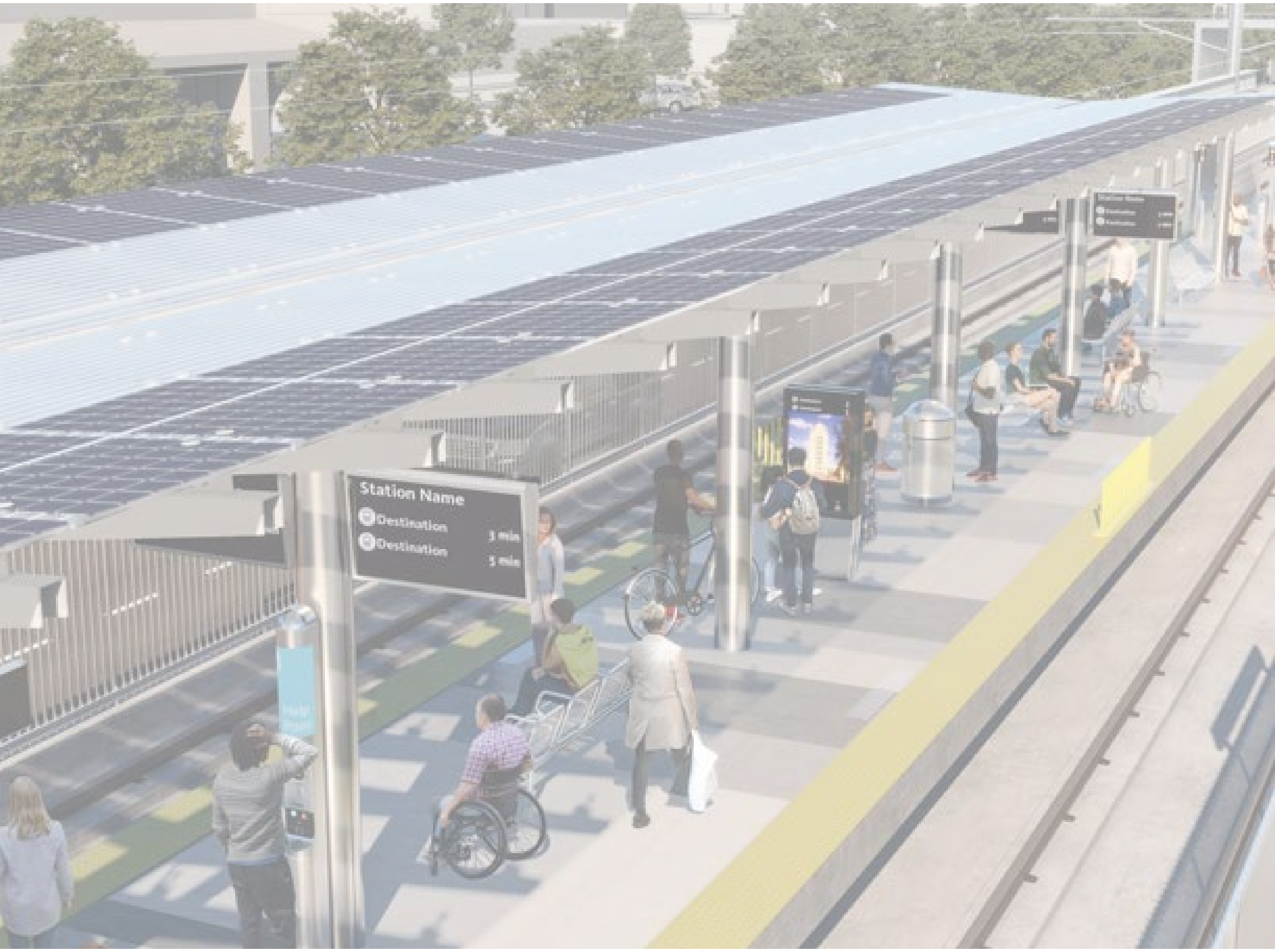
Metro

INTEGRATED STATION DESIGN SOLUTIONS (ISDS)



Solar Panels

Final White Paper

April 2020

Gensler ARUP RAW STUDIO-MLA Claris Strategy Kilograph

Solar Panels
White Paper

1.0 Element Overview and Problem Statement

1.1 Description of Element

Solar panels can provide a renewable "green" source of energy to transit station operations, reducing the amount of energy needed from non-renewable sources. During peak sunlight, a rail station may be able to run off the power generated by a sufficient number of solar panels. Metro's estimated existing station power usage for an underground station is 1,040,189 kWh/year, while an at-grade/aerial station is 126,590 kWh/year.

When the amount of green energy collected exceeds the needs of the moment, that power can be saved to Metro's system for later use or sold back to the power grid.

Currently, solar panel technology is used at several Metro facilities including bus divisions and the El Monte bus station. However, Metro rail stations have not yet employed the use of solar panels.

To implement solar panels at stations, panels should be integrated into Metro's existing station architecture. One design solution is to implement the solar panels in conjunction with, or replace, the current standard glass canopy. A solar canopy provides the required shade and weather protection, while also producing renewable energy.

The project goal for this element is to provide recommendations for a solar array design that is effective, easy to maintain and retains the design aesthetic and architectural language of Metro's Systemwide Station Design Standards.

1.2 Problem Statement

Metro relies mostly on conventional power sources to operate the current railway network and rail stations. This highly-centralized energy consumption behavior could lead to potential issues including:

- Higher operating costs due to increased electricity rates
- Dependence on emergency backup electrical systems, such as Uninterruptible Power Supply (UPS), during power outages (with associated incremental costs)
- Loss of potential government tax incentives due to lack of renewable energy power projects
- Loss of potential revenue from excess power that could be sold back to the power grid

1. 3 Sustainable Approach

Sustainability is broadly understood as meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Figure 1-1 Solar Panels at Metro Bus Division 15, Sun Valley, CA.

