Electric vehicle charging and extreme heat

California's Fourth Climate Change Assessment predicts that the Sacramento Valley region is expected to see an average daily temperature maximum increase of 10 degrees Fahrenheit by the end of the century, with temperatures that resemble those of Phoenix today.[1] According to Cal-Adapt, by mid-century, there will be an average of 28 days over 103°F per year, and by the end of the century, 45 days over 103°F, compared to six historically. Heat waves are projected to increase in frequency as well as duration from 2 days long historically to 7.5 days by mid-century to nearly 12 days by the end of the century.[2]

This current and projected increase in average temperatures will impact electric vehicle (EV) range and long-term vehicle battery health. It is widely known that under cold temperatures, lithium-ion batteries will lose capacity more rapidly. However, extreme heat results in long-term battery degradation that will reduce overall battery lifespan.[3]

Higher temperatures can impact short- and long-term EV range and battery health in the following ways:

- Slower charging speeds: Battery charging will be slower in the heat
- More energy required for charging: The thermal management system will consume more energy to keep the battery cool during the charging process
- Higher internal cabin temperatures will require more air-conditioning as well as battery thermal management when the vehicle is in use, which will consume energy and thus range
- Increased internal resistance, which measures the amount of voltage and current available from a battery. The higher the resistance, the lower the voltage and current available for use, and the more the battery heats up.
- Decreased long-term battery capacity, which measures the amount of charge the battery holds.

As the Capital Region and California aim for higher levels of vehicle electrification, it will be important to consider how EVs will be vulnerable to extreme heat and how they can be made more resilient. Designing public charging stations to incorporate passive cooling elements can help to protect EV batteries as they charge. Electrification is not just a risk, however: zero-emissions vehicles (ZEVs), especially when deployed at scale, can also help to reduce extreme heat, by reducing waste heat exhaust and thus reducing the urban heat island effect, which is discussed further in the UHI technical analysis report.

Extreme heat and electric range

Higher ambient temperatures can degrade battery performance and increase thermal management requirements. Lithium batteries charge more slowly in the heat, lengthening vehicle recharge times. Under hotter temperatures, the battery's thermal management system works harder to cool battery temperatures to prevent overheating. This consumes energy and thus depletes range, even when the

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[1] California's Fourth Climate Change Assessment: Sacramento Valley Region Report. https://www.energy.ca.gov/sites/default/files/2019-07/Reg%20Report-%20SUM-CCCA4-2018-002%20%20SacramentoValley.pdf

[2] https://cal-adapt.org/

[3] Reddy, T., Ed. Linden's Handbook of Batteries, 4th ed.; McGraw-Hill: New York, New York, USA, 2011; p1200.

vehicle is parked. EVs are also susceptible to energy loss from use of ancillary passenger comfort devices such as air conditioning, which is generally the second-largest power consumer in many vehicles.[4]

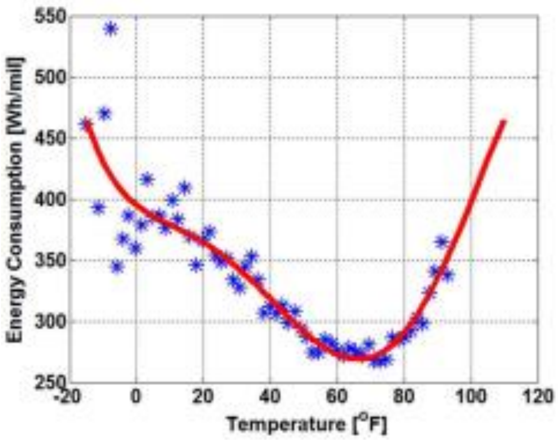

Figure 1. Nissan Leaf energy consumption per mile versus air temperature, using FleetCarma data. Source: [Yuksel and Michalek.]

One study modeling EV performance at a range of times of day found that EVs had the lowest range at noon compared to other times due to greater heat.[5] Furthermore, real-world driving data from vehicle charging company FleetCarma on 7,000 Nissan Leaf trip shows that energy consumption per mile climbs steeply when outside temperatures are 80°F or higher (***Figure 1***). Similarly, FleetCarma data for over 4,000 Chevrolet Volt trips and 7,300 Nissan Leaf trip show that available range peaks at about 65-70 degrees Fahrenheit and starts to decline thereafter (***Figure 3***)[6]. As this is based on real-world trip data, these range and energy consumption values account for the combined impact of cabin climate cooling, battery thermal management, and battery capacity drainage.

