Transitioning to a Solar-Powered Bus Fleet

Gauging the Potential of Solar Power in the MTA's Zero-Emission Fleet Transition

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Image Source: MTA

Recognizing the urgency of a changing climate, the Metropolitan Transportation Authority (MTA) has set ambitious goals to reduce its carbon footprint. On Earth Day 2023, the MTA announced a goal of reducing its greenhouse gas emissions by 85% by 2040.[1] To achieve this goal, the agency proposed a three-pronged approach:

- ***Update facilities*** to reduce fossil fuel use and energy consumption overall.
- ***Use energy efficiently*** with contemporary energy management and storage strategies.
- ***Transition its fleets***, particularly buses, to electric-powered vehicles.

At the center of this emissions goal is the critical task of electrifying the MTA's bus fleet of 5,900 buses by 2040.[2] This is a major undertaking (no North American city has electrified a bus fleet at this scale, though many agencies are currently making this transition) and requires significant investment to make it a reality. The MTA is starting from near zero: approximately 0.1% of bus travel was powered by electric batteries in 2022. The MTA estimates that an all-electric bus fleet would require a new 262 MW of power capacity to meet its daily peak energy demand (the equivalent of meeting 12 small towns' daily peak power demand[3]), an entirely new bus fleet, and significantly renovated bus depots. The costs of this transition are not publicly available, but are assumed to be substantial, and the indefinite pause on congestion pricing may impact the timeline for electrification. Starting in the 2025-2029 capital program, the MTA plans to begin rapidly expanding its electric fleet and updating its bus depots to accommodate in-depot charging.

The roadmap to this goal has yet to be announced in detail, but the MTA has committed to and begun developing major projects and studying new potential pathways forward. One of these ideas is about the role of renewable energy such as solar; the MTA has discussed installing large-scale solar panel arrays on its assets to support both the facilities and fleet transition initiatives, and has since been cited in its Earth Day press release as well as in several major planning documents.[4]

While this transition represents a generational overhaul of the MTA's bus operations and infrastructure, it poses an opportunity to combine these ***necessary*** changes with some ***ambitious*** ones as well. The electrical demand of these buses is substantial; upgrades to bus depots present an **opportunity** for the MTA to generate some of that electricity in-house through solar panels.

Installing rooftop and parking lot solar panels, combined with storage at MTA bus depots, is an exciting idea with significant potential to propel the MTA's fleet electrification program forward. This analysis explores the opportunities of solar power investments that would likely benefit the MTA as it develops its forthcoming capital plans.

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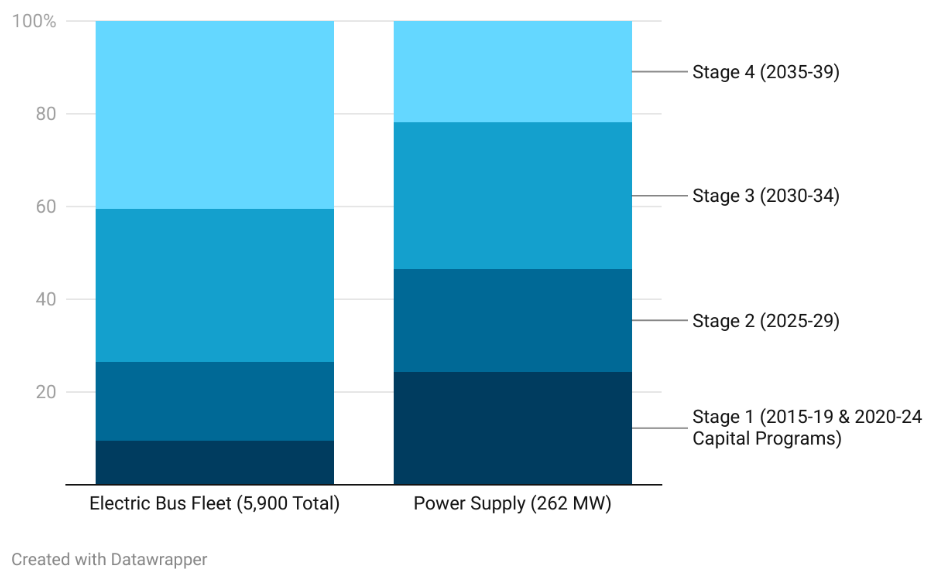
[1] MTA press release (link). The agency uses its emissions in 2015 as the baseline for an 85% reduction.
[2] 2023 MTA Zero-Emission Transition Plan (link)
[3] National Grid Electric Highways Study (link)
[4] Press release, 20-year needs assessment, 2023 MTA Zero-Emission Transition Plan (link)

Challenges and opportunities presented by the electric bus fleet transition

In April 2022, the MTA released its initial zero-emission fleet transition plan, setting out a pathway to a fully electric fleet and updated depots by 2040.[5] The report is ambitious, describing the transition to electric battery-powered buses, updating depots to serve this new fleet, and workforce development needs to maintain the same level of service the MTA's buses have today.

This analysis focuses on the updates to bus facilities, particularly the depots where buses will be recharged and repaired. The transition plan estimates that 262 MW of power supply will be required to charge an all-electric bus fleet, with 64 MW of that power supply required at select depots by the end of the 2020-2024 capital program.

Figure 1. MTA Transition Plan Bus & Power Supply Rollout by Stage



Source: MTA Zero-Emission Transition Plan

The MTA's plan acknowledges solar panels could be added to the transition, but does not commit to incorporating their use beyond a pilot. In the plan, the MTA describes solar power generation, when coupled with battery storage, as a valuable complement to electric bus upgrades for several reasons:

- It provides ***overall cost savings*** by reducing the MTA's reliance on the grid for all its electricity.
- On-site power generation can reduce bus depots' grid demand at ***peak periods*** of the day, when energy costs are highest and the grid is the most strained.

