Guide to Green Energy Adoption for Transit Agencies

Prepared by:

Drew Turro

Maggie Maddrey

Claudia Brand

Reese Rogers

Center for Transportation and the Environment

About N-CATT

The National Center for Applied Transit Technology (N-CATT) is a technical assistance center funded through a cooperative agreement with the United States Department of Transportation's Federal Transit Administration (FTA). Operated by the Community Transportation Association of America (CTAA), the mission of N-CATT is to provide small-urban, rural and tribal transit agencies with practical, replicable resources that help them apply technological solutions and innovations. Among its activities, N-CATT produces a series of white papers, technical reports such as this document, and other resources, all of which can be accessed online at https://n-catt.org.

About this Document

This document was prepared for CTAA by the Center for Transportation and the Environment (CTE) in February 2021 as part of the N-CATT cooperative agreement between CTAA and FTA. Primary authors were Drew Turro, Claudia Brand, Maggie Maddrey, and Reese Rogers of CTE. Opinions expressed or implied in this document are those of the authors. Nothing in this document is to be interpreted as position, policy, or guidance from the United States Government. Incidental use of companies' names or the names of their products is made solely to facilitate discussion and should not be regarded as recommendations or endorsements.

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Cecil Blandon, Director of Maintenance, Alameda-Contra Costa Transit District

Michael Yambrach, Capital Energy Projects Manager, Montgomery County

Calvin Jones, Division Chief - Fleet Management Services, Montgomery County

Jennifer Wallace-Brodeur, Director of Transportation Efficiency, Vermont Energy Investment Corporation

Tom McCarran, Energy Consultant, Vermont Energy Investment Corporation

Ruthie Norton, Engineering Consultant, Center for Transportation and the Environment

Jason Hanlin, Sr. Engineering Consultant, Center for Transportation and the Environment

Jaimie Levin, Sr. Managing Consultant, Center for Transportation and the Environment

Erik Bigelow, Sr. Engineering Consultant, Center for Transportation and the Environment

Lauren Justice, Development Director, Center for Transportation and the Environment

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Selected Glossary

The following glossary is a selection of relevant terms as defined by the U.S. Energy Information Administration. For more energy-related terms, please visit the Energy Information Administration Glossary.

Electric power: The rate at which electric energy is transferred. Electric power is measured by capacity and is commonly expressed in megawatts (MW).

Electric rate: The price set for a specified amount and type of electricity by class of service in an electric rate schedule or sales contract.

Electric rate schedule: A statement of the electric rate and the terms and conditions governing its application, including attendant contract terms and conditions that have been accepted by a regulatory body with appropriate oversight authority.

Electric utility: A corporation, person, agency, authority, or other legal entity or instrumentality aligned with distribution facilities for delivery of electric energy for use primarily by the public. Included are investor-owned electric utilities, municipal and State utilities, Federal electric utilities, and rural electric cooperatives. A few entities that are tariff based and corporately aligned with companies that own distribution facilities are also included.

Energy: The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Electrical energy is usually measured in kilowatt-hours (kWh).

Grid: The layout of an electrical distribution system.

> **Microgrid:** A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid is capable of connecting and disconnecting from the grid to enable it to operate in both grid-connected or island mode (U.S. Department of Energy).

Tariff: A published volume of rate schedules and general terms and conditions under which a product or service will be supplied. See *electric rate* above.

Introduction

The *N-CATT Guide to Green Energy Adoption for Transit Agencies (Green Energy Guide)* is a tool for educating small-urban, rural, and tribal transit agencies on existing and emerging options for powering their transit operations with green electric power. This whitepaper focuses on green electric power as a fuel supply for battery electric vehicles (BEV). It is segmented into chapters that each focus on an important aspect of understanding and procuring green energy technologies to power transit agency operations. Collectively, the chapters provide an overview of the green energy resources and technologies available to transit agencies, considerations regarding procurement of green power, and strategies that may maximize the benefits of these green energy charging options.

N-CATT produced a separate whitepaper, *Hydrogen as a Transportation Fuel in Rural Communities,* that describes technologies and strategies for deploying hydrogen-powered fuel cell electric vehicles. N-CATT also produced the whitepaper *Building Successful Partnerships between Rural Transit Systems Deploying Zero-Emission Vehicles and their Electric Utilities*, which is useful to agencies navigating relationships with their local electricity providers regardless of zero-emission vehicle technology being implemented.

What is green power?

The US Environmental Protection Agency (EPA) defines green power as “electricity supplied from a subset of renewable resources that provide the highest environmental benefit...Green power generally does not include some resources that are often considered as renewable energy including large hydropower and municipal solid waste” (EPA, 2018). Although the precise definition of green power may vary between jurisdictions for regulatory purposes, green power resources are often the resources designated as acceptable for emissions mandates and environmental goals under many regulatory schemes. For transit agencies voluntarily seeking to pursue cleaner operations, green power resources are the most environmentally friendly electricity sources available.

Why is green power important for transit agencies?

The transportation sector is the largest contributor to greenhouse gas emissions in the United States, accounting for almost 30% of the country’s total emissions. These emissions are produced by the burning of fossil fuels in vehicle engines but also through the extraction, refining, and transport of these fuels before they get to their end user.

Electricity production is second only to transportation in terms of greenhouse gas emissions by economic sector. The parallel growth of zero-emission electricity production alongside zero-emission vehicles provides opportunities for capturing environmental benefits in local communities while enhancing transit agencies’ abilities to adapt to new operational situations posed by zero-emission vehicles.

For the shift to zero-emission transit to be truly carbon-free, one must look at the entire energy lifecycle of the vehicle. The “pump-to-tailpipe” emissions are only one component of this cycle. The upstream emissions, those that come from the production of electricity or hydrogen that eventually power the vehicles, contribute GHG emissions to the lifecycle of the vehicles. Fortunately, zero-emission energy technologies, like solar panels and battery energy storage, are becoming more prevalent and available in the energy sector, just as zero-emission vehicles are being adopted in the transportation sector.

A transit agency may seek out green power for a variety of reasons: internal, local, or state emissions reduction goals, possible cost savings, or increased operational control of power sources as an agency deploys zero-emission vehicles. This series of connected yet standalone papers aims to shed light on the various types of green energy resources and technologies, how an agency can procure green energy, and operational strategies to maximize benefits from these renewable energy resources.

Chapter 1: Green Energy Sources for Transit

Transportation and electricity production are the two largest sources of greenhouse gas emissions in the United States, according to the US Environmental Protection Agency (EPA). Transit agencies deploying zero-emission vehicles lower transportation emissions, but these deployments often result in increased electricity usage from charging infrastructure or auxiliary services necessary to power the vehicles. The increasing prevalence of zero-emission vehicles and increased electricity usage presents an opportunity for transit agencies to further contribute to environmental and community benefits not only through the deployment of clean vehicle technology but also through their choice of electricity resources. Technological innovations in the twenty-first century have led to decreased costs of green energy sources, making green energy options more affordable for more organizations. This chapter defines and describes green energy resource options and their relative applications for transit agencies.

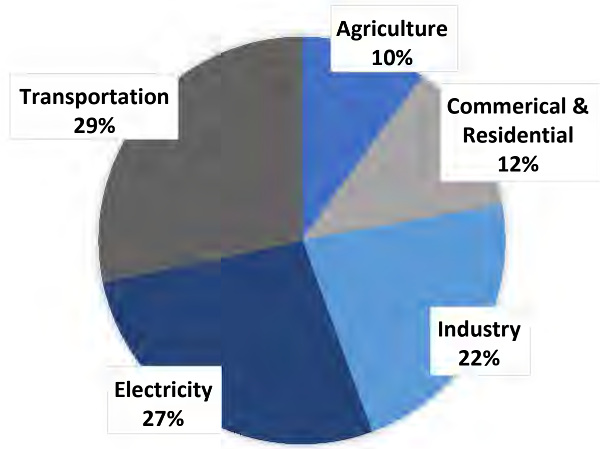


Figure 1. Total US greenhouse gas emissions by economic section in 2018 ("Sources of Greenhouse," n.d.)

For transit agencies looking to make their operations greener, there are a variety of avenues that allow agencies to produce or purchase energy from green energy resources. According to the EPA, green power is the subset of renewable energy sources that contains energy sources which are the most beneficial to the environment (EPA, 2018). The energy resources that the EPA classifies as green are shown in Figure 2. As agencies transition to zero-emission vehicles for their fleets, it will be important to ensure that the source of the replacement fuels—electricity and hydrogen—also support the zero-emission goals.

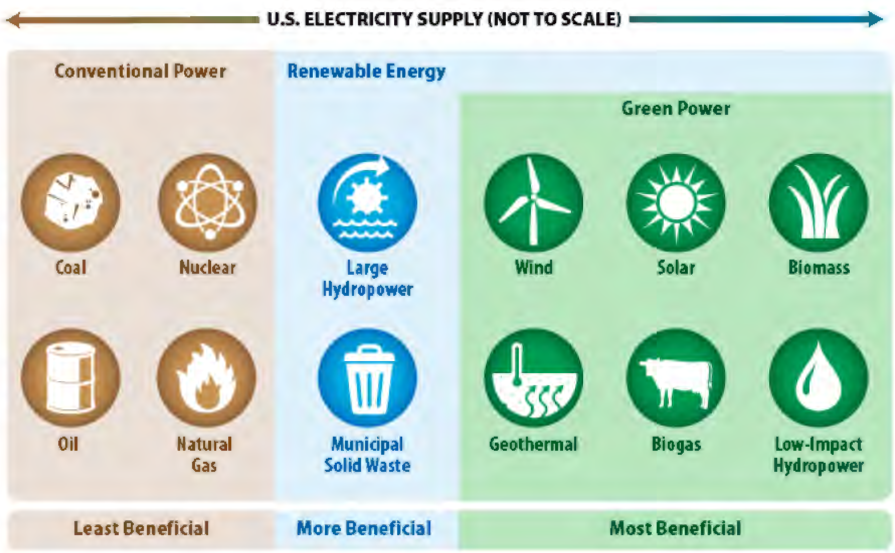


Figure 2. Depiction of conventional, renewable, and green energy sources in relation to their benefit to the environment

Source: EPA (2018) *Guide to Purchasing Green Power*

Green Power Resources

The following sections provide brief overviews of common green power resources and technologies. The specific green power resources that a transit agency may use will be dependent on local availability of the resource, operational needs and financial resources of the agency, and particular environmental goals. There are some generalities that can be stated regarding green power resources: solar power is by far the most prevalent resource and technology in use for on-site power generation. It is likely the cheapest to install on-site, as well, although particular circumstances could result in different resource cost calculations. Further information on each resource's relevant infrastructure can be found in Chapter 2: Green Energy Infrastructure. Information on green power procurement can be found in Chapter 4: Procurement Options for Green Energy

Table 1: Average cost assumptions for green power energy systems[1]

	Average Installed Cost (2019 $/kW)	Fixed Operation and Maintenance Cost (2019 $/kW/yr)
Solar PV, commercial	$1,539	$16
Wind, commercial	$1,548	$230
Biomass	$4,104	$125.2
Small hydropower	$600 - $4,500	$36 - $270
Geothermal	$2,000 - $5,000	$115

[1] Solar, wind, and biomass costs are from the Energy Information Administration. Hydropower and geothermal project costs are highly project and site specific. These approximate cost data are from a 2019 report by the International Renewable Energy Agency.

Solar Power

Solar power is one of the most common forms of green energy production, and the technologies are already in use by many transit agencies. The most common technology for solar power production is solar photovoltaic (PV), in which solar cells are arranged into panels and capture energy from the sun to convert it into electricity. Although power production may dip slightly on cloudy days, solar PV panels can still produce electricity with indirect sunlight. These systems are also versatile in that they can be installed on the ground, on building roofs, or as canopies over parking lots. Solar power is an easily scalable energy option, as the modular nature of the panels allows agencies to customize the size and orientation of the system.

Figure 3. AC Transit's solar trellis array with buses parked underneath (Source: AC Transit).

Alameda-Contra Costa Transit District (AC Transit) in California has four different solar arrays across their facilities, with the first installed in 2007. Three of the four arrays are roof-mounted on different facilities, and one is a trellis array. The trellis array is positioned in one of AC Transit's parking lots which provides shaded parking underneath for the agency's buses and is more accessible for maintenance purposes. Prior to receiving five battery-electric transit buses in 2019, AC Transit's solar arrays and on-site solid oxide fuel cell produced more energy than AC Transit consumed.

Solar PV technology has become popular for both residential and commercial applications. Costs for solar PV systems have fallen dramatically over the past decade, and the industry has matured to the point where there are many solar manufacturers, installers, and financing options to choose from when purchasing a solar power system. Agencies can size systems to power their entire operations or can offset a portion of utility-provided power from the grid for financial or environmental benefits. Solar power is often paired with an energy storage system (see Energy Storage section below) to provide resiliency or store power for operations at night.

