (2018 US$) in Q1 2018 down from US$5.43/Wp in 2010, a compound annual price drop of 12.7% per year or a total price decline of over 65%.

[11] An equity investor in a PPA refers to a project financing option whereby an investor would purchase a stake in the WSCP-1 and/or NSCP-1 in exchange for ownership of tax credits and typically SRECs. Generally, cities cannot qualify for solar tax credits or often SRECs because they are restricted to for-profit entities. It is vital for Wilmington and Newark to prepare a detailed project finance structure. This includes a description of the roles and responsibilities of key stakeholders, their percentage shareholder value in the project, any risk mitigation instruments adopted (for example standardization of the scope of work say through joint negotiations, financial guarantees, aggregation, tranching, or access to liquidity facilities) and their impact on the investment.

Table 4: SAM system design, cost, and financial assumptions

PV System Characteristics		
PV system installation tilt		5 degrees
Module area to roof area ratio		0.63
Azimuth		180 degrees (south facing)
Solar panel module efficiency (nominal)		21.1%
Inverter weighted efficiency		98.05%
Location and Resource, Module, Inverter and System design		
System Component	**Parameter**	**Value**
Location	TMY weather file	USA DE Wilmington New Castle County (TYM3)
Module	Mounting standoff	Ground or rack mounted
	Array height	Two story building or higher
System Design	Desired array size	Estimated technical potential
	Tracking and orientation	Fixed

System Cost (US$/watt)	
Parameter	**Wilmington and Newark (Commercial Size)**
Module cost	US$0.47/Watt
Inverter cost + warranty	US$0.08/Watt
BOS equipment	US$0.26/Watt
Installation labor	US$0.16/Watt
Installer margin and overhead	US$0.18/Watt
Permitting and environmental studies	US$0.10/Watt
Engineering and developer overhead + profit & grid interconnection	US$0.48/Watt
Land purchase	US$0.00 / acre
Operation and maintenance costs + insurance	US$0.016/Watt
Contingency	4%
O& M escalation	2%
Total	**US$1.83/Watt**

3. TECHNICAL SOLAR CITY PLANT POTENTIAL OF WILMINGTON AND NEWARK

The combined use of the LIDAR-GIS database followed by individual building-level analysis using HelioScope software and SAM PV modeling methods provides useful insights into the technical PV potential and generation profile of the public building stock across the two cities. These insights are highlighted below in order to better understand the benefits of SCP for both Wilmington and Newark.

3.1. The Wilmington 'Solar City' Plant

3.1.1. Project Summary

Our analytical method identified 30 buildings and properties in the city of Wilmington for the first phase of solar development, including 21 priority city-owned buildings, four city parking garages, one building in the Riverfront district (the Chase Convention Center), four large warehouses at the Port of Wilmington. Using the data and assumptions outlined in the previous section of this report, assessed technical potential of these priority city-owned properties is estimated at just over 3.0 MWp of solar PV capacity. Under full deployment, the identified building stock has an estimated electricity production capacity of approximately 7.9 MWp at an estimated installed cost of about US$14.5 million in the first phase.

In terms of the insured city-owned rooftops administered by the Department of Facilities, a total of 66 public buildings in the "insured file" and 88 buildings from the database downloaded from New Castle County GIS Data Viewer—were carefully inspected individually, using Google Earth software, to verify their physical locations, type of rooftops (flat or sloped), and presence of any mechanical equipment on the rooftops. The following three main principles define the WSCP-1:

- The SCP is owned by the city but day-to-day operations and management of the solar power plant is performed by a third-party, either a utility or a private developer through a lease for an agreed duration with the city;

- The city update its building codes to enable and accommodate using its public buildings for solar power development);
- The project is revenue-neutral to the city. In this regard, the net sales revenues the city receives from the SCP must be equal to or greater than the net revenues.

The following were identified as potential archetypes of a Wilmington SCP-1:

- Provide clean, renewable and sustainable sources of electricity to the city to meet its sustainability objectives.
- Meet the City's share of the State RPS policy targets through 2030.
- Enhance energy equity in the State through improved participation of Wilmington residents.[12]
- The SCP approach would lower technology costs due to City-anchored large procurements.
- It would produce indirect benefits such as increased property value as more buildings host power plants on their roofs, thereby attracting new businesses and incentivizing building owners to expand development in real estate.

3.1.2. Evaluating PV Technical Potential and Capital Cost for Rooftops in Wilmington

We applied a simple payback calculation methodology, expressed as "annual electricity generation x US$1.83/W". No consideration for the cost of capital, project lifetime, or financing structure is factored in this methodology. Tables 5 and 6 list city-owned priority buildings in Wilmington, and selected facilities in

[12] Wilmington is home to a high share of citizens eligible for financial assistance from federally supported Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP) funds. Therefore, it would be useful to examine a clean energy equity strategy in the Delaware SEU charter—solar lifeline rate: would benefit from the set aside share of SCP generation to eligible moderate income families at a reduced rate; for example a lower electricity rate for the initial 250 kWh per month of consumption.

the Riverfront area, the Port of Wilmington, and parking garages deemed suitable for rooftop solar energy, respectively.

A total of 21 city-owned rooftops and 4 garages were identified with an estimated total generation capacity of about 3.0 MWp and installed cost of US$5.9 million. The Public Safety building located at 300 North Walnut Street and the Emergency Management Operations building located at 22 South Heald Street had the highest estimated installed capacity of 154.1 kWp each. In the Riverfront area, the Chase Convention Center has an estimated PV generation potential of 655.2 kWp.

With a combined estimated capacity of approximately 7.9 MWp and installed cost of about US$14.5 million (all priority buildings), this estimated capacity can meet >100% of City's share of Delaware's solar carve-out.

Table 5: Estimated PV technical potential and costs of Wilmington public buildings

Building / Rooftop Unit	Address (Wilmington, DE) / Geo-location	HelioScope Estimated Output (kWp)	Installed Cost (US$)
Fire station #1	400 W. 2nd St. (39.739891, -75.555743)	41.0	75,030
Fire station #2	400 New Castle Ave. (39.729556, -75.542534)	41.8	76,494
Fire station #3	333 E. 30th St. (39.752485, -75.525237)	43.6	79,788
Fire station #4	2200 N Tatnall St. (39.753304, -75.540119)	45.6	83,448
Fire station #5 (new)	224 N Union St. (39.758851, -75.560958)	62.7	114,741
Fire station #6	1806 N. Dupont S. St. (39.748403, -75.573207)	41	74,620
Police dept. (public safety bldg.)	300 N. Walnut St. (39.738733, -75.548389)	154.1	282,003
Emergency management operations bldg.	22 S. Heald St. (39.732608, -75.541146)	154.1	282,003
Hot / cold storage building	500 Wilmington Ave. (39.722389, -75.540567; 39.721955, -75.539412; 39.722079, -75.539805; 39.722548, -75.539618; 39.7219267, -75.5401814)	896.6	1,640,778
Vehicle wash building			
Salt Storage Building			
Public works yard[13]			
Office block			
Porter filtration plant #1	2052 E. Park Dr. (39.773729, -75.541122)	104.6	191,418
Brandywine filtration station #2	303 E. 16th St. (39.749273, -75.542094)	274.5	502,335
Water quality lab	203 E. 16th St. (39.749920, -75.543360)		
City Louis Redding building	800 N French St. (39.742689, -75.546736)	79.2	144,936
Parks & recreation #1	13 E 7th St. (39.7387596, -75.5394002)	21.6	39,528
Parks & recreation #2	232 N Adams St. (39.7423068, -75.5602074)	418.7	766,221
Parks & recreation #3	300 N Clayton St. (39.746786, -75.568327)	7.20	13,176
Water division	103 East 16th St. (39.749259, -75.5421358)	248.0	453,840
Total Estimated Capacity for Priority Buildings in the "Insured Building File"		**2.417 MW**	**US$4,820,359**

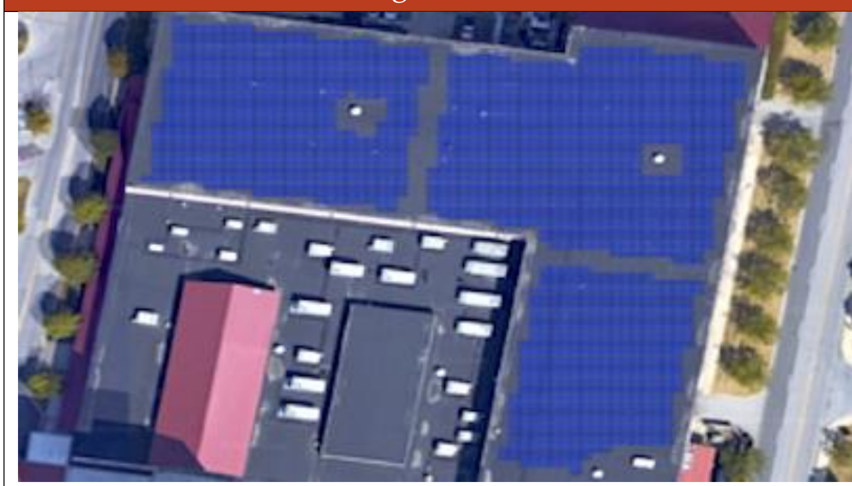
[13] Buildings in the Public Works yard include vehicle maintenance facilities, offices, repair garages, and above ground fuel pumping stations.

Table 6: Estimated technical potential and installed PV costs for the Riverfront district, the Port of Wilmington, and parking garages roof areas

Building and Other Facilities	Geo-location	Estimated Capacity / Annual Output	Installed Cost (US$)
Riverfront Business District			
Chase Convention Center	39.731384, -75.562872	655.2 kWp / 901.3 MWh	1,199,016
Port of Wilmington			
Large warehouse at Port of Wilmington (97,698 sf)	39.714040, -75.528427	961.4 kWp / 1.365 GWh	1,759,362
Large warehouse at Port of Wilmington (371,69 sf)	39.719657, -75.528293	1.62 MWp / 2.297 GWh	2,964,600
Large warehouse at Port of Wilmington (301,626 sf)	39.718915, -75.526354	1.21 MWp / 1.728 GWh	2,214,300
Large warehouse at Port of Wilmington (65,893 sf)	39.715931, -75.517564	256.6 kWp / 366.6 MWh	469,578
Sub-total of Chase Convention Center and Port of Wilmington rooftops only		*4.703 MWp / 6.658 GWh*	*$7,407,840*
Parking Garages Managed by the Wilmington Parking Authority (WPA)			
Corporate Plaza	39.749376, -75.553512	99.8 kWp / 136.7 MWh	182,634
Brandywine Gateway Garage	39.748300, -75.545207	214.1 kWp / 301.9 MWh	391,803
10th Street Garage	39.747628, -75.552252	98.2 kWp / 134.5 MWh	179,706
Train Station Garage	39.737221, -75.552425	186.2 kWp / 254.5 MWh	340,746
Parking garages sub-total		*598.3 kWp / 827.6 MWh*	*$1,094,889*
Estimated technical potential of city-owned buildings (priority buildings in the "Insured Building File" and parking garages) only		3,094.4 kWp	$5,915,658
Total Estimated Capacity of All Priority Buildings (City-Owned Buildings in the "Insured Building File" and Riverfront buildings, Port of Wilmington Warehouses, and City-Owned Garages)		**7.936 MWp**	**US$14,522,514**

The total capacity for city-owned buildings on the “insured buildings file” provided by the Department of Public Works is 2.4 MW and installed cost is estimated to be about US$4.8 million. However, we could not ascertain whether the “insured buildings file” contained all the buildings owned by the City of Wilmington. A further inspection of the “insured buildings file” shows that there are 37 city-owned buildings in the “state registry building file” that are not in the “insured buildings file”, including large buildings with flat roofs at the Port of Wilmington, the Riverfront area, city parking garages, and several buildings on Cherry Island. For example, we identified potential capacity of nearly 0.65 MWp, 4.048 MWp, and 0.59 MWp for the Chase Convention Center, Port of Wilmington, and four city parking garages, respectively, as shown in Table 6. Table 7 summarizes HelioScope performance estimation of priority PV capacity and generation potential for buildings in Wilmington (including those at the Port and in the Riverfront area, and the four city-owned garages).

