Planning for Resilient EV Charging Infrastructure

Developed by

The North Central Texas Council of Governments (NCTCOG)

under contract to

The Texas State Energy Conservation Office (SECO)

Contents

Summary

Planning for continued electric vehicle (EV) charging during grid outages is necessary as EV adoption becomes more prevalent in the coming years and EVs are assigned to critical operations. The Electric Reliability Council of Texas (ERCOT) electric grid has shown several vulnerabilities in recent years that will be exacerbated by increasing power demand associated with continued increases in weather events, population, economic growth, and transportation electrification. This whitepaper explores the state of the ERCOT grid considering the growth in EV adoption and the topic of EV infrastructure resilience. It highlights planning considerations needed to address electric grid impacts of transportation and ensure EV charging remains operational in the face of disruptions or outages.

Definitions

Battery Energy Storage System: An electrochemical device that stores electrical energy for later use, and it can store energy generated from various sources. Presently, the most used type of battery chemistry is lithium ion (Li-ion).

Carbon Intensity: Measures how much carbon dioxide (CO_2) equivalent are released for a given amount of a material or product. For purposes of measuring carbon intensity in the energy/electricity sector, this is usually expressed in grams of CO_2e per kilowatt-hour (kWh) of electricity. This metric accounts for the emissions of various greenhouse gases, converting them into CO_2 equivalents to provide a comprehensive view of the environmental impact.

Carbon Dioxide Equivalent (CO_2e): The Environmental Protection Agency (EPA) defines carbon dioxide equivalent or CO_2e as the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas and is calculated CO_2e = (Greenhouse Gases x Respective Global Warming Potentials).[1]

Cycle Life: Total number of charge and discharge cycles a battery can have before it fails.

Clean Hydrogen: The Department of Energy (DOE) defines clean hydrogen as hydrogen produced with a carbon intensity equal to or less than 2 kilograms of CO_2e produced at the site of production per kilogram of hydrogen produced.[2]

---

[1] Definition (epa.gov)
[2] Alternative Fuels Data Center: Regional Clean Hydrogen Hubs (energy.gov)

Climate Action Plan: A plan that outlines the goals, strategies, and actions to reduce greenhouse gas emissions and adapt to the impacts of climate change, such as extreme weather events or sea level rise.

Contracted Load: The maximum load agreed to be supplied by the licensee and specified in the agreement between the consumer and the licensee.

Data Center: A facility that houses computer servers and related equipment, such as cooling systems and backup generators, and provides internet connectivity and data storage services.

Demand-Charge-Management System: A system that monitors and controls the electricity consumption of a customer or a facility and reduces or shifts the demand during peak hours to lower the electricity bill.

Demand Load: The amount of electricity required to meet the needs of a specific customer or a group of customers at a given time.

Distributed energy resources (DERs) are technologies that provide energy generation and/or energy storage to provide electricity to where it is needed.

Electrification: The process of converting energy sources or systems that use fossil fuels to ones that use electricity.

ERCOT: The Electric Reliability Council of Texas (ERCOT) is the independent system operator that manages an electric grid encompassing about 75 percent of the land area in Texas and representing about 90 percent of Texas' electric load.

Green Hydrogen: Hydrogen gas produced by the electrolysis of water, using electricity generated from a renewable source, such as wind or solar.

Hydrogen Fuel Cell: Converts hydrogen into electricity through an electrochemical reaction which results in emissions consisting of only water and heat.

Large Flexible Loads (LFLs): A stand-alone load greater than 75 MWs that has the internal capability to interrupt its load and return to service as directed by ERCOT. Commonly includes cryptocurrency mining facilities, data centers, hydrogen production facilities, and other high-demand assets.[3]

Officer Letter: A letter received by ERCOT from a transmission service provider (TSP) officer attesting to the confidence that the expected customer load growth will materialize.

[3] https://capitol.texas.gov/tlodocs/88R/analysis/html/SB01929F.htm

Peak Demand: The highest level of electricity demand in a given period, usually a day, a month, or a year.

Peak Hours: The time periods when electricity demand is highest, typically during the morning and evening on weekdays.

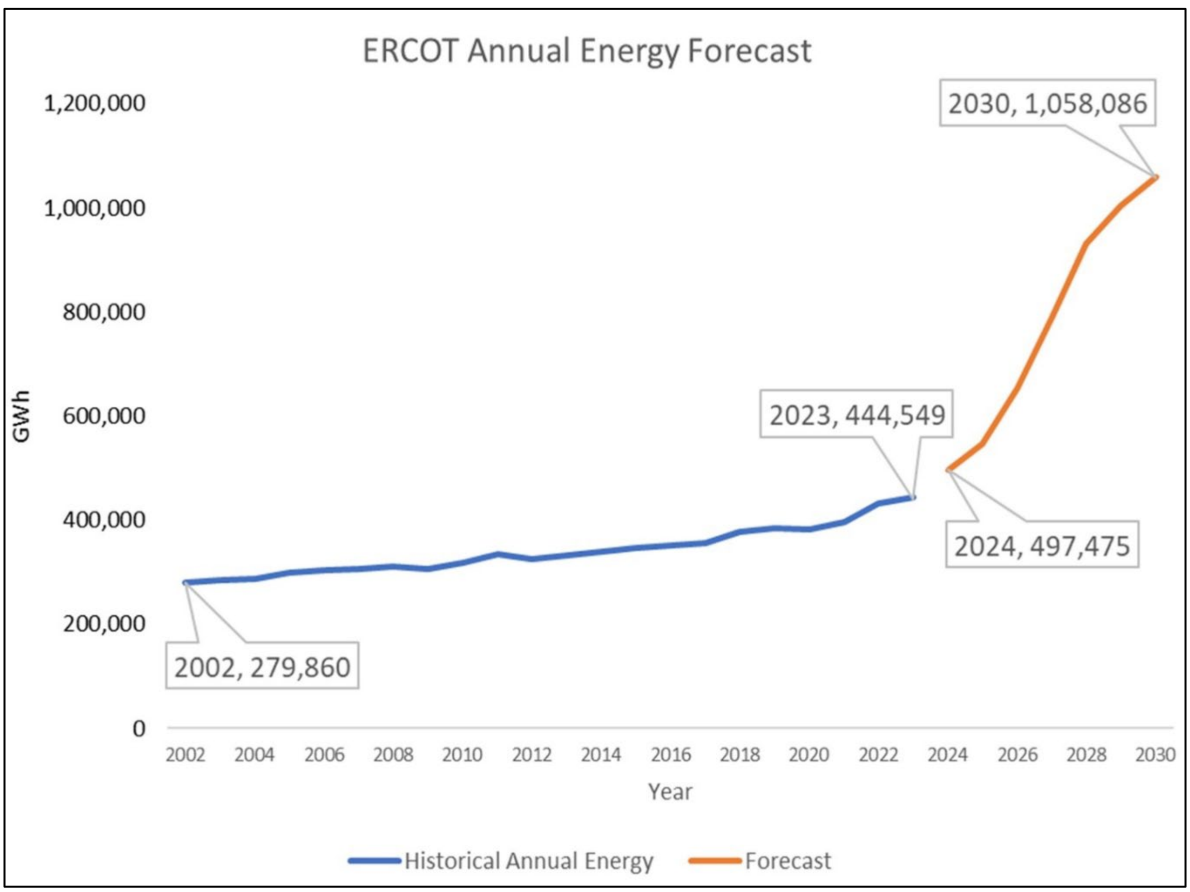
Peak Shaving: A strategy that reduces the peak demand of a customer or a facility by using distributed energy sources, such as batteries or generators, or by adjusting the operation of devices, such as EV chargers or HVAC systems.

Thermal Management System: A system that regulates the temperature of a device or a facility by using cooling or heating mechanisms.

Texas' Need for Energy Increasing

ERCOT recently updated the 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast. The average annual growth rate (AAGR) for energy in the ERCOT region is forecasted to be 13.6% from 2024-2033.

Exhibit 1. ERCOT Annual Energy Forecast



Source: Load Forecast (ercot.com)

As shown in Exhibit 1, the AAGR for 2014-2022 was 3.1%, which overall illustrates a slow and steady increase in power demand (electrical load).[4] This is a remarkably steady rate of load growth considering the substantial population and economic growth that the State of Texas has been experiencing, which has increased the number of homes, schools, buildings, manufacturing/industrial facilities, data centers, and number of cars and trucks on the road. Between 2000 and 2022, the population of Texas increased by 43.4%, making it the fourth fastest-growing state during that period and one of only two states with a population over 30 million.[5] The Texas economy is the 8th largest economy in the world, valued at more than $2.4 trillion, and grew at a faster rate than the nation as a whole for the seventh quarter in a row.[6] Through 2022, the ERCOT grid was able to absorb much of this increased activity with relatively little change in peak load. During this same period, EVs became commercially available and by the end of 2022 total EV registration across Texas reached 163,836.