Metro's Sustainability Policy is based on the three themes of connect, create and conserve. Over time, these themes and priorities will be increasingly embedded in planning activities to:

- Align and optimize transportation strategies implemented through various planning programs toward a common vision of sustainability
- Evaluate proposals for renewable energy funding programs
- Inspire project design, creativity, innovation
- Guide and communicate sustainability performance

In maintaining Metro's sustainability goals, the proper execution of a solar power system and integrated panel design will not only complement this vision, but also enhance future Metro project designs by:

- Promoting clean mobility options to reduce criteria pollutants, greenhouse gas emission, and dependence on fossil fuels from conventional power sources
- Supporting transportation improvements that minimize material and resource use through conservation, re-use, re-cycling, and re-purposing

2.0 Design Process and Principles

2.1 Design Process

The Project Design Team for this element was led by RAW International and included Gensler and ARUP. Based on the analysis and information collected by RAW, the Project Design Team developed initial design concepts, which were presented to Metro in October 2019. Based on analysis and information provided by Metro staff, the project design team developed a Draft White Paper that was presented to Metro in December 2019 and finalized in April 2020. For additional information, see “Table 2-1 Timeline of Design Process” on page 4.

2.2 Design Principles

Sustainability

Solar power systems can help achieve the following sustainable goals:

- Solar power can provide clean, sustainable energy to Metro stations and Metro-owned facilities
- Increase the use of renewable energy sources as a means of reducing Metro’s carbon footprint
- Align electrical power generation with Metro’s energy and sustainability goals
- Allow Metro to become more energy self-sufficient in the long term
- Help create an infrastructure that may include future EV charging stations as part of Metro’s solar power infrastructure

Solar Canopies

- In addition to generating power, solar panel canopies can provide rain and sun protection in lieu of, or in conjunction with the standard glass canopy (existing station canopies may not have been designed to support solar panels, so a structural analysis should be performed on a case-by-case basis)

Solar Power System

Two alternative solar power systems may be designed and installed at at-grade and aerial stations to collect and manage the energy produced by the solar panels.

- An **off-grid** solar power system can collect direct current (DC) captured by the solar panels, store it in battery banks and convert it to alternating current (AC) to power certain critical and essential station electrical load (this does not include the power required for emergency back up)
- A **grid-tied** solar power system can collect DC captured by the solar panels to power up certain electrical loads and when allowed, excess electricity may be sold back to the power grid

Operational Cost Reduction

- The solar power system can be used to power specific station loads, reducing the overall grid electrical consumption
- The solar power system can be interconnected with local power grids, allowing excess electricity to be sold back to the power grid
- Due to their size and array configuration, bifacial solar panels can maximize solar power production

Figure 2-1 Solar Panels at El Monte Station.

Table 2-1 Timeline of Design Process

October 2019	Solar panel presentation submitted to Metro.
December 2019	Project Design Team submitted a Draft White Paper to Metro.
March 2020	Revised White Paper submitted.
March 2020	Final White Paper submitted.
April 2020	Revised Final White Paper submitted.

3.0 Design Solution

In response to the need for solar power design guidelines for stations, the project team developed solar power design concepts that could be developed further into guidelines to be incorporated into the existing station design standards and current station infrastructure. In this way, Metro could potentially reduce operational and maintenance costs, while strengthening its role as a sustainable energy leader.

3.1 Solar Panel Recommendations

Bifacial solar panels are recommended as they generate power from both sides of the panel. These panels contain a transparent layer, typically glass, that allows cells on both sides of the panel to receive light. Traditional opaque-backsheeted panels are monofacial and only produce energy from one side.

Walking on bifacial solar panels is strongly discouraged because of the likelihood of cracking, causing the cells to lose power generation. Bifacial solar panels should be maintained by walking along the catwalk located on top of the central beam of station canopies. There exists flexible-type solar panels that allow maintenance personnel to walk directly on top of them, but these panels produce less energy output, and thus are not the type of solar panels recommended as part of the design solution concept.

Figure 3-1 Combination of framed bifacial solar panels and glass panels within a framed assembly, French Laundry Restaurant, Yountville, CA.

3.2 Solar Canopy Location & Design

Solar panels could be located on top of the station canopy structure, mounted on top of canopy outriggers in-place of or in conjunction with the current standard glass canopy panels. The current station design standards for at-grade, aerial, and underground portal canopies can be modified to incorporate this modification to use bifacial solar panels in lieu of the glass panels. To do so, Metro's standard kit-of-parts would need to be further engineered along with design details for the frame of the solar panels to ensure proper mounting and fitting of the solar panel system within the current canopy structure.

Figure 3-2 Rendered concept of continuous bifacial solar panels on Systemwide Station Design (SWSD) canopy.

Retrofits to older stations (outside of the kit of parts) will require case-by-case consideration, and some may be unsuitable due to artwork integration or other unique design conditions.

Solar panels are waterproof as solar cells are located within the glass panels. However, an array of solar panels must be waterproofed with tight rubber strips in between panels or sealed with weatherproof tape. A framed solar panel array with horizontal water chutes is another waterproofing technique, but it has a much heavier profile than tight rubber strips and weatherproof tape.

Additional study is required to determine if solar panels would be beneficial if installed on portal canopies at below-grade station entrances. Unlike aerial and at-grade station platform canopies which are intended to provide shade for transit riders, underground station portal entrance canopies are intended to be more highly translucent to maximize the amount of daylight that reaches into the station. Installing solar panels in this area may result in the need for additional light during the daytime and therefore increase energy use inside the station, potentially off-setting any environmental benefit.

3.3 Solar Panel Layout

Solar panels can cover the full extent of the canopy frame. Alternatively, they can be placed in a manner that will allow glass panels to be combined with bifacial solar panels to achieve different levels of translucency.

Solar panels may be installed frameless for aesthetic purposes or framed to protect panel edges from falling objects or other potential hazards. Further design and engineering is required to determine if the standard glass attachment system using spider clips can be used or if a different method of attachment is needed.

Figure 3-3 Rendered concept of continuous bifacial solar panels on SWSD center platform station with canopy running full length of platform to maximize energy production and shade on platform.

Figure 3-4 Rendered concept of a combination of bifacial solar panels and glass panels without a framed assembly on SWSD canopy.

3.4 Solar Power Array System Components Locations

While solar panels are integrated into the canopy structure, the solar power system components (circuit breaker, inverter, charge controller, battery bank) must be located in a safe area, concealed from public reach and view, and protected from inclement weather.