Table 7: HelioScope modeling results for selected city-owned buildings and other properties in Wilmington

Wilmington City-Owned Priority Buildings		
 Fire station #1: 400W 2nd St.	 Public Safety Building	 Fire station #5: 224 N Union St.
Size: 41 kWp Cost: US$75,030 Yield/yr: 55.93 MWh	Size: 154.1 kWp Cost: US$282,003 Yield/yr: 209.8 MWh	Size: 62.7 kWp Cost: US$114,741 Yield/yr: 86.19 MWh
Riverfront District Buildings		
 Chase Convention Center		 City County Louis Redding
Size: 655.2 kWp Cost: US$1,199,016 Yield/yr: 901.3 MWh		Size: 79.2 kWp Cost: US$144,936 Yield/yr: 107.9 MWh

3.1.3. Solar Parking Canopies and Emerging Innovations

Solar parking canopies refer to elevated structures that are installed in parking lots and multi-floor garages to support solar PV electricity systems. Major metropolitan urban regions in the U.S. and elsewhere are increasingly utilizing solar parking canopies and other urban fabrics as the solar power plant of the future (Byrne and Taminiau, 2018). In the case of Wilmington, a significant portion of the city's real estate is occupied by parking lots and garages. This makes parking canopy infrastructure a potentially vital "urban solar fabric" worth investigating for WSCP-1 due to the low cost of their serviceability and availability.

Solar parking canopies provide a range of economic, environmental, and social benefits. The clean, sustainable, and low-carbon electricity generated from the "urban solar fabric" can reduce electricity bills and support peak energy demands. For example, in a study summarized by the U.S. Environmental Protection Agency involving the University of Massachusetts car parking facilities, important shading and economic benefits are indicated (U.S. Environmental Protection Agency, 2017). Other researchers have analyzed the urban infrastructure benefits, including mitigating urban heat island (UHI) effect and reduced thermal impacts on surface temperatures and observed that their untapped potential will be enhanced as the cost of PV continues to decline (Golden et al., 2007); other researchers such as, Alghamdi et al. (2017), have found benefits as well.

While conventional parking canopies focus on shading properties from extreme weather conditions like hail, ice, snow, and sun, solar PV canopies are designed to maximize electricity production as well. As a result, asset protection may not be the primary objective in the design of PV modules' supports (Structural Solar, 2019). The canopies are designed either as a single or double row carport. Due to spacing and structural design considerations, the double row carport structure is the mostly used type of carport structure for parking of large number of vehicles (Umer et al., 2019). These structures are classified into three main forms:

a) Monopitch: A monopitch canopy has a single surface slope (Figure 3), which has the same slope angle at a given time. Our analysis shows a small gain (~4%) in solar PV generation at a tilt angle of 9.8° as compared to 5° or less, as shown in Figure 4, because, as the tilt angle changes, the irradiance level changes too, and this impacts the PV generation capacity.

b) Duopitch: A duopitch or dual-tilted inward structure canopy has two rows of roofs at the south and the north facing each other, as shown in Figures 5 and 6. It contains a decking and gutter system to provide drainage and structural integrity (University of Massachusetts at Amherst, 2017).

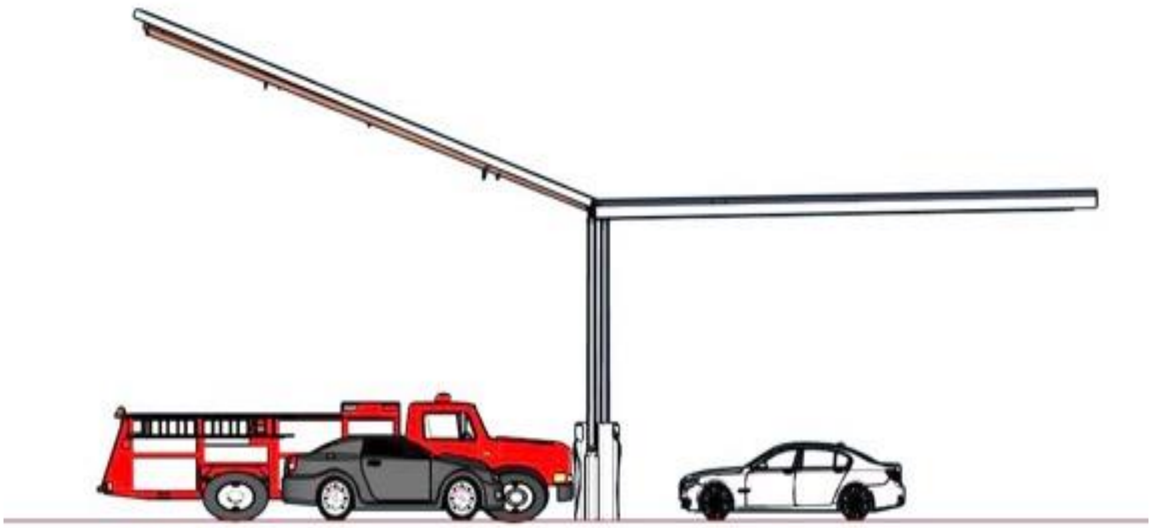


Figure 3: Aerial view of monopitch or single-tilted inward solar canopy

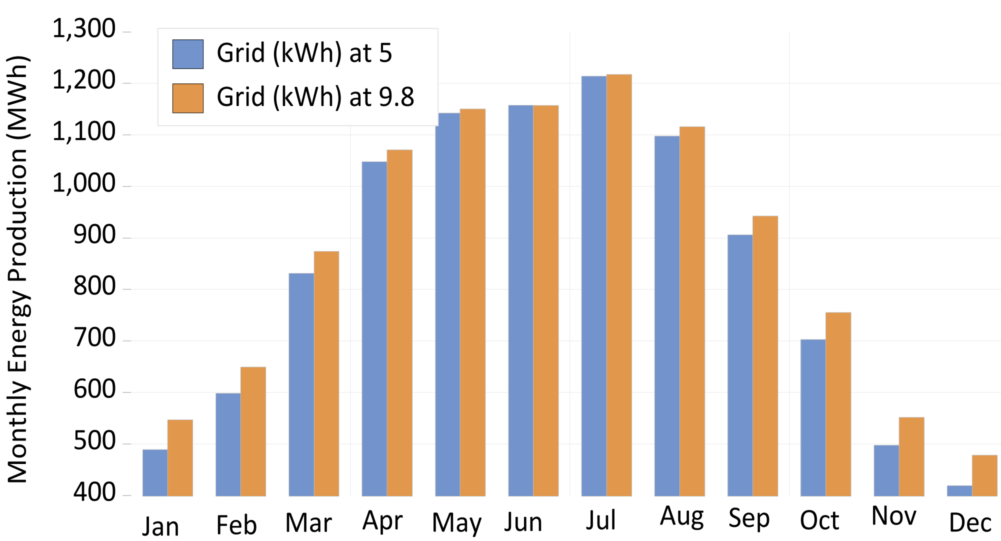


Figure 4: Monopitch monthly generation at tilt angles 5° and 9.8°

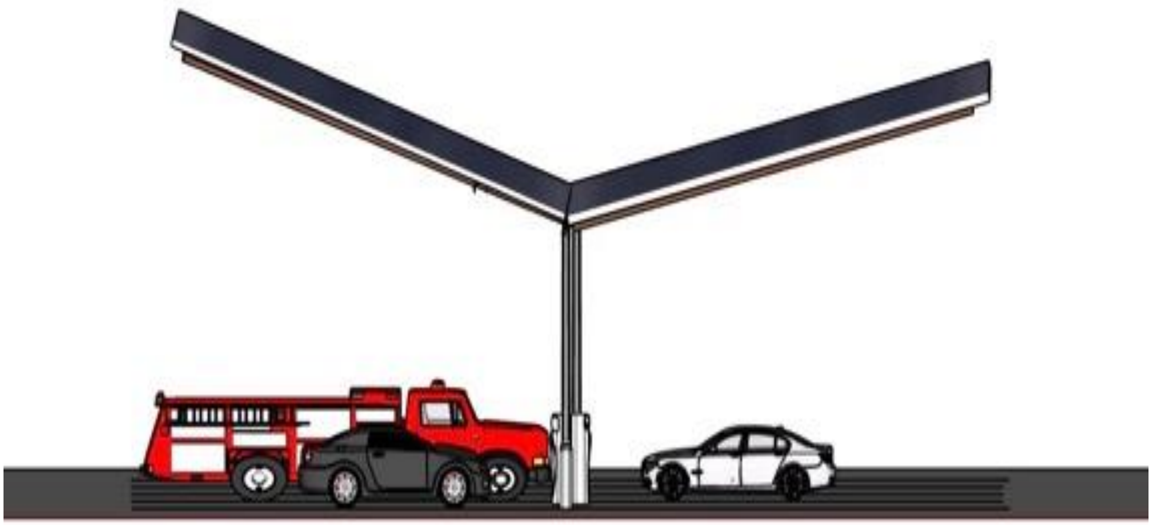


Figure 5: Side view of duopitch solar PV carpot

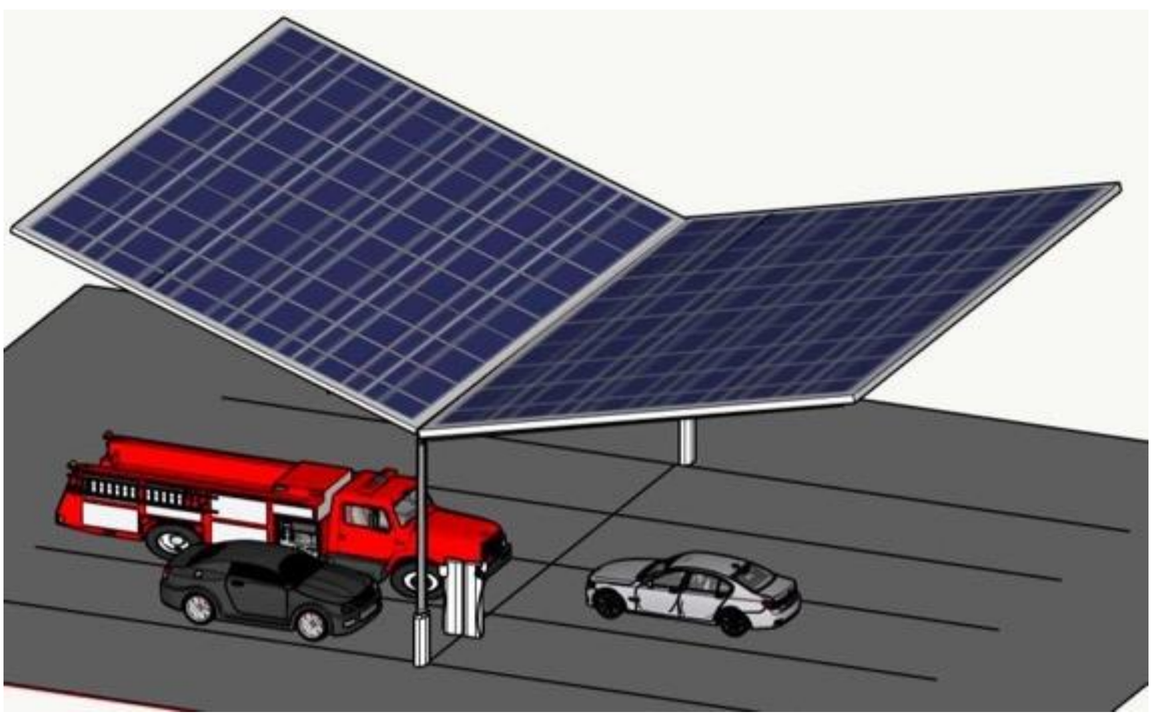


Figure 6: Aerial view of duopitch solar parking canopy

The most efficient structural design focuses both on load-bearing and space-saving. Figure 7 depicts a solar PV carport, covering only the entire parking areas, with PV modules resting on cables that are drawn across the parking garage (Neumann et al., 2012).