However, ERCOT is forecasting a marked increase in energy demand in the coming years, with forecasted load growth from 2024-2027 with an AAGR of 17.1%. This increase is visible in the chart in Exhibit 1, and is further detailed in Exhibit 2, which shows the AAGR by year from 2024-2030.[7]

Exhibit 2. ERCOT Average Annual Growth Rate by Year

Year	AAGR
2024-2025	9.88%
2025-2026	19.50%
2026-2027	21.06%
2027-2028	17.82%
2028-2029	7.94%
2029-2030	5.20%

Source: ERCOT 2024 Long-Term Hourly Peak Demand and Energy Forecast

While ongoing population and economic growth and a push for electrification across all sectors (including adoption of electric vehicles in the transportation sector) contributes to load growth, the most substantial contributors to new load are associated with adoption of newer technologies directly related to an increased need for computing power, such as the use of artificial intelligence and cryptocurrency mining; and future large industrial loads, such as liquefied natural gas facilities, oil and gas exploration, chemical processing

[4] Load Forecast (ercot.com)
[5] Texas Population Passes the 30-Million Mark in 2022 | Census.gov
[6] Texas Economic Overview
[7] 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast, pg. 4

plants, and hydrogen production facilities.[8] In addition, extreme temperatures add to the demand load for the heating and cooling of built structures, including the cooling of data centers.

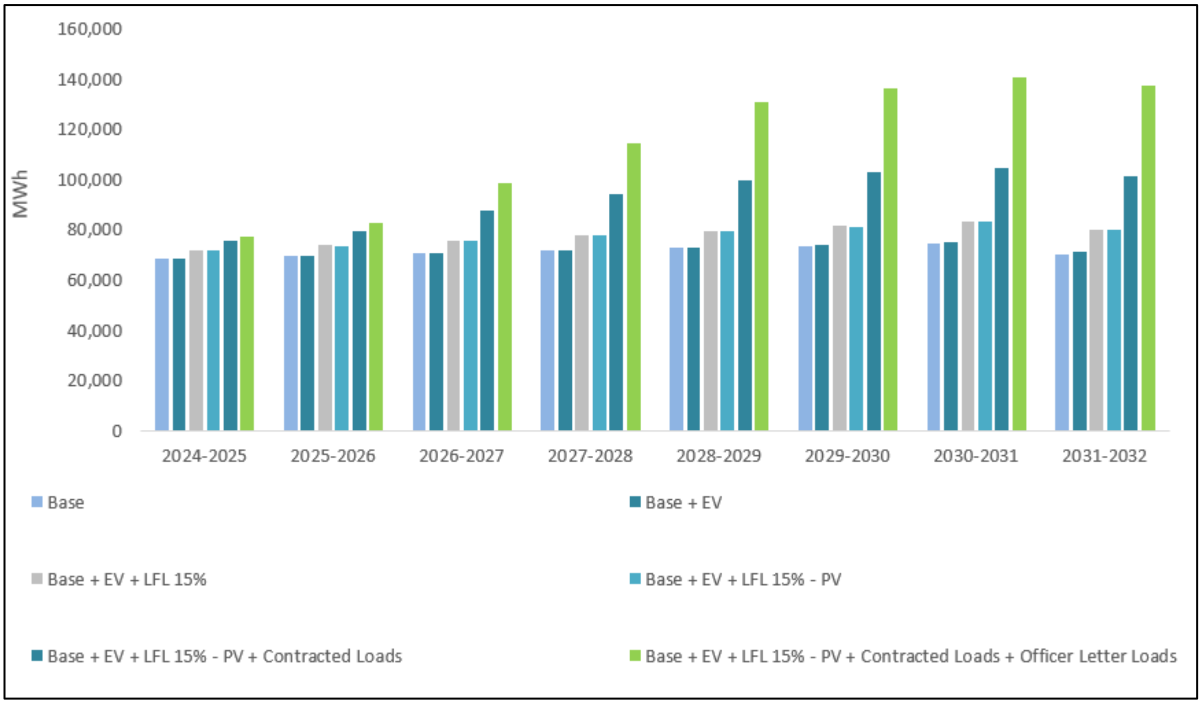
As shown in Appendix A, cryptocurrency mining, data centers, hydrogen production facilities, and large industrial loads are forecast to have a much greater increase in load from 2024 to 2030 compared to the 2024 base forecast.

Continued transportation electrification will increase the demand for electricity as more electric cars, trucks, transit buses, school buses, trains, aircraft, and e-micromobility (e-bikes, e-scooters, drones) are deployed and require charging. Per Texas Department of Motor Vehicles July 2024 registration data, there are over 296,000 EVs registered in Texas with an increase of more than 40% year over year in both 2022 and 2023.[9] ERCOT forecasts approximately 998,000 light duty vehicles and 103,000 medium/heavy duty vehicles will be electric by 2029 in Texas, representing 4% of all vehicles on the road. Of these, approximately 96% of light-duty EVs and 93% of medium- and heavy-duty EVs are expected to be registered in ERCOT's service territory, and thus would contribute to ERCOT grid load.

Despite the expected increase in EV registration, ERCOT forecasts the total EV charging load in 2029 to only add 1.25% of load to the load forecast in 2029, up from 0.2% in 2023.[10] Exhibits 3 and 4 show the forecast load increases to the base load contributed by various sources. Note that there is hardly any visible difference between the "Base" load peak forecast and "Base + EV" load peak forecast; notable increases in peak load are associated with forecasts that include "Contracted Loads" and "Officer Letter Loads". In addition, as shown in Exhibit 4, the ERCOT summer coincident peak shifts from 5:00 PM to 10:00 PM starting in 2028. This is relevant to considering when best to plan for EV charging, as further discussed on pages 14-15.

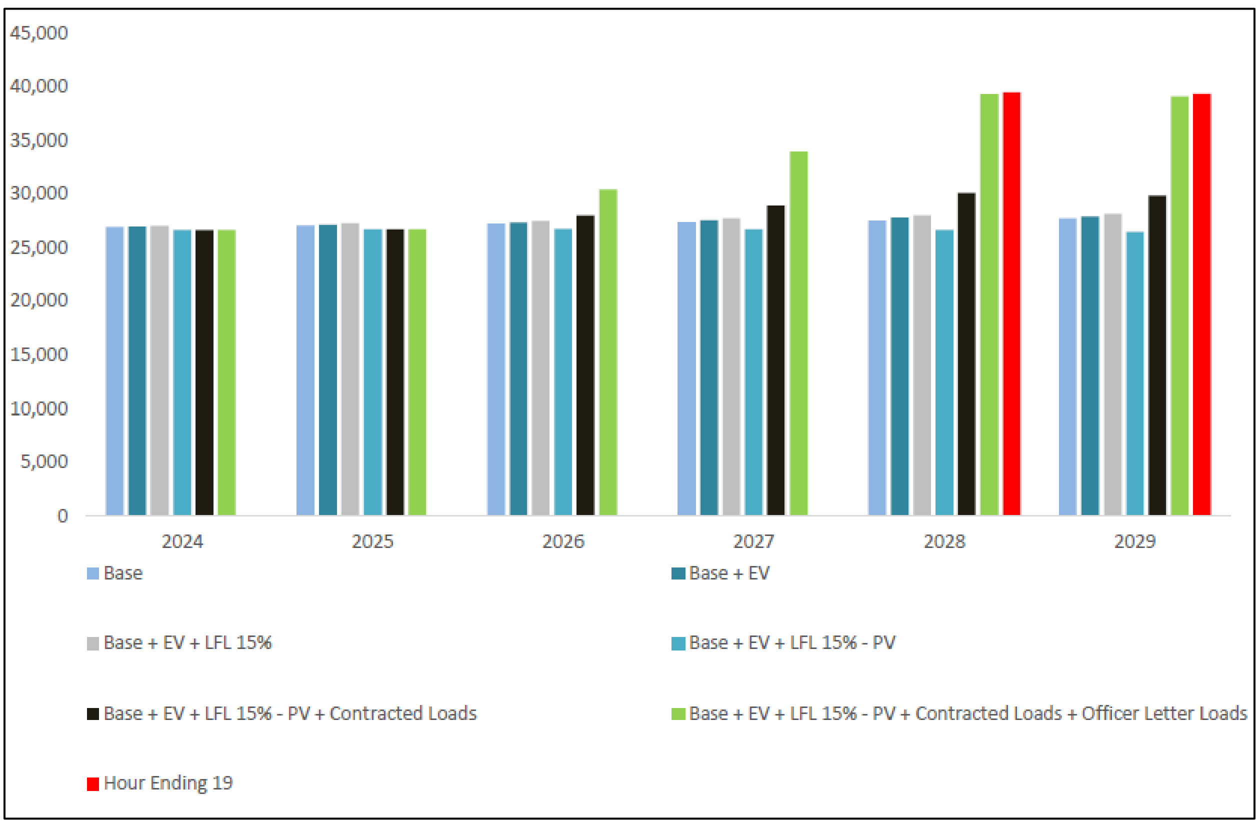
[8] 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast pg. 11, 14
[9] EVs in Texas | DFWCC
[10] 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast, pg. 15