For at-grade stations, it is recommended to install the components at the ticketing area within the TVM enclosure, or under the platform located inside a control room. These components, with the exception of the battery bank, should be mounted on a control panel that allows easy access to monitor and manage the solar power system. These components are not required to be close to solar arrays, but located where they can be easily accessed. Per the National Electrical Code (NEC) 690.12, inverters must be within one feet of solar arrays that include a rapid shutdown function, but if there are difficulties in meeting this criterion, there is a workaround. A module-level power electronics (MLPE) device can achieve the necessary shutdown and also optimize the performance of the modules. Depending on the manufacturer, some MPLE are separate from the inverter (TIGO), but there are some that are incorporated into the inverter (SolarEdge).

If solar panels are incorporated into underground station portal canopies, the required components should be located within a control room in the station ancillary space. Equipment should not be placed on plazas or other locations in the public view.

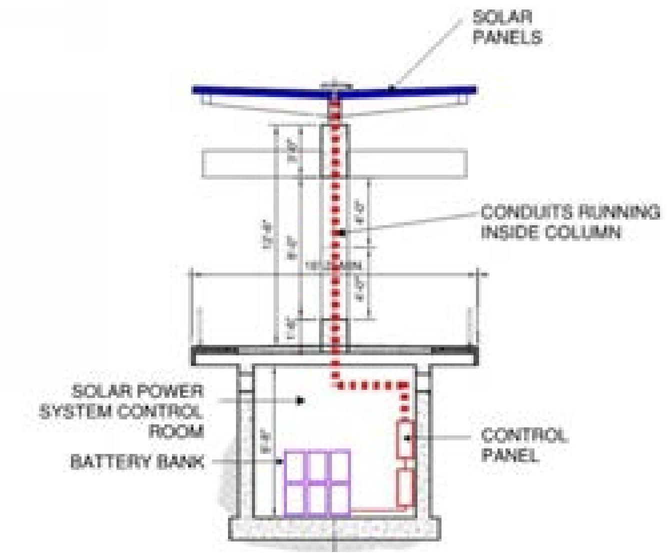


Figure 3-5 Proposed concept for a solar power system control room and battery bank below platform, at-grade stations. A similar layout should be used for aerial stations.

Solar Panels

White Paper

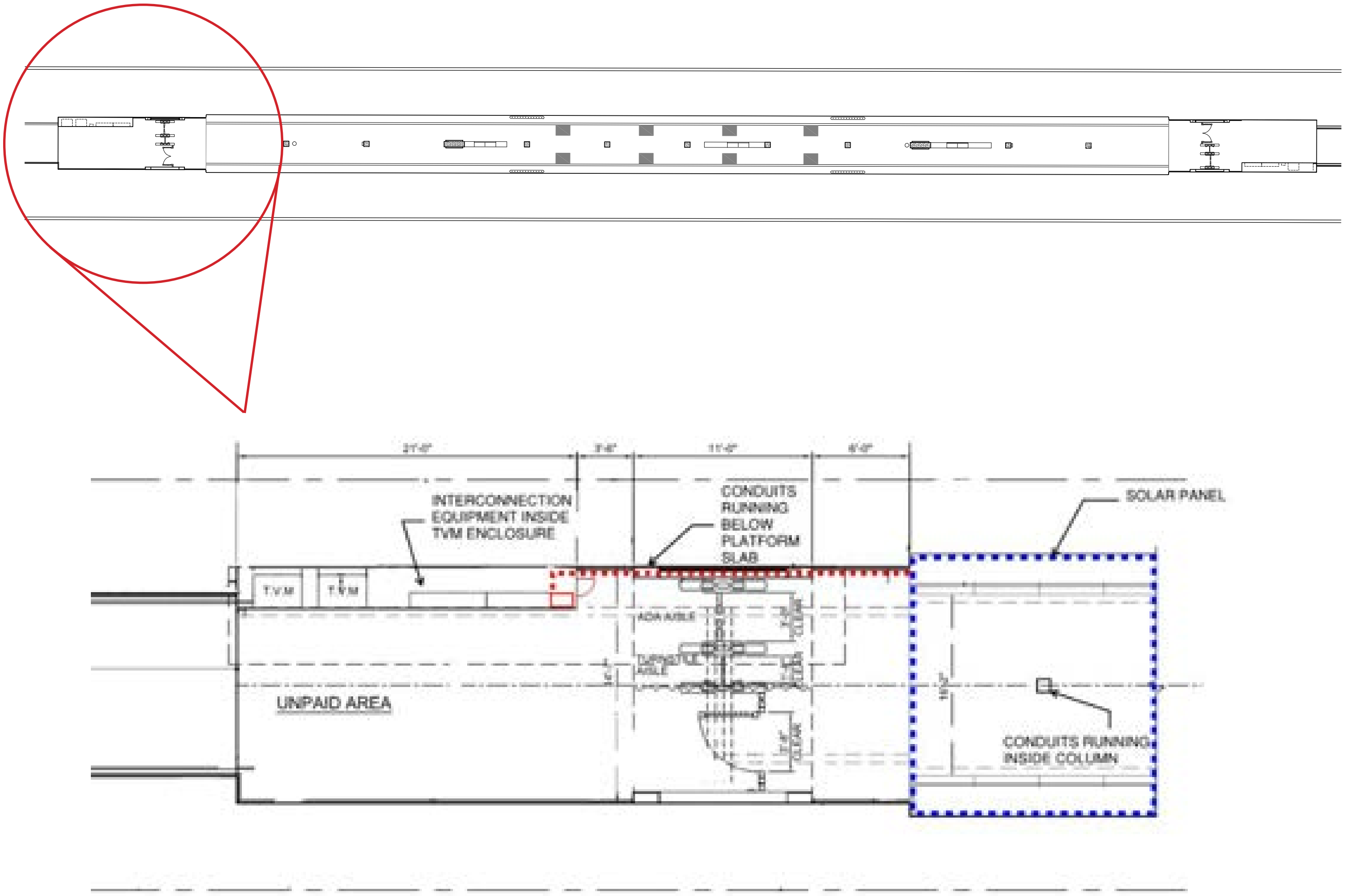


Figure 3-6 Proposed concept for a solar power system control room inside TVM chase of an at-grade station.