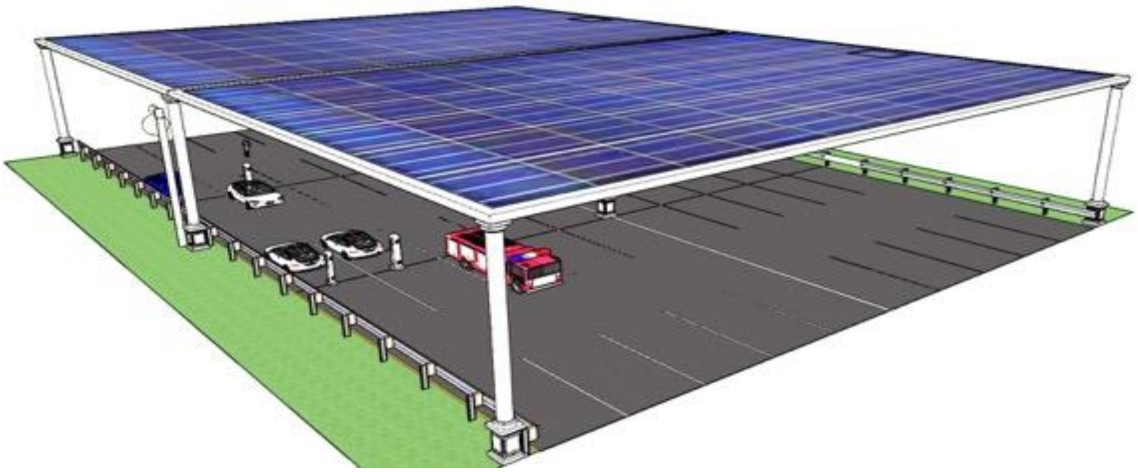


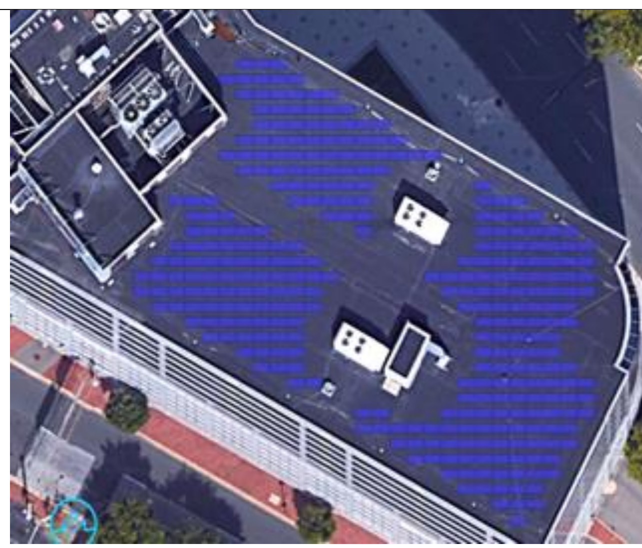
Figure 7: Side view of cable-based solar PV parking canopy

European countries like Germany have identified parking garages as a vital urban infrastructure for supporting solar PV installation and extended incentives to promote their development since 2011 (Enkhardt, 2017). Across the United States, a growing number of states have also recognized the potential of parking garages to promote solar energy deployment and have started extending financing incentives to these "urban solar fabric" infrastructure. For example, Massachusetts and Maryland provide dedicated grant programs for solar PV canopies (Maryland Energy Administration, 2019). Under section 48 of Maryland's Solar Photovoltaic Canopy with EV Chargers Grant Program, solar carport structures are eligible for ITC incentives (Sullivan, 2017). Nevertheless, to promote "urban solar fabric" development, it is imperative that building ordinances that regulate clearance heights for emergency vehicles and trucks, and building design needs, including structural functionality, equipment safety, and mismatch of the minimum lifespan of the parking garages and that of solar PV panels be standardized across cities.

The Wilmington Parking Authority (WPA) currently manages four parking garages, namely Corporate Plaza, Brandywine Gateway, 10th Street, and Train

Station garages, and there is significant potential for development of this urban solar architecture in the city. Table 8 summarizes HelioScope estimation for the four city parking garages in Wilmington.

Table 8: Estimated PV potential for parking garages in Wilmington

Parking garages in Wilmington	
 10th Street Garage: 1001 Washington Street	 Train Station Garage: 117 E Martin Luther King Blvd.
Size: 98.2 kWp Cost: US$179,706 Yield/yr: 134.5 MWh	Size: 186.2 kWp Cost: US$340,746 Yield/yr: 254.5MWh
 Brandywine Gateway Garage: 1320 N Market St.	 Corporate Plaza: 612 W 11th St.
Size: 214.1 kWp Cost: US$391,803 Yield/yr: 301.9 MWh	Size: 99.8 kWp Cost: US$182,634 Yield/yr: 136.7 MWh

3.1.4. Conclusions

The WSCP-1 focused on a priority pool of buildings with a total estimated generating capacity of about 7.9 MWp and installed cost of nearly US$ 14.5 million. Out of this, the estimated capacity for city-owned public buildings only, including the four parking gages, is about 3.0 MWp and the installed cost is estimated to be about US$5.9 million. Table 9 summarizes outputs of key metrics for the WSCP-1.

Table 9: Key SAM metrics for WSCP-1

Wilmington SCP1: Payback Period—20 Years

Metric	Year 1	Year 5	Year 10	Year 15	Year 20
System size (kWdc)	7,900				
Annual energy (kWh)	9,983,534	9,785,356	9,543,156	9,306,951	9,076,592
Capacity factor (%)	14.4				
Energy yield (kWh/kW)	1,264				
Performance ratio	0.82				
PPA price (¢/kWh)	9.68				
Levelized cost of energy (¢/kWh)	8.04				
Total installed cost ($)	~ $14.5 million				
Total revenues ($)	966,107	946,929	923,491	900,634	878,342
Total operating expenses ($)	270,603	281,020	295,258	310,977	328,333

NOTE: Levelized Cost of Energy (LCOE) "measures lifetime costs divided by energy production" calculating the "present value of the total cost of building and operating a power plant over an assumed lifetime." The method is widely used to compare different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, with different capital costs and operating and maintenance costs (including fuel costs—a major cost category for plants using non-renewable energy), and different risks, return, and capacities. See, U.S. Department of Energy (2013b).

The widely used method of LCOE (levelized cost of energy) can help the City of Wilmington to assess the competitive potential of the WSCP-1 proposal. Figure 8 indexes energy generation and end-use energy saving technologies by LCOE based on an analysis prepared by the Energy Information Administration of the U.S. Department of Energy for new plants that will be placed in operation by 2022 (see below) (U.S. Energy Information Administration, 2017). For new generation, solar PV plants rank below all but two conventional generation options in the US (advanced and conventional natural gas combined cycle units). And as an investment, it is cost-effective compared to several clean energy options and is tied with new hydro plants in LCOE. It has the special advantage (not measured by the LCOE method) of being capable of installation in cities. The economic benefits its contributions to environmental protection and public health are not captured by standard LCOE methodology. Thus, its economic benefit to the City is conservatively measured here and is found to be competitive.

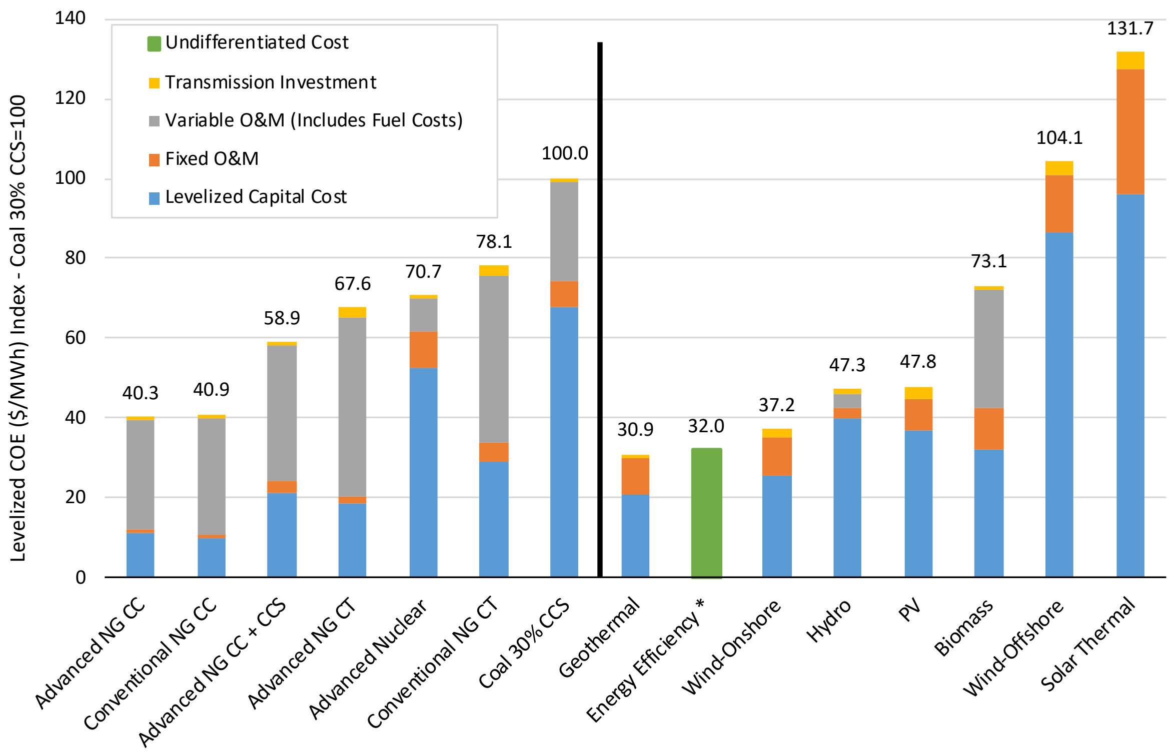


Figure 8: Estimated LCOE index for new generation sources, for plants entering into service in 2022

Source: U.S. Energy Information Administration (2017).

Note: Levelized cost with tax credits reflects tax credits available for plants entering service in 2022.
Note: EIA's Table 1B did not include energy efficiency. To estimate its LCOE, the following sources were used – Hoffman et al. (2017). Estimating the cost of saving electricity through U.S. utility customer-funded energy efficiency programs, Energy Policy 104: 1-12. doi: 10.1016/j.enpol.2016.12.044.
* Weighted average total cost of saved electricity was $0.046/kWh for 20 states in 2009–2013. An energy efficiency estimate for 2022 is based on an Automatic Energy Efficiency Indicator (AEEI) of 0.75%. This figure is derived from econometric studies by: Hassol et al, 2002 "Energy Efficiency: A Little Goes a Long Way." In: Watts, R, (ed.) *Innovative Energy Strategies for CO2 Stabilization*. (pp. 87-120). Cambridge University Press ; and Alcamo et al.,1998 "An instrument for building global change scenarios." In J. Alcamo, R. Leemans, and E. Kreileman (Eds.), Global Change Scenarios of the 21st Century (pp. 3-96). Oxford: Pergamon.

3.2. The Newark 'Solar City' Plant

The Newark SCP-1 is built on the following principles:

- The SCP is owned and operated by the city's municipal utility with all PV systems installed within its administrative boundary;
- The city would maintain current contractual obligations with DEMEC (and may choose to ask DEMEC to operate the plant on its behalf);
- The project must be revenue-neutral to the city—that is, the city must receive net sales revenues from the SCP that are equal to or greater than the net revenue received by the city for equivalent sales to its billed customers.

A range of potential benefits would accrue to the Newark solar city:

- Newark could obtain city-located electricity from clean, renewable and sustainable sources to further its sustainability planning;
- The city would meet its share of all state policy targets for solar and renewable electricity through 2030;[14]
- The city and its largest electricity consumer, the University of Delaware, could present themselves as low-carbon prosumers and improve electricity choices for their customers (Nyangon and Byrne, 2018), including advertising Newark as a Solar City realized by 'town-and-gown' cooperation;
- To ensure full participation of all of Newark's residents, a solar lifeline program could be added which sets aside a share of SCP generation to be credited to qualifying moderate income families at a reduced rate (for example, the initial 250 kWh of monthly household electricity consumption

[14] Assumes that Delaware pursues a requirement of 30% renewable electricity use and 6% solar electricity use by 2030. These estimates are above the existing requirement of 25% renewable electricity use and 3.5% solar electricity use by 2026. Higher state targets can be accommodated.

of families eligible for the State's Weatherization Assistance Program might be priced at a solar lifeline rate);

- The SCP can be designed to invite participation by real estate developers, business owners, and residents who would benefit from lower technology costs due to city-anchored large procurements;

- Participants could be offered long-term fixed price electricity contracts, or equivalent incentives, for the share of generation hosted on their roof, thereby attracting new businesses and residents and incentivizing building owners to expand their involvement.

3.2.1. Evaluating PV Technical Potential and Capital Cost for Rooftops in Newark

A total of 28 public buildings were identified from the LiDAR-GIS database. Each building meets our threshold criteria for hosting PV system based on shading, roof orientation and slope, and minimum (10 m^2) contiguous area (threshold criteria are described in Byrne et al. (2018)). Buildings had more than 140 square meters of rooftop space. A total of 14 city-owned buildings were then evaluated for their suitability for solar power production. From this sample, 4 city-owned buildings were selected for a Newark SCP-1 strategy (see Table 10).

