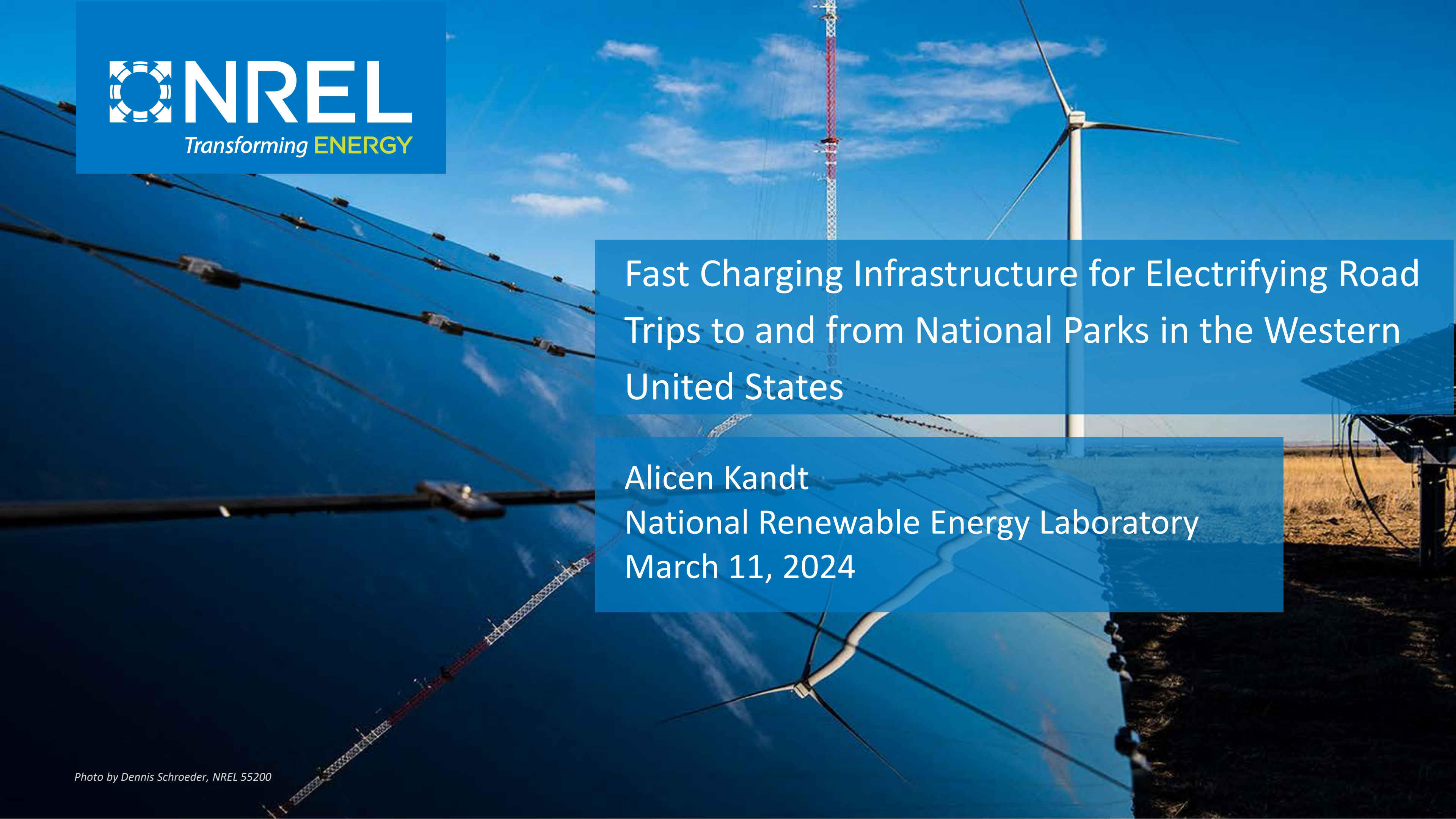


Fast Charging Infrastructure for Electrifying Road Trips to and from National Parks in the Western United States

Alicen Kandt
National Renewable Energy Laboratory
March 11, 2024

Photo by Dennis Schroeder, NREL 55200

Contents

NREL at a Glance

3,675 workforce, including:

- 2,732 regular/limited term
- 490 contingent workers
- 211 postdoctoral researchers
- 152 graduate student interns
- 90 undergraduate student interns.

