

Solar Canopies Can Turn Parking Lots into Power Plants

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ABSTRACT

While not always the first choice to deploy solar arrays, solar canopies over parking lots (often called “carports”) offer an excellent option where land area is too tight for ground-mounted systems and large rooftops are already covered by solar panels. Significant revenue may be generated for the parties involved, e.g., the developer and/or hosting entity. As an amenity, canopies also offer shade on hot sunny days and cover from snow and heavy rains at other times. Depending on the greenhouse gas (GHG) intensity of the local grid power, i.e., metric tons per megawatt-hour [MT/MWh] or pounds per kilowatt-hour [lb/kWh], reductions in such climate-changing emissions may also be quite significant. One of the largest canopy projects in the U.S. was completed in late 2024 at a commuter train station in lower New York State. The 4.18 MW system consists of 12 canopies running parallel to the Hudson River in the Village of Croton in Westchester County, just north of New York City. Revenue from the facility approaches half a million dollars a year. The \$16 million-dollar 4-year project was financed via the community solar process (in which residents and small businesses can subscribe to output from a project and receive a discount on their utility electric bills) and various incentives. Initiated during COVID, the project provided useful experience and “lessons learned” for the developer, the municipality, and sustainability advocates.

INTRODUCTION

There are several ways to deploy commercial-scale solar arrays:

- where large open area is available, ground mounting is common, with many systems ranging from 25 to 100s of MWs

- large unshaded rooftops, such as those atop big box stores, warehouses, and large institutions, offer easy siting and connection to existing electrical distribution systems
- often overlooked, however, are the many large parking lots where cars gather:
 - office buildings
 - shopping centers/malls
 - medical facilities
 - amusement parks
 - houses of worship
 - auto dealerships/car rentals
 - apartment complexes
 - industrial parks
 - convention centers
 - public sites: e.g., schools, colleges, train stations, airports, libraries, etc.

In some states, to that list may be added the many parking lots at municipal, county, and state parks. However, as discussed under “Lessons Learned,” that option may be limited by deeds and/or state restrictions on altering park land.

Covering a blacktopped lot with a solar canopy adds value to a site by providing covered parking that keeps cars cool in the summer and snow-free in the winter. Lot owners may rent the airspace above their lots (and perhaps underground space for electric conduits) to solar developers that become tenants for decades. In the project discussed below, rent of more than a dollar per covered square foot per year helped a balance a municipal budget while providing revenue for other projects.

Depending on the site and other factors, a battery energy storage system (BESS) may be included that stores solar power when hourly wholesale power pricing is low (e.g., weekends) and injects it into the grid when pricing is high. Doing so adds revenue/rent while displacing fossil-fueled power that would otherwise be generated by peaker plants.

As with any solar array, power output varies with latitude and location. Depending on design and siting, canopies may offer a higher average peak watt per square foot (SF) of site area than ground or rooftop-mounted systems and thus a higher annual kilowatt-hour (kWh)

output and revenue per SF. However, installed cost/SF will be greater, typically 25% to 40% higher than rooftop or ground-mounted systems. That differential may also be affected by steel pricing because more steel is required by canopy racking systems.

Parking lots are ideal sights in many ways and are home to systems ranging from 300 kW to over 6 MW. While smaller systems may be built, developers generally prefer at least 300 kW to amortize basic costs such as interconnection. Dozens have been installed in the northeast, and many more elsewhere, especially in the west and southwest where sunshine may be more intense.

ISN'T A CANOPY JUST ANOTHER GROUND-MOUNTED ARRAY?

No. Canopies over parking areas have a minimum height restriction of 13'6" to allow tall vehicles (e.g., fire trucks and tractor-trailers) to move below them. Ground-mounted arrays have no such height limit.

Canopies may also be roof-mounted atop parking structures and facilities that must keep roof space open for process-related equipment, e.g., industrial refrigeration systems.

To handle their own weight and wind loads, canopy racking systems are structurally more robust and require deeper and stronger foundations. The extra costs of steel and labor involved may add \$1 to \$2 per watt to the total installed cost. To minimize that financial impact, some states (e.g., NY) offer an extra per watt incentive for canopies.