[5] The plan was later updated in 2023; the updated version is used throughout this report.

- On-site solar panels can also provide some ***energy resilience*** after weather events and blackouts to keep powering parts of an electric bus fleet.

Figure 2. The Brookville Smart Energy Bus Depot combines solar and battery storage to power electric buses in Maryland

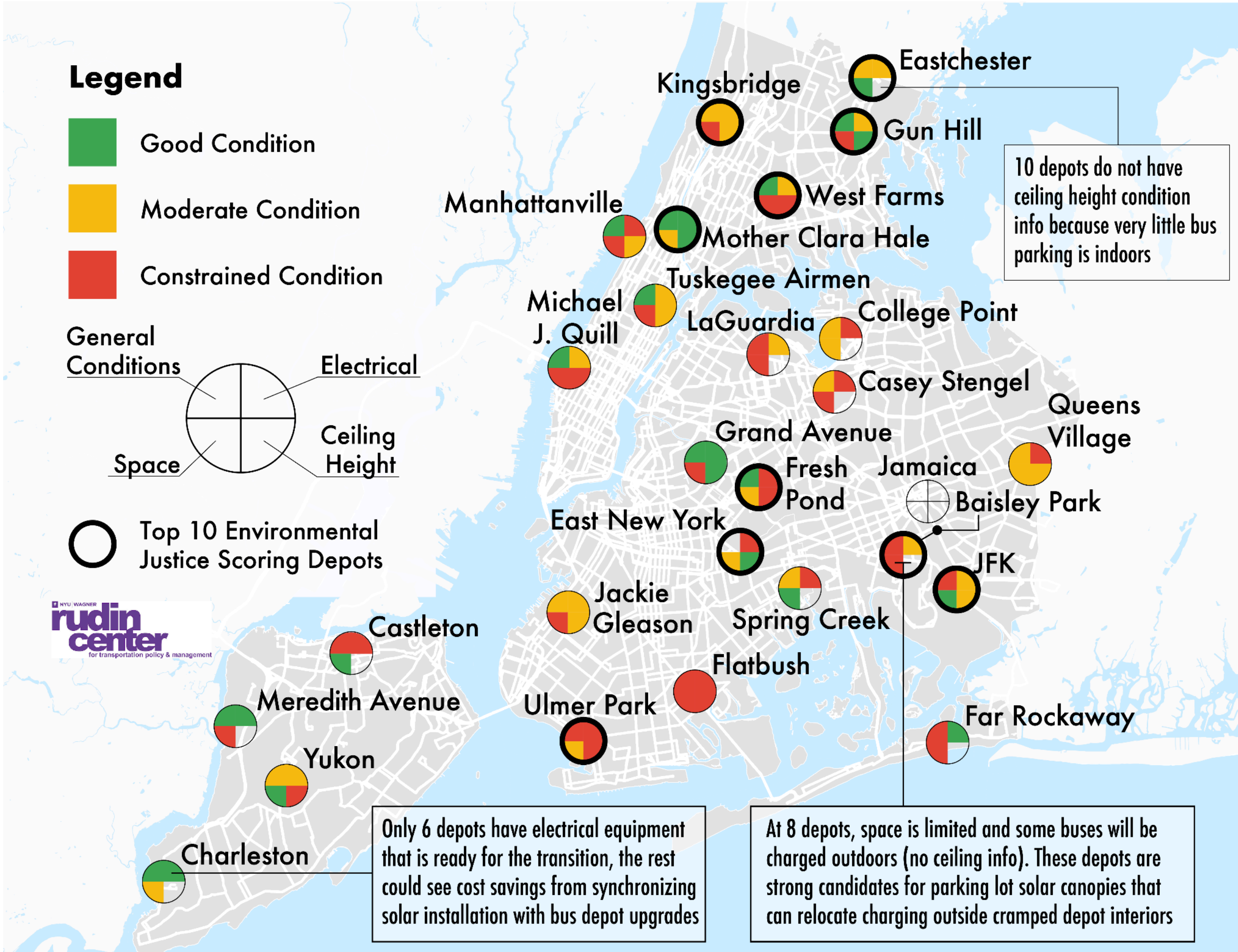
Image Source: Dynapower, Electrek.co

Bus depot upgrade needs

A transition to a fully electric bus fleet will require major renovations to all 28 of the MTA's bus depots. At a minimum, depots require substantial electrical equipment upgrades to accommodate bus charging and the installation of steel structures to install overhead pantograph bus chargers. But almost all depots require capital investments due to the age of the buildings and their roofs, or ceilings too low for chargers, and face challenges accommodating additional infrastructure within their constrained footprints.[6] Funding from congestion pricing would have helped to finance these upgrades; these investments and the timeline for their implementation may now also be in jeopardy.

[6] Adapting to an all-electric fleet is only part of the capital work required at depots. In its recently published Climate Resilience Roadmap, the MTA estimates that safeguarding bus depots from flooding will cost between $500 million to $1 billion, and should be aligned with the Zero Emissions Bus Transition Plan, creating more complexity.

Figure 3. Existing Conditions, Environmental Justice Priority Depots, and Solar Solutions



Sources: MTA Zero-Emission Transition Plan (2023), US Census

Notes: Yonkers depot is not included in this map; its existing conditions are reported in the Transition Plan. The East New York depot is currently undergoing a significant rehabilitation affecting its general conditions score; Jamaica is currently in design for a complete reconstruction and is not included in the data.

There is a window of opportunity for the MTA to save on capital costs by synchronizing depot upgrades with on-site solar power generation. Six depots have electrical systems that were ready for the transition, but the remaining 21 require major expansions or upgrades to adapt to an electric bus fleet.[7] Many of the electrical upgrades required for the bus fleet transition could be combined with those needed for depots to store and draw power from a solar plus storage system.