Exhibit 3. ERCOT Winter Coincident Peak Forecast



Source: 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast, pg. 11

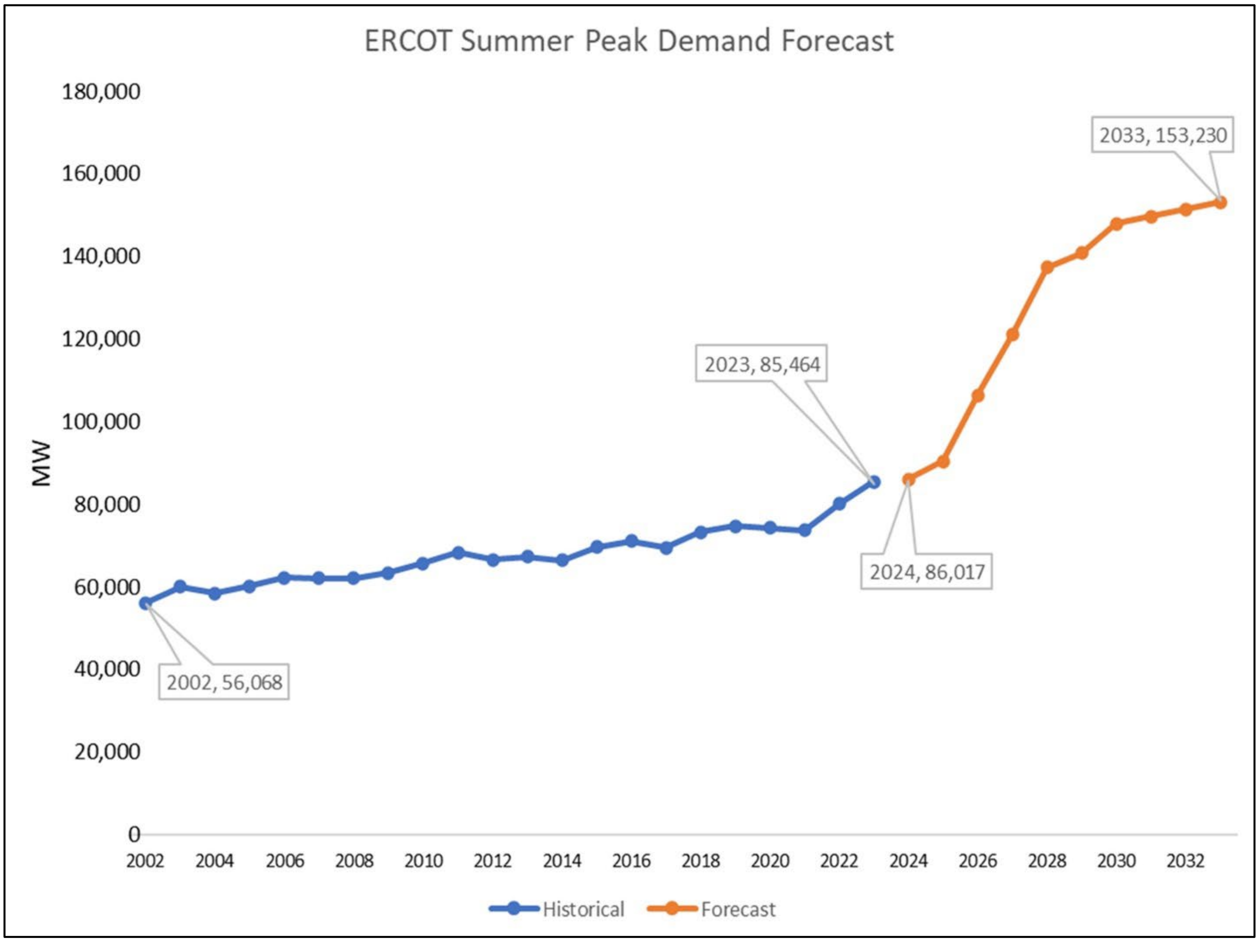
Exhibit 4. ERCOT Summer Coincident Peak Forecast



Source: 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast, pg. 14

Summer Peak demand is forecast to increase at an AAGR of approximately 6.8% from 2024-2033, as shown in Exhibit 5. This forecast assumes average summer weather conditions and that existing and planned large flexible loads, such as cryptocurrency mining, reduce consumption during summer peak hours to 15% of their normal consumption.[11]

Exhibit 5. ERCOT Summer Peak Demand Forecast



Source: ERCOT 2024 Long-Term Hourly Peak Demand and Energy Forecast

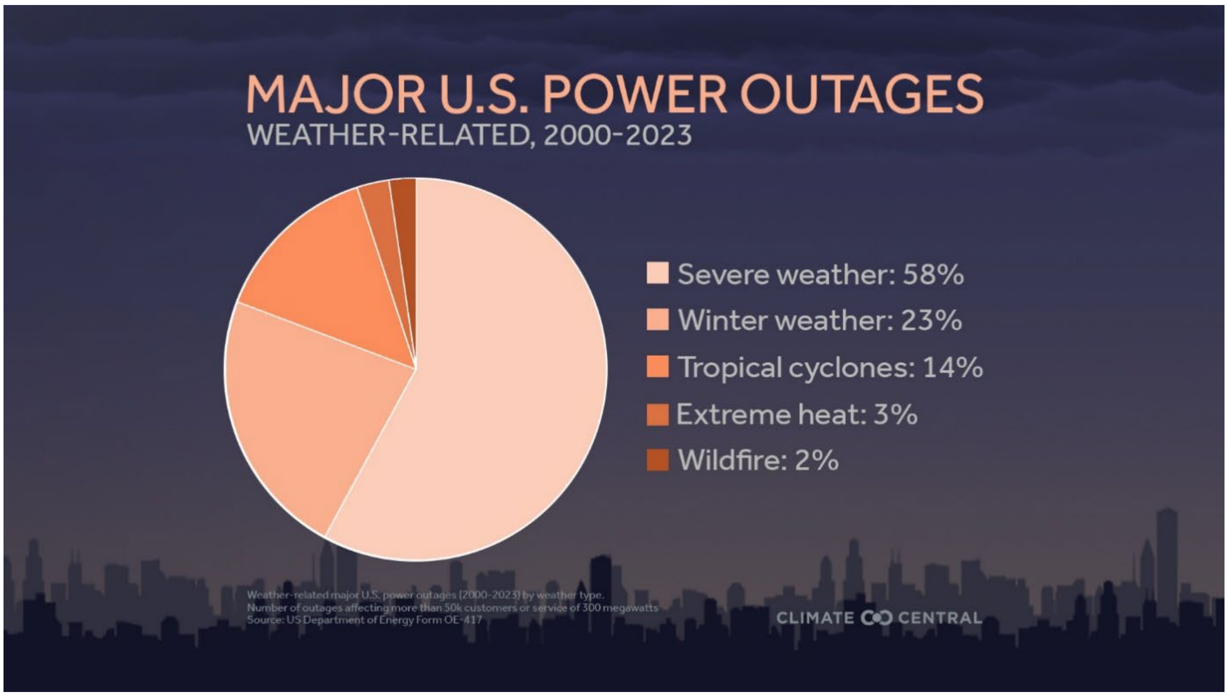
Electric Grid Outages

Electric grid outages can be caused by many things, including severe weather, natural disasters, human error, vandalism, equipment failure, fallen trees, animals, high energy demand, planned outages, excavation digging, geomagnetic disturbances from the Sun, and cyberattacks. Analysis by Climate Central, based on power outage data from the U.S. Department of Energy (DOE), showed that of all major U.S. power outages reported from

[11] 2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast, pg. 2

2000 to 2023, 80% (1,755) were due to weather. Weather-related power outages in the U.S. are on the rise, with about two times more weather-related outages occurring during the last 10 years (2014-2023) than during the first 10 years analyzed (2000-2009). This underscores the need to prepare for an increased number of power outages in the coming years. Exhibit 6 shows the percentage of major weather-related power outages in the U.S. in 2000-2023 with 58% of the outages caused by severe weather, such as high winds, rain, and thunderstorms.[12]

Exhibit 6. Major U.S. Weather-Related Power Outages, 2000-2023



Source: Climate Central

Exhibit 7, based on DOE data and provided by Payless Power, shows the number of outages Texas experienced over a 20-year and a 5-year period for all causes and severe weather. This data shows Texas' outages have increased in the last 5 years, mostly due to severe weather. Each outage in the last 5 years for all causes lasted an average of 160.4 minutes.[13]

---

[12] Weather-related Power Outages Rising | Climate Central
[13] Payless Power

Exhibit 7. Texas Outages

Cause of Outage	Outages Last 5 Years (2019-2023)	Outages Last 20 Years (2003-2023)	Percent of Outages in Last 20 Years Occurring in Last 5 Years
All Causes	263	435	60%
Severe Weather	111	193	58%

ERCOT Grid Capacity and Constraint

While Texas' demand for electrical power has continued to increase, to date the capacity of the ERCOT power grid has been able to keep pace with the increased load. Where peak load has grown to about 88 MW of total summer peak demand (before accounting for energy savings from efficiency programs), the ERCOT grid includes about 115,596 MW. Substantial amounts of new generating capacity, mostly from wind and solar, and the addition of utility-scale energy storage that can contribute power at the ERCOT grid level, have enabled Texas' demand to continue growing without the need for ERCOT to issue rolling brownouts or blackouts in recent years.

However, the grid does face risks as peak load creeps closer to installed capacity, and if the steep uptick in peak load materializes. Winter Storm Uri posed an extreme example, as record-setting winter peak load due to heating demand coincided with weather-induced equipment failures, resulting in the catastrophic statewide power outage of February 2021. Since this disaster, ERCOT has been more proactive at notifying the public at large when peak demand is coming "too close" to power capacity through the Texas Advisory and Notification System (TXANS), which consists of three levels: ERCOT Weather Watch, which notifies Texans that weather conditions and expected demand may lead to lower reserves; a Voluntary Conservation Notice; and a Conservation Appeal[14]. Under both the Voluntary Conservation Notice and Conservation Appeal, Texans are requested to voluntarily conserve power during specific periods if safe to do so, and government agencies are requested to "implement any and all programs to reduce energy use at their facilities"; the difference is that a Conservation Appeal is issued when reserves have the potential to fall so low that ERCOT may enter emergency operations. During 2023, ERCOT issued 13 conservation alerts[15], illustrating times when all efficiency and conservation efforts are needed to ensure that the grid can continue operating safely and reliably.