4.0 Off-Grid Solar Power System

A standard off-grid solar power system circuit diagram (Figure 4-1) includes the following components:

- Solar panels
- Charge controller
- Battery bank
- Inverter (DC to AC)
- Main circuit breaker panel

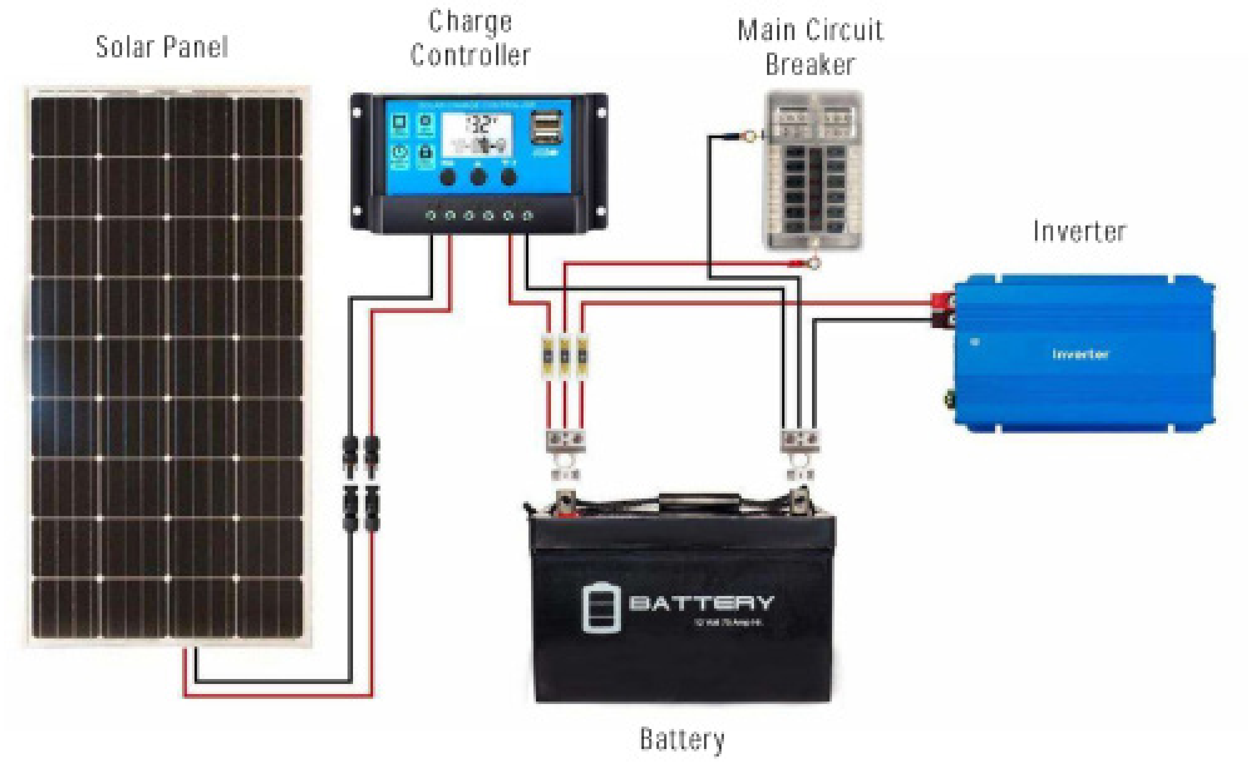


Figure 4-1 Typical Off Grid Solar Power System Circuit Diagram

Notes:

1. Station solar system to include web-enabled remote monitoring and revenue grade metering.
2. Remote monitoring will require either network access or cell modem.
3. System to coordinate with revenue grade meters for registration with the Western Renewable Energy Generation Information System (WREGIS).
4. Battery bank shall be kept inside a temperature regulated environment and will require a battery monitor to check voltage.
5. Fuses to be installed in circuit as required.

4.1 Solar Panel

The recommendation is for Metro to use bifacial panels for station applications. Bifacial solar panels have the capability to generate electricity by capturing sunlight from both sides of the panel. (Figures 4-2 & 4-3)

Bifacial panels produce more energy, have a better cell technology and have a lower degradation rate than standard monofacial panels. When assessing the financial returns of projects over their life cycle, these panels provide a significant levelized cost of energy (LCOE) savings. Most manufacturers indicate that bifacial solar panels have a lifespan ranging from 25 to 30 years.

Because bifacial panels can generate power from both sides of the panel, they have lower labor costs and balance-of-system costs to produce the same amount of energy. They can also produce more energy from the same project footprint, with minimal additional installation costs. Bifacial panels offer substantial savings for solar project financiers.

By using mono-crystalline silicon cells, bifacial panels can offer Metro much better energy conversion rates than traditional, polycrystalline PV panels. With higher efficiency cells (and dual-glass structure) comes a more durable, efficient system that can reduce project costs across the board and significantly increase equipment longevity.

It is important to provide proper distance between the station platform and the bottom of the canopy to provide sufficient unobstructed space and effective reflective surface for the bifacial panels to work as designed.

Even though bifacial panels can produce up to 30% more electricity than an equivalent monofacial panel (in certain environments), monofacial panels should not be excluded as they are panels which offer a sleek finish, perform efficiently and present a lesser cost premium.

Refer to Appendix B for Solar Array output calculation.

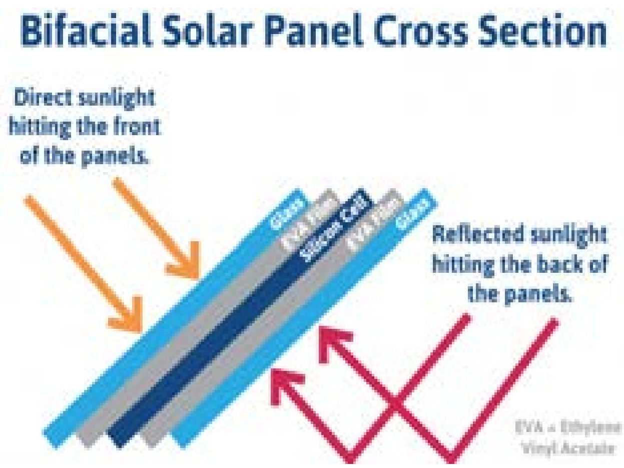


Figure 4-2 Bifacial solar panel schematic section.