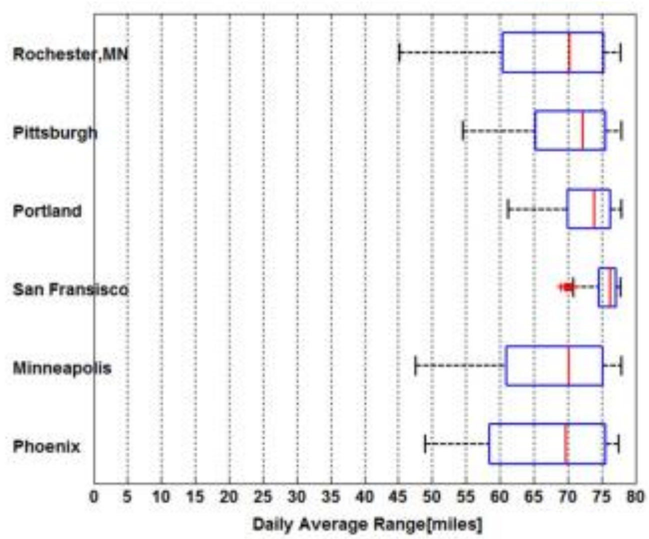

Figure 2. Distribution of driving range for Nissan Leaf cars in various US cities. Source: [*Yuksel and Michalek*].

Applying real-world driving data to average temperatures in US cities based on 1976-2005 weather data, another study found large swings in EV range for cities with greater extremes of temperature. For a mild-climate city like San Francisco, the first-generation Nissan Leaf (73-85 mile range) had a driving range over 70 miles 99 percent of the time, while in Phoenix driving range decreased by as much as 29 percent, to 49 miles.[7] The study notes that the real decrease may be even worse, as Phoenix's hottest days exceeded the maximum of 110°F used in their calculations. The results of the daily average range analysis (***Figure 2***) shows that San Francisco, with its mild Mediterranean climate, has the highest mean EV range among all studied cities. Notably, San Francisco EVs also experience the least variation in available range, which means greater predictability and confidence for drivers. By contrast, in Phoenix, where temperatures routinely eclipse 100°F in the summer months, the variation in electric range is almost as great as it is in

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[4] Johnson, V. H. Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach; SAE Technical Paper 2002-01- 1957; SAE International: Warrendale, PA, 2002; DOI 10.4271/2002-01-1957.

[5] Kambly, K.; Bradley, T. H. Geographical and temporal differences in electric vehicle range due to cabin conditioning energy consumption. J. Power Sources 2014, DOI: 10.1016/j.jpowsour.2014.10.142

[6] https://www.greencarreports.com/news/1089160_nissan-leaf-chevy-volt-range-loss-in-winter-new-data-from-canada

[7] Yuksel and Michalek. https://www.cmu.edu/me/ddl/publications/2015-EST-Yuksel-Michalek-EV-Weather.pdf

cold-climate cities like Minneapolis, and greater than in Pittsburgh. As Sacramento is predicted to become increasingly warmer, with future summer extremes expected to be similar to present-day conditions in Phoenix, this may become a growing concern for EVs in the region.

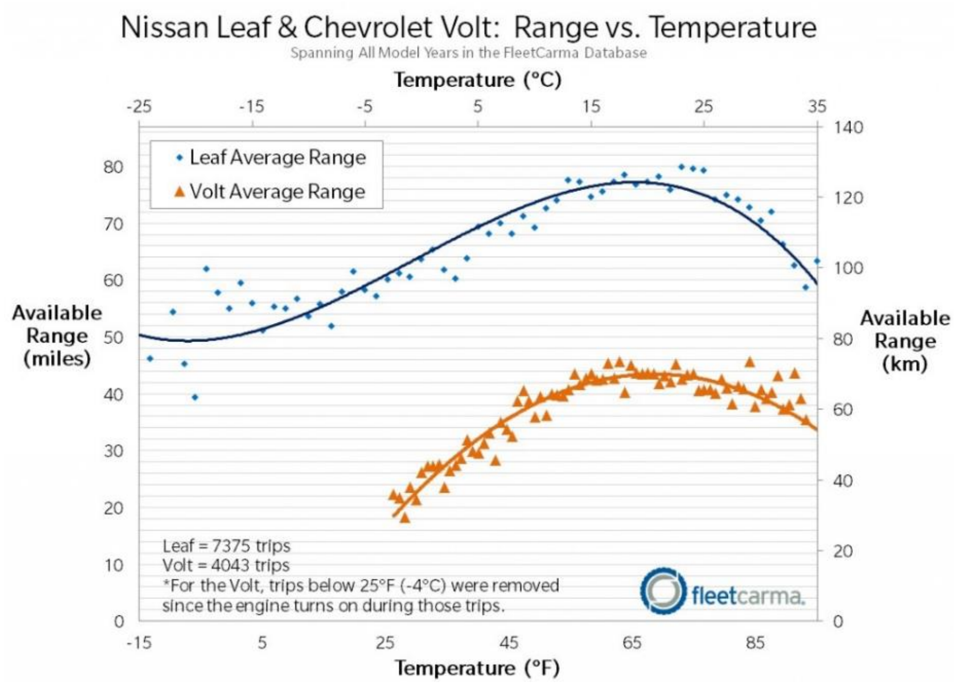

Figure 3. Chevrolet Volt and Nissan Leaf range and temperature, based on FleetCarma data.