—As of 9/30/2023

World-class research expertise in:

- Renewable Energy
- Sustainable Transportation & Fuels
- Buildings & Industry
- Energy Systems Integration.

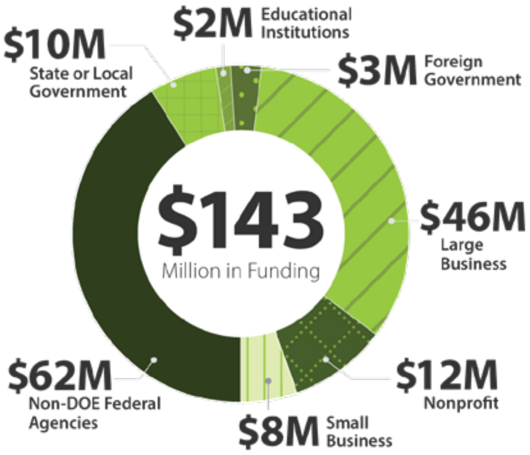
Partnerships with:

- Industry
- Academia
- Government.

4 campuses operate as living laboratories.

More Than 1,000 Active Partnerships in FY 2023

Agreements by Business Type



Funding by Business Type

NREL Science Drives Innovation

Renewable Energy

- Solar
- Wind
- Water
- Geothermal

Sustainable Transportation & Fuels

- Bioenergy
- Hydrogen and Fuel Cells
- Transportation and Mobility

Buildings & Industry

- Buildings
- Industrial Efficiency and Decarbonization
- Advanced Materials and Manufacturing
- State, Local, and Tribal Governments

Energy Systems Integration

- Energy Security and Resilience
- Grid Modernization
- Integrated Energy Solutions