Wind Power

Wind power is another quickly growing green power option. Wind energy is converted to electricity through the use of wind turbines. While wind itself is as ubiquitous as the sunshine that powers solar energy generation, wind turbines require certain wind speeds, known as the wind resource, to operate. The U.S. Department of Energy (DOE) recommends that the area where the wind turbines will be placed receives at least 10 miles per hour average annual wind speeds (DOE, 2021). In areas with adequate wind resources, wind power can be a very effective green power option and is often used for utility-scale power generation. Large, utility-scale wind turbines can stand over 260 feet tall and generate several megawatts of power each. Fortunately, smaller wind turbines exist for more local applications. Small wind turbines typically generate less than 100 kW and can require roughly one acre of land to install. According to the

American Wind Energy Association, small or “distributed” wind turbines can be found at farms, rural electric cooperatives, and schools throughout the country. Wind power could be an appealing options for many rural transit agencies with access to adequate wind resources. The WINDExchange Wind Resources tool, maintained by Department of Energy, has wind energy maps by state that can provide a good starting point for agencies to explore the feasibility of on-site wind at their facilities.

Biomass

Biomass is organic material that comes from plants and animals such as wood pellets, agricultural residues, and animal manure, which can be converted into electric power typically by combustion. Biomass systems may be an option for on-site electricity production at transit agencies that have access to a constant and sufficient source of local biomass fuel to maintain electricity production. On-site biomass systems may require more staff attention than sources such as wind or solar, as the fuel must be ordered and received on-site. In particular geographic areas, transit agencies may have access to local, third-party biomass generating plants as a green power option. More information on procuring green power through such third-party producers can be found in Chapter 4: Procurement Options for Green Energy.

Low-Impact Hydropower

Hydropower systems convert energy from flowing water to electricity through the use of turbine. Most hydropower, while considered renewable power, is not considered green power because of environmental impacts that hydropower dams have on local ecosystems and the greenhouse gas emissions required to produce the concrete to build the dams. Even small hydropower systems, categorized by the US Department of Energy as those generating 10 megawatts or less, produce much more power than any one transit agency will likely require. Low-impact hydropower projects are those that “involve little change to water flow and use and are unlikely to affect threatened and endangered species” (FERC, 2020). Hydropower’s role as a green energy source for transit agencies is likely limited and will likely be considered only in very specific, location-dependent circumstances. More often, hydropower will be part of a utility’s power generation mix and may provide power to a transit agency through the grid.

Geothermal

Geothermal systems harness the heat from the earth in order to do two main things: produce electricity and heat or cool buildings. To produce electricity, geothermal plant operators drill deep wells, up to two miles, into the earth and pipe steam or hot water to the surface to power a turbine and create electricity (U.S. Energy Information Administration, 2020). Geothermal power plants must be in an area that has sufficient geothermal reservoirs, which are found mostly in the western United States, making this a very location-dependent resource. Geothermal energy is often used to heat or cool buildings using a geothermal heat pump, which utilizes the near-constant temperature of the earth directly below the surface to moderate heating and cooling systems. This application is not location-dependent like geothermal power production as shallow earth temperatures are mostly constant throughout the United States. Transit agencies interested in offsetting facility heating and cooling loads with green power could explore geothermal heat pumps as an efficient and environmentally-friendly option to offset some electricity or gas consumption in facility heating/cooling loads.

Energy Storage

While not necessarily an energy resource itself, energy storage is a crucial component of many green power systems and on-site green energy installations. For transit agencies using hydrogen-powered fuel cell electric vehicles, energy is stored as liquid or gaseous hydrogen and used as vehicle fuel. The fuel cell then converts this hydrogen in to electric power onboard the vehicle. Historically, storing electricity has been difficult. In recent years, however, improvements in battery technology and reductions in costs for battery components have made lithium-ion batteries the go-to technology for energy storage in the electricity industry. Many green power systems now use lithium-ion battery storage to store energy.

Given that it is not consistently sunny or windy, green power systems relying on these resources produce power intermittently. Energy storage allows an agency to store energy that is generated, say, when it is sunny out for use when the solar PV system is less productive—at night or on cloudy days. This capability is especially important for transit agencies that may want to charge buses overnight in a depot but also find that solar power is generally their best green power option. Energy storage systems also increase the resiliency and reliability of an agency's power supply, whether that is on-site green power or supplied via the local grid. Even for agencies relying on grid power, energy storage can provide a backup power source for charging buses and maintaining operations in the event of a grid outage.

The decision to install a complementary energy storage system is going to depend on how an agency intends to procure green power. For agencies planning to power their operations entirely via on-site green power generation, energy storage will likely be a necessity and should be factored into the planning and cost analyses. For agencies interested in procuring green power through utility green power programs, energy storage may be less of necessity but could still add value in terms of resiliency and energy management options. The value proposition of energy storage should be researched in the context of a particular agency's green power needs and constraints.

Assessing Green Energy Resource Options

The green energy resources available to a given transit agency will depend on location and agency-specific factors. While solar and wind resources are ubiquitous as on-site generation and as utility resources, other resources like low-impact hydropower, geothermal, and biomass may only make sense to investigate as on-site options for agencies located in geographies with these resources nearby. More likely, these green power resources will be available through third-party generators or as utility resources that supply power to the electrical grid. Some agencies may, after consulting with their local electricity provider, realize that their provider already produces green energy from one of these energy resources and may have the opportunity to participate in a green power program or tariff. More information on green power procurement options can be found in Chapter 4: Procurement Options for Green Energy.

Resources for Transit Agencies

Once an agency decides to incorporate green energy into their operations, there are still quite a few more decisions to be made, as there are a variety of avenues to acquire green power. The EPA produced a Green Power Supply Options Screening Tool that could be a beneficial tool for agencies that are early in their decision-making process. An agency fills in some organizational details on the spreadsheet, and the tool provides green power supply options that might be best for the agency based on the details provides.

Additional Resources

- Wind Energy Maps and Data, WINDExchange Office of Energy Efficiency & Renewable Energy
- Distributed Wind Energy Zoning and Permitting, Clean Energy States Alliance
- Solar PV Project Financing Challenges for Third-Party PPA System Owners, National Renewable Energy Laboratory
- Energy Storage Systems Safety Fact Sheet, National Fire Protection Association
- Renewables Accelerator, American Cities Climate Challenge

Chapter 2: Green Energy Infrastructure

Transit agencies across the United States are exploring opportunities to install on-site green energy infrastructure. Transit agencies can utilize on-site green energy to support fueling infrastructure for a zero-emission bus (ZEB) deployment, offset energy use from the grid across its facilities, and pair with battery storage systems.

The cost of the most prevalent green energy resources, wind and solar, have decreased to the point that they are both among the most cost-competitive sources of energy to build. According to the Institute for Local Self-Reliance, a nonprofit research and educational organization, green energy made up the majority of the United States' new power generation capacity in the third quarter of 2020 (McCoy, 2020). This was the fifth quarter in a row, and ninth in the last twelve, in which the majority of the United States new power generation capacity consisted of green energy.

A transit agency's decision to pursue green energy is influenced by a number of factors, including:

- Agency electricity costs
- Available funding and/or credits for green energy
- Agency, city, or state GHG emission reduction goals and/or laws
- Available space for the infrastructure
- Availability and accessibility of renewable resources at the property
- Overall project costs

If a transit agency does decide to pursue the procurement of a green energy system, it is important to understand both the physical footprint and expected costs of the system. This chapter provides information as a starting point for agencies both actively considering or in the early stages of learning about green energy.

Sizing Energy Infrastructure: Utility-Scale vs. On-Site Generation

While transit agencies can produce energy on-site to support ZEB deployments or facility energy needs, transitioning 100% of operations to green energy may require utility-scale generation. The definition of "utility-scale" depends on the source of the energy generation and the entity defining the project. The Department of Energy defines utility scale as projects 10 megawatts (MW) or larger. Utility-scale solar facilities are defined by the US Energy Information System as being 1 MW or greater—such a facility would power approximately 197 homes per year. According to the Solar Energy Industries Associate (SEIA), 1 MW of solar generation capacity requires five to ten acres (SEIA). While some transit facilities may have enough rooftop space to facilitate a utility-scale solar installation, space limitations may prevent other agencies from building a system of this size.

Utility-scale wind turbines are defined by the Department of Energy as turbines greater than 100 kilowatts (kW) in size, which is large enough to power about 27 homes per year. While there are wind energy projects that fall under the threshold of utility-scale, the installed cost per kW of a small turbine is more than seven times the cost of utility-scale wind projects (Center for Sustainable Systems, 2020).

Alternatively, the cost gap between large-scale and small-scale solar energy systems is not nearly as large. Cost decreases of nearly 89% since 2009 have allowed homeowners and businesses to purchase an affordable, reliable way to produce energy on-site, while lowering energy costs and emissions impacts for their operations and buildings (Center for Sustainable Systems, 2020). As of November 2018, solar energy installations of less than 1 MW capacity made up nearly 40% of total solar capacity connected to the electricity grid in the United States (U.S. Energy Information Administration, 2019).

For transit agencies unable to host on-site green energy or interested in purchasing more green energy than on-site generation could produce, Chapter 4: Procurement Options for Green Energy opportunities to purchase green energy from utilities and third-party energy developers.

Green Energy Resources and Associated Infrastructure

Solar

Solar photovoltaic (PV) energy systems are the most common solar power technology. These systems are comprised of the following components:

- Semiconductor material: Used to facilitate movement of electrons, freed by energy from the sun, to drive an electrical circuit as a direct current. This material is formed into solar cells which are then connected to form a single solar panel.
- Glass covering or weather-proof material
- Inverter: Converts direct-current (DC) electricity generated by the solar panel into alternating-current (AC) electricity, which is used by the electrical grid

Solar PV systems can be roof or ground mounted, while some facilities incorporate solar panels into the design of carport shading structures. Solar PV systems can be outfitted with a number of different types of inverters. The two primary types are string inverters and microinverters.

Figure 4: A Valley Transportation Authority ZEB charging under a solar panel canopy
Source: Valley Transportation Authority

String Inverters

String inverters connect a set of panels to a single inverter, which then converts the electricity produced by those panels, the “string”, to AC electricity. Smaller systems can be supported by a single inverter while larger systems will require multiple string inverters. String inverters provide a cost-effective solution for moving electricity from the solar array to the electrical grid. Wiring multiple panels to a single inverter also allows for easier system maintenance as it minimizes potential failure points and limits the components to examine in the event of a system failure.

However, there are tradeoffs to the upfront savings presented by string inverters. String inverters typically come with a standard warranty period of eight to twelve years whereas microinverters are typically warrantied for up to 25 years. And because the individual solar panels are connected as a single series, decreased production from a single panel—whether from shading or dirt or defective cells—leads to decreased production for the whole string of panels.

Microinverters

Microinverters are smaller inverters that connect to every individual solar panel. This means that, unlike a system utilizing string inverters, shading and/or damage to one individual panel will not impact the energy that can be generated by the rest of the system. It also means that transit agencies are able to track individual panel production over time. This can allow an agency to identify defective panels or panels with consistently low production levels.

However, because a microinverter is needed for every panel, costs rise as the size of the installation rises. And although costs have come down, microinverters are typically more expensive than string inverters. Microinverters, because they are attached to each solar panel, increase the amount of equipment on a rooftop and require more involved maintenance than a string inverter.

Table 2: Solar Power Projects at Transit Agencies - Example Projects

Transit Agency	Installation Year	Solar Installation Size	Cost	Funding Source
Indianapolis Public Transportation Corporation	2016	1 MW	$2,200,000	Federal (80% total project cost)
Metro Transit (Minneapolis-St. Paul, MN)	2015	40 kW	$130,000	Local utility (45% total project cost)
Valley Metro (Phoenix, AZ)	2014	780 kW	$2,875,000	Federal (~95% total project cost)
AC Transit (San Francisco, CA)	2014	425 kW	Unknown	Federal

Wind

Small-scale wind energy systems, while not as common as utility-scale projects, are utilized in some locations with above average wind resources and that have ample space to site equipment. However, in addition to higher project costs (about four times greater cost per kilowatt-hour than commercial solar), wind energy systems can face obstacles to successfully zoning and permitting the project. While no jurisdiction is exactly the same, most zoning ordinances have a height limit of 35 feet. Utility scale wind energy systems can provide low electricity costs, especially during overnight periods when buses may be charging. Chapter 4 of the guidebook includes more information on additional procurement methods for off-site green energy.