Canopies may also involve additional equipment such as underside lighting, snow guards, and stormwater management, e.g., gutters, gaskets, and downspouts. Depending on design and size, significant underground wiring may be involved that requires trenching and repaving.

COMMON CHARACTERISTICS AND LINGO

As with any technical endeavor, solar canopies have terminology to describe them.

Tilt

Tilt is the angle(s) of the racks holding the panels relative to the horizontal plane. A canopy with one angled surface is "single tilt," like the

letter “T,” with an angled top (see Figure 1). Those that instead look like a “Y” are “double tilt” or “inverted” (see Figure 2). Those looking like many shallow “v”s (“vvvvv”) may be called “double wave” or “corrugated.”



**Figure 1. A single-tilt canopy at an elementary school
(Photo credit: Lindsay Audin)**



**Figure 2. A double-tilt canopy at a college
(Photo credit: Lindsay Audin)**

Most canopies have fixed tilt angles and contiguous surfaces. A few have featured variable-tilt systems that mechanically follow the sun along one axis. A few “louvered” canopies with fixed tilt angles feature spaces between panels that allow water and snow to slide through.

Span

Span relates to the number of rows of vertical support pillars (i.e., “pedestals”) holding up a canopy. If only one row (as is common with a double tilt canopy), we call it a “short span” (see Figure 3). If multiple rows (as may be seen with wide single tilt arrays), we call it “long span.”



Figure 3. A short-span canopy having one row of pedestals
(Photo credit: Leo Wiegman)

Facing

Facing describes if one or both sides of a panel contain solar cells. In the past, most panels were mono-facial, i.e., have cells on only their top side, but some recent canopies have bi-facial panels with cells on both their top and bottom sides (see Figure 4). Most solar power comes not from the visible part of the light spectrum but rather the ultraviolet (UV) band. While blacktop is a poor reflector of visible light, it may reflect enough UV to the underside of panels to merit installing bi-facials. While they cost more, they may produce 4% to 27% extra power, depending on tilt angle and canopy design.

During the first Trump administration, the 30% tariff on Chinese panels neglected to include bi-facials, thus offering a perverse incentive for them. Note, however, that a canopy’s structural design may affect use



Figure 4. Bi-facial panels have solar cells on the top and underside of a panel. (Photo credit: Lindsay Audin)

of bi-facials. To simplify panel mounting and drainage, some canopies use corrugated roof decking below their panels instead of metal frames (see Figure 5). Doing so creates an opaque surface that eliminates the bi-facial option.



Figure 5. Corrugated roof decking allows easy mounting of panels, but blocks use of bi-facial panels. (Photo credit: Lindsay Audin)

CROTON'S SOLAR CANOPY PROJECT

At the time of this writing (early 2025), the Croton train station canopy system is the largest canopy system on public property in New York State, and the second largest in the State. It covers about 10 acres of blacktopped area holding about 1,100 parking spaces. An adjacent lot of similar capacity could not be developed because the ground beneath it is not stable.

Twelve rectangular single-tilt, long-span, bi-facial canopies were erected, one almost as large as a football field (see Figure 6). Together, they hold almost 10,000 panels generating 4.18 peak megawatts (MWp). While the initial design exceeded 5 MWp, the design process required that canopy dimensions be adjusted to meet requests by the local fire department, the adjacent train station owner, and others. Some canopy corners had to be clipped due to underground obstructions blocking foundations.



Figure 6. The Croton train station canopy system includes 12 canopies. (Photo credit: Mike Bole, Bow Renewables, used with permission)

Each year, the system generates about 5,000 MWh and avoids over 2,000 MT of greenhouse gases. That's equivalent to the emissions of

over 600 cars, and greater than all emissions of Croton's municipal facilities and vehicles. Total cost (before incentives) was about \$16 million, paid by the developer. Rent revenue to Croton is about \$485,000 a year.