Extreme heat and long-term battery health

The impact of extreme heat on long-term battery health is even more significant. To further investigate the relationship between temperatures and battery capacity, the National Renewable Energy Laboratory (NREL)'s Battery Lifetime Analysis and Simulation Tool for Vehicles (BLAST-V Lite) was used to assess EV battery health over a range of driving patterns, distances, and climates across US cities.[8] This tool compares the effects of climate, driving, and battery thermal management on internal battery temperatures and overall battery life, with ambient temperatures and solar irradiation data across one year (365 days) derived from NREL's Typical Meteorological Year data, based on 1961-1990 and 1991-2005 historical data. For this analysis, BLAST-V Lite was used to simulate an EV with a 200-mile range, operating in Phoenix and Sacramento, keeping charging patterns and access constant.

The results (***Figure*** 4) show that for a modeled EV in Phoenix – where the annual average daily temperature is 74.8°F and the annual maximum 111.9°F – battery temperatures averaged 76.9 °F across the year and peaked at 113.3°F. From the period of May through September, when daily temperatures averaged 92°F, the EV battery temperature continued to trend closely with the ambient temperatures, averaging 93.9°F.

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[8] https://www.nrel.gov/transportation/blast.html

By comparison, for the same EV in Sacramento – with an average daily temperature of 60°F and a maximum of 104°F – the battery had an average temperature of 63.7°F, nearly 20 percent cooler than in Phoenix, and a maximum of 99.9°F. From May through September, Sacramento's average temperature was 71.7°F and the average battery temperature was 76.1°F, as much as 23 percent cooler than in Phoenix. This suggests that hotter summers in particular can be linked to higher battery temperatures, and providing cooling measures during this period can be helpful for long-term battery health.

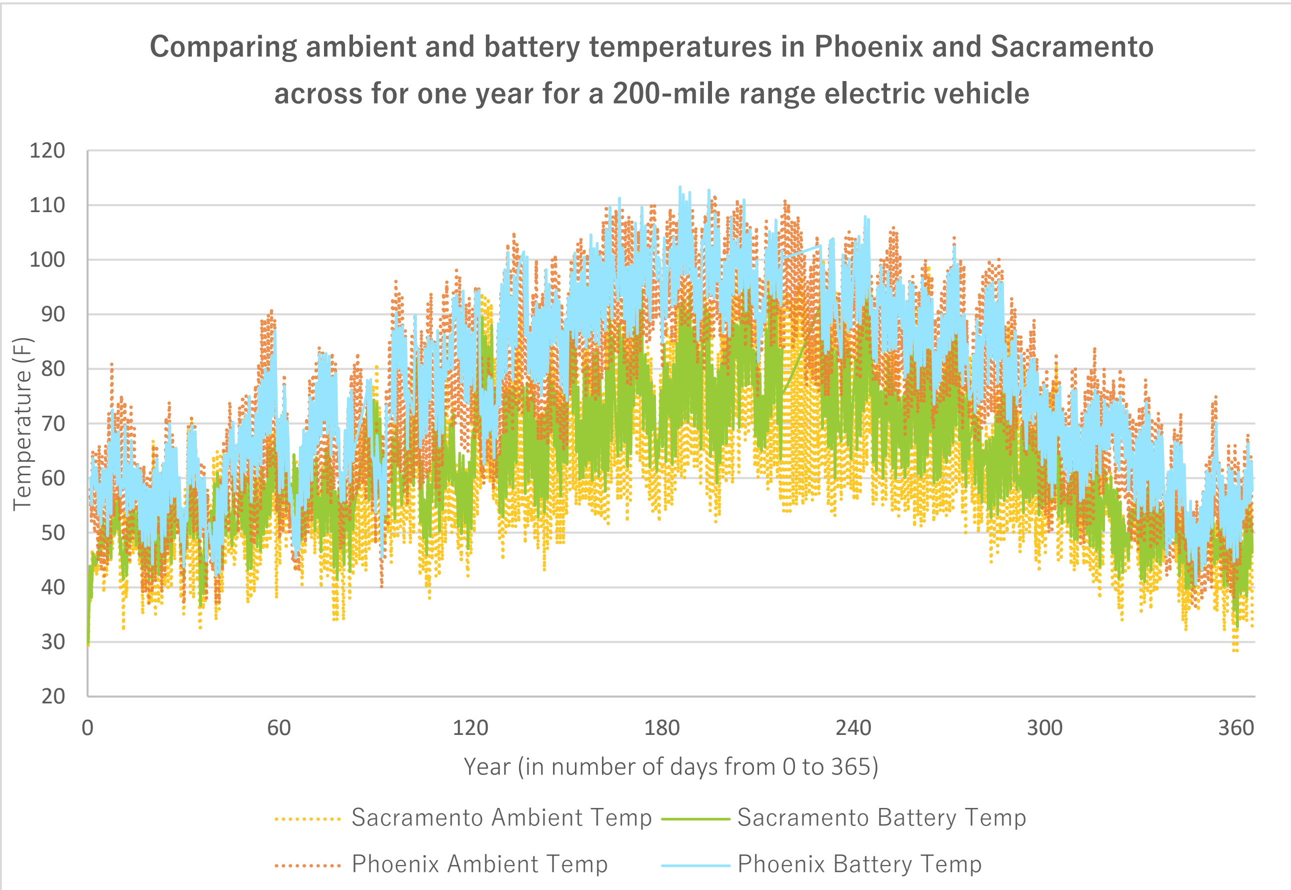

Figure 4. Results from BLAST-V Lite comparing for Sacramento and Phoenix ambient temperature and battery temperature for a 200-mile range ZEV with identical driving and charging patterns over one year (365 days).