Additional Resource: Small Wind Guidebook – Department of Energy

Biomass

Biomass energy systems are another potential source of on-site green energy production. Biomass is a physical material burned in a boiler. The heat generated from this process drives a steam turbine, which produces electricity. Potential reliable sources of biomass include the forest or agriculture sector, whose stream of waste products can provide a suitable fuel source. Biomass projects are best positioned in areas with consistent, readily available sources of biomass. Transit agencies located near an abundant source of biomass may find themselves well positioned to take advantage of a biomass project.

Biomass electric generation systems generally consist of some combination of the following items:

- Primary Items
  - Fuel storage and handling equipment
  - Combustor/furnace
  - Boiler
  - Steam turbine
  - Generator
  - Exhaust/emissions controls
  - System controls
- Other Items
  - Pumps
  - Fans
  - Condenser
  - Cooling tower

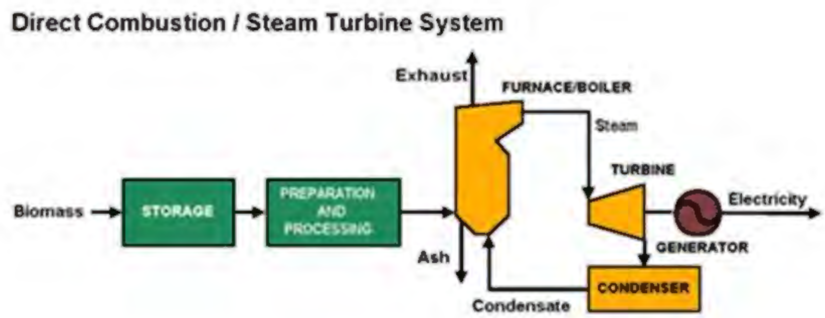


Figure 5: Biomass Electricity Generation Diagram
Source: Whole Building Design Guide

Deploying biomass energy systems at a small-scale can present challenges. The National Institute for Building Sciences found that the installation cost of small-scale biomass ranges from $3,000-$4,000 per kW, which is about twice the installed cost of on-site solar. This cost does not factor in the cost of delivering the biomass itself to the facility. Not all areas of the country have easily accessible sources of biomass, and the ongoing cost of fuel and staff support to keep the system operational are an important consideration to the overall project cost. The amount of space required to dedicate to the system can also be a limiting factor, as both on-site storage and access to the fuel source are needed.

In addition to these challenges, different states have different definitions of what qualifies as "green" or "carbon-free" sources of energy. It is important to determine whether the city or state in which an agency operates includes biomass among the list of approved green energy sources.

Additional Resource: State Renewable Portfolio Standards and Goals – National Conference of State Legislatures

Energy Storage

Transit agencies have used energy storage technologies to support operations in case of an unexpected power outage. However, the technology most often used to facilitate backup power has traditionally been a generator and the energy source has been liquid fuel, like diesel. Green energy storage technologies operate on the same principle of storing energy now to use in times of greater need. The primary green energy technologies being deployed to serve this function come in the form of batteries and electricity or hydrogen paired with electrolyzers and fuel cells.

Lithium-Ion Batteries

Lithium-ion batteries are the most widely deployed form of large-scale battery storage in the world, making up more than 90% of the market. Traditionally used in smaller products like cell phones and power tools, these batteries can achieve efficiency levels of up to 95% and have expected useful lifespans of 10-15 years. Lithium-ion batteries from electric vehicles are even being used beyond their initial useful life in stationary energy storage applications, as detailed in a 2020 whitepaper from the University of California-Davis and the Union of Concerned Scientists (Ambrose, Kendall, Slattery, & Steckel, 2020). The cost per kilowatt-hour (kWh) of lithium-ion batteries has decreased significantly in the past decade. Bloomberg New Energy

Finance, an energy research organization, found that lithium-ion battery pack prices dropped by from $1,100 per kWh in 2010 to $137 per kWh in 2020 (BNEF, 2020).

Lithium-ion batteries are also valued because of their energy storage density, or ability to hold greater amounts of energy within less physical space. According to Sage Energy Consulting, an independent renewable energy consulting firm, a 1-megawatt-hour (MWh) battery system has roughly the same physical footprint as one parking space.

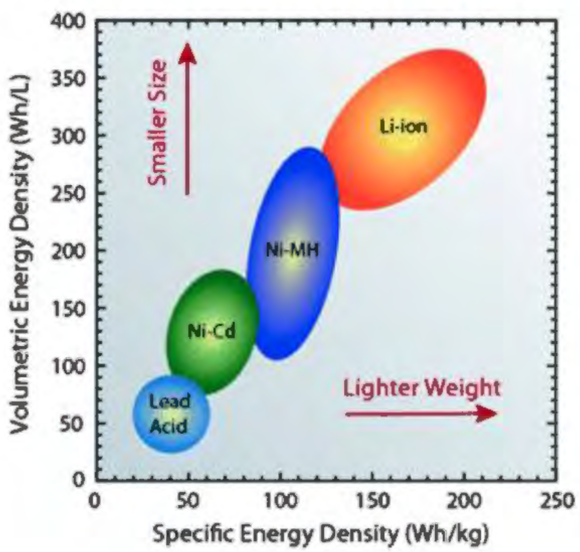


Figure 6: Comparative energy densities of different battery compositions

Source: University of Washington, Clean Energy Institute

Battery energy storage systems typically come attached with two numbers – the power rating (watts) and amount of available energy storage (watt-hours). For example, a battery may have a 500-kW power rating and 2 MWh (2,000 kWh) of available storage. If operating at full capacity, this battery could supply four hours of energy for up to 500 kW of demand (2,000 kWh/500 kW = 4 hours). This is typically what is meant when a battery storage system is referred to as an "X-hour" battery. However, battery storage systems do not have to operate at full capacity. The graph below shows some of the ways in which the energy stored in a battery can be discharged for use.

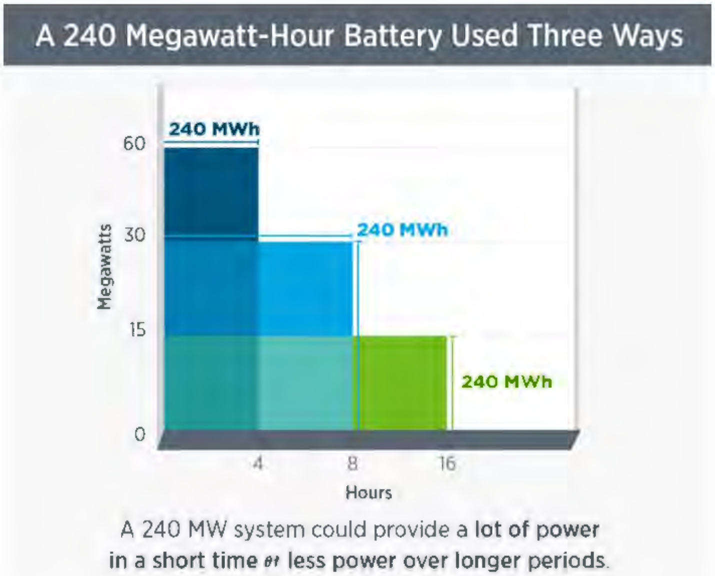


Figure 7: Energy storage use can depend on time and power output requirements.
Source: Department of Energy

Hydrogen

Although more commonly known for its applications in vehicle technology, hydrogen can also serve as a stationary energy storage system mechanism. When used in combination with fuel cells and green energy sources, hydrogen can be produced with a zero-emission energy cycle. While less energy efficient than lithium-ion batteries, hydrogen fuel cells can discharge energy over longer periods of time. Power Innovations, a provider of hydrogen fuel cell technologies, successfully provided 48 continuous hours of power for a data center with 250 kW of demand (Bailey, 2020). This demonstration followed up on a pilot program in partnership with NREL, which operated a single server rack at an on-site data center.

Table 3: Energy Storage System Characteristics

	Max Power Rating (MW)	**Typical Discharge Time**	***Max cycles* or lifetime**	**Energy Density (watt-hour per liter)**	**Efficiency (%)**
Pumped hydro	3,000	4h – 16h	30 – 60 years	0.2 – 2	70 – 85
Compressed Air	1,000	2h – 30h	20 – 40 years	2 – 6	40 – 70
Molten Salt (thermal)	150	hours	30 years	70 – 210	80 – 90
Li-ion battery	100	1 min – 8h	*1,000 – 10,000*	200 – 400	85 – 95
Lead-acid battery	100	1 min – 8h	6 – 40 years	50 – 80	80 – 90
Flow Battery	100	hours	*12,000 – 14,000*	20 – 70	60 – 85
Hydrogen	100	mins - week	5 – 30 years	600 (at 200 bar)	25 – 45
Flywheel	20	secs - mins	*20,000 – 100,000*	20 – 80	70 – 95

Source: Environmental and Energy Studies Institute

While the cost of hydrogen, fuel cells, and the accompanying infrastructure has continued to decrease, they are not yet cost-competitive with lithium-ion batteries. Hydrogen fuel cells also require equipment, and physical space, for on-site production and/or storage of green hydrogen. For agencies already deploying fuel-cell electric buses (FCEB), additional buildout of stationary storage could be incorporated into existing infrastructure.

Flow Batteries

Flow batteries comprise roughly five percent of the energy storage market. They serve as the primary alternative to lithium-ion batteries, and have longer expected lifespans. Flow batteries can also be scaled to service larger energy consumption needs.

Figure 8: Photo of a Vanadium redox-flow battery. UniEnergy Technologies
Source: IEEE Spectrum

Unlike lithium-ion batteries, flow batteries store energy in liquid form. These liquids are stored in two separate tanks, which can be scaled to meet the needs of the storage project. While project costs have decreased and are projected to continue, a 2019 report by the Department of Energy found that total project cost for lithium-ion batteries was a little more than half that of flow batteries on a per kWh basis (Mongird, et al., 2019).

Connecting Green Energy Infrastructure to Zero-Emission Bus (ZEB) Fueling Infrastructure

For agencies operating ZEBs, building on-site green energy can provide additional opportunities to decrease the costs and greenhouse gas (GHG) emissions associated with vehicle fueling. Whether it is charging infrastructure for battery electric buses (BEB) or green hydrogen fueling infrastructure for FCEBs, pairing on-site solar PV or energy storage with vehicle fueling could potentially add value to both projects. Agencies should coordinate with their utility early in the project development process to understand whether utility infrastructure upgrades are necessary to pairing on-site energy generation and energy storage with fueling infrastructure. If it is possible, the agency should then explore whether such a project might require any utility infrastructure upgrades and how utility rate structures may be impacted.

Alameda Contra-Costa Transit Agency (AC Transit) – Utility Rates and Solar Case Study

Alameda Contra-Costa Transit Agency (AC Transit) completed four separate solar installations between 2007 and 2014. The total size of the four systems is more than 1.4 MW, and they produce approximately 2,225,810 kWh annually.

The energy produced by the solar installations located at the depot where AC Transit's five BEBs are charged could be put on the same utility meter as the charging infrastructure. However, AC Transit's BEB charging is currently assigned to an electric vehicle (EV) utility rate schedule. This rate schedule provides AC Transit with the ability to charge buses during specific "off-peak" periods and pay a lower per-kWh rate for their electricity.

Due to the savings associated with the EV rate schedule, AC Transit decided to keep the energy produced by the solar installations at the BEB depot on the same meter as the larger depot facility. This facility's rate schedule has higher per-kWh electricity rates, and can therefore realize the cost savings of the solar production to a greater degree.

As evidenced by AC Transit's experience, installing green energy on-site can present a host of unfamiliar and complex decision-making paths. Many agencies find that hiring external experts to support assessing energy needs, options, and integration opportunities can make the unfamiliar world of electric utilities and energy technologies more approachable. At a minimum, transit agencies planning to install solar with charging infrastructure or connect existing solar to BEB charging infrastructure should consult with their utility and project developer to determine how solar may impact their current rate structure.

Chapter 3: Microgrids for Zero-Emission Vehicles

Transit agencies are expected to provide cost-effective, reliable service across a variety of conditions. Operating zero-emission buses does not change this basic mandate for agencies. Ensuring that consistent energy is being provided to zero-emission bus (ZEB) fueling infrastructure is crucial to meeting service requirements.

A failure of the electric grid, whether brief or extended, negatively impacts an agency's reliability for their ZEB fleet. Depending on the local conditions for an agency, there may also be challenges to bringing the necessary amount of electricity to a depot to power ZEB fueling infrastructure. And utility rate structures can be organized in ways that can result in significant cost increases or savings when fueling ZEBs compared to traditional vehicles fleets.