At the north end of the site, a 3.5 MW, 15 MWhr, battery energy storage system (BESS) holds lithium iron phosphate [LFP] (not lithium-ion) batteries (see Figure 7). Unlike lithium-ion units, LFP units have a clean record when it comes to battery fires. They are housed in four separate 25-ton steel containers 8 feet apart, with appropriate fire and smoke detection, etc., within 100 feet of a fire hydrant. To address concerns before construction started, Croton's fire department developed a fire evacuation plan. The system is $\sim\frac{1}{4}$ mile from residences and is surrounded by an opaque double metal fence. The installation meets NFPA Standard 855 for power storage systems.



Figure 7. The Croton system includes a 3.5 MW BESS consisting of four 25-ton enclosures. (Photo credit: David S. Goldman, used with permission)

Unlike canopies lacking a BESS, the Croton system can store solar power when wholesale power pricing is low, and then inject it into the grid during high-priced hours. Such “arbitrage” allowed the developer to offer greater revenue and provide a higher rental bid than its competitors.

By late 2025, the site will also host 18 L2 electric vehicle (EV) charge ports funded by grants from two New York State agencies, providing modest additional revenue to the Village.

BRIEF HISTORY OF THE CROTON PROJECT AND ITS FINANCING

In 1964, the Village of Croton on Hudson (a suburb 30 miles north of New York City) bought parcels of land from the New York Central Railroad (now the Metro-North Commuter Railroad), which had previously used it as a dump and landfill. The Village graded and paved it to create parking lots for commuters using the adjacent Croton-Harmon train station. The lots contain 2,000 parking spaces with users paying to park. The revenue became a significant part of the Village's budget.

Starting in 2017, solar developers suggested installing a solar canopy over a small portion of the lot closest to the station. However, their offerings and designs were too small to merit consideration. All that changed due to the 2020 COVID epidemic.

The pandemic's "stay at home" orders and fears resulted in a big drop in commuter traffic and a major reduction in parking revenue. The Village's Board of Trustees asked Croton's Sustainability Committee, a chartered group of volunteers, to develop a proposal for a much larger canopy project that could plug that budget hole.

During the summer of 2020, the committee created a request-for-interest (RFI) that was sent to all 168 (at the time) solar developers active in the State. It asked if they wished to receive a request-for-proposals (RFP) describing the opportunity. Twenty-one responded, with seven then providing acceptable proposals. By the spring of 2021, a winning bidder had been chosen and a long-term leasing contract developed. The developer became a tenant on the parking lot, funded and built the installation, and began paying rent to the Village.

Note that the Village did not lease the system: instead, the developer leased aspects of the lot from the Village, which made no commitment to buy the power. Under community solar, the power is sold to the local utility at base pricing set by the State's Public Service Commission (PSC).

Other canopies have either been fully owned by the hosting agent (which may be a private entity, such as a mall, taking all the power), or leased and operated by the host taking the power, or the host commits to take some (maybe all) of the power under a long-term power purchasing agreement (PPA).

Construction was delayed by COVID, weather, negotiations on a variety of post-contract issues, e.g., stormwater management, and legal

matters. During that development, the developer paid lower monthly rent. Work was essentially completed in early 2025. Power began flowing in April 2025, about 4 years after the contract was signed.

CANOPIES COAST TO COAST

The seven proposals received for the Croton project showed dozens of solar canopies across the U.S. Most were a few hundred kWp to a few MWp, with the largest being 8 MW across the parking lots of a New Jersey college campus.

The first solar canopies were constructed around 2004 in California. In New York, the first were in Suffolk County on the east end of Long Island. That County installed units at several train stations and over lots adjacent to County office buildings, the largest being 2.8 MW. None have power storage.

As of early 2025, the largest single system (i.e., covering one site) in New York is the 5.4 MW canopy at the IBM Watson Research Center in Yorktown about 30 miles north of New York City (see Figure 8). It is double tilt, narrow span, mono-facial, without batteries. Many smaller systems are installed over public parking lots, or private lots owned by firms having many employees.



Figure 8. The largest canopy in New York State is at IBM's Watson Research Center in Yorktown, located 30 miles north of New York City. (Photo credit: Arnie Vimba, IBM, used with permission)

While Croton's system is presently the largest on public property in New York, that distinction will likely be lost when a 6 MW canopy system under construction at JFK airport In New York City is completed in 2027. It will feature 7.5 MW of power storage.