Figure 4-3 Bifacial solar panel with 6x12 PV cells.

4.2 Charge Controller

A solar charge controller serves as a regulator. It charges the battery bank with power created by the solar panels. The charge controller takes the constantly changing 0-24 volts produced by the solar panels and produces a constant voltage that is suitable to charge a battery bank. Typically, charge controllers are sized in amperes. Amperage ratings can be between 1-60 amps and voltage ratings from 6-60 volts which relate to each other directly.

Charge controllers protect the batteries. Extended periods with a partial state of charge will cause the plates of a lead-acid battery to become sulfated, greatly reducing life expectancy. Lithium battery chemistries are equally vulnerable to chronic undercharging. Running batteries down to zero can reduce their life span. Therefore, load control for the connected DC electrical loads is very important. The low voltage disconnect (LVD) switching included in a charge controller protects batteries from over-charging (Figure 4-4). Overcharging all types of batteries can cause irreparable damage. Overcharging lead-acid batteries may cause excessive gassing that may damage a battery's plates by exposing them.

Figure 4-4 Charge controller.

4.3 Battery Bank (Energy Storage)

The battery bank stores the DC captured by the solar panels. It requires protection from the weather so it should be kept inside a utility room with proper ventilation. Returning power to the grid can be accomplished by means of net metering, regardless if a system has a battery bank. Battery efficiency depends on several factors including battery type and life span.

There are three basic types of batteries:

1. Lithium-ion batteries. Represents more than 80% of the installed power and energy capacity of large-scale energy storage applications
2. Nickel and sodium-based batteries. Represents around 10% of the market
3. Lead-acid and other chemistries. Affordable but less environmentally friendly

Figure 4-5 A Lithium-ion battery bank similar in size can be expected at typical Metro stations.

Lithium-ion's longer life cycle, lighter weight and decreased maintenance are the preferred choice for large-scale, EV and residential applications. Lithium-ion-based energy storage systems are the most common storage technology used within the solar market. Figure 4-5 above is a battery bank that would serve the needs of a single station, dimensioned at 4'-0" x 4'-0" x 3'-0". However, the size of a battery bank (kW) can vary according to the required capacity of the solar array.

Battery banks could be much larger, if for example, lead acid batteries are used (given that lead acid batteries can be discharged to only 50%, double the amount of lead-acid batteries would be required when compared to lithium-ion batteries). Batteries can be connected in a series or parallel to achieve different voltages including 12V, 24V and 48V. Batteries require a battery monitor. Refer to Appendix A for battery bank size calculation for a typical at-grade station.

Lithium-ion batteries are more expensive than other battery types mainly due to the need of battery management systems that monitors voltage and temperature. The different types of lithium-ion batteries are as follows:

- Lithium Cobalt Oxide (LCO)
- Lithium Manganese Oxide (LMO)
- Lithium Nickel Manganese Cobalt Oxide (NMC)
- Lithium Nickel Cobalt Aluminum Oxide (NCA)
- Lithium Iron Phosphate (LFP)

It is recommended that only one type of battery is selected for use throughout the Metro system for ease of purchase, installation and long-term maintenance.

4.4 Inverter

The inverter's main job is to convert DC power produced by the solar array into usable AC power. Inverters also have monitoring capabilities so installers and owners can see how a system is performing. Metro requires the ability to have web-enabled remote monitoring of the system. Inverters can also provide diagnostic information to help Operations and Facilities Maintenance crews identify and fix system issues.

Figure 4-6 String Inverter

Solar panels are installed in rows, each on a "string." For example, an array can have 25 panels with 5 rows of 5 panels, and can be as big as 9'-6" x 20'-0" x 8'-0". Multiple strings are connected to one string inverter. Each string carries the DC power that the solar panels produce to the string inverter where it is converted into usable AC power, which is consumed as electricity. (Figure 4-6).

Smaller installations, such as at typical at-grade stations, would be able to rely on string inverters while larger installations will require use of central inverters.

Central inverters are similar to string inverters, but are much larger and can support more strings of panels. Central inverter sizes range from 125kW up to 2.5MW depending on the size of the solar array (Figure 4-7). The inverter's physical dimensions will vary per kW capacity. For example, a 10 kW string inverter typically measures 18"L x 24"H x 10"D while a 125kW central inverter typically measures 46"L x 28"H x 13"D.

An inverter can also provide diagnostic information for operations and maintenance, such as an on-site data acquisition system (DAS). The DAS may be equipped to log the information critical to the evaluation of system performance, including AC energy production, solar irradiance, ambient temperature and wind speed.

For the duration of the service agreement (minimum of 25 years) with the third-party monitoring company, data services should include the processing, quality assurance, storage and daily backup of all system performance data.

Figure 4-7 Central Inverter

4.5 Main Circuit Breaker

The circuit breakers protect the PV system wiring from getting too hot and catching fire. They also protect the system components from more serious damage if there is a short circuit.

5.0 Grid-Tied Solar Power System

A standard Grid-tied solar power system circuit diagram (Figure 5-1) includes the following components:

- Solar panels
- Inverter (DC to AC)
- Net meter
- Electrical grid
- Station main panel
- Disconnect switch