In the long term, continued exposure to high temperatures can lead to increases in battery resistance and declines in battery capacity. Battery resistance is often used as an indicator of overall battery health; as resistance increases over time, voltage and current decrease as well. For a 200-mile-range EV driving 11,539 miles annually (the US average is 13,476 miles[9]), the Phoenix EV experienced accelerated rates of battery cell resistance growth, 1.6 to 1.7 times more than the same vehicle in Sacramento (***Figure 6***). By year 5, battery cell resistance increased about 11 percent in Sacramento, compared to 20 percent in Phoenix. By year 10, cell resistance has increased 29 percent in Phoenix, compared to 17 percent in Sacramento. As all other factors – driving distance and recharging cycles – are identical across the two cities, this difference can be assumed to be due to the greater temperatures in Phoenix.

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[9] https://www.fhwa.dot.gov/ohim/onh00/bar8.htm

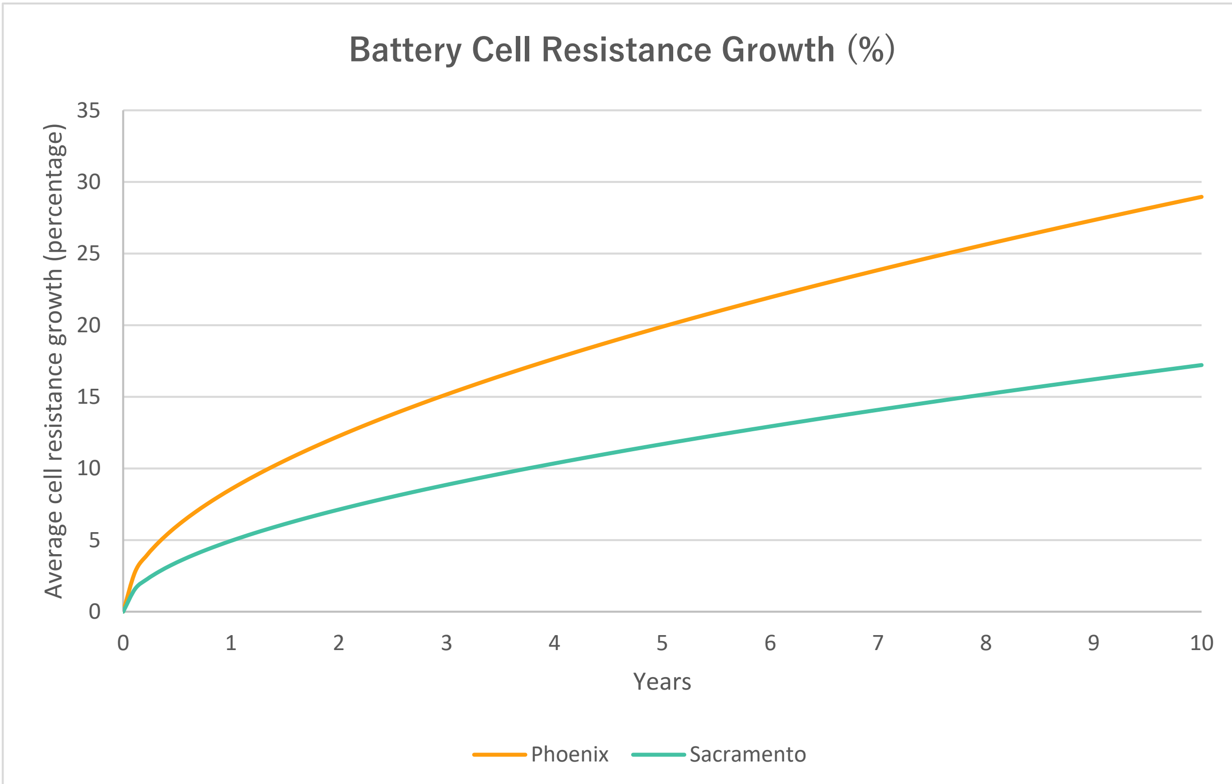

Figure 6. *Battery cell resistance growth over 10 years for a 200-mile EV with identical driving and recharging cycles in Sacramento and Phoenix. Modeled from NREL's BLAST-V Lite tool.*