DEVELOPMENT AND INSTALLATION ISSUES

All large solar projects have some issues in common, e.g., siting, financing, utility interconnection. However, canopies typically cost \$1 to \$2 a watt more than rooftop arrays, which may cost \$3 to \$4 a watt before incentives. A variety of other issues may pertain.

Foundations

Unlike roof and ground-mounted systems, canopies may entail additional and/or more involved installation issues. To ensure stability (even during hurricanes) they may require deeper drilling and robust foundations than ground-mounted systems. Installations atop parking structures may be easier, if the structures were designed (not just modified) to hold many vehicles.

At the Croton site, it was necessary to drill 80 to 100 feet down to bedrock due to the inconsistency of the landfill material. Over 200 "micropiles" (i.e., 6-inch steel pipes filled with grout and a 2-inch threaded steel rod) were installed, requiring use of a large crawler drill (see Figure 9). While relatively quiet (no pile driving is involved), such equipment needs working space that may require temporary re-location of parking spaces.

Smaller canopies, at sites with well-settled earth below them, may instead use shallower concrete piers (see Figure 10) dug with smaller equipment using auger drills (see Figure 11). Figure 12 shows such an installation.

Racking

How panels are to be mounted may also present challenges. The Croton system involved erection of a racking "skeleton" and insertion of assemblies (each holding five panels) from below that structure, avoiding the need for large cranes (see Figure 13). A different system involves assembling an entire canopy of many panels on the ground. It is then



Figure 9. To dig deep holes for micropile supports, a large crawler drill is needed. (Photo credit: David. S. Goldman, used with permission)

lifted into position atop previously installed pedestals using two large cranes, one at each end. (see Figure 14). As with drilling of foundations, large equipment may require careful scheduling and planning to accommodate it in an active parking lot.

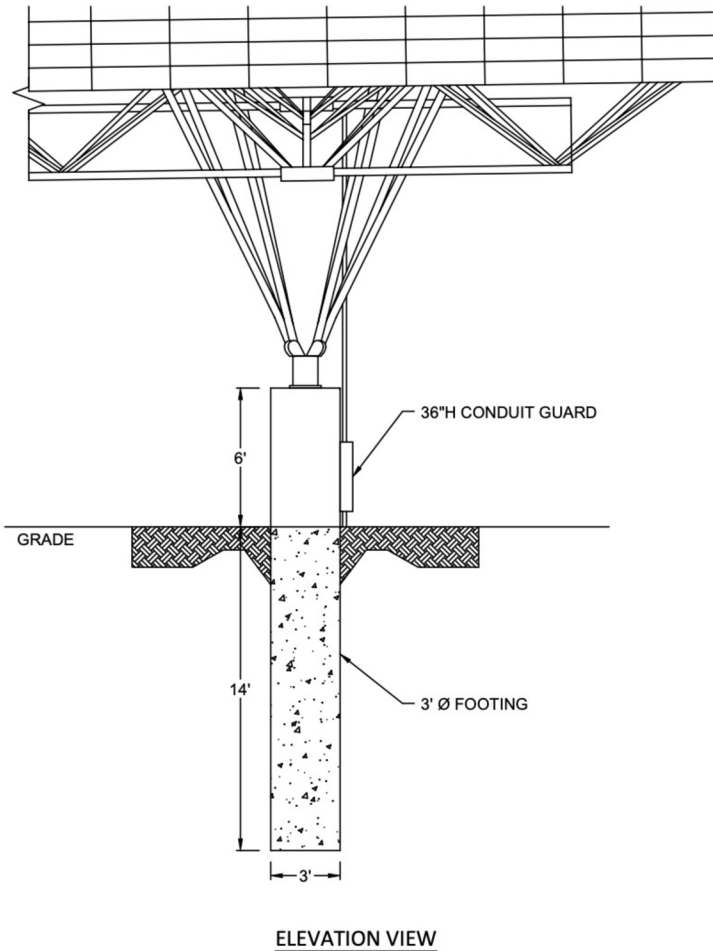


Figure 10. Smaller canopies may be supported by concrete piers buried in firm soils, (Drawing credit: Brock Gibian, used with permission)

Height

As previously mentioned, a canopy has a minimum 13'6" height limit above any area that may be transited by tall vehicles (e.g., fire trucks, tractor-trailer vehicles) (see Figure 15). For a wide-span single-tilt canopy, that may result in a height of 17 to 21 feet on its high side. In turn, that may limit or block access to overhead wiring, requiring careful siting and coordination with existing utilities.