Figure 3 shows the existing conditions of each bus depot across the four criteria presented in the transition plan, with the depots targeted for early investment highlighted. Besides illustrating the substantial investment that the MTA must make in these assets, it shows the potential for addressing space issues at sites with the vast majority (>85%) of parking space outside the depot building. ***When upgrading depots with this combination of conditions, the MTA should consider installing outdoor pantograph charging so that some depot uses can be relocated outside the building; these outdoor charging areas may be excellent candidates for solar panels.***

The MTA is factoring environmental justice (EJ) into its transition plan and aims to prioritize investments at depots with concentrated need and poor air quality. Bus depots see tremendous fleet traffic as buses come in and out of service, and electric buses can help minimize the environmental impacts of this necessary use. In its transition plan, the MTA developed an environmental justice score for each bus depot and ranked all 28; the agency is tracking how many of the depots with high EJ scores are in the early rounds of the transition plan to properly invest in the communities that currently face the largest burdens.

Figure 3 highlights the top 10 highest-ranked depots across the city; the three highest priority depots are in the Bronx (Kingsbridge, West Farms, and Gun Hill).[8] Many of these depots will require substantial investment to power an all-electric fleet and have the potential to generate substantial energy on-site; they should be considered for solar panels as part of new renovations.

Opportunity: Solar power

As the MTA is investing generational resources in its bus depots, the potential benefits of incorporating solar with battery storage are significant. In conducting a geospatial analysis of bus depot roofs and the parking lots used to store buses, I found that several bus depots could be strong candidates for solar, especially if they take advantage of parking lot space. On a regular weekday, the MTA runs more than 48,600 non-express bus trips across all five boroughs. The average bus route is 6.5 miles, and existing bus batteries use approximately 17.3 kWh for one trip (during average temperatures, though this rate increases significantly on colder days).[9]

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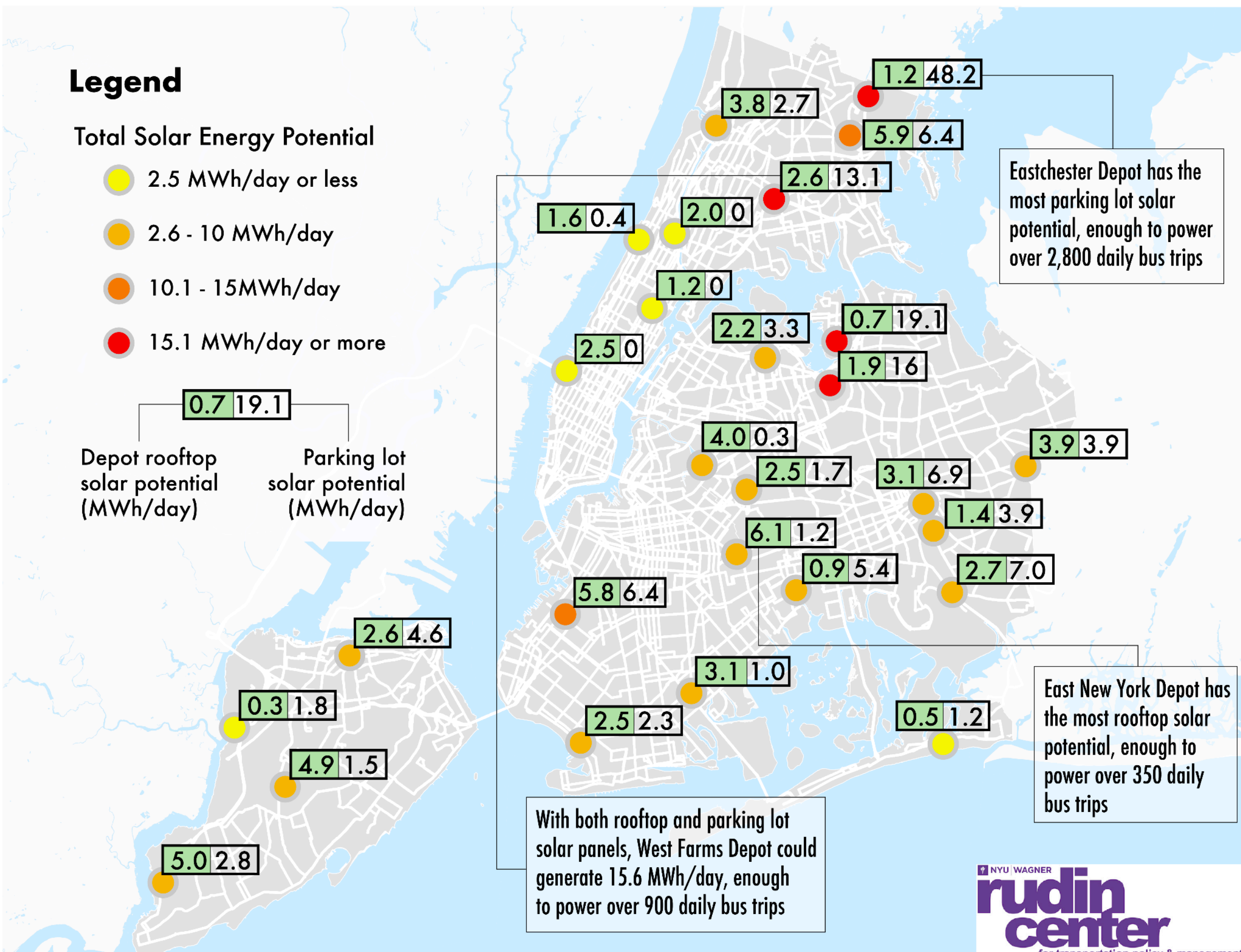
[7] One bus depot (Jamaica) was in design for a complete reconstruction when the Transition Plan was released and was not scored on its existing conditions.
[8] The Kingsbridge bus depot is located in the Inwood neighborhood of Manhattan. It is treated as a Bronx bus depot in the transition plan because it primarily serves bus routes in that borough.
[9] Appendix A details the methodology used to estimate solar energy potential.