The University of Delaware has more than 200 buildings in the city boundary. Some are on the State's historic registry and others are not eligible for evaluation because of roof condition, age, and other factors. In discussions with the University of Delaware Community Engagement Initiative Project researchers identified 12 "priority" buildings for faster evaluation. Table 11 denotes the University "priority" buildings for Newark SCP-1. The selected buildings have mostly flat roofs. The Carpenter Sports Building has a section of the rooftop that is curved (shaped like the University's Delaware Field House), which we have excluded from our analysis. The University buildings were grouped into three building complexes and represent 73% of the available public building rooftop area. With a combined estimated capacity of ~ 0.7 MWp, installed cost of ~ US$1.3

million, and greenhouse gas emissions reduction of ~255 $MtCO_2$ (buildings only), the priority pool of city-owned buildings (Table 10) can meet 60% of Newark's share of the state's RPS and >100% of City's share of Delaware's solar carve-out.

Table 10: Newark solar city priority building selection

City-owned Priority Buildings	Estimated Capacity (MWp / MWh)	Installed Cost (US$)
Municipal Building	~ 0.15 / 198	~ 274,500
City Warehouse Complex	~ 0.5 / 628	~ 915,000
George Wilson Community Center	0.03 / 42	~ 54,600
Total (7 rooftops in total)	**~ 0.7 / 868**	**~ US$1.28 million**

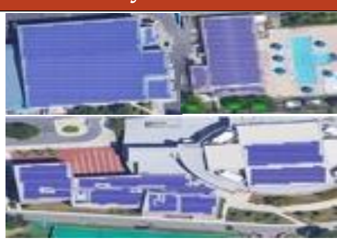
The city-owned "priority" buildings in Table 10 can serve ~ 22% of annual city government electricity use. The University-owned priority pool adds ~ 3.2 MWp of solar capacity at an estimated cost of nearly US$5.8 million. At this estimated capacity, the City of Newark would more than meet its share of the State's RPS and solar carve-out targets. Significant potential benefits can be achieved under the *City of Newark – UD Clean Energy Partnership*. Our estimates show that under this partnership that combines the City of Newark and the University of Delaware "priority" buildings, a total of ~ 3.9 MWp solar PV capacity generations ~ 5,354 MWh/year at an installed investment cost of ~ US$7.1 million is available.

Table 11: University of Delaware priority buildings (n=number of buildings)

Priority Buildings	Estimated Capacity (MWp /MWh)	Installed Cost (US$)
Perkins Student Center	0.39 / 553	713,700
Graham Hall Complex (Graham Hall, Pearson, Composite Materials, n=3)	0.35 / 490	640,500
UD Sports Buildings (Gold Ice Arena, UD Ice Arena, UD Carpenter Sports Building, Bob Carpenter Center, n =4)	1.28 / 1,785	2,342,400
UD Music & Arts Complex (n = 2)	0.241 /336	441,030
Trabant University Center	0.29 / 404	530,700
General Services Building	0.45 / 594	823,500
Total (12 rooftops in total)	**~ 3.2 / ~ 4,486**	**~ US$5.8 million**

Table 12 summarizes HelioScope outputs for the priority pool of city-owned and the University of Delaware-owned buildings in Newark.

Table 12: Estimated PV potential for priority rooftops in Newark

City of Newark Priority Buildings		
 Municipal Building	 City Warehouse Complex	 George Wilson Community
Size: ~ 0.15 MWp Cost: ~ US$274,500 Yield/yr: 198 MWh	Size: ~ 0.50 MWp Cost: ~ US$ 915,000 Yield/yr: 628 MWh	Size: ~ 0.03 MWp Cost: ~ US$54,600 Yield/yr: 42 MWh
University of Delaware Priority Buildings		
 UD Sports Complex (Incl. Gold Ice Arena, UD Ice Arena, and Bob Carpenter Sports Building)	 Carpenter Sports Building (Main Street, flat area only)	 General Services Building
Size: 1.28 MWp Cost: US$2,342,400 Yield/yr: 1,785 MWh	**Size: 0.47 MWp** Cost: US$823,500 Yield/yr: 660 MWh	**Size: 0.45 MWp** Cost: US$823,500 Yield/yr: 594 MWh
 Perkins Student Center	 Trabant Student Center	 Graham Hall (incl. Graham, Pearson, Composite Materials & Roundhouse)
Size: ~ 0.39 MWp Cost: ~ US$713,700 Yield/yr: 198 MWh	**Size: ~ 0.29 MWp** Cost: ~ US$530,700 Yield/yr: 628 MWh	**Size: ~ 0.35 MWp** Cost: ~ US$640,500 Yield/yr: 42 MWh

3.2.2. Conclusions

This first-phase of the Newark SCP analysis has identified a priority pool of buildings with a total of 3.9 MWp of rooftop PV potential, including 0.7 MWp of solar generation capacity hosted by 7 public buildings and 3.2 MWp hosted by 12 University of Delaware-owned building complexes. The initial economic assessment finds that a capital investment of approximately US$7.1 million (combining city- and university-owned buildings) can finance this estimated capacity at lower average electricity rates than currently paid by billed city customers provided that initial ownership of the facility includes a private company that can serve as the equity investor capable of taking advantage of federal tax incentives and the solar carveout provisions of the state's RPS. Table 13 summarizes outputs of key metrics for the NSCP-1.

Table 13: Key SAM metrics for NSCP-1

Newark SCP1: Payback Period—20 Years

Metric	Year 1	Year 5	Year 10	Year 15	Year 20
System size (kWdc)	3,900				
Annual energy (kWh)	4,925,998	4,828,215	4,708,710	4,592,164	4,478,502
Capacity factor (%)	14.4				
Energy yield (kWh/kW)	1,264				
Performance ratio	0.82				
PPA price (¢/kWh)	9.68				
Levelized cost of energy (LCOE) (¢/kWh)	8.04				
Total installed cost ($)	~ $7.1 million				
Total revenues ($)	476,694	467,231	455,667	444,388	433,389
Total operating expenses ($)	270,603	281,020	295,258	310,977	328,333

NOTE: Levelized cost of energy "measures lifetime costs divided by energy production" calculating the "present value of the total cost of building and operating a power plant over an assumed lifetime." The method is widely used to compare different technologies (e.g., wind, solar, natural gas) of unequal life spans, project size, with different capital costs and operating and maintenance costs (including fuel costs—a major cost category for plants using non-renewable energy), and different risks, return, and capacities. See, U.S. Department of Energy (2013b).

As observed in section 3.1.4 above, for new generation, solar PV plants rank below all but two conventional generation options in the US (advanced and conventional natural gas combined cycle units). And as an investment, it is cost-effective compared to several clean energy options and is tied with new hydro plants in LCOE (see Figure 8 above). It has the special advantage (not measured by the LCOE method) of being capable of installation in cities. The economic benefits its contributions to environmental protection and public health are not captured by standard LCOE methodology. Thus, its economic benefit to the City of Newark is conservatively measured here and is found to be competitive.

4. EMERGING INNOVATIONS IN SOLAR PV TECHNOLOGY

The analysis presented above uses the highest quality monofacial modules available today and best practices for orienting them on a flat roofs. In this report, we perform an early investigation of two innovative paths that could increase the estimated energy production on the same rooftops spaces beyond the well-established NREL guidelines. These innovations include:

a) Implementing bifacial PV modules that capture sunlight incident from both the front and back of the modules compared to the monofacial PV panels that capture sunlight from the front side only, as has been used in this report;

b) Using standard monofacial modules but orienting the modules in such a way that half the modules face east and the other half face west at very shallow angles. This dual tilt orientation allows more modules to be packed in the same area resulting in more energy production without the shading losses associated with placing the modules in close proximity, and;

c) Exploring the opportunity cost which evaluates whether it will be beneficial to install a solar system in the present time with today's module price and efficiency compared to waiting a fixed amount of time for the module price to drop and efficiency to increase.

The third innovation is not be covered in detail in this report. Below we expand on the first two innovations.

4.1. Bifacial PV Systems

There has been a significant increase in interest in bifacial modules mostly due to the realization that low cost electricity from PV can be achieved not only through cell and module efficiency or lowering their cost per Wp, but also through maximizing the energy output of a system. The main distinction between bifacial modules and standard modules is that bifacial modules can capture irradiance that strike the back surface as well as the front surface of the modules. Increasing the ground reflectivity on which bifacial modules are mounted is a key factor in maximizing the energy output of the system. Kopecek et al. (2015) report that utilizing ground reflected diffuse irradiance in a bifacial module can increase the system performance by up to 40%. This theoretical 40% increase, constitutes 30% from the bifacial gain and 10% from additional reflection to the front side. Data from several bifacial modules installed in different geographic locations show that bifacial gains of ~ 10-30% are achievable in the field depending on the ground reflectivity or albedo. This bifacial gain metric can be defined as the increase in specific energy yield (kWh/kWp) of the PV system with bifacial modules compared to monofacial modules at the same site, with the same configuration, and during the same time period. This typically refers to kWh for annual energy and kWp is the rated STC power.

Figure 9 shows the difference between a standard monofacial solar cell that captures both direct and diffuse light from the front and a bifacial cell that can utilize direct and diffuse light from the front as well as diffuse light from the rear side.[15] Assuming a typical or mid-range value of 20% for the bifacial module gain, their LCOE is still lower than any other monofacial module in the market (Kopecek et al., 2015). Appendix 3 summarizes annual production capacity gain for bifacial modules under different scenarios. At the end of 2016, the LCOE for the bifacial PERT module reduced from US$53/MWh to US$45/MWh, or by 17%. Simulation and outdoor testing have confirmed that the benefit with bifacial modules depends critically on the reflectance of the ground surface, the height and spacing of the modules. Commercial roofs with white membrane covering are ideal reflective surfaces. However the modules have to be mounted higher (1-2 feet) above the roof than for a typical flat rooftop project, therefore requiring consideration of wind loading.

[15] The schematic shows irradiance striking the back surface of a bifacial module that can result in a 40% increase in system performance (PV-Tech Power, 2018)

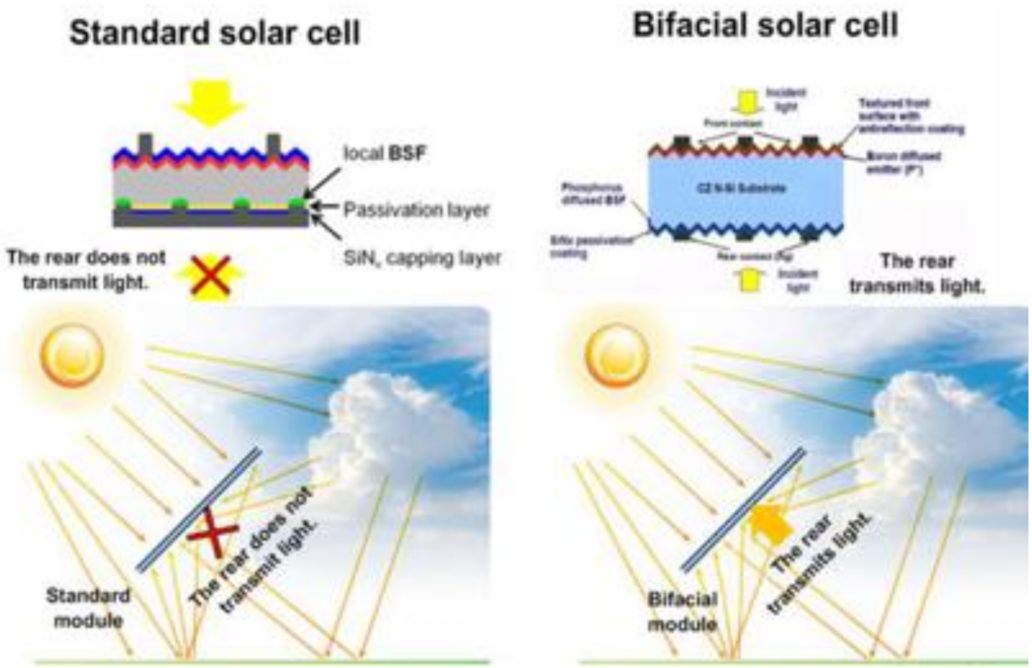


Figure 9: Schematics of standard and bifacial solar cells

Data for a small (5 kW) flat roof bifacial PV system installed by bSolar in Geilenkirchen, Germany and monitored by Fraunhofer/ISE shows a bifacial gain of 21.4% (KWh/KW) over nine months period in comparison with monofacial modules under the same conditions. The panels were 20 cm (8 inches) above the rooftop which is covered with a 78% reflective, white-coated membrane (Kopecek et al., 2015). Literature data shows that even locations with less than 0.2 albedo which might represent grasslands, show more than 10% increase in performance, as shown in Figure 10. Data was compiled by companies installing small scale bifacial modules (less than 5 KWp) such as PVG Solutions, bSolar, and Sanyo/Panasonic. If measures are taken to increase the ground albedo to more than 0.6, bifacial gains of 20 and 30% can be achieved. Ground albedo between 0.2 and 0.4 (dune sand) can occur naturally without enhancing the ground for increased reflectivity and thus span most site conditions. Fluctuations in bifacial gain shown in Figure 10 are attributed to i) climate (diffuse, snow), ii) installation height of modules, iii) distance between modules, iv) module tilt, v) rear side efficiency of modules, vi) design of modules and mounting racks (rear side shading).