Figure 11. An auger drill on a small crawler digs holes for concrete piers. (Photo credit: Brock Gibian, used with permission)

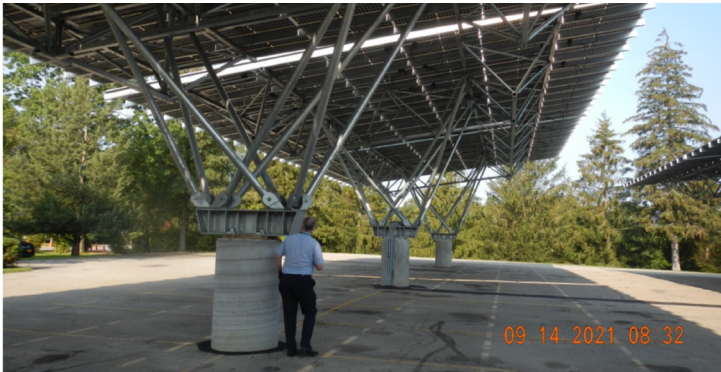


Figure 12. Smaller canopies can be supported by wide concrete piers. (Photo credit: Lindsay Audin)

Stormwater and Snow Management

Depending on local weather, failure to control runoff from precipitation could lead to heavy flow off the lower edge of a single-tilt canopy. In northern states, that may produce icicles and black ice, both of which create hazards. While diligent application of rock salt may be sufficient, it may at times (e.g., overnight) be insufficient to forestall accidents or vehicle damage. Users of the parking lot may also be hoping that canopies will not worsen existing conditions. But well-managed water and snow runoff may be seen as an added amenity.



Figure 13. Panel assemblies being inserted into a metal frame racking system. (Photo credit: David. S. Goldman, used with permission)



Figure 14. Another racking system involves assembling an entire canopy on the ground and lifting it into place using two large cranes. (Photo credit: Brock Gibian, used with permission)

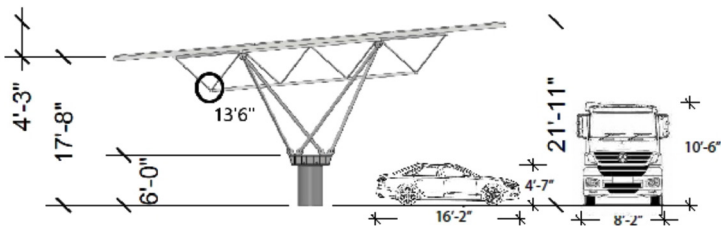


Figure 15. On its lowest side over traffic, a canopy must be no lower than 13'6" to accommodate large vehicles. (Drawing credit: Brock Gibian, used with permission)

Depending on local climate, canopy design, and the type(s) of parking lot users, it may be acceptable to allow water to drip between panels while still controlling flow off a canopy's edges. Students and employees, for example, may complain less than commuters paying for parking. A double-tilt unit directs all water and snow into a central gutter at the bottom of its "Y," eliminating edge runoff. If mounted on corrugated roof decking, even dripping between panels may be eliminated. Doing so, however, eliminates use of bi-facial panels and may reduce covered area.

Snow Guards

Snow guards (see Figure 16) are a small extra cost. Most bidders on the Croton project included them but some early (2012) canopies in New York lacked them. After a heavy snowfall followed by a bright winter day that quickly heated the panels, a thick layer of snow suddenly sloughed over a single-tilt edge, striking cars below with sufficient force to cause minor damage (e.g., broken antennas, dented hoods), resulting in insurance claims against the canopy's owner.