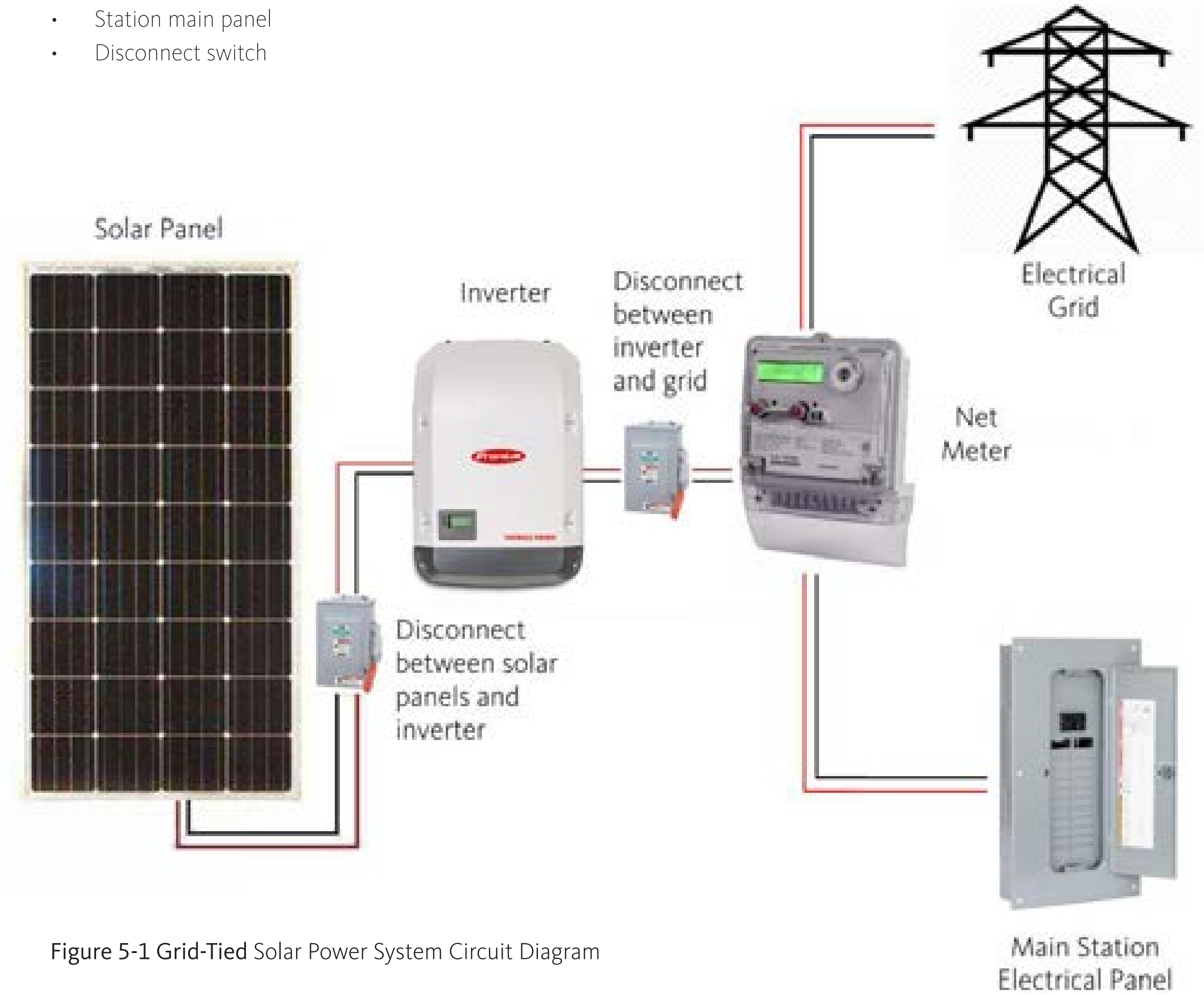


Figure 5-1 Grid-Tied Solar Power System Circuit Diagram

Notes:

1. Station solar system to include web-enabled remote monitoring and revenue grade metering.
2. Remote monitoring will require either network access or cell modem.
3. System to coordinate with revenue grade meters for registration with the Western Renewable Energy Generation Information System (WREGIS).
4. Provide fuses and disconnect switches as required. Disconnect switch distance from service meter should not exceed 15 feet.

Table 5-1 Key Design Features

Design Feature	Rationale
1. Solar Panels	• Bifacial panels produce solar power from both sides (front and back) of the panel, whereas traditional opaque-backsheeted panels are monofacial. • A bifacial solar panel replaces the traditional opaque back-sheet with a transparent layer, typically glass. That transparent layer allows cells on both sides of the panel to receive light. • Because a bifacial panel can be sandwiched between two layers of glass, the aluminum frame is often left out as well. These so-called frameless glass-on-glass panels have a very different appearance from conventional solar panels. • Monofacial PV panels should not be excluded as a possible design solution for Metro stations. There are monofacial panels that offer a sleek finish, perform efficiently and present a lesser cost premium when compared to bifacial panels.
2. Solar Panel Integration	• Solar panels can be placed on top of canopies at aerial and at-grade stations. • The current standard platform canopy design can be modified to incorporate bifacial solar panels in lieu of or in conjunction with the existing glass panels. Re-engineering Metro’s kit of parts may be required to allow proper solar panel mounting. • Retrofits to older stations (outside of the kit of parts) will require case-by-case consideration. Installing solar panels at some older stations may not be feasible due to artwork integration or unique design conditions. • Solar canopies shall be waterproofed with the use of tight rubber strips in between panels or sealed with weatherproof tape. They can also be waterproofed using framed assemblies with horizontal water chutes, but will have a much heavier profile. • Since at-grade and aerial station canopies are used to provide shade, it can be appropriate to install solar panel arrays on top of canopies if properly designed to integrate well with canopy architecture. Other locations such as the entry portals to underground stations may not be an appropriate location because the entry portals should provide natural light at the stairs and escalators to the underground stations. Installing solar panels here would reduce the amount of available natural light at the station entrance. However, a combination of bifacial solar panels and glass panels within a framed assembly could be a design solution. Additional study is required to determine feasibility and impact on station light levels.

Note: This table provides a summary of key features only and is not an exhaustive list of all design features. All materials and components of the solar panel array to comply with Metro’s standard materials.

Table 5-1 Key Design Features continued

Design Feature	Rationale
3. Solar Power System	There are two alternatives for solar power systems that may be used for Metro at-grade and aerial stations: 1. An off-grid solar power system, which captures solar energy and stores it in a battery bank to power up a station. During power outages, an off-grid solar power system may provide temporary electrical relief along with other emergency systems such as UPS. Components required for an off-grid solar power system are: -Solar panels -Charge controller -Battery bank -Inverter -Circuit breaker 2. A grid-tied solar power system, which captures solar energy and is used to power up a station while being able to return excess electricity to the utility grid. If the solar panels are not producing sufficient energy to meet the total needs of the station, Metro can supplement with additional energy from the grid. This type of solar power system requires approval from the utility company to interact with the grid. Components required for a grid-tied solar power system are: -Solar panels -Inverter -Net meter -Electrical grid -Station electrical main panel -Disconnect switch

Note: This table provides a summary of key features only and is not an exhaustive list of all design features. All materials and components of the solar panel array to comply with Metro's standard materials.