Figure 4 shows the potential energy that could be generated by installing rooftop and parking lot solar panel arrays.[10] Across all depots, approximately 112 MWh of energy could be generated from depot rooftop solar arrays per day, enough to power over 6,400 daily bus trips on a mild day.[11] Far more energy (240 MWh / day) could be generated from solar panels installed above bus depot parking lots, enough to power nearly 14,000 daily mild day bus trips. Rates vary considerably based on depot arrangements. Brooklyn bus depots can generate the most rooftop energy due to their building sizes, while Bronx and Queens bus depots can generate most of the parking lot energy.

Figure 4. Solar Energy Potential from Depot Rooftop and Parking Lot Solar Arrays



Sources: NYC DCP MapPLUTO, NYS GIS LiDAR, NYC Building Footprints, US Census

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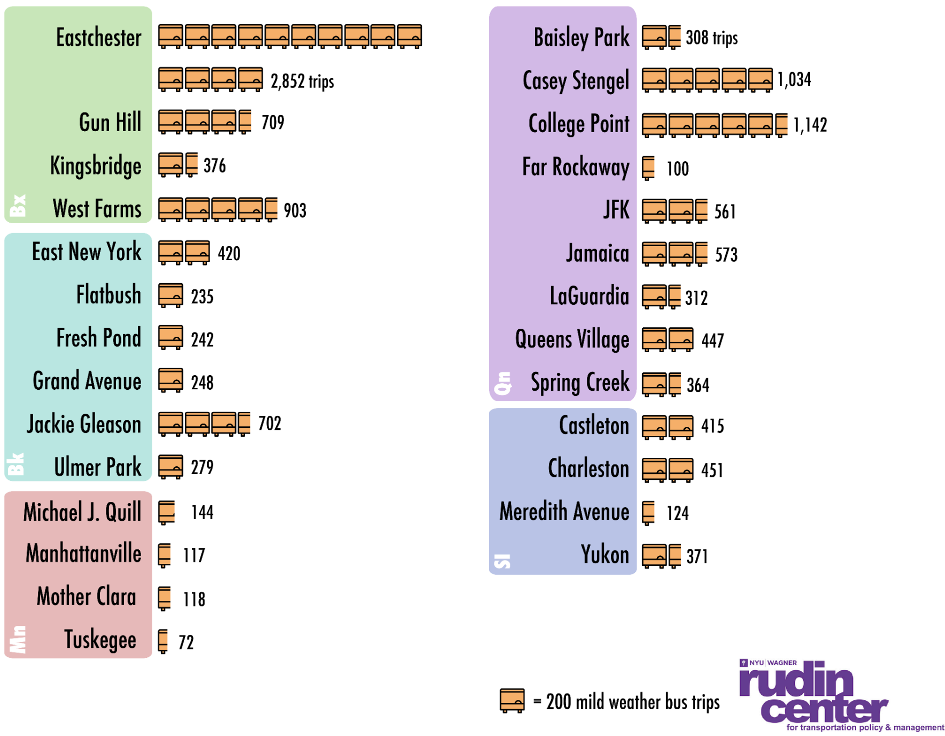
[10] See the methodology section at the end of this report for a detailed explanation of how this number was calculated.

[11] Daily power generation is an average of annual generation rates and would likely fluctuate between seasons. This likely overestimates the rooftop space that can be covered by solar panels, given NYC building codes and zoning, as well as usable roof space. Power generation is not available for the Yonkers depot because of data limitations outside the five boroughs. See the methodology section at the end of this report for a detailed expression of how the number of bus trips was calculated.

Figure 5 shows the number of daily mild weather bus trips that could be powered by solar panels at each depot (see Appendix B for solar potential information for every depot).

Figure 5. Daily Bus Trips That Could be Powered by Rooftop and Parking Lot Solar at Each Depot