Microgrids

A microgrid is one possible solution for transit agencies to address these challenges. The Department of Energy defines a microgrid as:

- A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid
- Capable of connecting and disconnecting from the grid to enable it to operate in both grid-connected or island mode

No single microgrid looks exactly the same, but all microgrids include the following components:

- Energy generation
- Energy storage
- Microgrid controller
- Utility service disconnect

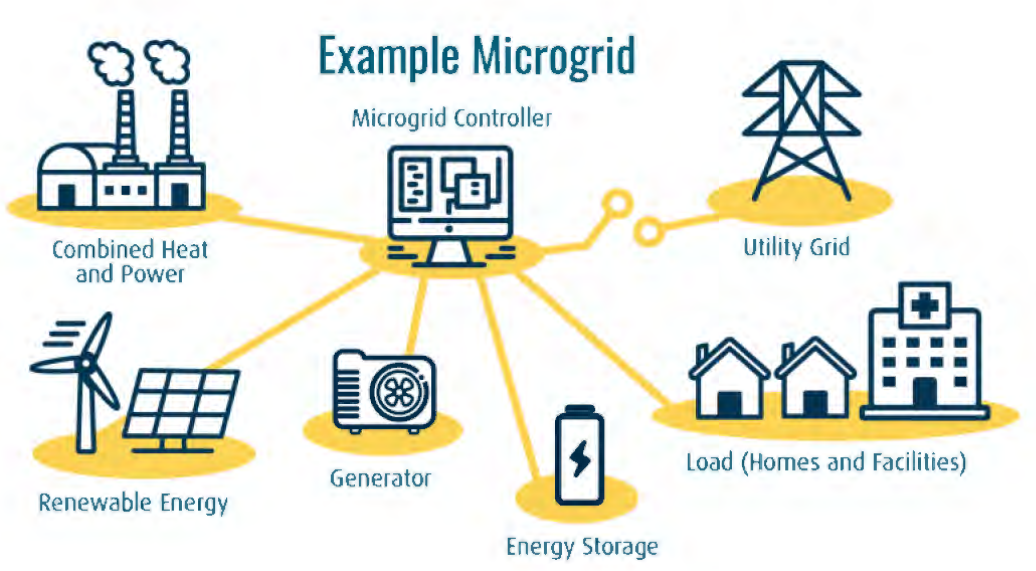


Figure 9: Components of a Microgrid

Source: National Association of State Energy Officials

Energy Generation

Traditional microgrids, such as a hospital using a diesel generator to provide electricity during a power outage, have operated primarily with fossil fuels. However, as outlined in Chapter 2 of this guidebook, the falling cost of solar photovoltaics (PV) has made this green energy technology a cost-competitive solution for green energy generation. The combination of no fuel costs and minimal operation and maintenance costs make solar PV an appealing option for energy generation as part of a microgrid. Solar PV can provide energy directly to the electric grid, energize a lithium-ion battery energy storage system (BESS), or power an electrolyzer to produce green hydrogen to store on-site. As discussed in Chapter 4: Procurement Options for Green Energy, different payment structures for the energy provided by solar PV have different impacts on the financial feasibility of the overall microgrid system.

Energy Storage

Microgrids using fossil fuels as the primary energy source have the advantage of being able to store energy in the form of liquid or gaseous fuel for long periods of time. For microgrid systems utilizing intermittent sources of green energy, such as wind or solar PV, battery storage is required. Lithium-ion batteries are the most common form of stationary storage, making up more than 90% of the total worldwide installed capacity for large-scale battery storage (EIA, 2020). Their prevalence is due in large part to cost decreases of 80% between 2010 and 2017 (Mongird, et al., 2019).

Microgrid Controller

The defining characteristic of a microgrid is its ability to operate independently from the electric grid, a process known as “islanding”. A microgrid controller provides a number of services, including:

- Frequency and voltage regulation
- System monitoring
- Distributed energy resource (DER) coordination
- Islanding and reconnecting the microgrid to the electric grid

Microgrid controllers are the component of a microgrid with the most variation in cost. A 2018 study by the National Renewable Energy Laboratory (NREL) found in a survey that among 21 microgrid projects, controllers made up anywhere from 0.5%-21% of total project costs with a median of 7% of total costs ($155,000/MW) (Giraldez, Flores-Espino, MacAlpine, & Asmus, 2018). NREL did find that costs showed a downward trend as project sizes reached and exceeded 2 MW in total size.

Utility Service Disconnect

To safely ‘island’ from the grid, a service disconnect must be opened at the site’s utility entrance substation to separate the microgrid from the main utility grid. Disconnection may be necessary to prevent the flow of electricity out into the grid, ensuring the safety of both grid infrastructure and utility workers who may be servicing that infrastructure in the case of a widespread power outage. The microgrid controller is often responsible for automatically engaging a microgrid’s islanding capabilities via the transfer switch that disconnects the microgrid from the electric grid.

Project Considerations

While microgrids have been successfully deployed across the country, transit agencies are still in the early stages of determining how microgrids can provide value to their operations. There is no one-size-fits all approach to developing a microgrid project that will satisfy every agency's needs. However, the following elements should be considered by any agency deciding whether to move forward on a microgrid project.

Microgrids in Development: Lessons from Transit Agency Case Studies

Two transit agencies, as of March 2021, are in the construction phase of microgrid projects: **Martha's Vineyard Transit Authority** in Massachusetts; and **Montgomery County Department of Transportation** in Maryland. For Montgomery County, this is the third in a series of microgrid projects at critical facilities within the county.

Both agencies identified a microgrid as means to ensure a resilient power supply to charge buses in the event of a widespread power failure. Each project will use a combination of solar and battery storage to provide power for vehicle charging.

A key to success of each project was early, consistent engagement with each agency's electric utility. Utilities will vary in their experience with microgrids and the sub-components that make up a microgrid, and starting those conversations early in the project timeline will inform each subsequent part of the procurement and construction of the microgrid.

Each agency also found it important to collaborate with reliable, experienced partners with a proven record of success in developing microgrid projects. Such collaboration is important on both the project management and financing portions of the project, as delays in securing project financing can prolong the project development process. Experienced project partners can also help agencies identify whether microgrids can provide cost saving opportunities, such as:

- Demand response
  - Reducing or shifting electricity usage periods of high system-wide energy demand in response to time-based rates or other forms of financial incentives
- Energy arbitrage
  - Purchasing power when the price is low, storing it in the battery system, and selling the power back to the utility when the price is high
- Ancillary services
  - Services provided by battery storage systems to provide additionally stability to the system-wide energy grid, including frequency regulation and peak capacity

While microgrids have the potential to provide these cost-saving opportunities, the ability to realize these benefits will depend on both utility business models to pay for services and local and state regulations. Transit agencies can coordinate with project development partners and their local utility to determine whether these opportunities exist for each individual project.

Additional Resource – National Renewable Energy Laboratory (NREL) – Grid-Scale Battery Storage: Frequently Asked Questions

Understand Energy Needs

The overall design of a microgrid should take into account the energy profile of the infrastructure for which it is providing services. For agencies integrating ZEBs into their service, the decision to pair microgrid resources with charging infrastructure will be influenced by the number of buses being charged and time of day during which they're charged. Other factors to consider will be an agency's electric rate structure and whether certain times of day have higher energy consumption charges.

Agencies will also need to balance current and future energy needs when determining the proper size of a microgrid. This information is especially important for those agencies who plan to grow the share of ZEBs in their fleet over time, which may require additional energy infrastructure needs both for the microgrid and supporting utility infrastructure. Factors to consider include:

- Upfront capital costs for the microgrid system
- Planned growth for the ZEB fleet
- Short and long-term energy needs to reliably meet service requirements
- Short and long-term utility infrastructure upgrades needed to support additional ZEB service

Coordinate with the Utility

Local utilities will play a crucial role in ensuring a microgrid project is able to connect and provide services to the electric grid. Transit agencies seriously considering a microgrid project should engage with their utility company early on in the project development process and continue engagement throughout the design and implementation phases. Early engagement will allow agencies to understand whether utility infrastructure upgrades or additions are necessary to facilitate interconnection to and islanding from the electric grid. Understanding these additional costs early provides a clearer picture for an agency as it continues to develop the project. Utilities may also offer financial incentives for the installation of green energy generation or storage to help offset some of the upfront project costs.

An agency can also engage with its utility to explore opportunities for electric rate structures that better suit their operational or financial needs. Agencies planning to primarily charge buses during times when the overall demand on the electric grid is low may find that utilities will be willing to offer time-of-use rates. Time-of-use rates assign different electricity prices during different times of the day and/or year. Time-of-use designations are generally assigned to Peak (high grid demand) or Off-Peak (low grid demand) periods, along with designations for Summer and Winter.

Determine Space Constraints

As discussed in Chapter 2: Green Energy Infrastructure, green energy infrastructure can be designed in different ways to accommodate space constraints. Agencies with outdoor bus parking can explore solar carports to utilize yard space, while large indoor facilities may be better suited for rooftop solar PV. Battery storage systems take up roughly 1 parking space per megawatt-hour (MWh) of storage capacity.

Engage Reliable Partners

Agencies may determine that engaging with one or more companies in a public-private partnership (P3) to help finance, develop, operate, and maintain their microgrid makes the most financial sense. Pursuing a partnership with an organization well-versed in successfully taking microgrid projects through the project lifecycle will increase the likelihood that an agency develops a system that best suits their needs and takes advantage of all available financial incentives.

Explore Financial Incentives

In addition to utilities, federal, state, and local government agencies offer financial incentives to help facilitate new green energy construction. It is important for agencies and project partners to evaluate how changes to assumptions on available financial incentive programs can impact long-term contracts for green energy infrastructure.

The two primary federal incentives are:

Investment tax credit (ITC)

- Allows the owner of the solar PV and/or battery storage system to deduct a percentage of the cost of the system from their federal taxes
- Public entities are not eligible for the ITC but can partner with a private developer and receive the benefits of the ITC passed down through to the overall cost of the system.

Modified accelerated cost recovery system (MACRS)

- Tax incentive that allows the owner of an asset to recover the cost of business or income-producing property through deductions for depreciation

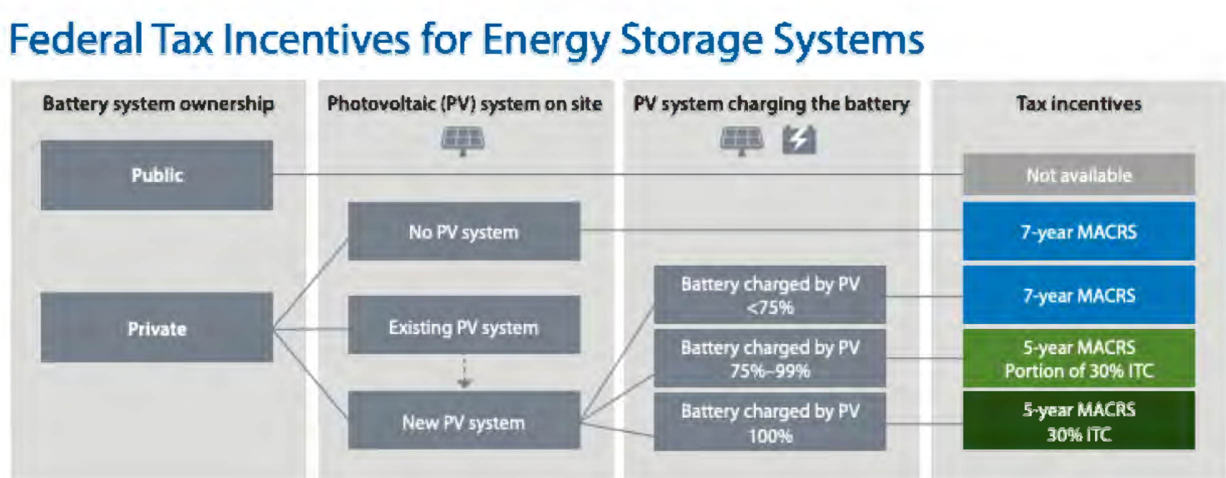


Figure 10: Federal Tax Incentives for Energy Storage Systems
(Source: National Renewable Energy Laboratory)

An updated list of green energy incentive programs at the state and local level can be found through the Database of State Incentives for Renewables & Efficiency (DSIRE), which is maintained by North Carolina Clean Energy Technology Center at North Carolina State University.

Alternative Resilience Options

A microgrid project may not be a suitable financial fit in the short-term for agencies primarily focused on operational resilience, especially if the agency has low electricity rates or faces a challenging regulatory or permitting environment. In the long-term, microgrids may become more amenable to agencies if green energy continues to decrease in cost and more state and local jurisdictions become familiar with the processes by which a microgrid can be integrated into the existing energy system. Alternative options for agencies seeking more immediate resilience for their operations, including those looking for backup power sources for ZEB fueling, include bringing dual power feeds into the depot facility and coordinating with local partners to utilize existing fueling infrastructure.

Dual Power Feeds

Dual power feeds allow an additional, independent electricity path to provide power to a facility. Requests for dual power feeds are not uncommon for utilities, as certain customers require an additional layer of resilience in the event of one power feed failing. However, this additional supply path does come with additional costs, which can be significantly increased in the event a utility line extension is needed. A dual power feed also requires additional equipment, which can be a challenge depending on space constraints.