For EV owners/operators – especially fleet managers with multiple EVs that may put greater charging load on the grid, it's important to consider not only conservation appeals but also be aware of when the grid is most likely to be constrained, and to plan to schedule

[14] TXANS (ercot.com)
[15] Understanding ERCOT Conservation Alerts (electricityplans.com)

EV charging to occur at hours where the grid is least constrained. Traditionally, the grid was most constrained at the same time as peak load, but as the composition of the grid has changed, and is continuing to evolve rapidly as more MW of renewable generation and energy storage are installed on the grid, this may vary. Typically, the evening hours of 5-7 pm were expected to be the hours where Texans would be asked to conserve. However, a review of ERCOT Monthly Outlook on Resource Adequacy reports for January-October 2024 reveals that from March to October, the risk of needing to issue a Voluntary Conservation Notice or Conservation Appeal was consistently highest from 8-9 pm, with slightly less risk from 7-8 pm. The hours immediately before and after this window occasionally had a small risk of needing to issue a conservation notice[16]. **This indicates that the hours from 7-9 pm are typically the hours where the grid is most constrained, and during which EV charging should be avoided to be "grid-friendly".** (As a note, risk of needing to issue a conservation notice was more evenly distributed across the day in January and February.)

EV Charging Planning for Critical Operations

Given the increasing frequency of grid outages, fleets must begin planning to consider strategies to enable electricity availability to charge vehicles that serve more critical functions even if a grid outage occurs. Typically, in the initial stages of fleet electrification, fleets procure electric vehicles for non-critical operations such as administrative travel and Code Enforcement. However, as fleets progress further into electrification plans, EVs will be assigned to more critical operations such as refuse collection, public works (e.g. trucks that respond to incidents to maintain proper operations of physical infrastructure), dump trucks (e.g. trucks that treat roadways to prevent freezing during winter storms), emergency services (police, fire, ambulance), and certain freight transport. In addition, general traffic needs certainty of power availability when traveling along evacuation routes in event of a weather event. Examples of critical operations already being electrified include:

- 4 electric sedans for non-pursuit police use implemented by City of Plano in 2020
- 6 electric sedans for non-pursuit police use implemented by Dallas County Sheriff in 2022
- 4 electric sedans for police detectives implemented by City of Carrollton in 2022
- an electric refuse truck implemented by the City of Plano in April 2024
- an electric fire truck ordered by the City of Denton, slated for delivery in October, 2024

[16] Resource Adequacy (ercot.com)

The ability to charge these vehicles in the event of a grid outage is vital for safety and continuity of critical operations and should be included in the planning of EV charging infrastructure. As fleets plan their budgets and procurement of EVs and EV charging infrastructure, consideration should be given to whether an EV will be assigned to a critical operation and how it will charge during a grid outage. EV charging infrastructure that can operate off-grid is more advanced technologically and typically more costly than EV infrastructure without the technologies discussed below. Further, fleets should ensure the compatibility between EVs and the EV charging technology in procurement decisions.

The North Central Texas Council of Governments (NCTCOG) conducted a regional survey to gather information on concerns, strategies, and technologies that organizations have in place or may have in place in the future to provide EV charging services in the event of a grid outage. Unfortunately, only two responses were received, underscoring a need for more awareness and resources in the resilient EV charging space. However, both respondents (a local government and an airport), reported that they do anticipate a need for available EV charging for critical operations during an outage within the next five years and anticipate incorporating resiliency elements in EV chargers in the future.

Resiliency Planning for Continuity of Operations

Even though ERCOT expects the overall grid impact of EVs to be low relative to other sectors, it is important to ensure that all loads are managed as efficiently as possible to maximize the ability of the ERCOT grid to absorb the impact of additional load growth with as little additional investment as possible. EV owners, especially fleets with multiple vehicles, should be mindful of the interplay between vehicle operation and grid load. One of the energy-saving tips that ERCOT recommends in the event of a conservation notice is to avoid using large appliances and to turn off and unplug non-essential lights and appliances[17]. Thus, **during conservation notices, charging an EV would be counterproductive to the actions being requested to maintain optimal grid conditions.**

There are two major methods to mitigate grid impact – enabling off-grid charging that can be used regardless of grid conditions, and managing charging to ensure it occurs outside of peak demand hours. Charging outside hours of peak demand helps level out the peaks and valleys of the demand on the grid, which helps the grid operate more efficiently and can help avoid the need for ERCOT to issue Voluntary Conservation Notices or Conservation Appeals – or at minimum, ensure that planned charging activities would happen outside the window of time identified in those ERCOT requests, so that the EV owner/operator does not have to make a last-minute change in plans to accommodate conservation requests. In addition, because the price of electricity in the ERCOT market fluctuates

[17] TXANS (ercot.com)

constantly based on demand, charging during off-peak hours can lower the cost of charging for the end-user.

The ability to charge an EV during a grid outage can be provided by technology that is integrated with individual chargers, such as energy storage and/or solar, or through technology supplying off-grid power to a network of chargers and potentially other electrical loads like buildings, such as a microgrid or larger-scale energy storage, solar or wind. Solar panels, battery storage, wind turbines, hydrogen fuel cells, electric vehicles, and generators are all examples of distributed energy resources (DERs) that can provide electricity to EV charging infrastructure and can be incorporated into a microgrid.

Technology Options

Following is a discussion of technologies that mitigate grid demand of EV charging and/or enables EV charging during a grid outage. Exhibit 8 provides a list of these technologies and indicates if the technology lessens grid demand or provides for EV charging during a grid outage or both. It should be noted that there are renewable energy versions for technologies using electricity, natural gas, propane, and hydrogen. Also, case studies are provided for some technologies as indicated in Exhibit 8 and carbon intensities from various energy sources shown in Appendix B.[18]

Exhibit 8. Technologies for Mitigating Grid Impacts and Resilient EV Charging

Technology	Lessens Grid Impact	Enables Off-Grid Charging	Case Study
Smart Charging Technology	X		X
Energy Storage System (Battery, Hydrogen)	X	X	X
Solar	X	X	X
Wind	X	X	
Generators (propane, diesel, natural gas)		X	
Mobile Charging		X	
Vehicle to Vehicle (V2V) Charging	X	X	
Microgrids	X	X	X

Smart Charging Management. Smart charging employs various strategies to improve the efficiency of EV charging. The system requires a data connection between the EV and the smart charger, and a data connection between the smart charger, the charge point operator's charging management platform and the grid. A smart charge system can optimize charging based on grid constraints, electricity prices, EV battery percentage,

[18] Life Cycle Greenhouse Gas Emissions from Electricity Generation Update | NREL

desired charge level, the vehicle's charging capacity, and by when the vehicle should be charged. Based on the settings, the system can dynamically distribute energy across multiple chargers and control when charging begins and ends throughout a period. In addition, when integrated with distributed energy resources (i.e., solar panels, wind, batteries), the system can coordinate charging with electricity generated from onsite renewable sources, further stabilizing the grid, and maximizing the use of low-carbon renewable electricity. [19,20,21]

Energy Storage Systems. Energy storage plays a pivotal role in modern energy management, offering solutions to store energy for later, therefore allowing it to be a reliable and efficient option for EV charger resilience. Two types of energy storage systems include:

> **Batteries.** Battery energy storage systems (BESS) which usually comes in the form of either lithium ion (Li-ion) batteries or lithium iron phosphate batteries (LFP), can provide energy to an EV charger during a grid outage. Besides the differences in chemical makeup, there is also a difference in power and safety. Li-ion batteries are more commonly used because they can store more energy, but they are highly flammable. LFP batteries cannot store as much power but are more difficult to ignite due to having a simpler battery thermal management system. [22] The cycle life for lithium-ion batteries used in BESS applications, the total number of charge and discharge cycles a battery can have before it fails, is between 4000 – 8000.[23] Environmental impact is an additional consideration when choosing resiliency options, and the carbon intensity of a lithium-ion battery is estimated to be about 89 kg CO_2-eq/kWh.[24] EV chargers connected to the grid that include battery storage can also save money and lessen the demand on the grid. Cost savings are realized by charging the battery when electricity prices are lower and discharging when electricity prices are higher during grid peak demand hours.[25] The Joint Office of Energy and Transportation explains that adding a BESS to store energy drawn from the grid to be discharged at a later time through a charger provides the added resiliency of a battery backup during an outage until the batteries are depleted and enables fast charging build-out where grid capacity is limited.[26] When determining the size of the BESS, consider the EV charging demand and the number of hours of