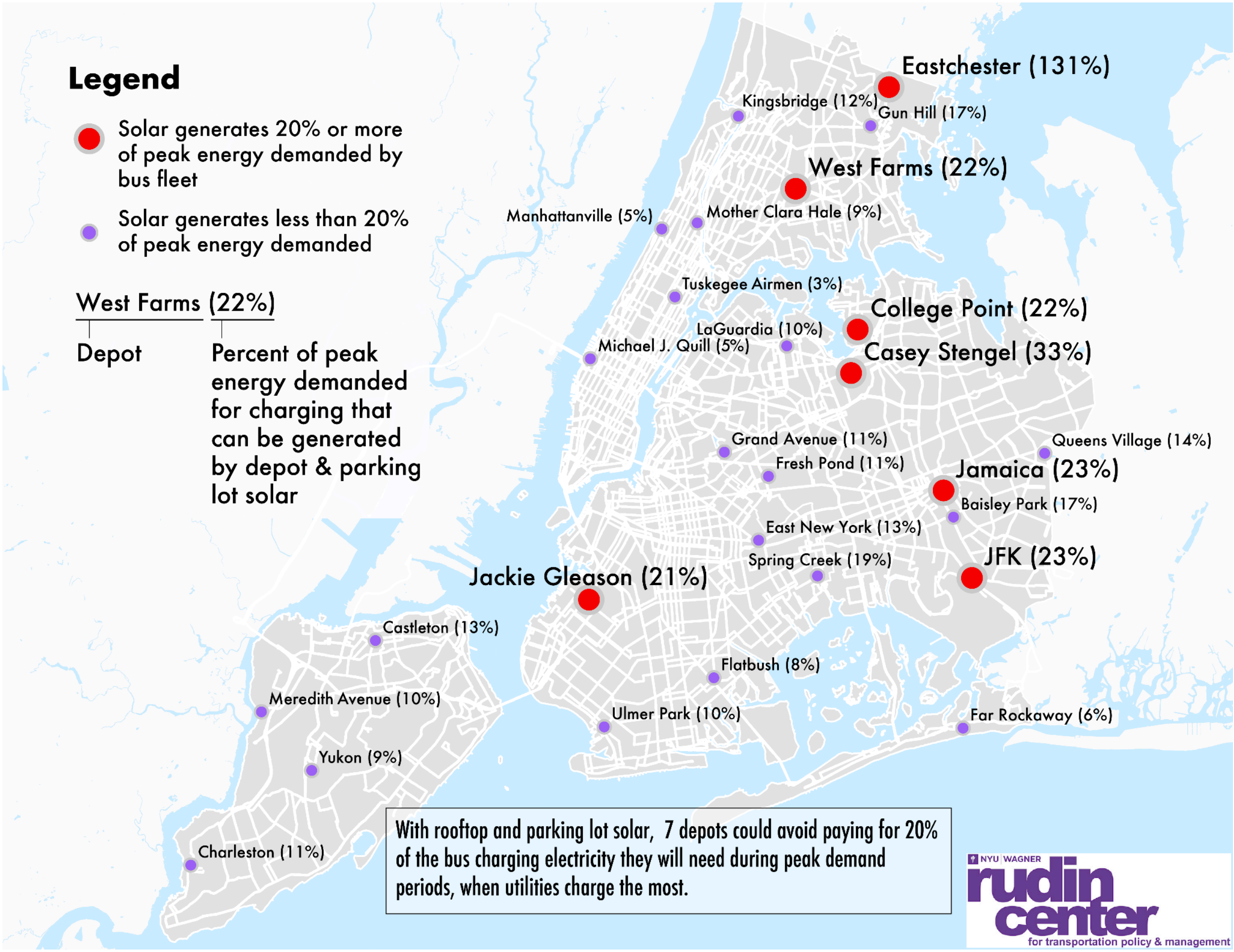


Sources: NYS GIS LiDAR, NYC Building Footprints, MTA GTFS data

When comparing this energy generation potential to an estimate of the energy required at each depot during peak periods, it becomes clear that renewable energy generation has tremendous potential. Figure 6 shows the proportion of daily peak energy demanded that could be covered by this solar power.[12] The clearest example is the Eastchester depot near Co-Op City in the Bronx: with its enormous parking area, the depot could meet all of its peak demand energy needs by installing solar panels and battery storage.

[12] Method for estimating energy potential can be found here: https://learn.arcgis.com/en/projects/estimate-solar-power-potential/. Daily peak energy was estimated using the peak power demand presented in Table 11 of the MTA's transition plan (p. 62) and estimating 6 hours of peak power demand per day, the current peak demand period in utility rate structures (p. 64 of transition plan).

Figure 6. Depots with the Greatest Solar Power Potential



Sources: NYC DCP MapPLUTO, NYS GIS LiDAR, NYC Building Footprints, US Census

The average depot could meet more than one-eighth of its peak energy demand from solar panels installed on depot roofs and parking lots. Borough-wide, Manhattan bus depots can cover the least proportion of their peak energy demand, while depots in the Bronx and Queens lead the city in energy that could be generated from on-site solar.[13]

Installing solar panels over depot parking lots does offer the same electrical system upgrade efficiencies that rooftop panels do, but can still be combined with depot upgrades to address space constraints within the building. The MTA has identified that space within its compact depots will become more complex to manage as areas are allocated within depots to bus charging. By combining outdoor solar panel installation with storage and pantograph charging, the MTA may be able to relocate some of its charging stations outside the depot building and simplify indoor operations.

[13] The Eastchester depot is an exception and is estimated to be able to generate far more than its peak energy demand from on-site solar. It is an outlier in this analysis and was excluded from the average.

Outdoor solar-powered bus charging may be the next frontier for zero-emission bus fleets, a model used beyond the five boroughs. To meet its goal of transitioning its fleet of 297 buses to all-electric by 2035, Austin's CapMetro agency is building a solar-powered pantograph bus charging station in its major bus depot.[14] The station is projected to charge more than 200 buses, the majority of the agency's bus fleet, greatly reducing the energy demanded by its transition. Construction began in fall 2023. ***The MTA could take valuable lessons from tracking CapMetro's experience with this form of bus charging and, if successful, considering replicating it at several depots.***

Outdoor charging could be expanded beyond bus depots in future stages of the bus transition. The MTA has ruled out on-street charging for now, citing myriad challenges, but will reevaluate this concept starting in the upcoming capital program. As the agency rapidly increases the number of electric buses it is operating, on-street charging at MTA-operated termini may be efficient, especially if it can be done with limited energy costs. The MTA could consider applying Austin's model to bus plazas with large open spaces, such as the Williamsburg Bridge plaza, the South Ferry terminal, or the Archer Ave Teardrop Canopy in Jamaica. Overhead pantograph charging takes 5 to 20 minutes depending on the power level, within the average bus waiting time. European demonstrations around wireless charging for public transport vehicles could also be used to charge future electric bus fleets in New York City. Further research is needed to gauge how much solar energy could be generated from installing panel arrays at each terminal, but that technology presents an option for the MTA to expand upon its solar assets as more electric buses are deployed.