Alternative Fueling Locations

The deployment of zero-emission vehicles across both public and private fleets, in addition to the general public, will necessitate a continued increase in the number of zero-emission vehicle (ZEV) fueling stations in communities over time. Transit agencies deploying ZEBs can coordinate with local partners to determine how this existing charging infrastructure could support some or all of a fleet's deployment needs during a localized power outage impacting their fueling facility. It is important for transit agencies to coordinate with their vehicle manufacturers to confirm that their vehicles are compatible with the specific makes and models of any alternative charging infrastructure being considered.

Making Microgrids More Accessible

Microgrids have historically been used by critical services and infrastructure to support operations during unexpected power outages. However, as the cost of green energy and energy storage has decreased in recent years, public and private organizations have found opportunities to deploy microgrids. Services provided by these microgrids include increased resilience, utility cost savings, and greenhouse gas emission reductions from their operations. While transit agencies are still in the early stages of understanding how microgrids can support their operations, the resilience and business case can continue to become more achievable for agencies if green energy costs continue to decrease over time.

The next step to make microgrids more accessible for all organizations will be for specific microgrid components and project development costs to decrease and become more predictable across different states and localities. Utilities will also continue to play an important role in any expansion of microgrid deployments, ensuring that grid interconnection processes and infrastructure are in place to successfully operate a microgrid. For more information on working with the local utility, please see N-CATT's whitepaper, *Building Successful Partnerships between Rural Transit Systems Deploying Zero-Emission Vehicles and their Electric Utilities*.

Chapter 4: Procurement Options for Green Energy

The growth of the renewable energy industry has benefited organizations seeking to procure green energy to power their own operations. Historically, organizations were dependent on whatever electricity was provided to them via the local electric utility. Electric utilities often built large power generating stations to serve a multitude of customers, and choices regarding how clean that energy production was did not exist for the customer. As the renewable energy industry has matured, more procurement options have been developed, making green energy now accessible to agencies that may not have green power sources available via their local electric utility in the past.

Transit agencies can now access green energy resources through options that provide flexibility for varying degrees of financial resources, physical constraints, and levels of operational control. Many electric utilities offer green power options through **green power products** and **green power tariffs**. For agencies with the available upfront capital and desire for more operational control over their energy supply, procuring and installing on-site green power generation is a viable option. In other instances, non-utility third-party energy providers can supply green power through energy-as-a-service business models.

Within these three green energy procurement options exist a range of choices that an agency should research before making a decision. The power needs of the operation, contractual terms, and state and local regulations are just a few of the considerations an agency may need to research to decide which green energy supply option is right. Some options may be limited depending on geography or jurisdiction. For instance, green energy tariffs are an option in regulated electricity markets but may not be available in unregulated markets. This chapter of the *Green Energy Guide* seeks to provide an overview of green energy procurement options available to transit agencies. For each of these options, collaborating with your local electric utility is highly recommended and often necessary. Please see N-CATT's whitepaper, *Building Successful Partnerships between Rural Transit Systems Deploying Zero-Emission Vehicles and their Electric Utilities* for approaches.

Utility Green Power Programs

The easiest place to start exploring green energy procurement options is looking into what the local electric utility or electric providers in the area offer. Many utilities are beginning to offer programs for customers, both residential and commercial, that want to purchase green energy to power their homes or businesses. Two common green power programs that are gaining traction among utility offerings are **green power tariffs** and **green power products.**

Green Power Tariffs

Transit agencies may have access to green tariff programs through their usual electric utility. Utility green tariffs are programs that offer commercial and industrial customers, like transit agencies, the option to buy green energy under a special utility tariff rate. If eligible for a green tariff program, a transit agency could buy up to 100 percent renewable power from the utility. The utility supplies this renewable power from renewable projects owned by the utility or from independent, third-party power producers connected to the regional grid.

The mechanism through which a utility procures and delivers green energy to a green tariff customer varies. Depending on the circumstances and the particulars of the utility program, the green tariff may manifest as a market-based utility rate or as a utility-facilitated power purchase agreement (see section on power purchase agreements below). Agencies interested in such programs should contact their local electricity provider to see what green tariff options, if any, exist in their service area.

These tariffs are available only in certain states and through certain utilities. Each green power tariff will have specific requirements depending on the utility company that administers them. These programs are increasing in popularity across the country; in the last six years, these programs have grown from being available in six states in 2017 to being available in 15 states as of 2020.

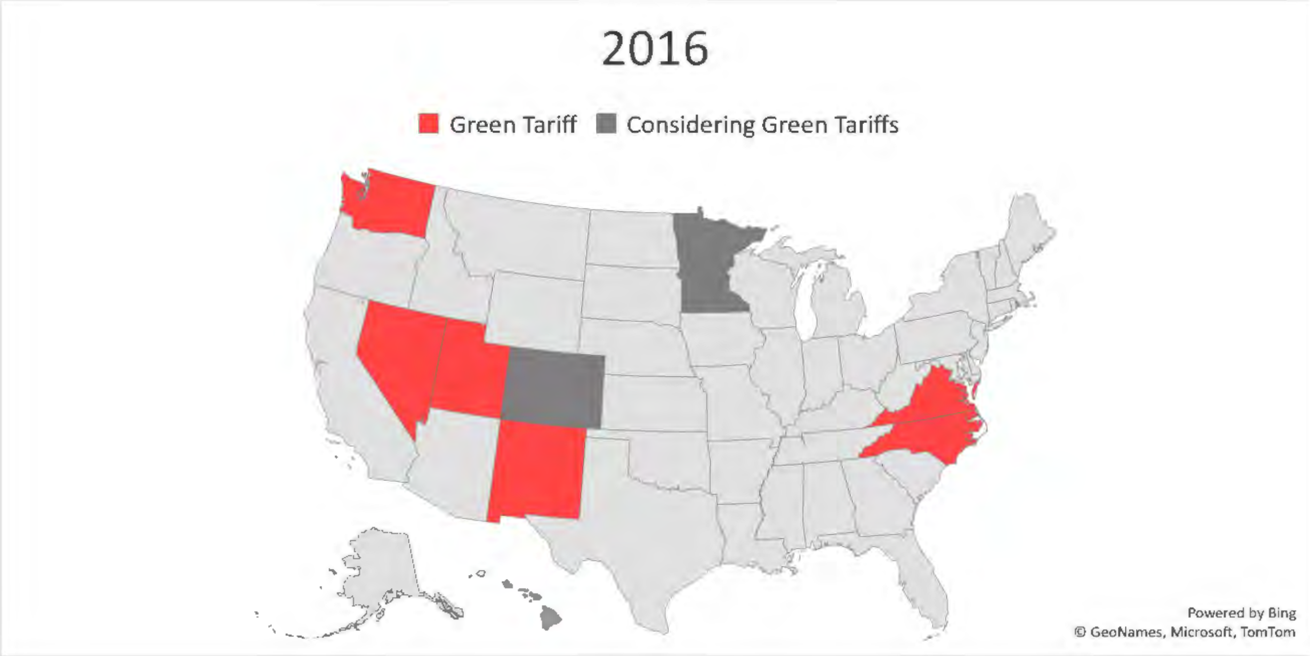
San Mateo County Transit District (SamTrans): Case Study

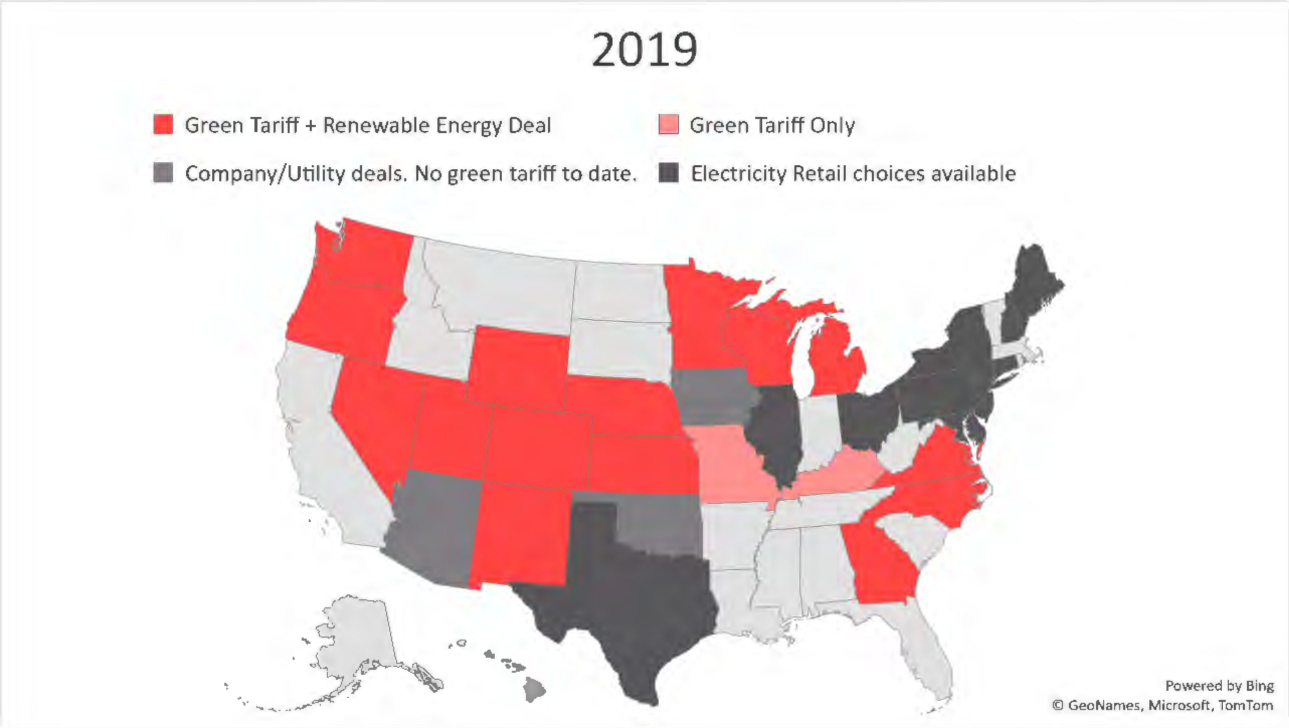
In California, SamTrans' electricity has been 100% green since 2017 thanks to an agreement with Peninsula Clean Energy (PCE), which owns and operates green energy generation systems that include solar and wind farms. PCE is a public, locally-controlled community choice aggregator that works with Pacific Gas and Energy (PG&E), the investor-owned utility that operates the power lines, processes billing, and runs maintenance services.

The arrangement with PCE provides SamTrans with green energy for a lower price without the need for building their own green energy system (San Mateo County Transit District, 2021). These savings have allowed them to consider building their own solar canopy, which will help power their upcoming fleet of electric buses while continuing to be sustainable (San Mateo Daily Journal, 2021).

For an updated resource on currently available green tariff programs, please see World Resources Institute's "*Map of U.S. Green Tariffs and Utility Renewable Energy Solutions for Large Buyers*."

Figure 11: Comparison between available green power tariffs and other programs available, from 2016 to 2019 (World Resources Institute, 2021).





Utility Green Power Products

Utility green power products are similar programs to green power tariffs but operate slightly differently. While green power tariffs require longer-term commitments to purchase power from specific projects, green power product programs are shorter-term, and customers can often unsubscribe at any given time as subscriptions are month to month. Under a utility green power product program, customers typically pay a cost premium on their utility bill to support the supply of electricity from a mix of renewable or green energy sources. Through these programs, customers choose an amount of renewable or green electricity they would like to receive each month either in increments of kilowatt-hours or a specific percentage of their monthly electricity bill (U.S. Environmental Protection Agency, 2021).

On-Site Power Generation

Many people, when hearing the terms “renewable energy” or “green power”, think of images like solar panels on the roof of a building, powering the facility they sit on. This is the idea behind on-site green power generation: power is produced at or near the site of consumption. Many on-site power systems are “behind-the-meter,” meaning that the power production happens on the customer side of the utility’s electric meter and minimizes or eliminates reliance on the utility grid. In reality, on-site power generation often offsets a portion of utility-supplied electricity. Most, if not all, transit agencies installing on-site power generation will still maintain a connection to the utility-operated electrical grid. The benefits of on-site power generation include the opportunity to produce greener energy than exists on the grid, possible financial savings from offset utility costs, and increased resiliency from grid outages. Successfully installing on-site power generation comes with a few challenges as well, although many transit agencies have successfully navigated these challenges to install their own on-site green power.