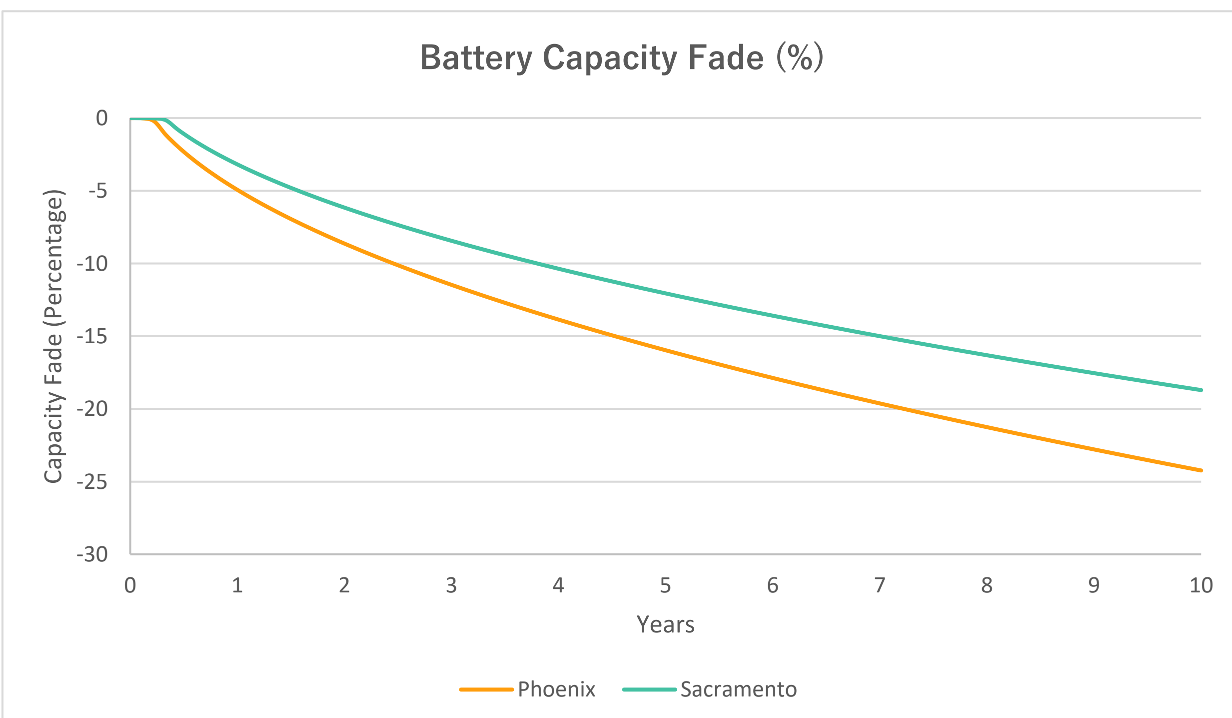

Figure 5. *Average battery cell capacity fade over 10 years for a 200-mile EV with identical driving and charging cycles in Phoenix and Sacramento. Modeled from NREL's BLAST-V Lite tool.*

Similarly, the modeled EV in Phoenix also experiences a much steeper decline in battery capacity, a critical indicator of battery health. Decreased battery capacity results in decreased available driving range. For the Sacramento EV, battery capacity declines about 3.2 percent the first year, around 2 percent the second and third years, and then between 1 to 2 percent each year for years four through ten. For the Phoenix EV, the initial decline in battery capacity is steeper, at about 5 percent the first year, 3.7 percent the second year, and the rate of decline remains higher than in Sacramento for subsequent years. Overall, battery capacity decline is 1.3 times faster in Phoenix than in Sacramento. At the end of ten years, the Sacramento EV battery has lost about 18 percent in capacity, compared to 24 percent for the Phoenix EV.

These modeling results are corroborated by real-world evidence: Nissan Leaf drivers in Arizona and Dallas have reported experiencing faster-than-predicted battery capacity loss for their new EVs, with some drivers experiencing significant decline in as little as after 9 months of purchase.[10] Specifically, EV drivers in Arizona and Texas reported at least a 15 percent loss in battery capacity after one year of car ownership. The article notes the link between charging in hotter environments and battery health, observing that "with all of the cases we're aware of taking place in warmer climates, it does underscore the crucial importance of knowing how and when to recharge your electric car, not to mention the effect that charging a Nissan Leaf in hot conditions can have on its battery."

These modeled results suggest that as Sacramento faces increasingly warmer temperatures and more heat waves, EVs in the region are also likely to face related impacts on battery resistance and capacity. Incorporating cooling strategies in EV charging station design can be particularly important to protect battery health during vehicle recharging, while implementing the UHI mitigation measures in this project can help to offset local temperature increases. EVs can in turn help to reduce the urban heat island.

EVs and urban heat

Traditional internal combustion engine vehicles lose 58 to 62 percent of the energy contained in gasoline as waste heat, which is then radiated as exhaust heat into the surrounding environment.[11] This waste heat contributes to the urban heat island effect, which is further amplified by low-albedo highway and roadway surfaces. In contrast, ZEVs, including both EVs and hydrogen vehicles, are far more efficient, with very little energy lost as waste heat.[12] One study found that EVs emit only 20% of the total waste heat emitted by conventional vehicles, and predicted that a total conversion of all cars to electric models could lower summer urban temperatures by 1.7 F for the modeled city of Beijing. [13] This would in turn save 14.4 million kilowatt-hours from reduced air-conditioning usage. As this study assumed that the average Beijing EV refuels using electricity generated by coal-fired power plants, the temperature cooling benefit could potentially be even greater for the Sacramento region, where electricity is cleaner. Cooling impacts may also be more significant in areas with high-mileage commuters.