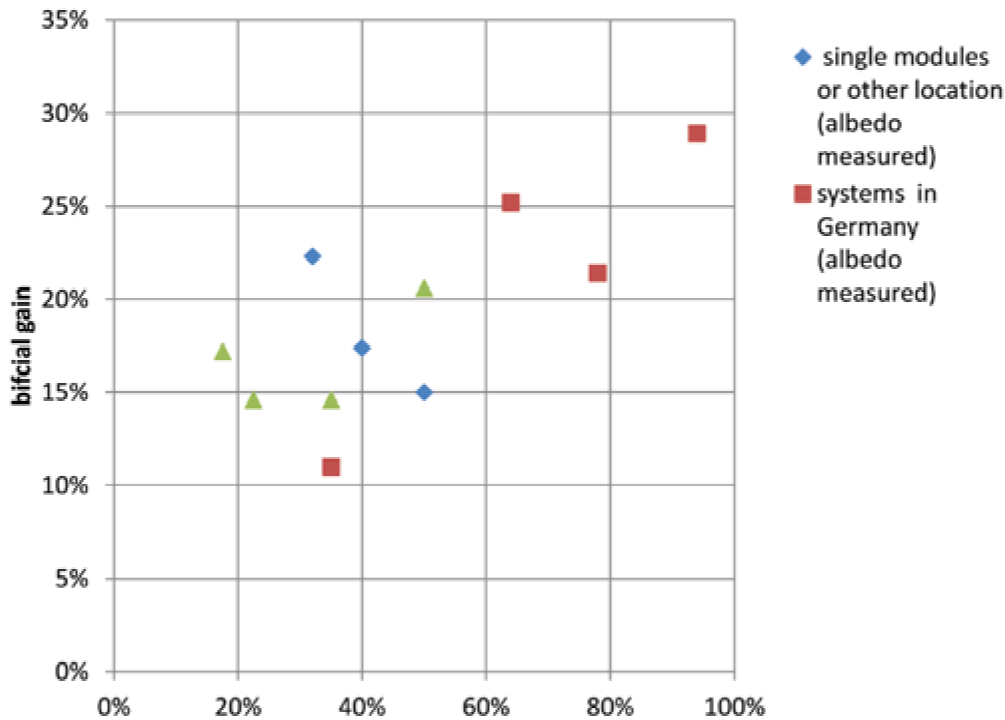


Figure 10: Bifacial gain as a function of ground reflectivity or albedo

Source: (Kopecek et al., 2015)

Table 14 shows albedo or reflectivity values for a range of ground types covering different geographic conditions ranging from dry soil to fresh snow.

Table 14: Typical albedo values for different ground cover types

Surface	Albedo / Reflectivity
Dry dark soil	0.13
Grass	0.17-0.28
Dry sand	0.35
Dune sand	0.37
Old snow	0.4 - 0.7
Fresh snow	0.75 - 0.95

4.2. Dual East-West Panel Facing Orientation

The second innovation that can be applied to standard modules involves orienting the modules with a slight tilt, with half the modules in an east orientation and the other half in a west orientation in alternating rows oriented along a N-S axis. This deviates from the conventional layout where all the modules are usually arranged horizontal, as we have assumed in this work so far. (Some flat roof arrays install modules facing south with a tilt of typically 5-15 degrees oriented along an E-W axis. This requires set-back for each row to avoid self-shading at low angle sunlight.) Falling module prices have created new strategies to capture maximum financial gains at the system level. One strategy is to install more modules per area to increase overall energy production even though each module may not be optimized.

Figure 11: Dual tilt, shallow angle flat rooftop

Figure 11 shows modules arranged at shallow tilt in alternating rows stacked very close to each other.[16] In addition, the back to back row design tend to reduce wind loads and dual tilt modules tend to be more structurally interconnected than fixed tilt modules which tend to reduce installation costs. Rain and snow tend to run off quicker than for flat designs. Energy production during the day could also be smoothed out by more evenly capturing the morning and afternoon irradiance. Data calculated for Atlanta, GA shows ~50% higher solar energy yield for a given

[16] They are installed so that their axis runs N-S; i.e. the one on the left faces due W and the one on the right faces due E.

rooftop area with this dual east-west tilt compared to a single tilt 25 degrees, this is higher and more effective in comparison to reducing the single tilt to a shallower angle of 10 degrees which will only increase the solar yield by ~22%. Much of this gain is due to avoiding the need to space rows apart to avoid shading each other. Traditional ballasting or mounting can be used and there is no added wind loading.

5. FINDINGS

This report is part of a three-year research effort focused on a detailed analysis of PV technical potential at city-scale. The focus of the third year's research is the use of "priority" public buildings as the hosts of a phase 1 PV development strategy in Newark, DE (a college town of approximately 40,000) and Wilmington, DE (a previously industry-based city that has transitioned to a financial services hub with a population of approximately 80,000). The report identifies four main priority building stock portfolios for Wilmington: (i) flat rooftops of city-owned buildings, (ii) public buildings in the Riverfront area, (iii) the Port of Wilmington, and (iv) city parking garages. For Newark two main categories comprise the priority building stocks: (i) flat rooftops of city-owned buildings, and (ii) a set of buildings owned by the University of Delaware.

Phase 1 of the Wilmington SCP-1 analysis has identified an estimated technical potential for priority rooftops of about 7.9 MWp, with city-owned buildings accounting for about 3.0 MWp. This estimated capacity represents 4% of the total city-wide estimated potential (Byrne et al., 2018). Evaluation of the Newark SCP-1 identified a priority pool of buildings with a total of nearly 3.9 MWp of rooftop solar energy potential, including 0.7 MWp hosted by 7 city-owned buildings and 3.2 MWp hosted by 12 University of Delaware-owned rooftops. The stimated installed cosst for WSCP-1 and NSCP-1 are US$14.5 million and US$7.1 million, respectively.

Achieving the goals of phase 1 zero emission electricity generation requires the use of supporting programs, including the State's RPS, its Weatherization Assistance Program, its Energy Standards for Public Buildings program, and its Sustainable Electric Utility (SEU)-SREC Purchase program to stimulate installation by private companies of rooftop PV on municipal facilities (Byrne et al., 2017; Byrne et al., 2016; and Byrne et al., 2009). In response to a growing need for city-scale solar strategy, this research presents an effective building-level methodology for simulating the rooftop solar PV energy technical and economic potential in a mid-size urban area in East coast of the United States. The objective of this effort is to highlight the potential and benefits of "solar cities" especially in smaller municipalities so as to catalyze PV deployment. Figure 12 summarizes our estimates of installed costs for Phase 1 city-scale PV development for the two cities by cost category.

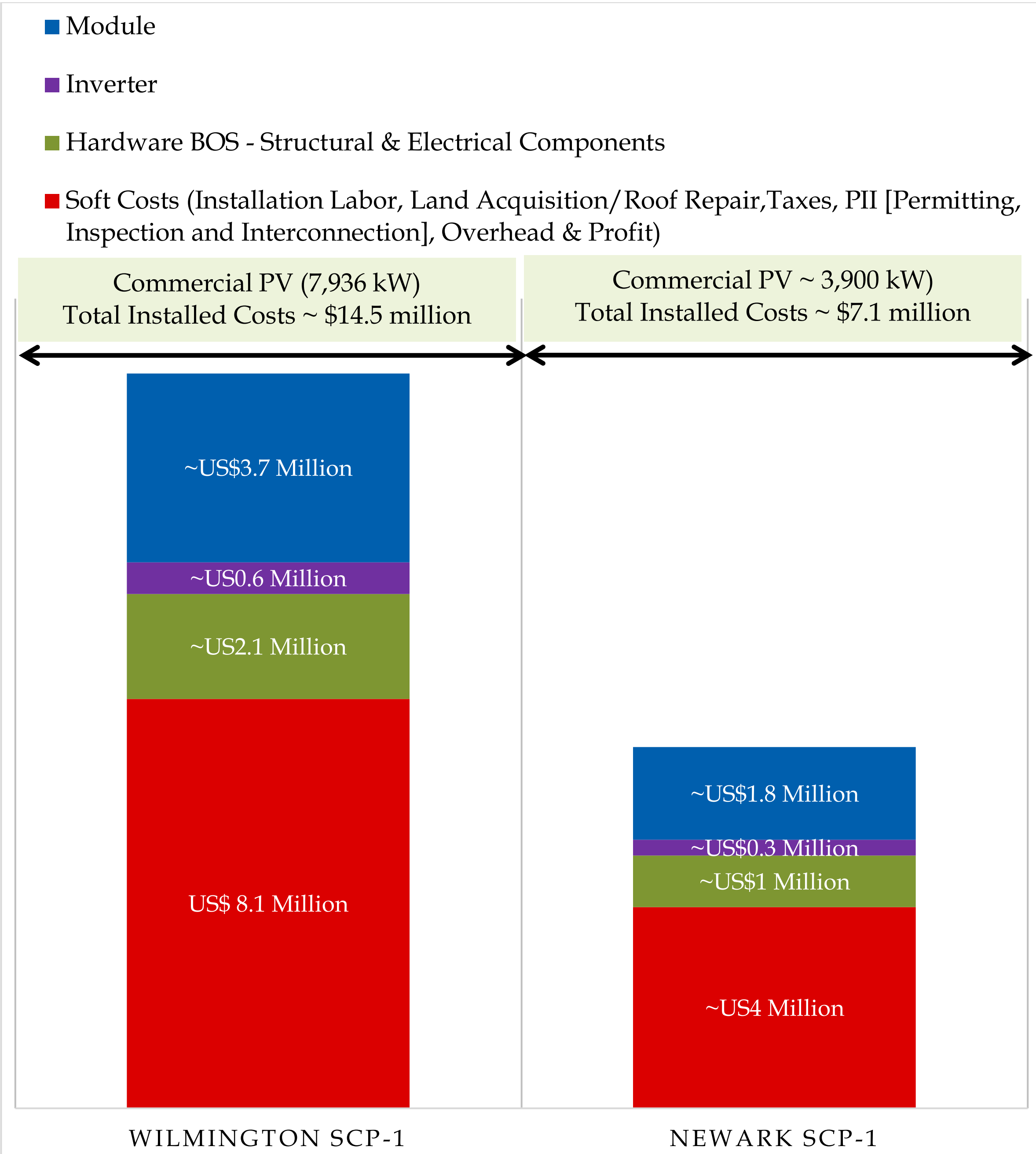


Figure 12: PV system cost benchmark summary for Wilmington and Newark

The potential benefits for the Wilmington and Newark SCP-1s include:

- Both Wilmington and Newark could obtain city-located electricity from clean, renewable and sustainable sources to further their sustainability planning;
- The installation of SCP-1s would contribute to local economic development, would provide local employment from design and engineering to construction to post-commissioning management;
- Both cities would meet or exceed their share of all state policy targets for solar and renewable electricity through 2030;
- In the case of Newark, the City and the University of Delaware could present themselves as low-carbon investors and advertise Newark as a solar city realized by 'town-and-gown' cooperation;
- A solar lifeline program could be added to ensure that a share of SCP generation is set aside to be credited to qualifying moderate income families at a reduced rate thus enhancing participation (for example, the initial 250 kWh of monthly household electricity consumption of families eligible for the State's Weatherization Assistance Program might be priced at a solar lifeline rate); and
- Participants could be offered long-term fixed price electricity contracts, or equivalent incentives, for the share of generation hosted on their roof, thereby attracting new businesses and residents and incentivizing building owners to expand their involvement.