At a site lacking gutters, gaskets, and snow guards, all was fine until the first heavy winter storm in 2023, a few months after startup. Water from melting snow trickled between the panels and over the canopy edges, forming icicles and pools of black ice. The host (a monastery) was quite unhappy, threatening the canopy owner with a lawsuit. The two parties eventually agreed to split the costs of gutters and gaskets, which was higher than if they had instead been installed during construction.

The Croton system has gaskets between panels to minimize dripping and icicles, snow guards to avoid sloughing of loose snow, and gutters and downspouts to catch runoff and direct it to existing underground storm drains (see Figure 17).

Underground Utilities

Unlike ground-mounted systems in rural areas, canopies over parking lots are likely to be in more populated areas on sites adjacent to developed properties. At such sites, it's not unusual to encounter underground utilities, e.g., storm drains, water supply piping, and utility lines. A thorough survey using ground-penetrating radar (i.e., GPS) is essential before nailing down a site design.



Figure 16. Snow guards are a low-cost way to hold snow while it melts. (Photo credit: David. S. Goldman, used with permission)



Figure 17. The Croton system includes gutters on the low edges of its canopies. (Photo credit: David. S. Goldman, used with permission)

Visibility

Unlike roof-mounted systems, canopies may be quite visible, sometimes raising concerns about aesthetics. In one case, a canopy to be installed next to an athletic field was seen as “too much like an industrial installation.” A member of the local planning board got a court order blocking it, eventually killing the project.

A canopy near a developed area may need to be “blessed” by a variety of regulatory boards that might otherwise just rubber-stamp a non-canopy installation. Acceptance of the Croton system involved presentations to a half-dozen commissions, departments, and agencies, any one of which could have killed the project.

LESSON LEARNED

As with any large project, hindsight provides useful lessons, starting with drafting the RFP, and ending with managing expectations.

Development Issues

Focus on revenue, not GHG reductions—The primary driving force to keep the development process moving is the potential for large annual rent payments. Nobody wants to be responsible for losing that opportunity.

Limits on site use—Check deeds for limitations in use based on how the site was purchased. If government or private foundation funds were involved (e.g., to create a preserve), there may be “strings” attached as to how the land may be used. In some states, land associated with an existing park may require a variety of conditions be met before it may be “alienated,” i.e., used for a purpose other than as park land. Such limits may pertain even if that land has already been paved over with blacktop.

Others’ development plans—A serious threat may arise from other (potentially more lucrative) ways to develop a site and produce more revenue, such as a multi-story multi-use complex involving housing, offices, and a mall. Finding such a developer with deep pockets could, however, take years (delaying and/or killing a canopy project). Merely suggesting such an option may elicit demands from competing interests wishing to be involved.

Manage potential negative impacts—Instead of just waiting for them to arise, anticipate them as though you were a critic. Look for ways to identify and minimize them. Issues such as loss of parking spaces, noise, dirt, fire, disposal, runoff into waterways, etc. may otherwise invite early

naysayers. However, do not be surprised if others show up much later in the process as construction appears complete, with spurious issues such as how the rent will be spent, and why an architect wasn't brought in to make it "prettier."

RFP issues

Detail stormwater management—The cost for managing drainage needs to be built into all bids. Despite language on the matter in Croton's RFP, none of the seven bidders' designs and pricing included water management. To ensure an "apples-to-apples" comparison, specify how water and snowmelt runoff will be handled, e.g., if and how they will be conducted from the canopies to nearby existing storm drains.

While snow guards may not be needed on double-tilt designs, some form of guttering and downspouts will be needed, unless personnel parking below the canopies can be safely assumed to have no basis for complaints about dripping, icicles, black ice, etc. Proper drainage may add a few percent to the installation cost, or reduce expected rent by several percent.

To that end, tighter language may be found in the U.S. Department of Energy (DOE) guidance document titled "Procurement Specifications Templates for Onsite Solar Photovoltaic: For Use in Developing Federal Solicitations" downloadable at <https://buildings.lbl.gov/renewables-procurement-0>

Reserve space for EV chargers—Unless chargers are already installed in a parking area, set aside space for them and their power conduits. Canopies will require underground wiring that, once installed, cannot be disturbed or re-routed without incurring legal and cost issues. Chargers need not be installed as part of the canopy work, but reserving space for them will avoid later conflicts. Failure to do so required multiple re-designs for Croton's charging stations.