Thus, transitioning the region's fleet to ZEVs can help to reduce the urban heat island effect as well as mitigating GHG emissions and air pollution. Sample results from this study show, in one modeled

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[10] Green Car Reports: https://www.greencarreports.com/news/1077107_more-nissan-leaf-battery-loss-nissan-doesnt-blink

[11] Department of Energy: https://www.fueleconomy.gov/feg/atv.shtml

[12] Department of Energy: https://www.fueleconomy.gov/feg/atv-ev.shtml

[13] Li C., Cao Y., et al. https://www.nature.com/articles/srep09213

scenario, that 30 percent vehicle electrification in central Sacramento can cool roadway surface temperatures by up to 4.3°F and surrounding air temperatures by up to 3°F at 5pm.[14] This is a significant cooling benefit, especially for maintaining road pavement, and can be amplified if other heat mitigation measures are deployed as well.

Charging station design to mitigate extreme heat

Designing charging stations to incorporate shade and passive cooling can be one key way to help protect EV battery health and maintain charging time, even in hot temperatures, as well as to help reduce the overall UHI effect. Guidance from charging companies such as FleetCarma and Clipper Creek suggest that EVs should park underground, inside, or in the shade to reduce heat impacts on batteries and reduce energy consumption by thermal management systems, which will help to maintain battery range.[15,16] As charging heats up the battery, particularly fast charging, it is also advised to charge in cooler temperatures, and to charge at slower speeds.[17] Thus, it could be particularly important for DC fast charger stations to incorporate cooling elements. One test found that EVs charged 15 minutes faster when shaded, and used 2kWh less energy per charge, in addition to benefits to cabin comfort and long-term battery life.[18]

Suggested solutions for EV charging stations could include the use of shade canopies, solar photovoltaic (PV) canopies, higher-albedo pavements, permeable pavements, and trees and other vegetation. Conventional pavements can have surface temperatures that are 50 to 90 degrees Fahrenheit warmer than surrounding air temperatures through absorbing 80 to 95 percent of incoming solar energy, which would then be radiated back to nearby objects such as parked EVs.[19] Permeable and cool pavements, in contrast, would absorb less heat and remain cooler. Shaded parking can also reduce the internal temperature of a parked car, saving battery power needed to cool down the interior while driving. An appropriately sized solar PV canopy can provide some or all of the electricity for vehicle charging. If designed well, greenery and urban vegetation can not only provide cooling but also a place of rest and rejuvenation as travelers wait for their vehicles to recharge.

As battery health and performance is a critical component of EV range, especially for commuters and other long-distance drivers, it would be ideal for EV charging stations to be designed and built to provide cooling for both vehicles and people. In turn, ZEVs can in turn help to lower ambient air temperatures for the region.

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[14] Dr. Haider Taha, Capital Region Heat Pollution Reduction: Atmospheric Modeling for the Development of a Regional Heat Pollution Reduction Plan – Technical Project Report.

[15] FleetCarma: https://www.fleetcarma.com/tips-for-florida-drivers-to-get-the-most-out-of-an-electric-vehicle/

[16] Clipper Creek: https://www.clippercreek.com/extend-life-ev-battery/

[17] Green Car Reports: https://www.greencarreports.com/news/1077731_how-to-keep-your-nissan-leafs-battery-pack-happy-in-hot-weather

[18] https://chargedevs.com/features/studies-indicate-that-evse-and-shade-structures-could-attract-prime-customers/

[19] Lawrence Berkeley National Laboratory: https://heatisland.lbl.gov/coolscience/cool-pavements

Best Practices for EV Station Design

Charging stations with shade and green infrastructure

The Sortimo Innovationspark Zusmarshausen

The largest electric vehicle fast-charging station in the world aims to make EV charging a pleasant and productive experience – not just lost time spent waiting. The design evokes the experience of being in a park, with green spaces and walking paths, as well as green roofs shading the chargers, all of which can help to provide passive cooling for charging vehicles, people, and the surrounding environment. The station will also feature reservable meeting rooms, office spaces, restaurants, and shopping. There will be 144 chargers, including fast chargers, that can handle up to 4,000 cars daily.[20] The electricity will be largely sourced from onsite solar combined with battery storage, while waste heat from the transformer, battery, and EV service equipment (EVSE) will provide building heating through heat pumps.[21] Overall, the station is projected to help reduce 60,000 tons of greenhouse gas emissions reductions each year. The station is located in Bavaria near Augsburg, on the A8 highway that links automotive powerhouses Mercedes Benz in Stuttgart and BMW in Munich; construction is underway and was scheduled to be complete in mid-2020. [22]

Figure 7. Concept design of the Sortimo Innovationspark Zusmarshausen. Source: [FutureZone.de]

Figure 8. Conceptual design of the Sortimo Innovationspark Zusmarshausen. Source: [Yardi].