Table 5-1 Key Design Features continued

Design Feature	Rationale
4. Code Compliance	The solar panels and solar power systems are required to comply with the following codes: • California Building Code, Title 24, Part 2 • California Electrical Code, Title 24, Part 3 • California Mechanical Code, Title 24, Part 4 • California Plumbing Code, Title 24, Part 5 • California Energy Code, Title 24, Part 6 • California Fire Code, Title 24, Part 9

Note: This table provides a summary of key features only and is not an exhaustive list of all design features. All materials and components of the solar panel array to comply with Metro's standard materials.

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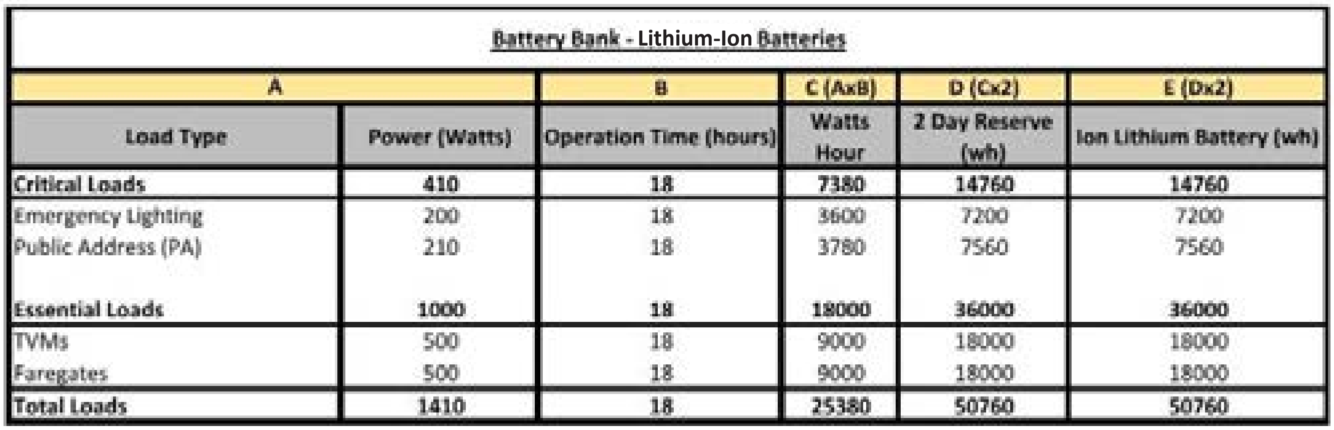
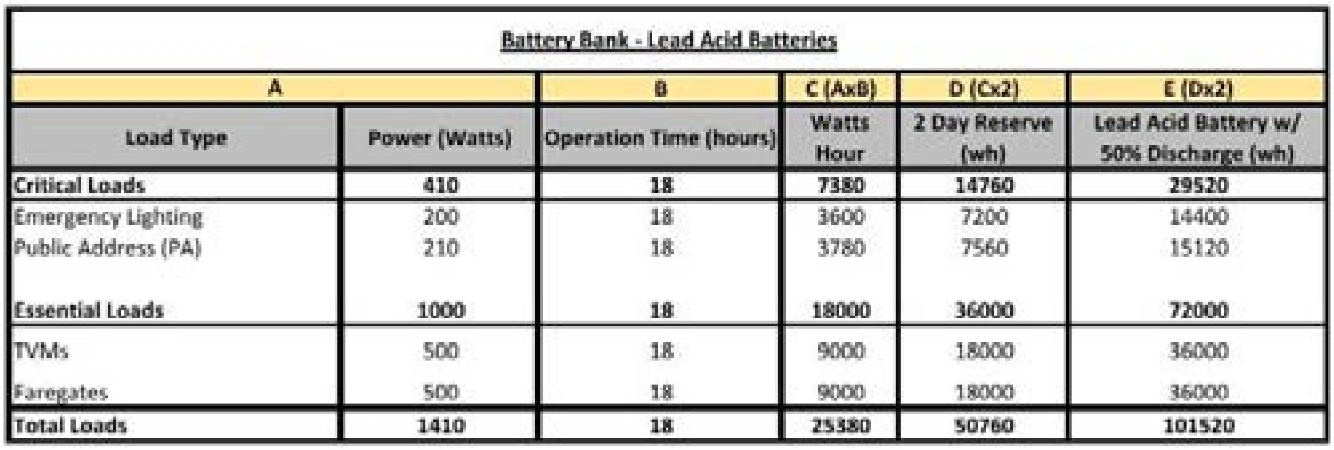
Appendix A Battery Bank Sizing



Battery Bank - Lithium-Ion Batteries

A		B	C (AxB)	D (Cx2)	E (Dx2)
Load Type	Power (Watts)	Operation Time (hours)	Watts Hour	2 Day Reserve (wh)	Ion Lithium Battery (wh)
Critical Loads	**410**	**18**	**7380**	**14760**	**14760**
Emergency Lighting	200	18	3600	7200	7200
Public Address (PA)	210	18	3780	7560	7560
Essential Loads	**1000**	**18**	**18000**	**36000**	**36000**
TVMs	500	18	9000	18000	18000
Faregates	500	18	9000	18000	18000
Total Loads	**1410**	**18**	**25380**	**50760**	**50760**