---

[19] Electric Vehicle Grid Integration | Transportation and Mobility Research | NREL
[20] Smart Charging: The Definitive Guide (2024) - AMPECO
[21] What Is Smart EV Charging? (octopusev.com)
[22] Electric Vehicle (EV) Battery Management Study
[23] Enabling renewable energy with battery energy storage systems | McKinsey
[24] Lithium-Ion Vehicle Battery Production | Swedish Energy Agency
[25] The Benefits of Energy Storage for EV Charging - EVESCO (power-sonic.com)
[26] Joint Office of Energy and Transportation

off-grid charging needed. For example, a BESS with 500 kWh of energy storage will provide up to 10 hours of charge if the average charging demand is 50 kW. EV charging demand estimates should consider the number of EVs to be charged, to what level of charge is needed (i.e., 50% charge, 80% charge) and the energy needed to charge those vehicles. (Note, the energy needed to obtain a certain level of charge will vary by vehicle). For example, a Ford F-150 Lightning Pro 4WD Extended Range has usable battery capacity of 131 kWh[27] and uses 49 kWh/100 miles.[28]

Hydrogen Fuel Cell. Hydrogen fuel cells are another energy storage option to supply electricity for EV charging. Hydrogen fuel is used for the electrochemical reaction in the fuel cell to generate electricity.[29] EV chargers powered by hydrogen fuel cells are an emerging technology, but hydrogen fuel cells for backup power and stationary power for electricity generation are currently used in microgrids and larger scale applications. Clean hydrogen, which is produced with zero to few carbon emissions, plays a critical role in these systems. Depending on the production method, the amount of carbon dioxide emitted can range from 0-27 kilograms for every kilogram of hydrogen.[30] The availability and use of hydrogen fuel is expected to increase alongside hydrogen production thanks to increased governmental funding for hydrogen-related projects, making hydrogen a more common option for powering EV chargers in the future. Currently the industrial sector is the largest producer of hydrogen, at 10 million metric tons (MMT) produced a year in the U.S., and as much as an additional commercial production of 12 MMT could come online by 2030 if hydrogen projects currently being pursued come online by that year.[31]

Solar. Solar photovoltaic (PV) is a renewable energy source which generates electricity from sunlight and is scalable based on the number of solar panels installed. A group of solar PV cells are called a solar module or panel, and a grouping of panels is called an array. The amount of energy generated depends on the amount of sunlight (solar radiation), with energy generation lessening as the sun sets. No energy is generated through moonlight and minimal to no energy is generated when there is cloud cover during the day. Depending on the atmospheric conditions of the day, solar radiation can be reduced by 10% on clear days and 100% on thick cloudy days.[32] Solar panels emit about 41 grams of

---

[27] F-150 Lightning Product Frequently Asked Questions (ford.com)
[28] How many solar panels do you need to charge an electric car? | EnergySage
[29] Fuel Cell Basics | Department of Energy
[30] Executive summary – Towards hydrogen definitions based on their emissions intensity – Analysis - IEA
[31] https://www.hydrogen.energy.gov
[32] Solar Radiation Basics | Department of Energy

CO2 equivalent emissions/kWh. Most of these lifecycle emissions are tied to the process of manufacturing the panels and are offset by clean energy production within the first three years of operation. [33] Though there are some emissions with PV, integrating EV with solar panels and the grid does reduce grid impact by obtaining part of its energy from solar, a renewable energy source and avoiding the emissions associated with conventional thermally generated electricity.

An EV charger integrated with solar PV and energy storage (usually battery) is an option for off-grid charging. While the grid is down, the EV charger can be powered by the battery and the solar panels, with the solar panels also recharging the battery.[34] There are a few EV chargers on the market that combine both solar and battery storage. Refer to the Case Studies section below for more details.

Wind. Electricity generated by wind turbines is one of the available renewable energy sources. Like solar, wind turbines provide a renewable energy source to replace grid power, and thereby reduce energy cost, grid impact, and the emissions associated with the grid. Wind turbines at the distribution level of an electricity delivery system, either connected to the part of the grid that delivers electricity from the main power lines to homes and businesses or to off-grid applications, are known as distributed wind.[35] While wind turbines are not integrated in the EV charger, but instead are located at a distance to generate electricity, incorporating them as a DER adds a renewable energy source and resiliency to EV charging. The turbines can generate electricity at any time of day so long as there is wind and depending on their size can generate anywhere from 10s of kilowatts to several megawatts (MW) of energy. The DOE Office of Scientific and Technical Information reports that the carbon intensity of wind is about 13 g CO_2e/kWh. [36] Larger scale wind turbines are more suitable for rural areas due to needing large, open spaces, and unobstructed airflow to work efficiently. Rural settings would also allow for more turbines (wind farms), providing even more energy. As with solar, integrating wind turbines with energy battery storage ensures access to electricity in times of low or no wind.

Generators. Deploying emergency generators at key EV charging locations would ensure that critical response vehicles can be charged during prolonged power outages. These generators traditionally have been powered by diesel, propane, and natural gas and are a common backup power source. Depending on their size, generators can be used in mobile charging, which is discussed in the next section. An issue with generators is they require

[33] What is the Carbon Footprint of Solar Panels? | Solar.com
[34] Solar Integration: Solar Energy and Storage Basics | Department of Energy
[35] Distributed Wind | Department of Energy
[36] Wind Vision: A New Era for Wind Power in the United States | DOE

fuel resupply in extended outages and more maintenance than battery and solar. There are advantages and disadvantages to using combustion-fueled generators. Advantages include high fuel efficiency, durability, longevity, energy, and power density; however, they also have greenhouse gas and other air pollutant emissions as well as ongoing fuel costs and maintenance needs. The upfront cost of diesel and natural gas generators is low compared to battery backup and solar. Both non-fuel annual operating cost and fuel cost of diesel and natural gas generators are higher than solar or battery. A comparison of the costs can be found in Exhibit 9 below. [37] Another item to consider is the carbon intensity of the energy source being used. Propane has a lower carbon intensity than electricity from the Texas grid. The former emits 78 grams of carbon dioxide (CO_2) equivalent per megajoule (MJ), while the latter emits 140 grams of CO_2 per MJ.[38]

Exhibit 9. Example Average Costs for Backup Power Systems

System[a]	Upfront Costs	Non-fuel Annual Operating Costs	Fuel Costs
Diesel Generators	$800/kW [3]	$35/kW [3]	$0.27/kWh[c]
Natural Gas Generators	$1,000/kW [3]	$35/kW [3]	$0.10/kWh[d]
Solar Power	$1,630 – 1,840/kW [4]	$5-6/kW [4]	$0/kWh
Battery Energy Storage System	$392 – 493/kWh[b] [5]	$4-5/kWh [5]	$0-$0.13/kWh[e]

a. Due to its niche applications, backup power fuel cell system costs are not widely reported.
b. The relevant cost metric for battery storage systems is energy (kWh) rather than power (kW).
c. Based on $4 per gallon offroad diesel price.
d. Based on $10 per thousand cubic feet commercial gas price.
e. Lower end assumes onsite solar generation and upper end based on average commercial electricity cost.

Source: Power-Resiliency-Electric-Fleets | Environmental Defense Fund p. 15

Mobile Charging. Mobile charging is an off-grid EV charging option for various situations including grid outages, inoperable chargers, stranded EVs, low power areas, and areas where EV infrastructure does not yet exist. Advantages include the ability to deploy at any location and no need for permits, electrical upgrades, or construction. Various levels of charging speeds, including fast charging, are typically available to accommodate various EV charging capacities. Also, mobile chargers can be powered by electricity generated from a variety of fuel sources, sometimes within the same mobile charger platform, adding

[37] Power-Resiliency-Electric-Fleets | Environmental Defense Fund
[38] Texas Power Outages Highlight Reliability Issue. (2024, August). *Texas Propane*, p. 24.

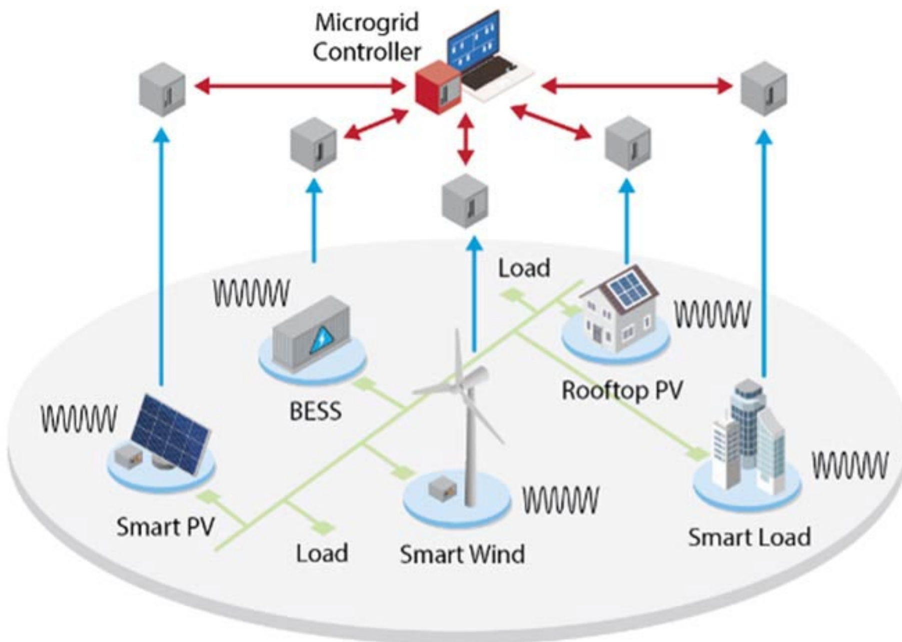
to mobile charging resiliency when some fuel supply chains may be compromised. Electricity generation can be from energy storage (battery, supercapacitors, or hydrogen fuel cell), propane, natural gas, or diesel. Some mobile charging companies offer larger scale electricity generation platforms to accommodate charging multiple vehicles and other power needs. Typically, a van, medium-duty truck or heavy-duty truck hauls the mobile charging platform to the charging site depending on the size of the platform.