[20] Yardi: https://www.yardi.com/blog/technology/largest-ev-station/18864.html

[21] https://transsolar.com/projects/sortimo-campus-elektromobilitaet-zusmarshausen

[22] SWP: https://www.swp.de/wirtschaft/in-weniger-als-zehn-minuten-31065065.html

point.one S: Collaboration between BMW and EIGHT

German firm EIGHT and BMW collaborated to develop an innovative shaded charging station at the BMW museum in Munich, Germany. The interactive LED lighting system changes color and brightness as users approach the station – it can alert people from a distance if the charger is in use/ booked or available.[23]

Figure 9. The point.one S charging station from BMW and EIGHT. Source: designboom.

Standardizing shade structure into EV station design

A shade structure is part of the standard EV charging station design for Fastned, a Dutch fast-charging company with over 100 stations in the Netherlands, Germany, and the UK. Standardized designs make installation cheap and reliable, while shade structures can also increase visibility for EV charging stations, making them easily recognizable (as gas stations are).[24]

Figure 10. Examples of Fastned's EV station with its standardized shade structure. Source: Fastned

[23] https://www.designboom.com/technology/eight-point-one-s-solar-powered-charging-station-bmw-welt-08-21-2014/

[24] https://fastnedcharging.com/en/blog/post/the-fastned-freedom-plan

Fabric shade structure: Florida House, Sarasota

A fabric canopy can be a less expensive option for shade cooling. UV-resistant fabrics can block a significant amount of incoming radiation and can provide up to 20F cooling.[25] Canopies, awnings, and solar sails designed for gardens, patios, and playgrounds can be easily configured to shade EV charging stations. One example is installed at Florida House, a demonstration house in Sarasota County, Florida, that displays energy efficient and sustainable designs suitable for the hot and humid climate of the south.

COBE: Ultra-Fast Charging Station, Frederica, Denmark

Designed by COBE, an architecture firm with a focus on reinventing public spaces, this station is a harmonious combination of natural elements, green spaces, and efficient, fast charging. According to COBE, "the station takes the form of a series of structural 'trees'," with 'crowns' of wood panels, green roofs, solar PV, and open space that provide a mix of light and shade.[26] The modular approach ensures a scalable design, and one 'tree' can easily be expanded into a 'forest', adapting to parking lots of all shapes and sizes. The design comes as a kit that can be easily assembled, reused, or recycled. The use of wood, instead of cement or steel, replaces a heat-absorbing material, and the station is surrounded by real trees

Figure 11. Images of COBE's ultra fast charging station in Frederica, Denmark. Source: COBE.

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[25] Charged EVs. https://chargedevs.com/features/studies-indicate-that-evse-and-shade-structures-could-attract-prime-customers/

[26] http://www.cobe.dk/project/ultra-fast-charging-station-for-electric-vehicles

and vegetation selected by the Danish Society for Nature Conservation to enhance biodiversity. The green spaces provide not only passive cooling but also a relaxing nature experience for travelers as they wait for their recharge (just 15 minutes on 150 to 350 kW chargers). The design won the Danish Building Award 2018 in the infrastructure category. Built along the E20 motorway in Frederica, Denmark, the station will be the first of a network of 48 across Scandinavia.[27]

Charging stations shaded with solar photovoltaic panels

Built directly over EV spaces, solar photovoltaic panels can both generate electricity for vehicle charging as well as provide shade and cooling for parked vehicles. In addition, solar panels can also be expanded to cover additional conventional parking spaces. Co-benefits include reduced greenhouse gas emissions, lower operating costs for station owners, and reduced strain on the electrical grid, especially if combined with battery storage. There are numerous examples of solar PV shading being deployed at both commercial and public lots, likely due to the economic savings from on-site renewable generation. As early as 2010, the City of Vacaville installed the US's first publicly available DC fast charger underneath a 45-kilowatt solar canopy, which also shades six other EV stations.[28]

Figure 12. *Solar-shaded EV charging station in Vacaville. Source: [Plugshare](#).*

Solar Forest

Playing further on the tree and forest analogy, designer Neville Mars deviates from typical charging station design with his set of PV leaves that branch out from a central trunk.[29] The base of each trunk hosts a power outlet. An example of biomimicry, the leaf-shaped solar panels follow the path of the sun and provides shading to parked cars, both EV and conventional. Though a model was presented in 2009, a full-scale version has yet to be built.

Figure 13. *Neville Mars' Solar Forest. Source: Burb.tv*

Combining, solar, fast-charging, and battery storage

Charging company EVgo is deploying innovative new stations that deploy second-life batteries repurposed from retired BMW test EVs to store electricity generated onsite by solar PV canopies.[30] The combination of solar, storage, and fast charging helps to ensure that vehicles are charged with renewable energy and alleviates energy demand on the grid. According to staff at UC San Diego, which hosted the

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[27] https://www.domusweb.it/en/architecture/gallery/2019/05/29/modular-roof-designed-by-cobe-is-an-oasis-of-sustainability.html

[28] https://www.plugincars.com/vacaville-calif-gets-first-public-electric-car-rapid-charger-us.html
https://www.plugincars.com/vacaville-calif-gets-first-public-electric-car-rapid-charger-us.html

[29] https://burb.tv/view/Solar_forest

[30] https://www.evgo.com/about/news/evgo-wins-energy-storage-north-america-2016-innovation-award/

demonstration site for the project, users appreciate the solar shade canopies. The design has since been introduced elsewhere, including Baker, California.