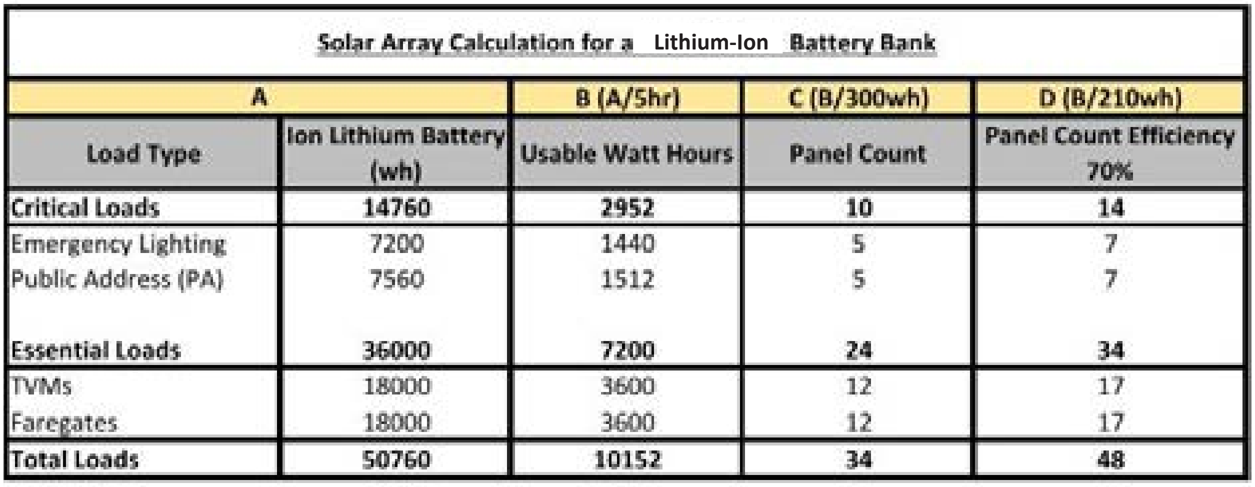
Battery Bank - Lead Acid Batteries

A		B	C (AxB)	D (Cx2)	E (Dx2)
Load Type	Power (Watts)	Operation Time (hours)	Watts Hour	2 Day Reserve (wh)	Lead Acid Battery w/ 50% Discharge (wh)
Critical Loads	**410**	**18**	**7380**	**14760**	**29520**
Emergency Lighting	200	18	3600	7200	14400
Public Address (PA)	210	18	3780	7560	15120
Essential Loads	**1000**	**18**	**18000**	**36000**	**72000**
TVMs	500	18	9000	18000	36000
Faregates	500	18	9000	18000	36000
Total Loads	**1410**	**18**	**25380**	**50760**	**101520**

Assumptions:

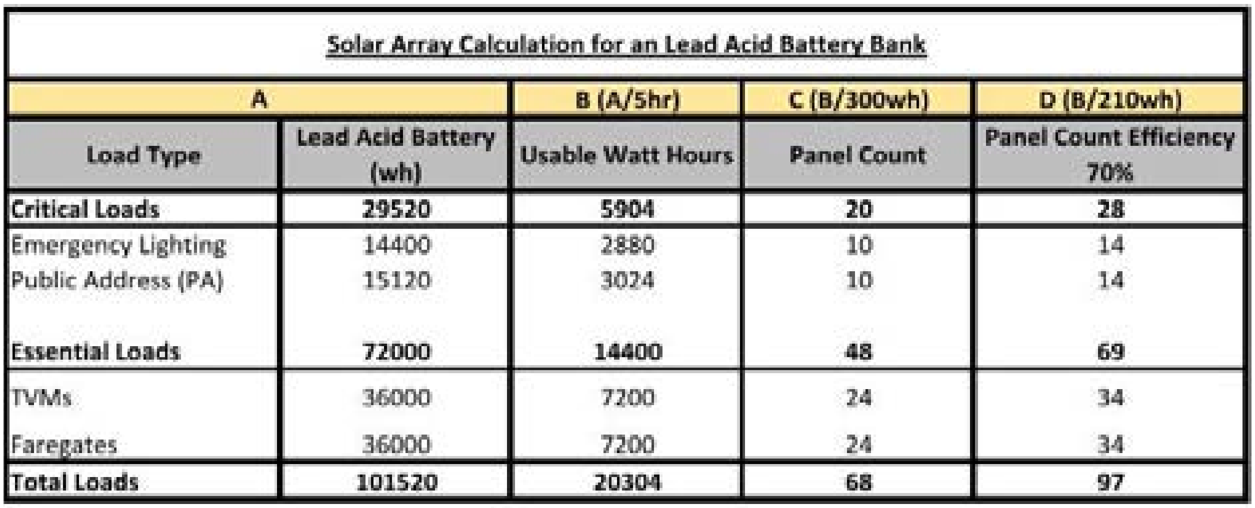
- Station operations is no more than 18 hr per day.
- Two-day reserve is considered for bad weather, lack of sunshine, etc.
- Ion lithium batteries can be discharged 100%.
- Lead acid batteries can only be discharged up to 50%.
- Refer to battery manual for maximum safe charging rate.
- 2%-5% wire loss.
- Electrical loads were selected for notional purposes.
- Actual electrical loads shall be determined by Metro.

Appendix B Solar Array Calculation



Solar Array Calculation for a Lithium-Ion Battery Bank

A		B (A/5hr)	C (B/300wh)	D (B/210wh)
Load Type	Ion Lithium Battery (wh)	Usable Watt Hours	Panel Count	Panel Count Efficiency 70%
Critical Loads	**14760**	**2952**	**10**	**14**
Emergency Lighting	7200	1440	5	7
Public Address (PA)	7560	1512	5	7
Essential Loads	**36000**	**7200**	**24**	**34**
TVMs	18000	3600	12	17
Faregates	18000	3600	12	17
Total Loads	**50760**	**10152**	**34**	**48**



Solar Array Calculation for an Lead Acid Battery Bank

A		B (A/5hr)	C (B/300wh)	D (B/210wh)
Load Type	Lead Acid Battery (wh)	Usable Watt Hours	Panel Count	Panel Count Efficiency 70%
Critical Loads	**29520**	**5904**	**20**	**28**
Emergency Lighting	14400	2880	10	14
Public Address (PA)	15120	3024	10	14
Essential Loads	**72000**	**14400**	**48**	**69**
TVMs	36000	7200	24	34
Faregates	36000	7200	24	34
Total Loads	**101520**	**20304**	**68**	**97**

Assumptions:

- 5hr usable watt hours per day.
- 300 watt bifacial solar panel w/ 210 watt actual output (70% efficiency).
- Solar panel efficiency may vary per station location in relation to the equator.
- Electrical loads were selected for notional purposes.
- Actual electrical loads shall be determined by Metro.