Bidirectional Charging. An EV with bidirectional functionality can be thought of as mobile energy storage. Bidirectional functionality is currently available in a limited number of EVs and allows an EV to discharge energy (aka bidirectional charging) from its battery, providing alternating current (AC) power to something else like an appliance or electric drill (vehicle-to-load (V2L).[39] This is done through a V2L adapter plugged into the charge port or through a power outlet inside the vehicle.[40] An EV with V2L capability and the proper plug adapter and charging connector can charge another EV (known as vehicle-to-vehicle (V2V)). An example is a Ford F-150 Lightning which can charge another EV at level-2 (7.2 kW) charging speed. V2V charging allows vehicles to assist each other, promoting resilience and ensuring critical transport needs can be met even without a stable grid connection. Given the energy storage capacity of EV buses, which ranges from 76 kWh to 660 kWh, these vehicles could become an integral part of EV charging resiliency planning by providing V2V charging to city EV fleets.[41] Other bidirectional functionality capabilities include vehicle-to-home (V2H) and vehicle-to-grid (V2G) which are made possible with a compatible charger connected to a home or grid.

Microgrids. A microgrid is a group of interconnected DERs and electrical loads that can be controlled as one unit (Exhibit 10). It can connect and disconnect from the grid allowing it to operate either as a grid-connected element as any other facility, or isolated from the grid, also known as “island” mode.

Exhibit 10. Example Microgrid

[39] Bidirectional Charging and Electric Vehicles for Mobile Storage | Department of Energy
[40] Bidirectional Charging - A Complete Guide — Lectron EV (ev-lectron.com)
[41] Electrifying Transit: A Guidebook for Implementing Battery Electric Buses - NREL



Source: NREL Transforming Energy[42]

Microgrids are relatively small compared to the main high-voltage transmission system (macrogrid) and are located close to where its power is used, so is thought of as a form of distributed generation. A microgrid can be a completely off-grid system with its own power generation sources or can connect into the macrogrid and draw power from the macrogrid when conditions are beneficial to do so.[43] Electrical loads (e.g., buildings, EV charging, appliances, etc.) within the microgrid are not affected by grid outages as the microgrid is either already isolated off-grid or can disconnect for a certain length of time and maintain necessary operations. A microgrid provides several advantages including the opportunity to include more renewable energy sources than the macrogrid, thereby reducing emissions. Other advantages are increased power transmission efficiency since the microgrid is located close to its energy users and helping to reduce peak demand pressures on the main grid, enhancing overall energy security. [44]

The DERs in the microgrid can be a mix of dirty, clean, and renewable energy sources like diesel generators, solar PV, wind, battery storage, geothermal energy, hydrogen fuel cells, bidirectional EVs, etc., providing a variety of options to meet different goals. Microgrids that incorporate a higher proportion of renewable energy sources like solar and wind have

[42] NREL Transforming Energy
[43] Microgrids - Center for Climate and Energy SolutionsCenter for Climate and Energy Solutions (c2es.org)
[44] Empowering Tomorrow: Considerations for Resilient Electric Vehicle Infrastructure Amidst Natural Disasters | NC Clean Energy Technology Center

lower carbon intensities than those relying on fossil fuel. [45] Additionally, a case study mentioned later in the paper shows a county creating a microgrid which supplies over 6 MW for its bus depot, and another microgrid supplying just over 5 MW.

Case Studies

The following are case studies of local governments implementing EV charging resiliency efforts and planning around the increase in EVs:

City of Allen, Texas - *A Superhub Project by XCharge North America*

Once the project is complete, the Superhub will feature over 20 charging spaces with max outputs ranging from 200kW to 400kW per port with 3MWh of **battery storage** capacity. [46]

US Department of Agriculture Forest Service – *Remote Charging Station*

In 2021, the United States Department of Agriculture Forest Service deployed an off grid charging system that uses **solar and battery storage** to power an EV charger at their Wolf Creek Job Corps Conservation Center in the remote wilderness of Oregon. [47] The system is mobile and charges the center's five-vehicle fleet with 100% renewable energy. The technical specifications from the manufacturer, Beam Global, for the EV Arc 2020 charger include a 4.4 kW solar array attached as a canopy to the charger, providing up to 5.76 kW of power at a level-2 charging speed.[48] The charger battery storage options vary from 20 – 40 kWh to allow for charging at night and during power outages. For comparison, it is estimated a level-2 charger with 5.76 kW of power will fully charge a Chevrolet Bolt in about 10.5 hours. [49]

City of Phoenix, Arizona – *Transportation Electrification Action Plan*

In 2022, the City of Phoenix put together a committee as outlined in their Climate Action Plan, to create the Transportation Electrification Action Plan. The plan was to facilitate the transition to EVs for the city, businesses, and public. As of 2022 the city had 13 EVs in its light-duty fleet and plans to transition 200 gas powered LDVs over to EVs in the next eight years. To accommodate these new vehicles, they plan to install 100 or more fleet charging ports at city facilities by 2030. The charging resiliency efforts Phoenix is implementing are managed charging and fleet use guidelines that reduce utility expenses and demand charges during peak times, while taking advantage of **energy storage and microgrids**.

---

[45] Emissions – Global Energy & CO2 Status Report 2019 – Analysis - IEA
[46] Texas trailblazes with DC fast chargers with integrated battery storage (electrek.co)
[47] United States Forest Service Leverages EV Charging Solution for Remote Areas | Department of Energy
[48] Beam Global EV ARC™ Questions Answered to Drive on Sunshine | Beam Global (beamforall.com)
[49] Time-to-Charge-Chart-Clipper-Creek.pdf (energywisemnstore.com)

Third-party systems will also be explored to help lower costs and mitigate risk. [50] While this case study does focus more on the overall preparation for the increase in EVs and EV charging infrastructure in their city, it does present the case that planning holistically for the integration of EVs into city services does require more than just resiliency. It requires planning, time, and buy-in from a variety of stakeholders living in and working within a city.

Montgomery County, Maryland – *Brookville Smart Bus Depot and Equipment Maintenance & Transit Operation Center (EMTOC)*

Through a public-private partnership, Montgomery County created a 6.4 MW **microgrid** for their county owned EV buses at their bus depot in 2022. [51] The EV charging management system helps staff optimize when to charge, produce, and store energy. The depot can support the charging of 70 EV buses through this microgrid. The county then broke ground on another microgrid in June 2024, designed to run indefinitely without being connected to the grid. The new microgrid will come with 5.5 MW of **solar generation**, 2 MW of **battery storage**, and have a 1 MW **hydrogen electrolyzer** powered by the on-site renewable energy of the microgrid.[52] The depot will power a mix of 200 EV and hydrogen fuel cell electric buses (FCEB), and open in Fall 2025.

Challenges and Considerations

Fleets across Texas are at varying stages of EV adoption. Regardless of status, it is important for fleet and facility managers to begin the planning for resilient EV charging now. While this may be challenging, especially in convincing city and agency planners across North Texas and at the state level, the importance of starting this planning process cannot be overstated.

There is a lack of centralized systems, online data, and maps showing information like resiliency features of EV chargers currently in operation. Currently, there is a time lag in online access to the operational status of existing EV chargers as well as the inclusion of new EV chargers. Also, current data for EV chargers do not include information on any resiliency technologies integrated, like previously stated, into the charger or the available capacity of that technology such as battery backup or generator or fuel cell. The focus here is not just on real-time operational status but on integrating resilience features into applications that display this status. This integration would allow planners to assess current charger resilience and identify where additional investments are needed. To achieve this, all EV chargers must transmit real-time operational data to a centralized regional database. This visibility is crucial for local governments and emergency personnel

[50] Transportation Electrification Action Plan | City of Phoenix
[51] Brookville Smart Energy Bus Depot | AlphaStruxure USA
[52] EMTOC Bus Depot, Montgomery County, MD | AlphaStruxure USA

to coordinate EV charging during grid outages, especially for vehicles involved in critical operations.

One of the challenges in creating resiliency in the charging infrastructure is the lack of risk assessment cities have done to convey the need for these upgrades. As mentioned earlier, there will be an increase in severe weather events in Texas that will impact the grid's reliability. Some cities have taken efforts to address these concerns through climate action plans, like the City of Dallas, where they will be working with the North Texas Renewable Energy Group (NTREG) to evaluate the potential of energy storage and solar-powered microgrids. [53] Local governments should include EV charger resiliency in future planning documents to address strategic location of resilient EV chargers, how many will be needed and the types of resiliency technology that will be integrated with the charger. Including EV charging resiliency in climate action plans, zoning codes, comprehensive plans, etc., will save time and money and ensure the continuity of critical operations as fleets continue to electrify.

Smaller municipalities with a lack of dedicated staff or without the time, experience, and funding are not likely to prioritize EV charger planning. To ensure continuity of critical operations at the regional level, assistance for these communities in the form of funding and expertise is needed. Leveraging public-private partnerships may help mitigate this issue.