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APPENDICES

Appendix 1: Comparison of Solar PV Modules

Company	PV Module Name	Power Rating (W)	Panel Dimensions (W/L) (mm)	Conversion Efficiency (%)	Warranty (years)[17]
SunPower	X-Series[18]	335 - 345	1046 / 1558	21.50	25 C and P
	E-Series: E20-435-COM[19]	435	1072 / 2073	20.10	
	P-Series 1500 Volt[20]	335 - 355	998 / 2067	17.20	
Panasonic	N330 Photovoltaic Module HIT®[21]	325 - 330	1053 / 1590	19.70	25 C and P
LG	LG365Q1C-A5[22]	365	1016 / 1700	21.10	25 C and P
	LG350Q1C-A5	350		20.30	
	LG335N1C-A5	335	1016 / 168 6	19.60	
	LG400N2W-A5	400	1024 / 2024	19.30	
Trina Solar	DUOMAX M PLUS - DEG5(II) White EVA - 60 Cell[23]	280 - 315	992 / 1662	19.20	10 (C); 25 (P)
	TALLMAX M PLUS-DE14A(II) - 72 Cell[24]	340 - 375		19.30	
	Tallmax Split M-Plus TSM-DE14H(II) - 144 Cell[25]	350 - 380	950 / 2000	19.20	
	ALLMAX M PLUS. DD05A.08(II) - 60 Cell	280 - 315	992 / 1650	19.20	

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[17] Warranty is expressed in years and is grouped into combined power (C) and product warranty (P).

[18] https://us.sunpower.com/products/solar-panels/

[19] https://www.bloomberg.com/news/articles/2018-06-20/solar-prices-nosedive-after-china-pullback-floods-global-market

[20] https://www.nrel.gov/docs/fy17osti/68925.pdf

[21] https://na.panasonic.com/us/energy-solutions/solar/solar-panels

[22] https://www.lg.com/us/business/solar-panel/products

[23] https://www.trinasolar.com/us/product/commercial

[24] https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/

[25] Exhibit 1 and 2 in upper cell shows a list of companies with their efficiency ratings (not the most up-to-date data)

	ALLMAX M PLUS. DD05A.05(II) - 60 Cell	275 - 310		18.90	
Yingli Green Energy	YLM-VG 60 Cell Series[26]	290 - 310	992 / 1640	19.70	10 (C); 25 (P)
	YLM-VG 60 Cell Series	310 - 335	992 / 1960	19.00	
	YLM-VG 72 Cell Series	340 - 370	992 / 1956	19.10	
	YGE-VG 60 Cell Series 2	270 - 290	992 / 1640	18.40	
	YGE 72 Cell Series 2 1500V	305 - 330	992 / 1960	18.50	
Canadian Solar	HIDM CS1U-MS[27]	395 - 410	992 / 2078	19.89	10 (C); 25 (P)
	HIDM CS1H-MS[28]	320 - 350	992 / 1700	19.86	
	60-CELL STANDARD PANELS[29]	260 - 285	992 / 1650	18.63	
	MAXPOWER PANELS	310 - 340	992 / 1960	18.00	
	HiKu CS3W 405P 144 Cell	390 - 405			
Hanwha SolarOne	Q. PEAK DUO L-G5.2 144 Cell	380 - 395	1000 / 2014	19.90	12 (C); 25 (P)
	Q. PEAK L-G4.2	360 - 370	1000 / 1994	18.80	
	Q. PLUS L-G4.2	340 - 350		17.80	
Jinko Solar	Eagle PERC 48[30]	220 - 240	992 / 1324	18.27	10 (C); 25 (P)
	Eagle PERC 60	295 - 315	992 / 1650	19.24	
	Eagle PERC 72	340 - 360	992 / 1956	18.55	
	Eagle PERC Plus 60	280 - 300	992 / 165 0	18.33	
	Eagle Plus 72	340 - 360	992 / 1956	18.57	
	72-Cell Mono PERC	300 - 375	991 / 1960	19.30	12 (C) - limited to repair or
	72-Cell Mono PERC Double Glass	355 - 370	992 / 1968	19	
	60-Cell Mono PERC	365 - 380	991 / 1650	19	

[26] http://www.yinglisolar.com/us/products/solar-modules

[27] https://www.canadiansolar.com/solar-panels/dymond.html

[28] https://www.solarreviews.com/blog/are-canadian-solar-panels-the-best-modules-to-install-on-your-home

[29] https://news.energysage.com/comparing-top-solar-manufacturers-sunpower-vs-lg-panasonic-solarworld-suniva/

[30] https://www.jinkosolar.com/product_256.html

JA Solar	72-cell Mono PERC Half-Cell	325 - 380	991 / 2000	19.20	replacement; P (limited)
	60-cell Mono PERC Half-Cell	300 - 320	991 / 1678	19.20	
Sharp	Sharp ND-250QCS	250	993 / 1640		
	40 Sharp ND-Q250F7	250	993 / 1640		
	36 Sharp ND-Q250F7		993 / 1640		
	33 Sharp ND-Q250F7		993 / 1640		
	26 Sharp ND-Q250F7		993 / 1640		
ReneSola	Mono PERC	355 - 370	992 / 1956		10 (C) - limited to repair, replacement, or refunded remedy
	Virtus II 5BB	315 - 335	992 / 1956		
	Double Glass	290 - 330	992 / 1968		
	Virtus II	295 - 310	992 / 1956		
	72-cell(Half-Cut) Poly Solar Panel 5Busbar	290 - 340	992 / 1986		
First Solar	First Solar Series 6™	420 - 445	1232 / 2009		10 (C); 25 (P)
	First Solar Series 4™ PV Module	110 - 122.5	600 / 1200		
	First Solar Series 4™ PV Module	110 - 117.5	600 / 1200		
	First Solar Series 4™	105.0	600 / 1200		
Kyocera	KU260-6MCA[31]	260	990 / 1662		10 (C); 25 (P)
	KU265-6MCA	265	990 / 1662		
	KU270-6MCA	270	990 / 1662		
	KU315-7ZPA	315	992 / 1956		
	KU320-7ZPA	320	992 / 1956		

[31] https://www.kyocerasolar.com/dealers/product-center/spec-sheets/KU265-6MCA.pdf

Appendix 2: Comparison of Solar PV Inverters

Company	Product Name	Dimensions (W / H / D) (mm)	AC Power Output (kW)	Peak Efficiency (%)	Warranty
SMA Solar Technology	Sunny Boy (string inverter)[32]	535 / 730 / 198	3-7.68	97.60	10-year product warranty
	Sunny Tripower (string inverter)	780 / 790 / 380	12-30	98.60	
	Sunny Tripower CORE1 (string)	621 / 733 / 569	33.3-62.5	98	
	Sunny highpower peak3 (central inverter)	770 / 830 / 444	125-150	98.50	5-year standard warranty w/ 10, 15 or 20-year extension
Omron	KPL100L (String inverter)[33]	455 / 700 /270	11	97.50	5-year standard warranty
ABB	TRIO-20.0-TL-OUTD[34]	1060 / 701 / 292	20	98.20	5-year standard warranty w/ 10-year optional extension
	PVS980 (Central inverter)	3180 / 2443 / 1522	2000-2300	98.80	
	PVS800-57B (Central inverter)	4030 / 2150 / 720	1645-1732	98.50	
	PVS800-57 (Central inverter)	(2630-3630) / 2130 / 708	500-1000	98.80	
Tabuchi	M25-6: 3-Phase 25 String Inverter[35]	950 / 640 / 300	25	98.70	10-year product warranty w/ 20-year optional extension
TMEIC	SOLAR WARE[36]		833-3360	98.90	minimum 5-year warranty
Advanced Energy	Discontinued Utility Solutions AE 1000NX/1100NX Utility Inverter[37]	4420 / 2286 / 1057	8.25-23	98.10	20-year optional extended warranty
	Discontinued AE Commercial Inverters: AE 500NX		12-23.2	98.60	5-year warranty w/ 20-year optional extension
	Discontinued AE Commercial Inverters: AE 500TX		20-24	97.80	10-year warranty w/ 20-year optional extension
	Discontinued String: AE 3TL 8-23	535 / 601 / 277	40-46	98.30	unknown

[32] https://www.sma-america.com/products/overview.html

[33] https://www.enfsolar.com/pv/inverter-datasheet/8898

[34] https://search-ext.abb.com/library/Download.aspx?DocumentID=BCM.00202.1&LanguageCode=en&DocumentPartId=&Action=Launch

[35] https://www.tabuchiamerica.com/commercial

[36] https://www.tmeic.com/products/pv-inverters?certification=ul&region=All&enclosure_type=All&voltage=All

[37] http://solarenergy.advanced-energy.com/solar-inverters

	Discontinued AE Commercial Inverters: AE 333NX			98.30	20-year optional extended warranty
Enphase Energy	Enphase IQ 7X Microinverter[38]	212 / 175 / 30.2 (no bracket)		97.50	up to 25 years
	Enphase IQ 7/7+ Microinverter	212 / 175 / 30.2 (no bracket)		97.50	
	Enphase IQ 6/6+ Microinverter	219 / 191 / 37.9		97	
Schneider Electric	Conext CL125 String Inverter[39]	670.5 / 892 / 295	1800	98.80	10-year standard warranty
	Conext CL-60E String Inverter	958 / 907 / 250	2000	98.70	3 years, unless stated otherwise
	Conext CL-60A String Inverter	958 / 652 / 250	2200	98.70	
Huawei	Smart String Inverter SUN2000-100KTL-H1[40]	1,075 / 605 / 310	105	99	
	Smart String Inverter SUN2000-60KTL-M0	1,075 / 555 / 300	60	98.90	
	Smart String Inverter SUN2000-60KTL-HV-D1-001	930 / 600 / 270	66	99	
	Smart String Inverter SUN2000-42KTL	930 / 550 / 283	47	98.80	
	Smart String Inverter SUN2000-17/20KTL	520 / 610 / 266	40	98.60	
SolarEdge	Inverters Phase Inverters For 480V/277 Grid[41]	533 / 318 / 267	40.5-45	98.50	12-years without 20/25-year optional extension
	Inverters Phase Single S	775 / 318 / 183	19.4	98	
	Three Phase Inverter with Synergy Technology for the 277/480V Grid	940 / 315 / 260	66.6-100	98.50	
	SolarEdge Three Phase Inverters for the 277/480V Grid	540 / 315 / 260	10-33.3	98.50	

[38] https://enphase.com/en-us/products-and-services/microinverters

[39] https://solar.schneider-electric.com/products/grid-tie-string-inverters/

[40] http://solar.huawei.com/eu/products

[41] https://www.solaredge.com/us/products/pv-inverter/single-phase#/

Appendix 3: Monofacial Vs. Bifacial Module Estimated PV Production Gain

Model	Key Considerations	Wilmington	Newark	% Bifacial Gain
		Annual Production (MWh)		
Base Model	Monofacial PV module; Tracking and Orientation (Fixed); Inverter (SMA STP24000)	10,104	5,048	3.76%
	Bifacial PV module; Tracking and Orientation (Fixed); Inverter (SMA STP24000)	10,485	5,238	
Scenario 1	Monofacial PV module; Tracking and Orientation (Fixed); Inverter (ABB)	9,993	4,997	3.76%
	Bifacial PV module; Tracking and Orientation (Fixed); Inverter (ABB)	10,369	5,185	
Scenario 2	Monofacial PV module; Tracking and Orientation (1-axis); Inverter (SMA STP24000)	13,582	6,786	2.53%
	Bifacial PV module; Tracking and Orientation (1-axis); Inverter (SMA STP24000)	13,926	6,958	
Scenario 3	Monofacial PV module; Tracking and Orientation (2-axis); Inverter (SMA STP24000)	15,745	7,867	2.08%
	Bifacial PV module; Tracking and Orientation (2-axis); Inverter (SMA STP24000)	16,072	8,033	

Appendix 4: Sample HelioScope Performance Modeling Outputs

A. City of Wilmington - Fire Station #1

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

City of Wilmington Fire Station #1

Wilmington, DE

REPORT	
Project Name	Fire Station # 1
Project Address	400 West 2nd St, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	41.0 kW
Inverter AC Nameplate	48.1 kW
Annual Production	55.93 MWh
Performance Ratio	85.7%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION

COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

March 29, 2019

B. City of Wilmington - Fire Station #2

CENTER FOR ENERGY & ENVIRONMENTAL POLICY
University of Delaware
http://ceep.udel.edu

Annual Production Report

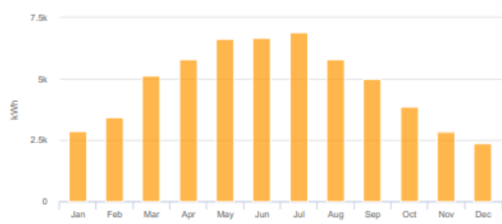
City of Wilmington Fire Station #2

Wilmington, DE

REPORT	
Project Name	Fire Station #2
Project Address	400 New Castle Ave, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	41.8 kW
Inverter AC Nameplate	48.1 kW
Annual Production	57.28 MWh
Performance Ratio	86.3%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