Challenges to installing solar panels: funding and prioritization

The MTA has been exploring solar energy for decades, mostly through pilots and demonstration projects. Considering this history can inform the strategy for adding solar to the zero-emissions bus transition.

In the early 2000s, the MTA piloted installing solar panels within station canopies at the Jackson Heights-Roosevelt Avenue station and as a roof over the massive Stillwell Terminal station. In 2019, the MTA announced a solar rooftop lease RFP for seven of its assets as possible sites for commercial solar arrays.[15] The agency chose the initial RFP sites because they are representative of how rooftop solar could function across the MTA's diverse assets. However, the agency has yet to incorporate renewable energy projects into its standard practices for capital planning, due to several challenges; this section will offer recommendations for overcoming these setbacks.

Aligning priorities among MTA departments can cause solar projects to be deprioritized. Renewable energy pilot projects often originate in the capital planning and construction arm of

[14] Austin is sunnier than New York City, but CapMetro's charging station could still suit New York's environment. Austin sees an average of 5.3 peak sun hours, while NYC has 4.6 hours on average.
[15] The MTA is restricted from having a third party install solar due to complications with its tax status. This has stymied its success with the rooftop solar lease program.

the MTA, while operating staff are responsible for maintaining a good state of repair once the solar pilot projects have been installed. Running these pilot projects involves regular maintenance, operation of the equipment, regular upgrades, and other tasks that station operators must fit into their existing workload; without buy-in on the value of the project, the agency has struggled to maintain these pilots, according to MTA professionals interviewed for this study. For example, the solar panel roof at Stillwell Terminal was a groundbreaking project; while in operation, it was generating over 200 MWh / year to power the terminal. However, Hurricane Sandy damaged the electrical equipment at the station in 2012, and the MTA has yet to reconnect the still-functioning solar panels. This is a missed opportunity for cost savings, as the solar panels were saving the MTA more than $50,000 annually in operating costs.

Figure 6. The solar panels at Stillwell Terminal still work, but have been disconnected since 2012

Image credit: Adam Friedberg, Brooklyn Eagle

MTA staff have indicated that it is difficult to prioritize renewable energy assets among the MTA's more urgent challenges.[16] While staff at headquarters may be excited about the potential of expanding solar energy, the success of these projects is contingent on operating staff buy-in, in terms of personnel, budget and time resources and competing operations needs. This misalignment can stymie continual operations and maintenance, posing challenges to improvements or repair major investments. These shortfalls can become cautionary tales that deter future investment in renewables, and demonstrate that operational needs must be allocated during the planning process.

The bus transition may present a strong opportunity to overcome these silos. Because the fleet transition will already require substantial changes to many aspects of bus operations

[16] Interview with Tom Abdallah, Vice President of Environmental Services & Chief Environmental Engineer at MTA Construction and Development, February 2024

and depot processes, there is an opportunity to incorporate solar panel maintenance into an already-changing routine. This is especially true if solar panels can help address pain points in daily operations, such as moving bus charging to outdoor pantograph chargers instead of squeezing them into crowded depots. The MTA's bus depot transition plan also lays out a thorough workforce transition plan, with projections for training time and topics that should be covered. This transition period may also pose a useful opportunity for developing solar buy-in from operating staff who will be trained on new systems.

High capital costs limit the MTA's progress on renewables. The other major challenge to expanding renewables is the upfront capital cost required for these projects. The MTA prioritizes urgent physical needs around aging infrastructure, climate change protection, and state of good repair, which can make it difficult to add projects that may seem inessential. Instead of leveraging the long-term cost-savings as a reason to invest heavily in solar energy, the agency continues to consider solar on a case-by-case basis for individual sites. Uncertainty around major funding sources, like congestion pricing, also discourages the agency from pursuing well-aligned but non-essential capital projects. This explains the slow growth in solar power generation across the agency to date, according to MTA staff.

The transition to electric buses, and their necessary ancillary infrastructure updates, presents a cost-effective opportunity for investing in solar panels with battery storage at bus depots.

- *Mitigating future costs*. An additional 262 MW of peak power will be demanded by the new bus fleet, at an enormous cost, which can be mitigated by on-site solar generation.
- *Streamlining existing costs*. The fleet transition requires upgrading electrical equipment, a step that is also required when installing solar. By synchronizing the two, the MTA can save on construction costs.
- *Resilience*. Though difficult to measure, the potential to help power electric buses during a blackout has significant potential for resilience. Because solar panels do not rely on the grid, on-site solar generation could continue to generate power even if a storm disrupts the grid or a blackout occurs. Climate resilience has been a major focus of MTA capital planning documents and may be another way to justify costs in the capital budget.

To minimize the upfront capital costs of installing solar and storage, the MTA can seek out alternative sources of financing and take advantage of existing federal funding, such as:

- *Energy Performance Contracts and related agreements (EPC)*. This is a budget-neutral approach to financing renewable energy upgrades, where the energy savings in the future are used to pay for present day capital investments. EPCs are often financed by a third-party contractor, which provides the upfront costs and receives payments comparable to the energy savings harnessed by the investment. EPCs are open to public authorities as well as private homeowners: this is an approach that the New York City Housing Authority (NYCHA) has used to fund hundreds of millions of dollars of energy efficiency projects at its developments over the past decade and is scaling up to meet its own sustainability commitments. Transportation agencies outside of New York have also used EPCs to finance sustainability investments outside of a capital budget.

EPCs are often used for building efficiency and decarbonization measures, other programs with a similar financing model such as energy conservation measures may be more appropriate for bus depot solar panels.