Closing Statement

In conclusion, the need for resilient EV charging infrastructure is critical given Texas' vulnerable electric grid. The increasing demand for power due to weather events, population growth, economic expansion, and the rise of transportation electrification underscores the importance for planning to begin for continuity of operations for EVs assigned to critical operations and to lessen the impact of EV charging on the grid.

It is vital for local governments and fleets to recognize the need for resilience EV charging infrastructure planning to begin now. For planning efforts to be successful, local governments and fleets across the region need to understand the importance of planning and be knowledgeable of resilient EV charging technologies and learn about relevant options. This paper is intended to serve as a resource for local governments and fleets on grid-friendly charging best practices and resilient EV charging technologies. NCTCOG along with regional stakeholders will be taking steps to create a regional plan for resilient EV charging with the aim to ensure that EVs used in critical operations can charge reliably even during grid outages.

[53] Energy | Dallas Climate Action Plan

To begin this planning, EV owners should:

- Reach out to their peers who have successfully implemented resilient charging infrastructure
- Learn about the resilient technologies available
- Become familiar with the times that the grid is most constrained and take measures to avoid adding EV load during those hours
- Consider the technologies addressed in this whitepaper when planning procurements of EVs and EV infrastructure

At regional and state-level, collaboration across agencies/organizations is needed to solve the need for real-time data on both EV chargers' status and level of resiliency and capacity to inform emergency operations planning and real-time decision making by emergency personnel and fleets. This visibility will also help identify where additional investments are needed to increase the resilience of the charging network.

Finally, funding is needed to assist local governments in education, risk assessments, and planning efforts specific to resilient EV charging. Also, funding is needed for the upgrade of existing EV charging infrastructure and the training for and implementation of new technologies necessary to mitigate impacts to the grid and to achieve continuity of operations during grid outages.

This whitepaper was developed by NCTCOG staff; the closing statement was developed with the assistance of AI.

References

1. Environmental Protection Agency. (n.d.) *CO_2e* https://www3.epa.gov/carbon-footprint-calculator/tool/definitions/co2e.html

2. Alternative Fuels Data Center. *Regional Clean Hydrogen Hubs*. (n.d.). https://afdc.energy.gov/laws/13033#:~:text=Clean%20hydrogen%20is%20defined%20as,per%20kilogram%20of%20hydrogen%20produced.

3. Texas Legislature. (2023, June 14). *Bill Analysis: S.B. 1929*. Texas Legislature Online. https://capitol.texas.gov/tlodocs/88R/analysis/html/SB01929F.htm

4. Electric Reliability Council of Texas. (2024, July) *Load Forecast*. https://www.ercot.com/gridinfo/load/forecast

5. US Census Bureau. (2023, March 30). *Texas Joins California as State with 30-Million-Plus Population*. Census.gov. https://www.census.gov/library/stories/2023/03/texas-population-passes-the-30-millionmark-in-2022.html
6. *Texas Economic Snapshot*. (n.d.). https://gov.texas.gov/business/page/texas-economic-snapshot

7. Electric Reliability Council of Texas. (2024). *2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast Mid-Year Update*. https://www.ercot.com/files/docs/2024/01/18/2024_LTLF_Report.docx, pg. 4

8. Electric Reliability Council of Texas. (2024). *2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast Mid-Year Update*. https://www.ercot.com/files/docs/2024/01/18/2024_LTLF_Report.docx pg. 11, 14

9. Dallas-Fort Worth Clean Cities Coalition. (2024, September) *EVs in Texas*. https://www.dfwcleancities.org/evsintexas

10. Electric Reliability Council of Texas. (2024). *2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast Mid-Year Update*. https://www.ercot.com/files/docs/2024/01/18/2024_LTLF_Report.docx, pg. 15

11. Electric Reliability Council of Texas. (2024). *2024 ERCOT System Planning Long-Term Hourly Peak Demand and Energy Forecast Mid-Year Update*. https://www.ercot.com/files/docs/2024/01/18/2024_LTLF_Report.docx, pg. 2

12. Climate Central. (2024, April 23). Weather-related Power Outages Rising. https://www.climatecentral.org/climate-matters/weather-related-power outages rising

13. Payless Power. (n.d.). *Blackout Tracker*. https://paylesspower.com/blog/blackout-tracker/

14. Electric Reliability Council of Texas. (n.d.). *TXANS: Texas Advisory and Notification System*. https://www.ercot.com/txans

15. Bedrich, K., & Bridges, R. (2024, June 3). *Understanding ERCOT Conservation Alerts*. Electricity Plans. https://electricityplans.com/ercot-emergency-conservation-alerts/

16. Electric Reliability Council of Texas. (n.d.). *Resource Adequacy*. https://www.ercot.com/gridinfo/resource

17. Electric Reliability Council of Texas. (n.d.). *TXANS: Texas Advisory and Notification System*. https://www.ercot.com/txans

18. National Renewable Energy Laboratory. (2021). *Life Cycle Greenhouse Gas Emissions: Update*. https://www.nrel.gov/docs/fy21osti/80580.pdf

19. National Renewable Energy Laboratory. (n.d.). Electric Vehicle Grid Integration.https://www.nrel.gov/transportation/project-ev-grid-integration.html

20. AMPECO. (2024). *Smart Charging: All you need to know*. https://www.ampeco.com/guides/smart-charging/

21. Octopus EV. (2024, April 23). *What is smart EV charging and how does it work?* https://octopusev.com/ev-hub/what-is-smart-ev-charging

22. Peak Sustainability Group, Roberts, D., Clark, J., Erikson, V., Sacker, N., Stikeen Strategies, Jantz, J., GDS Consulting, Duckwall, J., Williams, T., Gschwend, A., & Smith, M. (2023). *Electric Vehicle (EV) Battery Management Study Preliminary Report*. Solid Waste Management Program. Washington State Department of Ecology. https://apps.ecology.wa.gov/publications/documents/2307040.pdf

23. Jarbratt, G., Jautelat, S., Linder, M., Sparre, E., Van De Rijt, A., & Wong, Q. H. (2023, August 2). *Enabling renewable energy with battery energy storage systems*. McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/enabling-renewable-energy-with-battery-energy-storage-systems

24. Emilsson, E., & Dahllöf, L. (2019). *Lithium-Ion Vehicle Battery Production - Status 2019 on Energy Use, CO2 Emissions, Use of Metals, Products Environmental Footprint, and Recycling*. https://www.ivl.se/english/ivl/publications/publications/lithium-ion-vehicle-battery-production----status-2019-on-energy-use-co2-emissions-use-of-metals-products-environmental-footprint-and-recycling.html

25. Spendiff-Smith, M. (2023, July 20). *The benefits of battery energy storage for EV charging*. Power Sonic. https://www.power-sonic.com/blog/the-benefits-of-battery-energy-storage-for-ev-charging/

26. Joint Office of Energy and Transportation. (2024, June). *Battery Energy Storage for Electric Vehicle Charging Stations*. https://driveelectric.gov/files/battery-buffered-help-sheet.pdf

27. Ford Motor Company. (n.d.). *F-150 Lightning General Product Information*. https://www.ford.com/support/how-tos/electric-vehicles/f-150-lightning/f-150-lightning-product-frequently-asked-questions/#Towing

28. Fields S., McDevitt C. (2024, February 28). *How many solar panels do you need to charge an electric car?* Energy Sage. https://www.energysage.com/ev-charging/how-many-panels-do-you-need-for-your-ev/

29. U.S. Department of Energy (n.d.) *Fuel Cell Basics*. https://www.energy.gov/eere/fuelcells/fuel-cell-basics

30. IEA (2023*), Towards hydrogen definitions based on their emissions intensity*. IEA, Paris. https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity/executive-summary

31. U.S. Department of Energy. (n.d.). *U.S. National Clean Hydrogen Strategy and Roadmap*.https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf

32. U.S. Department of Energy. (n.d.). *Solar Radiation Basics*. Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/solar/solar-radiation-basics

33. Wigness, S., (2023, August 31). *What is the Carbon Footprint of Solar Panels?* Solar.com. https://www.solar.com/learn/what-is-the-carbon-footprint-of-solar-panels/

34. U.S. Department of Energy. (n.d.). *Solar Integration: Solar Energy and Storage Basics*. Solar Energy Technologies Office. https://www.energy.gov/eere/solar/solar-integration-solar-energy-and-storage-basics

35. U.S. Department of Energy. (n.d.). *Distributed Wind*. Wind Energy Technologies Office https://www.energy.gov/eere/wind/distributed-wind

36. U.S. Department of Energy. *Wind Vision: A New Era for Wind Power in the United States*. United States. https://www.osti.gov/biblio/1220428/

37. Di Filippo, J., & Wilkins D., (2024 April). *Power Resiliency for Electric Fleets*. Environmental Defense Fund. https://www.edf.org/sites/default/files/2024-04/Power-Resiliency-Electric-Fleets.pdf

38. Texas Power Outages Highlight Reliability Issue. (2024, August). *Texas Propane*, p. 24.

39. U.S. Department of Energy. (n.d.). *Bidirectional Charging and Electric Vehicles for Mobile Storage.* Federal Energy Management. https://www.energy.gov/femp/bidirectional-charging-and-electric-vehicles- mobile-storage

40. Manansala, J., (2024 February 7). *Bidirectional Charging a Complete Guide*. EV-Lectron. https://ev-lectron.com/blogs/blog/bidirectional-charging-complete-guide