 March 29, 2019

C. City of Wilmington - Fire Station #3

Annual Production Report

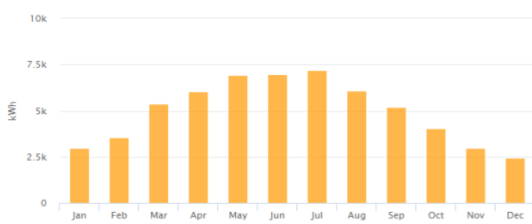
City of Wilmington Fire Station #3

Wilmington, DE

REPORT	
Project Name	Fire Station #3
Project Address	333 East 30th Street, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	43.6 kW
Inverter AC Nameplate	48.1 kW
Annual Production	59.86 MWh
Performance Ratio	86.7%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

 March 29, 2019

D. City of Wilmington - Fire Station #4

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

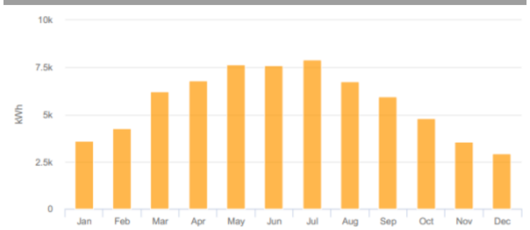
Fire Station #4

Wilmington, DE

REPORT	
Project Name	Fire Station #4
Project Address	2200 N Tatnall St, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	45.6 kW
Inverter AC Nameplate	48.1 Kw
Annual Production	60.10 MWh
Performance Ratio	83.1%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

March 29, 2019

E. City of Wilmington - Fire Station #5

Center for Energy & Environmental Policy
University of Delaware
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Annual Production Report

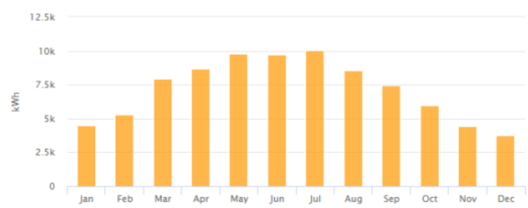
City of Wilmington Fire Station #5 (new)

Wilmington, DE

REPORT	
Project Name	Fire Station #5
Project Address	1806 N. Dupont Street, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	62.7 kW
Inverter AC Nameplate	72.2 kW
Annual Production	86.19 MWh
Performance Ratio	84.8%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

March 29, 2019

F. City of Wilmington - Fire Station #6

Center for Energy & Environmental Policy
University of Delaware
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Annual Production Report

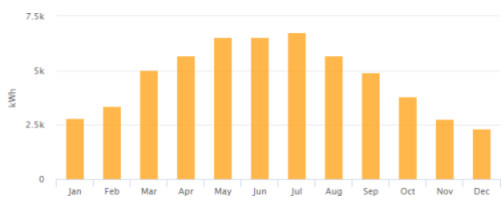
City of Wilmington Fire Station #6

Wilmington, DE

REPORT	
Project Name	Fire Station #6
Project Address	224 N Union St , Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	41.0 kW
Inverter AC Nameplate	48.1 kW
Annual Production	56.20 MWh
Performance Ratio	86.2%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

March 29, 2019

G. City of Wilmington - Public Safety Building

Center for Energy & Environmental Policy
University of Delaware
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Annual Production Report

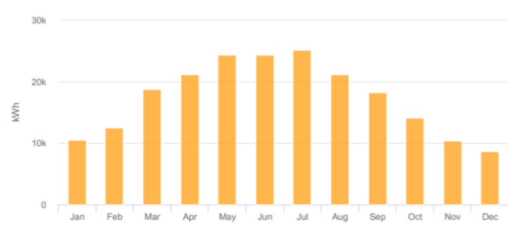
City of Wilmington Public Safety Building

Wilmington, DE

REPORT	
Project Name	Public Safety Building
Project Address	300 N Walnut St, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate	154.1 kW
Inverter AC Nameplate	144.4 Kw
Annual Production	209.8 MWh
Performance Ratio	85.7%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

 March 29, 2019

H. City of Wilmington – Public Works Yard

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

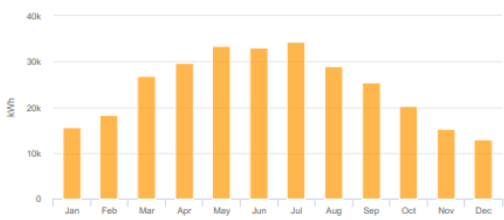
City of Wilmington Public Works Yard

Wilmington, DE

REPORT	
Project Name	Public Works Yard
Project Address	500 Wilmington Avenue, Wilmington, DE
Prepared for	City of Wilmington

SYSTEM METRICS	
Module DC Nameplate 896.6 kW	
Inverter AC Nameplate 752.0 Kw	
Annual Production	1130.2 MWh
Performance Ratio	84.1%
kWh/kWp	1,231.4
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

 March 29, 2019

I. City of Newark - Municipal Building

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

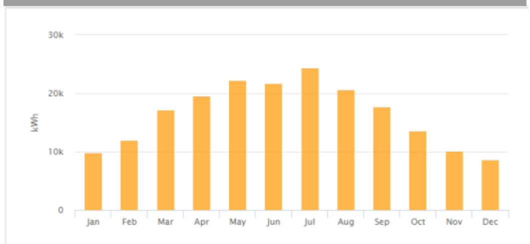
Annual Production Report

Newark Municipal Building

Newark, DE

REPORT	
Project Name	Newark Municipal Building
Project Address	220 S Main Street, Newark DE
Prepared for	City of Newark Government

MONTHLY PRODUCTION



SYSTEM METRICS	
Module DC Nameplate	146.0 kW
Inverter AC Nameplate	120.0 Kw Load ratio: 1.22
Annual Production	197.8 MWh
Performance Ratio	85.5%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

March 29, 2019

J. City of Newark - Warehouse Complex

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

City Warehouse Complex (6 buildings)

Newark, DE

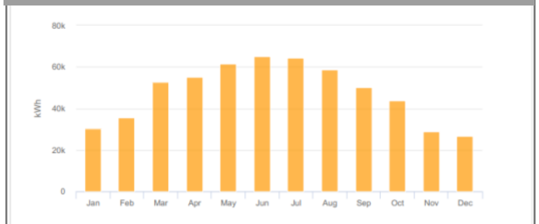
REPORT

Project Name	City Warehouse Complex (6 buildings)
Project Address	406 Phillips Avenue
Prepared for	City of Newark Government

SYSTEM METRICS

Module DC Nameplate	425.9 kW
Inverter AC Nameplate	360.9 Kw Load ratio: 1.18
Annual Production	572.3 MWh
Performance Ratio	82.5%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS

Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

 March 29, 2019

K. City of Newark – George Wilson Community Center

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

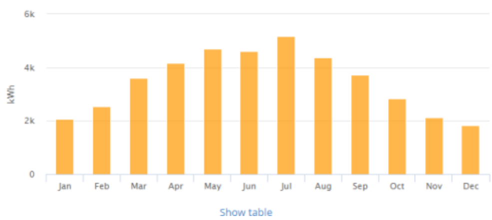
George Wilson Community Center

Newark, DE

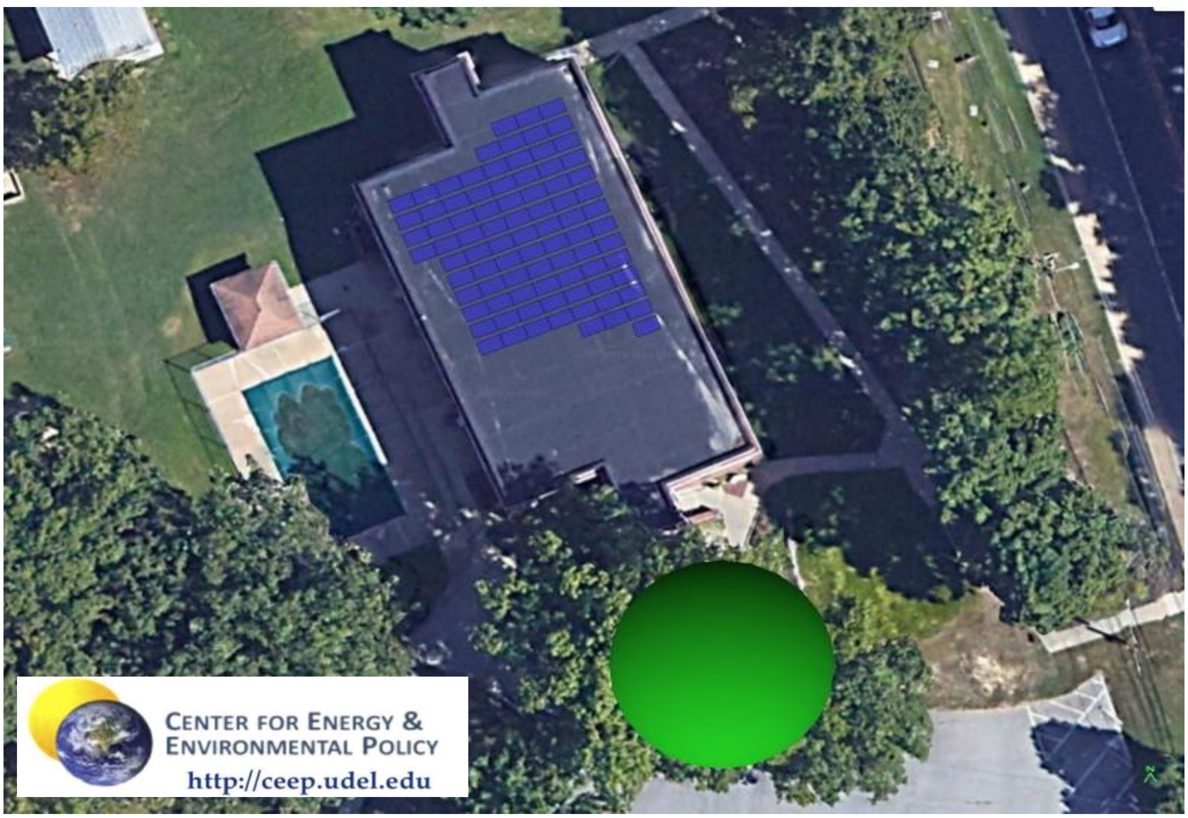
REPORT	
Project Name	Newark Municipal Building
Project Address	303 New London Road, Newark DE
Prepared for	City of Newark Government

SYSTEM METRICS	
Module DC Nameplate	31.0 kW
Inverter AC Nameplate	37.6 Kw
Annual Production	41.75 MWh
Performance Ratio	85.4%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)



March 29, 2019

L. University of Delaware - Carpenter Sports Building

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

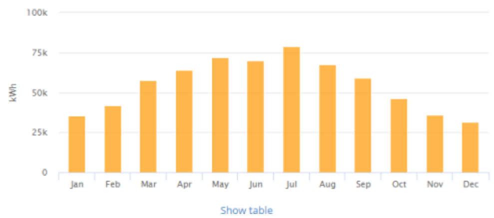
Carpenter Sports Building

Newark, DE

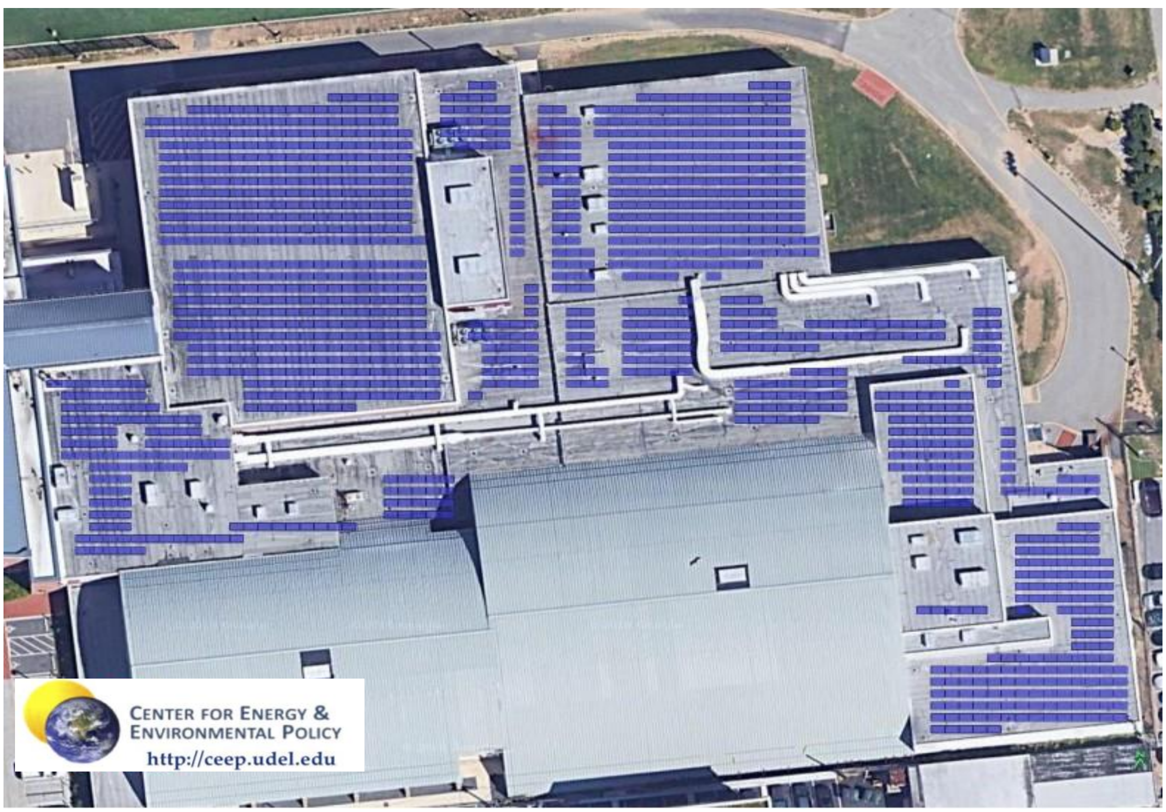
REPORT	
Project Name	Carpenter Sports Building
Project Address	30 E Main Street, Newark, DE
Prepared for	University of Delaware