- *Public financing through NY Green Bank*. The NY Green Bank (NYGB), operated by NYSERDA, is a state-sponsored investment fund that provides financing for clean energy and sustainability infrastructure projects that struggle to receive private financing. NYGB has served as the lender for EPCs and covers upfront capital costs so they can be repaid through a 'pay as you save' model instead. NYGB has not yet worked with mass transit agencies but has a clean transportation portfolio. It does have a history of working with public authorities like NYCHA and has helped to finance some of its EPCs in the past.

In the future, the MTA may also need to contend with agency emissions standards put into place by Executive Order 22. That order stipulates that all state agencies must reduce their emissions at a particular rate or purchase renewable energy credits (RECs) to fund renewable energy work elsewhere in the state. Should the MTA ultimately be required to comply with this executive order (a challenging feat for the agency as it transitions to an all-electric bus fleet), investing in renewable energy at bus depots is one way to reduce the number of RECs it purchases.

Limitations to solar

The MTA has identified other limitations that make it challenging to invest in solar at bus depots. They are:

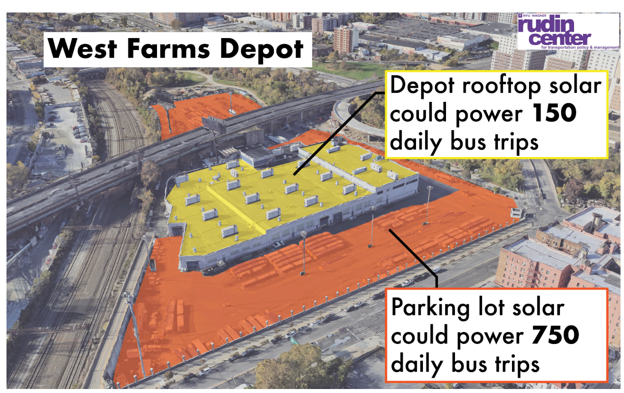
- Depot roofs are often very old and have limited load bearing capacity. Their old age may also make it unsuitable for adding solar canopies which are expected to be in place for decades.
- Energy estimates assume that solar would be equipped with battery storage that would maximize daily energy storage and could work with the pantograph charging system the

Case in point: West Farms Depot

The MTA is at a pivotal moment with its zero-emission bus transition. As the agency develops its 2025-29 capital program, it must move into the second phase of the transition: doubling the number of electric buses purchased by the agency and installing new power supply at six depots.

One of those depots is West Farms in the Bronx, the second highest priority depot based on the MTA's environmental justice score and the depot with the third largest amount of electrical power demand for its bus fleet. The depot has ceilings that are too low to easily accommodate overhead charging, and its parking lot is almost completely occupied by its current fleet.

All these factors could be improved by adding solar power into the capital plan at West Farms. Solar power and storage installed onto the depot's large roof and over its parking lots could generate more than 23 MWh of energy for charging buses every day, enough to power 1,300 bus trips. Put another way, solar energy could cover one third of the electricity required to charge buses at the depot during the most expensive peak demand periods. Buses could also be charged outside, relieving some pressure on operations within the depot.



MTA is planning to implement across its system
- Especially when combined with battery storage, large-scale solar panel arrays can be expensive to build. It was beyond the scope of this analysis to conduct a cost-benefit analysis of the Net Present Value of installing rooftop and parking lot solar panels on depots, although this would be an important step to do in advance of investing in these panels.

Conclusion

This research shows the tremendous energy potential that the MTA could generate with solar plus storage infrastructure. As the agency contends with its rapidly growing energy needs that come along with a zero-emission bus transition, solar may present a cost-effective solution that meets its sustainability and climate resilience goals simultaneously.

Unfortunately, the congestion pricing pause has thrown the entire zero-emission transition plan into jeopardy. Many of the major capital investments of this plan were to be funded through financing made possible by the revenue from congestion pricing tolls; without this, the timeline for the transition is completely thrown into jeopardy. Regardless of this uncertainty, the benefits from incorporating solar into the transition remains a valuable and cost-effective approach.

Solar-powered bus charging presents a substantial opportunity for the MTA that is most feasible to implement right now, during the bus transition. As the agency undergoes its capital planning process for the 2025-29 capital program, the MTA should consider the benefits from including this program in its plans for bus depots.

Appendix A. Methodology

This section details the methods used to (1) estimate the solar power potential of solar panels placed on bus depot roofs and above bus depot parking lots and (2) translate this into bus trips.

SOLAR POWER POTENTIAL

There are two sections: one listing out the data sources used in the analysis and another describing the methods used to produce the solar power potential estimate based on that data. This analysis was conducted in ArcGIS Pro using its native Area Solar Radiation tool.

Data Sources

All data used in this analysis is publicly available through NYC and NYS open data resources. Some data are only available within New York City while one MTA bus depot is sited outside the five boroughs in Yonkers. Information on this site is limited because of this.

LiDAR data

To estimate solar radiation potential, satellite LiDAR data collected and published by NY state is critical. This data was downloaded from the state's GIS data application using FileZilla.

Building footprint data

To estimate solar radiation potential and to describe the bus depots, building footprint data is critical as well. This information was downloaded from NYC Open Data.

Parking lot data

To estimate the solar power potential of parking lots used at bus depots, a planimetric shapefile of parking lots in NYC is used to assess these areas. This data was downloaded from NYC Open Data.

MapPLUTO data

To work with the parking lots shapefile, the data must be filtered to lots that sit on tax lots associated with MTA bus depots. This can be done using MapPLUTO, accessible from NYC DCP's Bytes of the Big Apple.