For agencies looking to procure green power in locations where a utility does not supply it, on-site power generation may be one of limited options. On-site green power generation provides environmental benefits by offsetting the need to burn fossil fuels for power and cutting down on the need for additional transmission and distribution infrastructure. The reduction in fossil fuel use leads to less local air pollution and less global greenhouse gas emissions. On-site generation can have financial upsides, as well. Once installed, all the power that is generated and then consumed by the agency is paying for the initial investment. Utility electricity rates often increase over time and offsetting those costs can have long-term financial benefits for transit agencies, especially if those agencies are deploying zero-emission buses and expecting a large, resulting increase in electricity usage.

In some jurisdictions, on-site power generation can even produce a net financial gain for an agency. Programs like **net metering** allow utility customers with on-site power generation to sell excess electricity generated by the on-site project back to the utility-owned grid, either at retail or at wholesale prices. These programs can help offset the initial costs of green power installations.

However, net metering programs often limit project eligibility. It is important to research programs in the relevant area and discuss the programs with the local electricity provider to fully understand the opportunities and constraints provided by these programs. For instance, the State of California limits net metering systems to 1 megawatt (MW) in size, and the total of all net metered systems’ capacity cannot produce more than 5% of a utility’s peak demand (U.S. Environmental Protection Agency).

Transit agencies considering on-site generation must be aware of the challenges and should plan their project carefully. Upfront costs for installation and commissioning of an on-site project is one major hurdle. Agencies must have enough capital to cover the initial expenses, including energy storage backups, utility infrastructure upgrades, and facility upgrades to handle the new power systems. Other costs may involve energy management software and training for staff. An agency looking to build on-site generation will likely need to discuss the project with a project developer, local permitting authorities, and the local electric provider to understand the costs of design, construction, permitting, and utility interconnection processes.

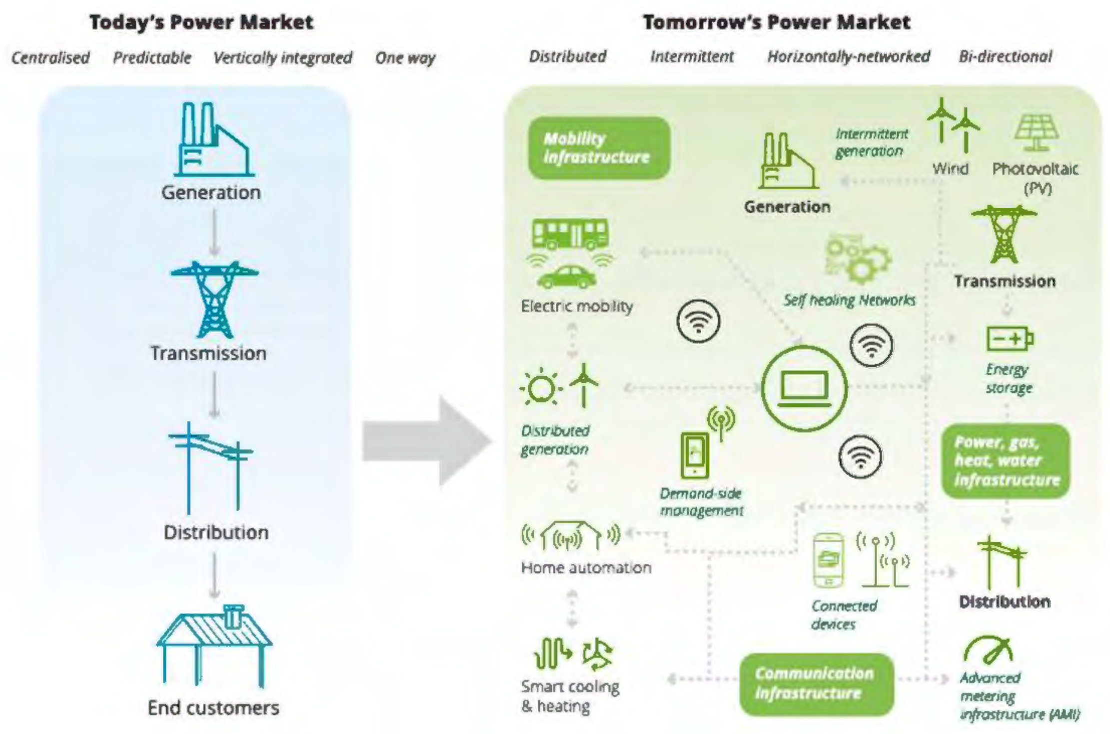
On-site generation also requires physical space, which may be at a premium for some transit agencies. Understanding the physical footprint of the desired power generation technology is important. After installation of the green power system, the agency will also need to cover maintenance and operations of the system or pay a third-party to do so. For more information on green power infrastructure requirements, please see Chapter 2: Green Energy Infrastructure.

Many transit agencies are considering or have installed on-site green power generation to power their operations. Owning and operating on-site generation provides many environmental benefits and can offer many financial and operational control opportunities. Successfully integrating on-site generation, however, requires careful planning, initial investment, and commitment to a continued maintenance and operational plan. Fortunately, other options to besides owning and operating on-site generation exist for transit agencies interested in green power for their operations.

Energy-as-a-Service (EaaS)

Traditionally, power generation has been centralized by highly regulated, vertically integrated utilities. The emergence of green energy technologies, like solar and wind, that can be installed in a more modular fashion have supported the creation of business models that take advantage of the more decentralized capabilities of these power production technologies. While the electricity industry has become more complex in many ways, there are also many new opportunities to access clean energy, manage energy consumption, and produce new revenue streams for both producers and consumers of electricity than there were in the historical vertically integrated system. These new opportunities are being captured by energy providers and often provided to customers, such as transit agencies, through energy-as-a-service models.

Figure 12: Traditional power market compared to the evolving power market, where energy-as-a-service presents opportunities for green energy procurement (Deloitte UK, 2019).



Energy as-a-service (EaaS) is the catch-all term for a category of business models that can provide green power to customers beyond what the local utility might offer. Typical EaaS models that transit agencies may be interested in are **solar leasing**, **community solar**, and **power purchase agreements.**

The general idea behind EaaS approaches is that a third-party develops, builds, and operates the green power production system (e.g. a solar power plant) and simply sells the power to a customer or group of customers. This transaction takes place outside of the typical utility-to-customer arena, although the utility may still be involved in delivering the power through utility-owned transmission and distribution lines.

Solar Leases

Solar leases are essentially a pay-for-output green power model. Solar leases have gained popularity in the residential solar markets, but could possibly work for a small transit agency. Under a solar lease, a solar company designs a solar power system to meet the customer's needs, then installs and maintains the solar system at the customer's facility at no upfront cost, supplying electricity for the duration of the contract. The solar company retains ownership of the power system and charges the customer for the output of the system. This business model works well for customers who do not want to pay the upfront cost of a system or do not want to commit to operations and maintenance of a green power system.

Community Solar

While typically emerging as an option for residential customers, community solar could be a green power procurement option for small transit agencies that can collaborate with other local businesses or residents to form a customer group and support a community solar project. Community solar operates as a subscription model in which customers subscribe for solar energy delivery from a nearby solar (or other green energy) project. The community solar project is typically developed, owned, and operated by a solar company. Solar companies benefit from economies of scale in this scheme because the larger projects, supported by the subscribing customers, are less expensive per kilowatt to develop than individual solar installations (Resources for the Future, 2019).

Power Purchase Agreements

A power purchase agreement (PPA) is at its core a service agreement. In more detail, a PPA is a financial agreement where a third party (e.g. a solar generation company) usually owns, operates, and maintains an electricity generation system, and enters into an agreement with the customer (in this case, a transit agency) to provide the electric output from the system to the agency either on or off site.

Under these agreements the energy generation company is considered an independent power provider (when this provider is not a utility company), which enables the project to qualify for federal and state tax incentives (U.S. Department of Energy, 2011). These agreements provide options for lower cost electricity to the agency and revenue and tax credits for the supplier via Renewable Energy Credits (RECs) (see section on RECs below).

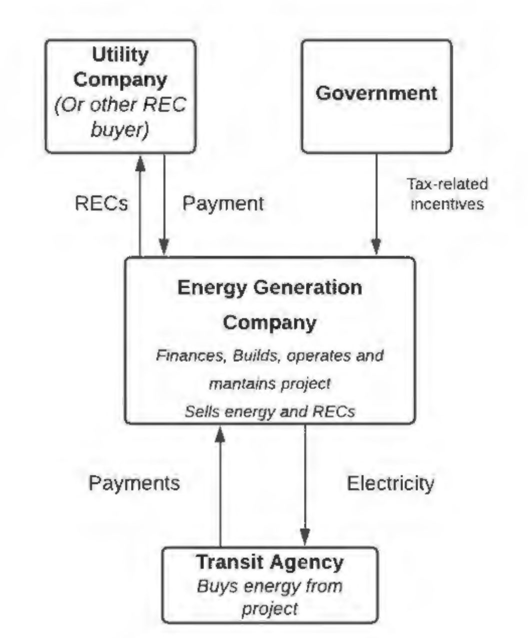


Figure 13: Example flowchart of a PPA contract with REC transaction

Types of PPAs

There are two types of PPAs, physical and virtual, depending on where the electricity was generated and delivered and the type of contract between parties.

A physical PPA is a long-term contract where the generator and the agency are in the same electricity market to allow for energy delivery. The contract specifies electricity prices with year-over-year escalation and includes details on electricity deliveries, schedules, and renewable energy credits.

A virtual PPA is a long-term contract where the generator and the agency are not necessarily in the same electricity market. The contract states long-term electricity prices, and electricity in itself is not directly delivered to the customer but put into the grid. This is a “contract for differences”—the difference between earnings and cost to the generator is transferred to the customer. If more is earned by the generator, then the difference is paid to the customer. If the generator makes less than the contracted price, then the difference is paid by the customer to the generator. The idea behind this type of PPA for green power is that the customer is paying to support and increase the proportion of clean energy being delivered to the grid.

Considerations for PPA Contracts

Under a PPA, a third-party finances, constructs, and operates the energy generation system, ensuring that energy delivery is performed as it was contracted. PPA contracts can include other clauses such as minimum outputs. Minimum output clauses establish that failure to deliver the contracted amount of energy may result in penalties to the generation company. Other contract details that may benefit the transit agency customer include fixed prices for energy and the possibility of establishing detailed management of price escalations, which help when budgeting for projects with longer lifespans.

Southeastern Pennsylvania Transportation Authority: PPA Case Study

In early 2020, the Southeastern Pennsylvania Transportation Authority (SEPTA) signed a long-term PPA for off-site solar generation with Lightsource BP, a developer of utility-scale solar energy projects. This PPA will see the building of two off-site solar farms, with an estimated total annual generation of over 67,000 MWh (pv magazine USA, 2021).

This PPA is projected to produce yearly savings for SEPTA, alongside progress towards sustainability goals, thanks to the fixed price on energy and the RECs that will be kept by the agency. Furthermore, the construction of the two solar facilities will utilize local labor, and the land where they will be located is leased to local landowners (SEPTA, 2020).

The green energy produced by these PPAs is certifiable as such by the production of **renewable energy credits**. Ownership of these credits is negotiable by both the generation company and the agency, and may be sold separately from the energy distributed. More information on renewable energy credits is provided in the following sections.

As noted above, virtual PPAs are contracts for differences and the specific terms of the contract will dictate when an agency may have to cover energy price increases, for instance. Energy generated by renewable sources such as wind and solar can fluctuate, and the demand for energy might not be met by the PPA's energy output. In this case, a separate traditional power agreement with the project site's utility provider (i.e. a standard utility contract) can be used to ensure that this demand is met. In turn, this creates the possibility for two separate electricity bills and their associated administrative costs. These details are just a few of the numerous terms that must be considered in the somewhat complex challenge of negotiations and contract drafting between parties.

Renewable Energy Credits (RECs)

The U.S. Environmental Protection Agency defines RECs as "a market-based instrument that represents the property rights to the environmental, social, and other non-power attributes of renewable electricity generation." Electricity flowing through the grid comes from a variety of sources—coal, natural gas, hydropower, solar, and others—and determining the exact resource an electron originated from after it reaches a customer delivery point is not possible. This fact posed a challenge for implementing renewable energy compliance regulations and programs. To solve the issue, a system of **renewable energy certificates** was developed to track renewable generation and delivery to the grid, providing a means of distinguishing renewable energy from fossil energy and serving as a tool for consumers and utilities.

RECs are used for environmental claims and can be used to claim eligibility for programs or financial incentives. Due to the characteristics of the tracking system, the tracked energy cannot be double counted or claimed by more than one party.

A REC is issued when one megawatt-hour (MWh) of electricity is generated from a renewable energy source and delivered to the grid. RECs are legal instruments and are tradeable. There are differences in state definitions for RECs but it is generally agreed that they verify the attributes of the energy from generation to point of use (U.S. Environmental Protection Agency, 2018).

There are two types of REC markets: compliance markets and voluntary markets. Compliance markets require electricity providers to produce a percentage of their generation from renewable sources. Voluntary markets are for RECs that are demanded because of client preference to use green energy but renewable energy use or production is not mandated by law.