SYSTEM METRICS	
Module DC Nameplate	473.0 kW
Inverter AC Nameplate	385.0 Kw
Annual Production	659.7 MWh
Performance Ratio	85.0%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)



April 12, 2019

M. University of Delaware - General Services Building

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

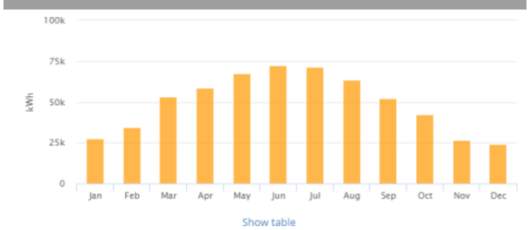
General Services Building

Newark, DE

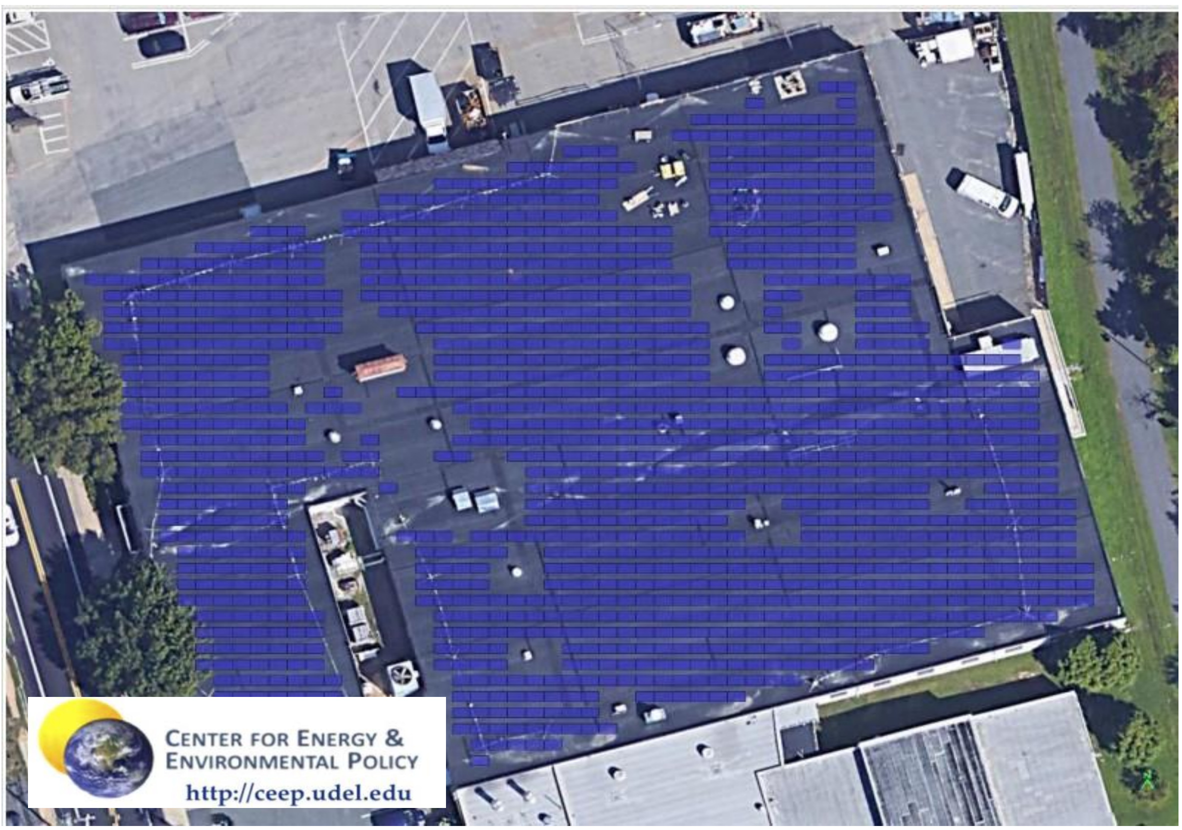
REPORT	
Project Name	General Services Building
Project Address	262 Haines Street, Newark DE
Prepared for	University of Delaware

SYSTEM METRICS	
Module DC Nameplate	451.1 kW
Inverter AC Nameplate	360.9 Kw
Annual Production	593.8 MWh
Performance Ratio	85.6%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)



 April 19, 2019

N. University of Delaware - Perkins Student Center

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

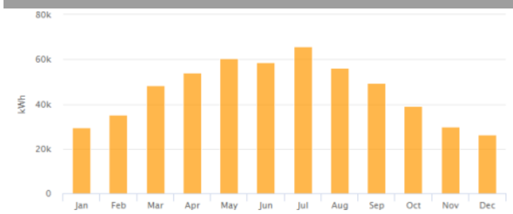
Perkins Student Center

Newark, DE

REPORT	
Project Name	Perkins Student Center
Project Address	262 Haines Street, Newark DE
Prepared for	University of Delaware

SYSTEM METRICS	
Module DC Nameplate	394.2 kW
Inverter AC Nameplate	336.8 Kw
Annual Production	553 MWh
Performance Ratio	85.5%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

April 19, 2019

O. University of Delaware - Trabant University Center

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

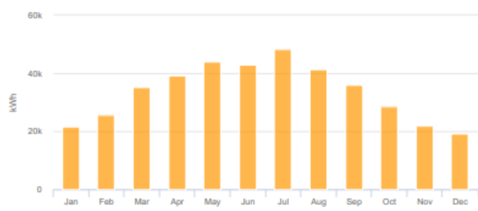
Trabant Student Center

Newark, DE

REPORT	
Project Name	Trabant Student Center
Project Address	17 W Main Street, Newark DE
Prepared for	University of Delaware

SYSTEM METRICS	
Module DC Nameplate	288.4 kW
Inverter AC Nameplate	240.6 Kw
Annual Production	403.6 MWh
Performance Ratio	85.3%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

 April 19, 2019

P. University of Delaware - Graham Hall Complex

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

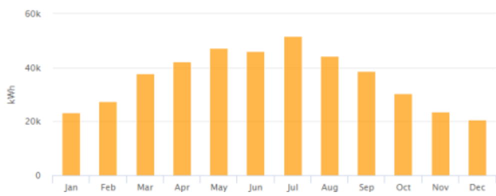
Graham Hall Complex

Newark, DE

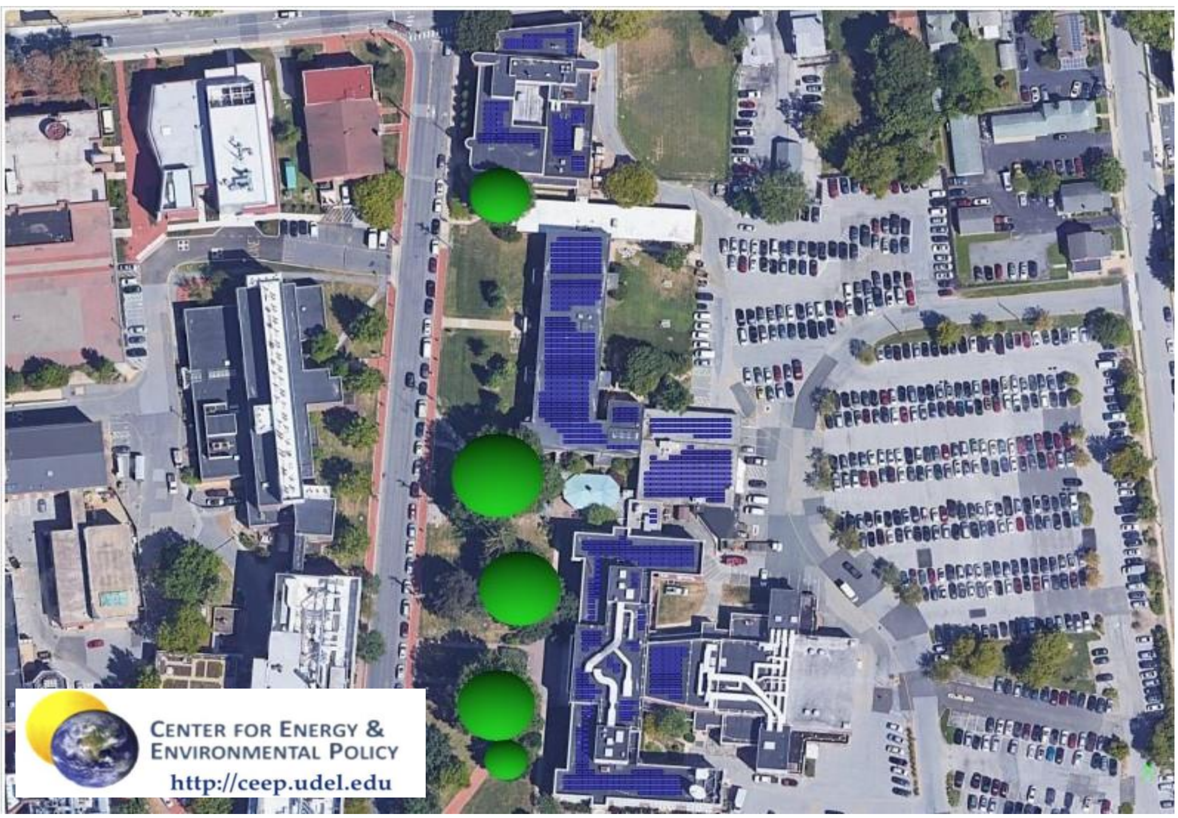
REPORT	
Project Name	Graham Hall Complex
Project Address	101 Academy Street, Newark DE
Prepared for	University of Delaware

SYSTEM METRICS	
Module DC Nameplate	350 kW
Inverter AC Nameplate	284.7 Kw
Annual Production	490.0 MWh
Performance Ratio	85.5%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)



 April 19, 2019

Q. University of Delaware - UD Sports Complex (3 Buildings)

Center for Energy & Environmental Policy
University of Delaware
http://ceep.udel.edu

Annual Production Report

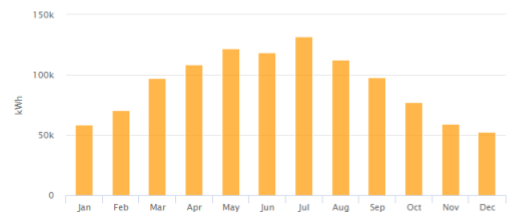
UD Sports Complex (3 buildings)

Newark, DE

REPORT	
Project Name	UD Sports Complex (3 buildings)
Project Address	631 S College Avenue, Newark, DE
Prepared for	University of Delaware

SYSTEM METRICS	
Module DC Nameplate	1,280 kW
Inverter AC Nameplate	385.0 Kw
Annual Production	1,785 MWh
Performance Ratio	85.0%
kWh/kWp	1,343.7
Weather Dataset	TMY3, Wilmington New Castle County AP, NSRDB

MONTHLY PRODUCTION



COMPONENTS	
Inverter	Sunny Tripower 24000TL-US (SMA)
Strings	10 AWG (Copper)
Module	LG, LG365Q1C-A5 (365 W)

April 19, 2019