Contractual Issues

Localizing community solar enrollment—If your state allows community solar, consider focusing enrollments toward local community members. Doing so may create a sense of community involvement that adds support for the project. The vendor will likely already have a "customer acquisition contractor" to find and enroll customers whose power

usage will account for most (maybe all) of the solar output. If so, seek a written arrangement with the vendor to direct its contractor to give “first dibs” to locals within a defined time frame, before opening subscriptions to its own waiting list. Such a deal needs to be specified in the contract, lest the contractor move quickly to sign up only those on its own waiting list. Doing so costs the vendor nothing.

Expediting installation—If there is no penalty for delays, installation (and thus rent) may be delayed, and inconvenience added for users of the parking lot. A proposed installation schedule should be part of the contract, with provisos for allowing some delays while deeming others unacceptable. In times of inflation, the actual value of rent stated in the contract may be diminished if delays stretch beyond an acceptable point. Penalties need not be mandatory, but merely specifying them may provide a useful deterrent.

Minimum notice for temporary parking adjustments—During construction, it will be necessary to cordon off some parking areas and require users to park elsewhere. Unless contractors are required to give at least 48 hours of notice, it may decide to block off space based solely on its own convenience. Doing so may create confusion and possible hazards for those using the lot. Time is needed to provide advance notice, install temporary signage, etc. Merely emailing a parking manager the night before a change that 500 cars must be relocated by 6 AM the next morning is not acceptable.

Addressing extra (possibly unforeseen) costs—If the installation is over a landfill (common with parking lots), include a proviso that covers how disposal costs will be handled. Some waste may be deemed hazardous (e.g., asbestos from 20th century construction), requiring testing and disposal to a specialized site. Deciding in advance how to split such costs (resulting in either reduced rent or payments from the host) will save time and avoid legal fees.

Adjusting for changing economics—While a fixed rate escalator (to increase rent a few percent to mimic typical utility rate hikes) is common in contracts, it does not account for inflation or increases in incentives. Croton’s contract was signed over a year before the federal

Inflation Reduction Act (IRA), which then greatly increased incentives for the developer. The end result was a windfall, and no requirement to adjust its rent based on it. While no one has a crystal ball, some thought needs to be given as to how to capture and/or require sharing of such benefits.

Managing Expectations

Care is needed when sharing information on the value of a winning bid, e.g., expected annual rent and duration of the work. Many changes may occur as a design is refined to meet local requirements. Actual rent/revenue may be proportional to actual installed kWp, which may change during design and installation. Construction schedules may get stretched due to weather and other issues such that inconvenience threatens to become an issue. It should be understood at the outset that a large project may take years to complete. For months, the parking lot may (as described by one commuter) “look like it was neatly carpet bombed with rectangular craters” during its excavations (see Figure 18). Providing photos of (and perhaps visits to) completed canopies may help allay such concerns.



Figure 18. During construction, excavations to accommodate underground power conduits may create large craters and trenches. (Photo credit: David. S. Goldman, used with permission)

CONCLUSION

Embarking on any large solar project may seem like a daunting task entailing years of effort, attention, and risk. At all times, it pays to keep an “eye on the prize” (be it money or reduced GHG) and push ahead. Solar canopies are not the easiest way to help save the planet, but they offer revenue and amenities that may make even an ardent climate change denier smile.

Canopy Information Resources

Each of these free websites provides useful education on the variety and options available for canopy design, specification, installation, etc.

Parasol Structures. Available at <https://www.parasolstructures.com/>. (Accessed April 8, 2025.)

Wolf, S. (n.d.) Ultimate Guide to Solar Carports. Paradise Energy Solutions. Available at <https://www.paradisolarenergy.com/blog/guide-to-solar-carports>. (Accessed April 8, 2025.)

Carport Structures Corporation. (2015). Covered Carport Solutions. Available at <https://www.carportstructures.com/>. (Accessed April 8, 2025.)

Much of this article is derived from a November 2024 PowerPoint presentation to the Long Island (New York) AEE chapter. An updated PDF is available and may be requested from the author at energywiz@aol.com.



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