RECs are issued by state or regional electronic trackers. The tracking agency issues RECs to registered generators that report verified generation to the tracking system.

If there is a generator that is not registered into a tracking system but provides RECs or energy attributes, then these RECs can be conveyed to another party via contracts. Generation must be measured and attributes verified, and ownership/attributes verification must be independently audited, which is also true for self-generation (U.S. Environmental Protection Agency, 2018).

Details on environmental claims, REC markets, and decisions surrounding them are beyond the scope of this paper. It is important to know that RECs and environmental claims are an important consideration when signing a contract for green energy, whether via a PPA or other contract type. A good resource for more information on environmental claims is the EPA website, *Making Environmental Claims.*

Procurement Process Flowchart

The following list and graphic provides a broad-strokes overview of the green energy procurement process and can be used as a guide for planning a green power procurement project. The information below is adapted from the EPA's *Guide to Purchasing Green Power.*

1. **Identify key decisionmakers:** For transit agencies, integrating green energy into operations will likely require decisionmakers from facilities and transit operations departments. Identifying all decisionmakers and stakeholders is important.
2. **Collect energy data:** How much energy does the agency use right now? At what times of day does electricity use peak? How much will electricity use increase with zero-emission buses?
3. **Determine scope:** Is your organization buying energy only for a particular project, a facility, or the entire agency?
4. **Evaluate the options:** The availability of green power products varies by state and type of project. Green-e® offers an online search tool that helps simplify this step and locates renewable energy that meets EPA's standards.
5. **Develop criteria:** Agency-defined factors such as budget, green energy source, contract type or project length will serve as filters for the available options.

Figure 14: Visualization of green energy procurement process (U.S. Environmental Protection Agency, 2021).

6. **Contact product providers:** Once the providers have been pre-selected, contact them to determine current rates for renewable energy products. Some providers might offer other services in addition to energy delivery (e.g. demand management).
7. **Buy green power:** When drafting contracts to buy green power, ensure that it clearly conveys the rights to make environmental claims from the energy purchased.
8. **Benefit from your purchase:** EPA's Green Energy Partnership allows for organizations to submit their energy purchase to qualify as Partners, who receive benefits such as assistance on press releases, Green Power Partner mark on websites and other communication materials (U.S. Environmental Protection Agency, 2021).

Chapter 5: Charger Modeling and Charge Management

Zero-emission bus (ZEB) deployments differ not only in the operational characteristics of the buses themselves, but also in the fueling infrastructure required. For battery electric bus (BEB) operators, a number of considerations arise when determining how to develop and deploy charging infrastructure for their buses:

- Charger power
- Number of chargers
- Number of charging dispensers per charger
- Physical space constraints
- Expected charging periods
- Utility rate structures

This process attempts to find the right balance between ensuring resilience is built into the infrastructure design (i.e. having one charger go offline will not prevent service requirements being met) and minimizing cost by not overbuilding infrastructure.

Charger Modeling

Charger modeling is one method for agencies to better understand how fueling ZEBs will impact their operational costs. It also has the potential to inform infrastructure project development.

For BEBs, charger modeling begins with an agency's electric utility. Early engagement with the electric utility allows an agency to ask questions about how their current electricity rate is structured and how that structure will impact the cost of charging BEBs.

Green Energy and Hydrogen Fueling

Agencies deploying fuel cell electric buses (FCEBs) have a unique set of challenges to successfully deploy fueling infrastructure cost-effectively. Determining whether hydrogen fuel will be delivered or produced on-site via electrolysis will influence all other aspects of the project.

On-site electrolysis offers an opportunity to pair fuel production with a green energy source, such as on-site solar PV. On-site fuel production may provide cost-saving opportunities if there is not robust regional hydrogen supply network, requiring agencies to source hydrogen that comes with higher delivery costs. However, electrolysis is an energy intensive process that requires about 55 kWh of electricity to produce each kilogram (kg) of hydrogen fuel. Fuel production costs can rise rapidly without a utility rate structure that provides opportunities to produce hydrogen during lower-cost times of day. Electrolysis also requires water as an input, which adds to operating expenses for hydrogen fuel production.

Pairing solar and on-site electrolysis for hydrogen production also provides challenges when scaling up fueling as the size of the fleet increases. As available space to expand on-site solar decreases, an agency may find it difficult to scale green energy with on-site hydrogen production. Managing the upfront capital costs, in addition to ongoing operating costs, can provide a challenge for agencies working to keep overall project costs low in both the short and long-term.

Overview of Electric Bills

Electric utilities generally design their rates to account for two different measures – power, which is typically measured in kilowatts (kW), and energy, which is measured in kilowatt-hours (kWh). In addition to charges for power and energy, utility bills will generally include a fixed monthly cost and may also include assorted other charges and/or taxes.

Table 4 shows three different scenarios in which a charger could consume 300 kWh of energy. Power, or the rate that energy is consumed or moved, varies across the three scenarios. This impacts the amount of time needed by the charger to consumed 300 kWh. Actual charge times may be longer due to charge limitations. An engineering analysis is required to determine accurate charge times.

Table 4: Examples of Charging Power and Relationship to Time and Energy

Charger Power (kW)	x Time Charging (hrs)	= Energy (kWh)
50	6	300
150	2	
450	0.67	

Demand Charges

A demand charge is calculated based on the highest amount of power needed by the customer during a specific window of time, typically 15 or 30 minutes. Demand charges allow a utility to cover the cost of building enough energy generation and distribution assets to meet the highest level of demand at any given point across its service territory. While calculating a demand charge is typically straightforward [highest average power (kW) over a specific period of time multiplied by the rate ($/kW)], utilities have different ways they can quantify peak demand. Some utilities forgo demand charges altogether. Demand charges may be broken up into short-term (hourly) and/or long-term (seasonal) periods, or may be based on an overall annual peak demand.

The following examples illustrate how peak demand is calculated based on different usage Scenarios. Each scenario assumes a 15-minute demand window, and the calculations below do not take into account efficiency losses, which may result in higher demand charges.

Example 1: Six 125 kW depot chargers are installed on the same meter that services a transit facility for overnight bus charging. The facility utilizes an average of 200 kW during the day and 50 kW overnight. Under these conditions, the previous peak demand was during the day. Without any charge management strategies, the new peak demand would now occur overnight, from simultaneously charging six buses on the 125 kW chargers. Assuming the buses require more than 15 minutes to charge, the chargers, alone, would create the following power demand:

6 chargers × 125 kW × (15 minutes of charging / 15-minute demand window) = 750 kW

When you add that to your existing average overnight facility demand (50 kW), your new peak demand now occurs overnight:

50 kW (existing overnight demand) + 750 kW (overnight charging demand) = 800 kW

In this example, the chargers created 750 kW of additional demand. However, the previous peak demand, occurring during the day, was 200 kW. The new overnight peak demand was only 800 kW, an increase of 600 kW instead of the entire 750 kW the chargers created. Because the charging occurred during previously off-peak hours, a portion of the charger demand was offset by the daytime facility usage.

Example 2: A separately metered 450 kW fast charger is installed. The highest demand possible for that charger would be approximately 450 kW, which would occur if a bus took 15 minutes to charge:

1 charger × 450 kW × (15 minutes of charging / 15-minute demand window) = 450 kW

However, many buses fully charge in less than 15 minutes. If a bus takes 10 minutes to charge, the peak demand would be approximately:

1 charger × 450 kW × (10 minutes of charging / 15-minute demand window) = 300 kW

For separately metered fast chargers, the peak demand will occur during the longest charge event for each month.

Energy Charges

Energy charges are typically calculated by adding up the total amount of energy use (kWh) over a billing period and multiplying that amount of energy by a pre-determined rate ($/kWh). Utilities may charge the same dollar amount per kWh of energy used no matter when it is consumed. However, utilities may also place different values on a kWh of energy consumption depending on the time of day or season, or tier rates based on the overall amount of energy consumed.

Fixed and Other Costs

Utilities may charge a monthly service fee to connect to the electric grid, which typically makes up a small fraction of a monthly bill. Other bill charges may include local taxes, renewable energy production, energy efficiency, and the method and source of energy production.

Electricity Rate Modeling

An agency can begin to estimate expected charging costs once they have developed an understanding of their electricity rate and how it is structured. Developing an electricity rate model can allow an agency to explore the potential range of outcomes for the cost of charging their BEBs. An electricity rate model should incorporate the following elements.

- Estimated bus mileage and energy efficiency, including seasonal variations
- Estimated or actual charger power, including an estimate of efficiency losses
- Estimate the expected time of day charging will take place
- Estimate the maximum overall peak demand (kW) and energy consumption (kWh)
- Include additional power and energy loads if chargers are on the same utility meter as other facilities
- Include multiple scenarios to estimate a range of outcomes

While an agency will be unable to capture each and every scenario, a utility rate model can provide an expectation of the range out outcomes possible based on vehicle utilization and charging profiles.

Charge Management

Charge management is the process by which a vehicle operator attempts to limit the power needed to charge vehicles. This optimization can be achieved through operational processes or software management solutions. From an operational perspective, there are two main strategies that can be used to limit power needed to charge vehicles:

- Reduce the number of vehicles charging simultaneously
  E.g. A fleet with 10 BEBs charges the first five buses simultaneously, followed by the remaining five buses, cutting the agency's demand for kilowatts by half.
- Reduce the amount of power used to charge vehicles
  E.g. An agency has an eight-hour window to recharge buses that would only require four hours to recharge using their charger's full power output. The agency reduces the power output of the chargers to charge the buses over the 8 hours and cuts their demand for kilowatts by half.

It is important that an agency has a clear understanding of the service needs of the BEBs when assessing whether a charge management strategy is viable. Charge management may be difficult when deploying buses that return from service simultaneously and have a short window in which to charge before their next pullout time. However, for agencies that have more flexibility in how they deploy BEBs, there are ways to meet service requirements while minimizing power needs and charging costs.

Software solutions do exist from both charging manufacturers and third-party companies to automatically manage charging. These solutions vary in level of automation but have the potential to provide savings both in charging costs and staff time required to oversee a charge management solution. Software-based charge management is still in the early phases of rollout and utilization in the United States, although fleets in other countries have more experience with these solutions.

There are also training-based solutions that can provide immediate benefits and minimize charging costs. It is recommended that training be provided to all relevant staff including operators, maintenance, and management personnel. Proper training can decrease the likelihood that a bus will be charged during a time that would cause the peak demand to increase beyond the agency's goal or that buses are left plugged in well beyond when they reach 100% state-of-charge, which can lead to unnecessary additional costs.

Charge modeling and management represent opportunities both pre-and-post-deployment for agencies to develop a better understanding of the impact of BEB operations on charging costs. Charging costs are informed by both the power required by the chargers and overall energy consumption of the BEBs. Early partnerships and conversations with an agency's utility can lead to a better understanding of how charging will impact electricity bills. These conversations may even lead to the utility agreeing to revisit an agency's electricity rates and offer new rates that better serve both the customer and utility. And while the number of options for charge management may be limited for some agencies based on service requirements, there are still opportunities to ensure that charging is done in the most efficient and cost-effective way possible.

Additional Resources

- Building Successful Partnerships between Rural Transit Systems Deploying Zero-Emission Vehicles and their Electric Utilities, *National Center for Applied Transit Technology*
- Guidebook for Deploying Zero-Emission Transit Buses, *Transportation Cooperative Research Program*
- Preparing to Plug in your Bus Fleet: 10 Things to Consider, *Edison Electric Institute*
- CyRide: Zero Emission Bus Roadmap, *Center for Transportation and the Environment*

Chapter 6: Supporting Deployments of Green Energy and Zero-Emission Vehicles

Deploying new technologies like zero-emission vehicles and green power systems into ongoing operations requires planning, coordination, training, and ongoing monitoring for the deployments to be successful. This chapter of the *Green Energy Guide* focuses on pre-deployment and post-deployment activities that transit agencies should consider once they procure zero-emission vehicles. These activities include inspections, testing, and staff training for both operations and safety. While the activities discussed focus on zero-emission vehicle deployments, considerations for integrating green power systems are discussed as well. Both zero-emission vehicles and on-site green power will present new operational and new safety considerations for transit agencies.

Many of the activities discussed in this chapter are dependent on terms agreed upon in the procurement contract with a zero-emission vehicle (ZEV) original equipment manufacturer (OEM). Before deploying new zero-emission vehicles, both pre- and post-delivery inspections and acceptance testing of the vehicles must be completed to ensure that the vehicles are built and perform according to the contractual and performance requirements that were agreed upon with the OEM in the procurement and contracting process. The procurement contract should also contain stipulations for the amount of training to be provided by the OEM. Bus manufacturers are intimately familiar with their products and can provide agency staff with the necessary knowledge to operate and maintain the ZEVs safely, efficiently, and in line with best practices. Agency staff will need to be trained on details of the vehicles and supporting systems so that they can perform actions after the buses are deployed, such as maintenance of the vehicles and tracking of certain key performance indicators. These activities are discussed in more detail in the following sections.