Similarly, many of Tesla's newest Supercharger stations incorporate solar panels over every stall as well as battery storage.

Figure 14. EVgo's charging station in Baker, California, has a 20kW solar system in combination with fast chargers (50-350kW) and a 60kW / 88 kWh storage system. (Source: EVgo)

Cool and Permeable Pavements in EV Stations

There are few examples of EV charging stations intentionally installing cool or permeable pavements as a solution specifically for reducing heat impacts on charging vehicles. However, there are various examples of parking lots and streets that aim to improve their overall sustainability through deploying combinations of measures that include both EV charging and cool or permeable pavements, as well as green infrastructure and other elements. Examples include the City of Tacoma's rehabilitation of the access road and parking lot for its stadium with permeable pavements, rain gardens, landscaping, and EV charging stations.[31] A more comprehensive approach would be the City of Fort Lauderdale's sustainable parking program. As part of a demonstrator project in 2013, they retrofitted an existing city hall parking lot to showcase various green parking technologies, which include EV charging, two spaces with permeable pavers, a high albedo coating for the rest of the lot (with a solar reflectance index of 35), and Florida-friendly landscaping.[32] Newer parking lots and garages include features such as cool pavements, permeable pavements, greenery and vegetation, solar panels, and EV charging.[33] Other examples can be found in West Union, Iowa, a small town of 2,500 people that adopted EV charging, rain gardens, permeable pavements, and improved walkability as part of a comprehensive main street revitalization program.[34]

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[31] https://www.cityoftacoma.org/government/city_departments/environmentalservices/surface_water/green_stormwater_infrastructure__gsi_/gsi_projects/cheney_sustainable_stormwater_project

[32] https://www.parking.org/wp-content/uploads/2016/01/TPP-2013-12-Greening-the-Lot.pdf

[33] https://gyr.fortlauderdale.gov/greener-government/transportation-connectivity/greener-driving-and-parking/sustainable-parking-lot-design

[34] https://www.iowaeconomicdevelopment.com/userdocs/programs/GreenStreetsPilotProject-ProjectNarrative-WestUnion.pdf

In addition, while the primary aim of painting EV spaces with bright colors is to bring attention to the availability of EV chargers, this practice can also be further enhanced to increase pavement albedo. Greens and blue paints are higher in albedo than conventional asphalt, and thus allow these parking spaces to absorb less heat, providing a cooler space for the EV to park on. The use of a reflective or infrared-reflective paint color would raise the albedo even more. A coating of paint would typically wear off quickly on a high-volume road, but it would last longer – and be easier to reapply – in parking spaces primarily used by light-duty vehicles.

Figure 15. Painted EV charging spaces in Hannover (top left) and Hamburg, Germany (top right and bottom). Source: Hannover.de, Wikimedia Commons, and Frankfurter Allgemeine Zeitung.

Gaps in EV charging station design

Many jurisdictions have published design guidelines and best practices for building EV charging stations, but few provide recommendations to protect charging vehicles from heat impacts, mitigate the urban heat island effect, or address other environmental concerns.

One exception is the City of Berkeley's manual for their pilot residential curbside EV charging program – designed for residences that lack parking space on their property – which notes that "vehicle-related paving for EV charging through this Pilot should be constructed of a permeable surface." It also requires a "landscaping screening strip at least 2 feet wide between the paving and any adjacent rear or interior side lot line". Established in 2014, the program resulted in eight installations in three years; in February 2018 the program was extended through December 2020.[35]

Thus, one opportunity would be to include recommendations for shading, solar PV canopies, trees and green infrastructure, and cool and permeable pavements into standard design guidelines for new EV stations. For example, the Electric Vehicle Charging Station Permitting Guidebook, published by the

[35] https://www.cityofberkeley.info/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/Resolution%20No%2068,345-N.S.%20Extending%20Pilot.pdf

California Governor’s Office of Business and Economic Development, provides a guide to the regulatory requirements, planning, permitting, and grid interconnections process of building a new EV station, but it does not address any of the logistics of incorporating solar PV or battery storage as part of the station design. The permitting guidebook also discusses future proofing – how to enable the station to undertake easy, low-cost future expansions and upgrades to charging equipment – but not climate proofing. These elements should be addressed in future updates to the guidebook, as well as other guides and manuals to EV station design.

As the Capital Region and California move toward statewide goals of 1.5 million ZEVs and 250,000 shared chargers by 2025, and 5 million ZEVs by 2030, it is critical to ensure that these stations and vehicles are as resilient as possible to the future impacts of climate change. Batteries represent a significant portion of an EV’s cost – as well as its environmental footprint – and thus minimizing exposure to high temperatures when charging or parked can help to maintain battery health and lifespan, prolonging the useful life of the EV. For EV drivers, especially low-income and multi-family housing residents who may rely more on shared public charging, these improvements can help to protect their investment and mobility choices in the long term. As EVs are a critical part of California’s long-term transportation and climate change plans, protecting their long-term performance can help to support EV adoption throughout the state, and thus help to reduce greenhouse gas emissions, improve air quality, and reduce the urban heat island effect.