Solar Energy Estimation

First, LiDAR data must be converted to a digital surface model (DSM). The steps do this are the following:

1. Download .las files from NYS GIS Clearinghouse
2. Create a LAS Dataset in ArcGIS using the 'Create LAS Dataset tool'
    a. This takes a long time to run, be patient
    b. Instructions on this step and the following can be found here
3. Create a Raster file using the 'LAS Dataset to Raster' step

a. Before doing this, right click on the LAS Dataset and select “LAS Filters/All points” to make sure buildings and non-surface points will be included in the Raster output
b. Make sure to draft the LAS Dataset from the Contents pane to the Geoprocessing pane

To estimate the solar energy potential of bus depots, this ESRI instruction document was used as a guide. The Area Solar Radiation function was run two times: once using building footprints as a mask and another using parking lots.

Note that the MTA bus depot in Yonkers is not included in the tax lot, building footprint, or parking lot shapefiles because the data only spans buildings within New York City. Because of this, it was not possible to estimate solar energy potential on that building.

Rooftop and parking lot solar energy potential is calculated for the entire space, and then restricted to account for roof tilt, orientation, and shading. Solar potential locations are restricted based on the following criteria:

- Areas that are sloped greater than 45 degrees
- Areas that are north-facing
- Areas that generate insufficient energy to be worth siting a solar array (due to shading)

Then, the total solar energy produced at each building and parking lot is summarized, and electricity generation is estimated based on current solar panel *efficiency* (16%) and *performance ratio* (86%). To account for the practical limitations of rooftop solar installation, a *rooftop blockage factor* (50%) is also used to estimate electricity generation in practice. The final variable shows the total energy produced per year by each building and parking lot, expressed in megawatt hours (MWh).

BUS TRIPS POWERED BY SOLAR

The MTA’s zero-emission transition plan details energy consumption and range data collected during its initial piloting phase of the transition. The data, presented on page 42, shows that standard buses use energy more quickly during colder days. This analysis uses the average daily temperature for New York City (54 degrees); based on Figure 6 in the transition plan report, it is estimated that standard buses use 2.65 kWh to travel one mile. Buses use significantly more energy per mile traveled during colder and warmer days, up to 50% more in 20-30 degree weather.

To measure the number of miles buses travel, GTFS data for bus routes was used. For this analysis, weekday bus trip data for conventional and select bus trips were analyzed to calculate the total number of miles traveled and total number of trips per bus route. From this, the average distance traveled per route was calculated and used along with energy consumption data to estimate the number of trips that could be powered from solar panels.

- Note that this does not include non-revenue miles traveled from the bus depot to the start of revenue service, as information on which depots house buses for particular routes is not publicly available.
- Commuter bus routes were excluded from route mile averages because the MTA has not collected energy consumption data for this bus type. All estimates in the report refer to standard bus trips.

Appendix B. Solar Energy Potential

Five bus depots have roofs that could power more than 200 bus trips every day with rooftop solar and storage:

- East New York (351 bus trips - 6.1 MWh / day)
- Gun Hill (338 trips - 5.9 MWh / day)
- Jackie Gleason (332 trips - 5.8 MWh / day)
- Charleston (289 trips - 5.0 MWh / day)
- Yukon (282 trips - 4.9 MWh / day)

Ten depot parking lots could power at least 200 bus trips every day with solar panel canopies:

- Eastchester (2,781 bus trips - 48.2 MWh / day)
- College Point (1,104 trips - 19.1 MWh / day)
- Casey Stengel (923 trips - 16.0 MWh / day)
- West Farms (753 trips - 13.1 MWh / day)
- John F Kennedy (403 trips - 7.0 MWh / day)
- Jamaica (396 trips - 6.9 MWh / day)
- Gun Hill (371 trips - 6.4 MWh / day)
- Jackie Gleason (370 trips - 6.4 MWh / day)
- Spring Creek (311 trips - 5.4 MWh / day)
- Castleton (267 trips - 4.6 MWh / day)

Note that some of the parking lots used by buses appear to be shared with other nearby transportation and utility uses. Property ownership and easements may make it challenging to harness all the solar power potential available at this site, but even half of the solar energy generated at the site is greater than all other bus depots.

		Solar Energy Potential (MWh/day)			**Total bus trips powered by solar**
Borough	**Depot**	**Depot Rooftop**	**Parking Lots**	**Total**	
	Eastchester	1.2	48.2	49.4	2,852
	Gun Hill	5.9	6.4	12.3	709
	Kingsbridge	3.8	2.7	6.5	376
	West Farms	2.6	13.1	15.6	903
Bronx	Yonkers	-	-	-	-

		Solar Energy Potential (MWh/day)			Total bus trips powered by solar
Borough	**Depot**	**Depot Rooftop**	**Parking Lots**	**Total**	
Brooklyn	East New York	6.1	1.2	7.3	420
	Flatbush	3.1	1.0	4.1	235
	Fresh Pond	2.5	1.7	4.2	242
	Grand Avenue	4.0	0.3	4.3	248
	Jackie Gleason	5.8	6.4	12.2	702
	Ulmer Park	2.5	2.3	4.8	279
Manhattan	Michael J. Quill	2.5	0.0	2.5	144
	Manhattanville	1.6	0.4	2.0	117
	Mother Clara Hale	2.0	0.0	2.0	118
	Tuskegee	1.2	0.0	1.2	72
Queens	Baisley Park	1.4	3.9	5.3	308
	Casey Stengel	1.9	16.0	17.9	1,034
	College Point	0.7	19.1	19.8	1,142
	Far Rockaway	0.5	1.2	1.7	100
	Jamaica	3.1	6.9	9.9	573
	JFK	2.7	7.0	9.7	561
	LaGuardia	2.2	3.3	5.4	312
	Queens Village	3.9	3.9	7.7	447
	Spring Creek	0.9	5.4	6.3	364
Staten Island	Castleton	2.6	4.6	7.2	415
	Charleston	5.0	2.8	7.8	451
	Meredith Avenue	0.3	1.8	2.1	124
	Yukon	4.9	1.5	6.4	371