Pre-Deployment Considerations

Successfully deploying ZEVs into transit service requires the completion of a few pre-deployment steps: pre-delivery inspections, post-delivery inspections, and acceptance testing. Completing these activities will help ensure that vehicles meet specified performance requirements before an agency fully accepts the vehicle delivery and deploys the vehicles into service.

Pre-delivery Inspections

Pre-delivery inspections ensure that vehicles meet the specifications included in the contract before the vehicle ever leaves the OEM's facility. This type of inspection is generally not a requirement for projects using federal funds unless a bus order is for more than 10 buses. If a bus procurement is using federal funds and seeks to deploy more than 10 buses into the service area, the Federal Transit Administration (FTA) requires that a resident inspector conduct inspections of the vehicles at the OEM's facility (FTA Circular 5010.1 E). The resident inspector must visually inspect the vehicles and conduct road tests. Regardless of the federal grant rules, industry best practice is to have a vehicle inspector at the OEM facility, specifically one who has knowledge of electric drive vehicles and high-voltage systems, to perform inspections of the vehicle before it leaves the OEM's facility. There are zero-emission bus (ZEB) experts available that can be contracted in order to perform such inspections, if needed. In-house inspectors could also be educated by a ZEB expert on the electric drive technology through an assisted inspection. These inspections help to identify any deviations from the contracted specifications or any defects in the product so that the OEM can address any issues before the vehicles are delivered to the agency.

Post-delivery Inspections

Once the vehicles arrive at the transit agency's facility, post-delivery inspections confirm that the vehicles were not damaged during the delivery process. If zero-emission technology is new to an agency's fleet, the agency's maintenance staff may need assistance in conducting a post-delivery inspection.

Prior to delivery, transit agencies should ask the vehicle OEM to provide training on the new bus components so that agency staff can more effectively conduct an inspection. Naturally, it is important to arrange this training with the vehicle OEM before the vehicles arrive, so that the OEM can come prepared to provide that training. Agency staff should also make sure they are aware of any of the specific hazards unique to zero-emission vehicles and associated infrastructure, such as high-voltage cables and battery-specific fire hazards. If any issues are noticed during the post-delivery inspection, the transit agency should communicate those issues with the bus OEM. All items should be addressed to the agency's satisfaction before an agency officially accepts the vehicles. Post-delivery inspections are especially important for zero-emission vehicles. ZEVs are transported from the OEM to the agency's facility, unlike new conventionally fueled vehicles that are driven from the OEM to the customer. As such, ZEVs spend less time on the roads before delivery and therefore there is less time to identify potential issues with the vehicles before they arrive at the agency.

Acceptance Testing

Acceptance testing is the process of testing the performance and functionality of the buses and fueling infrastructure to ensure that the contractual requirements specific to operations are met. Acceptance testing can occur in conjunction with or after the post-delivery inspections. The fueling infrastructure and any facility upgrades must be completed before acceptance testing is conducted. As such, agencies intending to install on-site green energy infrastructure along with new ZEB deployments should review their project schedules carefully to ensure that all necessary infrastructure is in place before post-delivery inspections and acceptance testing of the vehicles occur. The U.S. Department of Energy suggests accepting PV solar systems after the system has proven to operate for ten continuous days at energy and power production levels congruous with the PV manufacturer's estimated energy production (DOE, 2020). Agencies should ensure there is contractual language between the green energy system manufacturer and installer that specifies expected energy performance and regulatory and design specifications that must be met before accepting the technology.

Acceptance criteria is typically detailed in the final vehicle contracts, with specific criteria for both bus and infrastructure technologies. The criteria should cover performance standards that the vehicles must meet; standards for component functionality or cabin temperature in extreme weather conditions, and standards for uptime or the requirement that all systems function at the time of acceptance.

The time period for acceptance testing is an important detail to include in the contract terms along with the acceptance criteria itself. Two common ways to define acceptance periods in the contract are a specific period of continuous time (e.g. 40 hours) or a testing period (e.g. 15 to 30 days). Under the continuous time approach, the bus must operate in the specified time period without any issues. If an issue does arise, the clock resets and the acceptance period will extend until the conditions are met. The testing period approach allows the agency to test the bus in any way it sees fit for the number of days detailed in the contract. The contract terms should also clearly define the criteria that must be met and under what conditions to inform acceptance or non-acceptance of the vehicles.

Public Engagement

Public engagement should be considered at the outset of any zero-emission technology deployment project, even before procurement begins. It is important to work closely with local communities before, during, and after the transition process to ensure that community needs continue to be met by the transit service and new technologies. Effective public engagement can provide a platform for a successful deployment by ensuring that community buy-in and resources can be leveraged to overcome any deployment hiccups.

A key to building authentic broad-based community support for a green energy project or zero-emission bus deployment is to identify natural local partners at the very outset of the project. Agencies should consider cultivating relationships with community-based organizations, local air quality groups, and/or local electric vehicle advocacy groups who can work with the transit agency to develop community outreach strategies and communicate local issues and interests back to the agency. Deploying initial zero-emission vehicles on routes with high ridership or high visibility in the community is one strategy to help advertise the use of zero-emission technology, especially if an agency intends to complete a full fleet transition in the future.

Most communities welcome the opportunity to breathe cleaner air and be on the forefront of transportation and energy technologies. By highlighting the environmental benefits and the agency’s commitment to maintaining transportation services for the community, agencies can garner support for the current project and possible future projects.

Training

Zero-emission vehicles pose different safety and operational considerations than conventional vehicles. Staff training is therefore a crucial part of a successful ZEV deployment, especially if it is the first deployment of the zero-emission technology for an agency. The contract between the agency and the bus OEM should detail the type and amount of training the bus OEM will provide, as well as requirements for aids, materials, tools, and diagnostic equipment. An agency should aim to have the training take place soon after the buses are delivered so that staff are adequately trained on safety and operations when the vehicles are deployed in revenue service. Adequate pre-deployment training does not preclude additional training after buses have been deployed.

Operations Training

Zero-emission vehicle technology functions differently than conventional internal combustion engine (ICE) vehicles. This statement may seem obvious on its face but there are important implications for operator training because of these differences. Small operational details, such as the dashboard displays, will differ in a zero-emission vehicle. For instance, rather than a fuel gauge, the dashboard in a battery electric bus will most likely have an indicator for the state of charge (SOC) of the battery with estimates on remaining operating time and estimated range remaining.

One of the most significant differences for operators is the braking mechanism. Zero-emission buses use regenerative braking as opposed to conventional friction braking. Regenerative braking technology takes the kinetic energy created during the braking action and converts it into electrical energy, which then gets stored in the vehicle's battery and helps extend the vehicle's range. As such, driving and braking behavior will affect the amount of energy captured; more energy is captured when drivers brake gradually versus slamming on the brakes (McIntosh, 2019). To properly prepare operators for ZEB service, the bus OEM should provide training on regenerative braking of the vehicles. Agency staff should test drive the vehicles to understand how driving habits can significantly affect the efficiency and performance of the zero-emission buses, including recommended levels of acceleration and deceleration.

Safety Training

All staff who operate or support zero-emission vehicles in any way should go through the proper safety training for the vehicles and their associated infrastructure. Agency staff familiar with fossil fuel safety procedures and precautions will need to be retrained to safely work with and around hydrogen or high-voltage batteries. The National Fire Protection Association's (NFPA) website contains a collection of free Emergency Response Guides from multiple battery electric and fuel cell electric bus manufacturers such as Nova Bus, Proterra, GILLIG, BYD, and Van Hool Bus.

Local first responders should also be contacted and included in any OEM first responder safety training before the buses are placed in revenue service. First responders who are unfamiliar with zero-emission vehicles must learn to recognize the difference between a conventional bus and a zero-emission bus, as well as the difference between internal combustion engine fires and battery electric or hydrogen vehicle fires, so that appropriate response measures can be taken. The National Fire Protection Research Foundation produced a report that discusses best practices for emergency response procedures specifically for electric drive vehicle battery incidents, which is available for free on NFPA's website.

Driver training should also include notable safety points. ZEBs produce much less noise than conventional internal combustion engine vehicles. Driver training should include a review of the risks that this silent operation presents to unaware or hearing-impaired pedestrians. The lack of noise may also pose issues in situations where it is not clear that a bus has not been turned off because there is not the usual engine noise.

Post-Deployment Considerations

Once ZEVs have been deployed, agencies will transition to conducting maintenance and tracking key performance indicators (KPI). Like operations, maintenance for zero-emission vehicles has key differences from that of ICE vehicles. Key performance indicators are used to monitor the performance, efficiency, environmental benefits, and costs associated with zero-emission vehicles and on-site green energy systems.

Maintenance

Bus Maintenance

Zero-emission bus components include fewer moving parts than internal combustion engines, which in general leads to less preventive maintenance required for ZEBs. Maintenance data from U.S. ZEB deployments are still being collected and analyzed, so it is too early to state definitively that maintenance requirements for ZEBs are lower, but examining the component parts of each bus could lead one to that reasonable conclusion.

The Federal Transit Administration (FTA), in collaboration with the Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL), are working to produce initial insights into zero-emission bus maintenance compared to conventional bus maintenance. Evaluation reports of battery electric and fuel cell electric buses are available on the FTA website.

Battery health will be a new factor to consider for maintenance departments at agencies deploying ZEBs. Batteries degrade over time, which impacts the performance of the vehicles. This degradation will need to be measured and tracked. Having a plan to measure and track battery health to manage bus performance and battery warranty claims is an important part of a successful ZEB deployment.

Maintenance also requires spare parts. Transit agencies should make sure to receive a recommended spare parts list from the bus and fueling infrastructure OEMs. For spare parts that an agency does not plan to keep onsite, understanding common lead times are for those parts will be important, especially as zero-emission technologies evolve. Tracking maintenance history is one strategy that can help an agency understand future maintenance needs and provide insight into the type and number of spare parts they need to have available at any given time.

Charger Maintenance

Transit agencies deploying battery electric buses will also need to be prepared for preventative and corrective maintenance on charging infrastructure. Depot charging will mostly require minimal maintenance due to the fact that they are typically modular in design, allowing individual components to be replaced versus the whole unit. Fast charging systems usually require more periodic maintenance as they have additional components, such as cooling systems and filters, that depot stations do not (Smith & Castellano, 2015).

Green Energy System Maintenance

Required maintenance for energy generation equipment will differ depending on the technology and installation components. For ground-mounted solar, routine maintenance entails vegetation management, snow removal, and cleaning panels of dirt and debris. Roof-mounted solar arrays also require periodic cleaning and clearing along with the additional maintenance of the load-bearing roof (NREL, 2018). Due to the rotating nature of wind turbines, periodic maintenance like lubrication, oil changes, and brake pad replacements will likely be necessary. (Olsen & Preus, 2015). Each agency will need to assess their green energy maintenance needs and determine whether or not current staff will be capable of operating and maintaining the green power equipment or if the agency should contract with the equipment vendor or a separate service company (U.S. Environmental Protection Agency, 2018).

Key Performance Indicators (KPIs)

Key performance indicators (KPIs) are metrics used to monitor the performance, efficiency, environmental benefits, and costs of zero-emission vehicles and on-site green energy systems. Not every agency will want to track the same indicators, so it is important for agency staff to determine what metrics are relevant to the success of their specific ZEB and green energy deployment.

KPI Examples for Bus Deployments

- Fuel cost per mile
- Emissions reductions
- Utilization
- Energy Performance

KPI Examples for Energy Generation

- Energy produced
- Emissions reductions
- Cost savings

KPIs are important for tracking the benefits and paybacks of investements in zero-emission technology, both from a cost perspective and an emissions reduction perspective. If an agency received grant money for the purchase of their zero-emission vehicles, there may be a requirement for reporting KPIs. Even if KPIs are not required, developing either monthly or quarterly reports to have on record can be beneficial to successful zero-emission technology deployments. Tracking KPIs plays an important role in determining improvements that could be made to increase effectiveness of zero-emission technology as an agency gathers data and experience with the vehicles and infrastructure.

For example, *utilization* is a KPI that compares the number of days an agency's vehicle was put into service to the number of days the vehicle was available for service; this KPI shows the actual usage of an agency's zero-emission vehicle fleet compared to the possible usage. If an agency is experiencing low utilization, it could point to operational issues that the agency needs to address, such as availability of drivers trained on the zero-emission technology. By tracking this KPI and others, agencies can work to identify the root cause of operational challenges and develop a plan to address them.

Figure 15: Example KPI - Tracking Utilization of Vehicles

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