41. Aamodt, A., Coney, K., & Cory, K., (2021 April). *Electrifying Transit: A Guidebook for Implementing Battery Electric Buses.* National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy21osti/76932.pdf

42. Nothing to Fear for High-Renewable Systems: *NREL Shows Scalable, Resilient, and Secure Systems With Communication-Less Controls*. (2021 October 26). https://www.nrel.gov/news/program/2021/nothing-to-fear-for-high-renewable-systems-nrel-shows-scalable-resilient-and-secure-systems-with-communication-less-controls.html

43. Center for Climate and Energy Solutions. (2023, July 25). *Microgrids*. https://www.c2es.org/content/microgrids/

44. NC Clean Energy Technology Center. (2023 December 18). *Empowering Tomorrow: Considerations for Resilient Electric Vehicle Infrastructure Amidst Natural Disasters*. https://nccleantech.ncsu.edu/2023/12/18/resilient-electric-vehicle-infrastructure-amidst-natural-disasters/

45. IEA (2019), *Global Energy & CO2 Status Report 2019*. IEA, Paris. https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions

46. Lewis, M., (2024 February 12). *Texas trailblazes with DC fast chargers with integrated battery storage.* Electrek. https://electrek.co/2024/02/12/texas-dc-fast-chargers-integrated-battery-storage-xcharge-north-ameri/

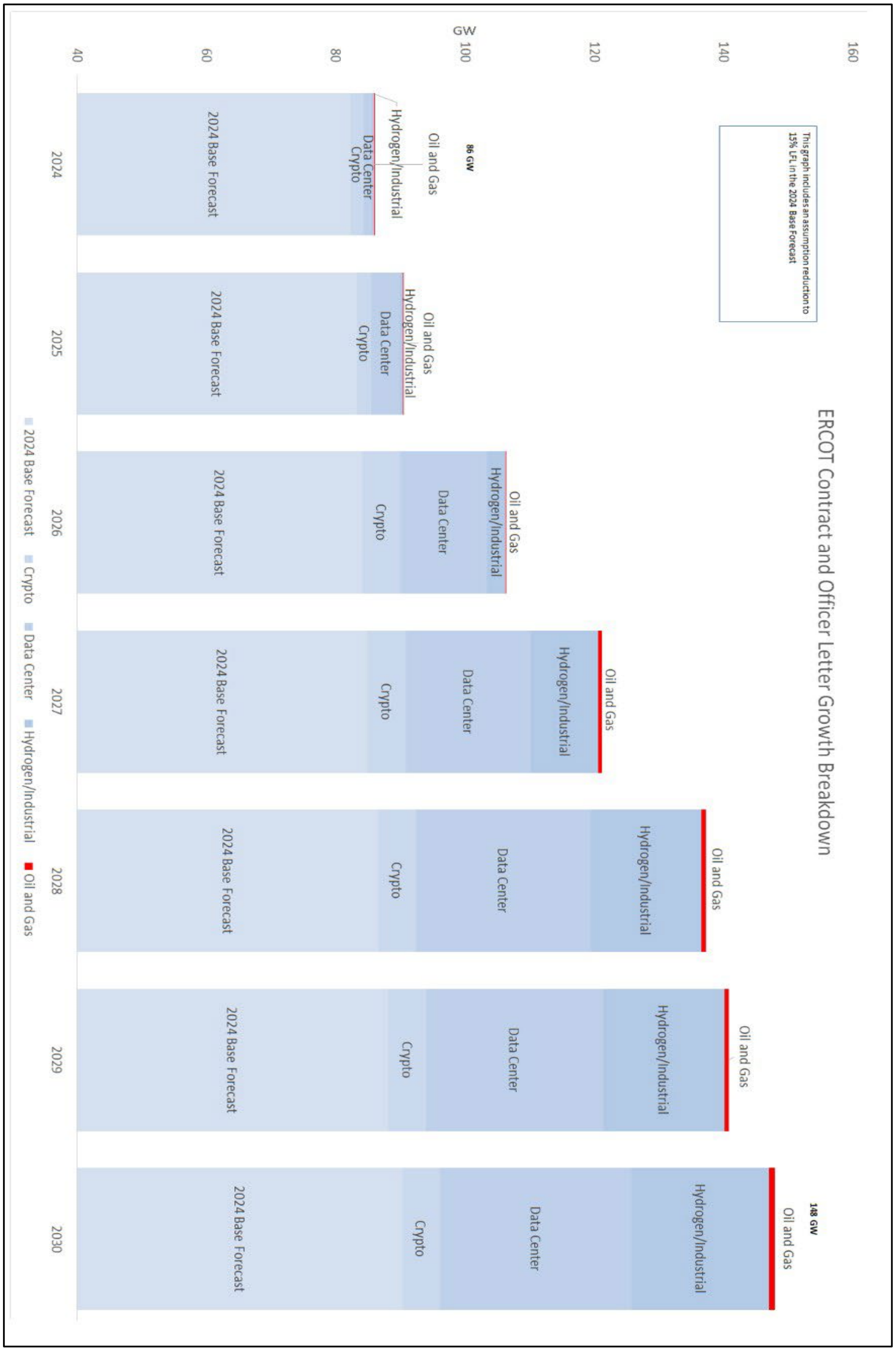
47. U.S. DOE Federal Energy Management Program (n.d.). *United States Forest Service Leverages EV Charging Solution for Remote Areas.* https://www.energy.gov/femp/united-states-forest-service-leverages-ev-charging-solution-remote-areas

48. Beam Global. (2024). *Top Tips to Drive on Sunshine.* https://beamforall.com/ev-arc-user-top-tips/

49. ClipperCreek. (2019). *Estimated Charge Times Chart for (Pure) Electric Vehicles.* https://energywisemnstore.com/content/Time-to-Charge-Chart-Clipper-Creek.pdf

50. City of Phoenix (n.d.). Transportation Electrification Action Plan. https://www.phoenix.gov/sustainabilitysite/MediaAssets/sustainability/electric-vehicles/Draft%20Transportation%20Electrification%20Action%20Plan.pdf pg. 39
51. AlphaStruxure. (2022, June 2). *CASE STUDY: Montgomery County Drives the Future of Sustainable, Resilient Mass Transit*. https://alphastruxure.com/case-studies/montgomery_county_brookville_bus_depot/
52. AlphaStruxure. (2023, September 12). *Introducing the country's largest renewable energy-powered transit depot*. https://alphastruxure.com/case-studies/emtoc/
53. City of Dallas (2020, May). *Dallas Comprehensive Environmental and Climate Action Plan*. https://www.dallasclimateaction.com/energym pg. 75, 78

Appendix A



Source: [Load Forecast (ercot.com)]

Appendix B

Median Published Life Cycle Emissions Factors (Carbon Intensity) for Electricity Generation Technologies, by Life Cycle Phase

Category	Generation Technology	One-Time Upstream	Ongoing Combustion	Ongoing Non Combustion	One-Time Downstream	Total Life Cycle	Sources
Renewable	Biomass	NR	—	NR	NR	52	EPRI 2013 Renewable Electricity Futures Study 2012
Renewable	Photovoltaic[a]	~28	—	~10	~5	43	Kim et al. 2012 Hsu et al. 2012 NREL 2012
Renewable	Concentrating Solar Power[b]	20	—	10	0.53	28	Burkhardt et al. 2012
Renewable	Geothermal	15	—	6.9	0.12	37	Eberle et al. 2017
Renewable	Hydropower	6.2	—	1.9	0.004	21	DOE 2016
Renewable	Ocean	NR	—	NR	NR	8	IPCC 2011
Renewable	Wind[c]	12	—	0.74	0.34	13	DOE 2015
Storage	Pumped-storage hydropower	3.0	—	1.8	0.07	7.4	DOE 2016
Storage	Lithium-ion battery	32	—	NR	3.4	33	Nicholson et al. 2021
Storage	Hydrogen fuel cell	27	—	2.5	1.9	38	Khan et al. 2005
Nonrenewable	Nuclear[d]	2.0	—	12	0.7	13	Warner and Heath 2012
Nonrenewable	Natural gas	0.8	389	71	0.02	486	O'Donoughue et al. 2013
Nonrenewable	Oil	NR	NR	NR	NR	840	IPCC 2011
Nonrenewable	Coal	<5	1010	10	<5	1001	Whitaker et al. 2012

Notes for Table 1

All values are in grams of carbon dioxide equivalent per kilowatt-hour (g CO_2e/kWh)

[a] Thin film and crystalline silicon

[b] Tower and trough

[c] Land-based and offshore

[d] Light-water reactor (including pressurized water and boiling water) only

NR = Not Reported.

Funding for this fact sheet was provided by the Joint Institute for Strategic Energy Analysis in support of its Energy and Atmospheric Systems Catalyzer, a collaborative effort that explores the multidirectional relationships across climate, air quality, and energy systems.

See Also

General information about life cycle assessments: "Life Cycle Assessment Harmonization," NREL, https://www.nrel.gov/analysis/life-cycle-assessment.html

Data visualization and data downloads: "LCA Harmonization," OpenEI, https://openei.org/apps/LCA/

Additional distributional statistics and subtechnology emissions factors augmenting Table 1: https://data.nrel.gov/submissions/171

Source: Life Cycle Greenhouse Gas Emissions from Electricity Generation Update | NREL p. 3