Photo by Werner Slocum, NREL 66364

WSEV@Scale Theme & Objectives

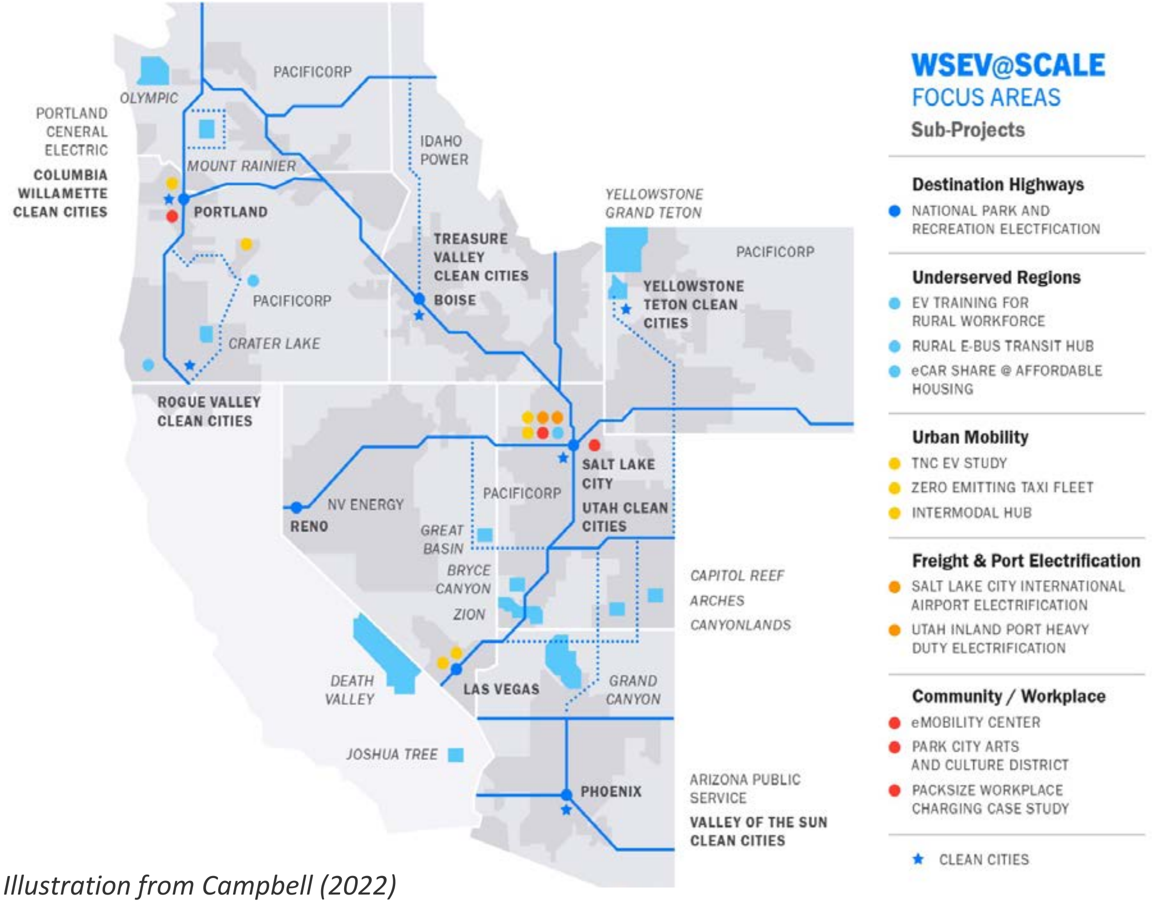


Illustration from Campbell (2022)

Project objectives:

- Develop regional relationships, publish best practices, and carry the banner for electrification at scale across the region.
- Establish an electrification plan for Utah and the Intermountain West.

WSEV@Scale: Western Smart Regional EV Adoption and Infrastructure at Scale

Study Context

Photo from iStock

- From the Grand Canyon to the majestic Tetons, national parks in the western United States draw more than 80 million visitors per year. Most of these visitors rely on their personal vehicles or rentals to get them there.
- Today, electric vehicles (EVs) account for more than 7% of new light-duty vehicle sales in the United States, and EV sales are expected to soar to 30%–50% by 2030. On the high end, this would translate to about 40 million light-duty EVs on the road, according to the National Renewable Energy Laboratory's (NREL's) national charging network analysis.

Study Context (Continued)

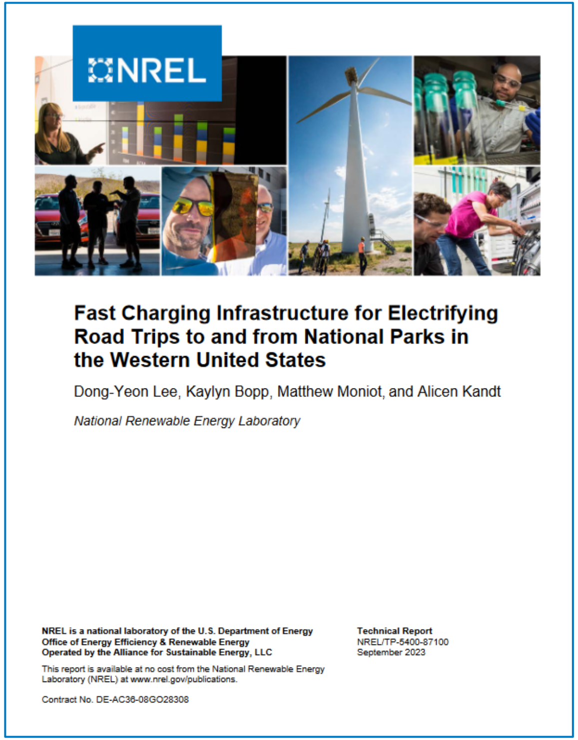
- The lack of sufficient charging infrastructure connecting U.S. cities and population centers becomes even more pronounced in the western part of the country, specifically along the roads to and from national parks, which are often located in remote or rural areas.
  - The western United States (U.S. Census Bureau 2022), excluding Hawaii and Alaska, represents approximately 20% of the U.S. population (U.S. Census Bureau 2021) but is home to approximately 30% of the approximately 500 National Park System (NPS) units (National Park Service 2002) (e.g., national parks, national monuments) in the country.
  - NPS units in the west draw more than 80 million domestic and international visitors annually (National Park Service 2002), more than the total number of residents (76 million) in the region (U.S. Census Bureau 2021).

Study Context (Continued)

- Each month, the region has intra-regional and inter-regional visitors—equivalent to approximately 10% of the total number of residents—traveling to and from the NPS units in its territory.
- This highlights the significance of the NPS units in the region and the importance of developing proper and sufficient charging infrastructure to enable and support electrified road trips to and from those NPS units.
- More broadly, such an effort is critical to improve fuel diversity and reduce greenhouse gas emissions across the region (Campbell 2022).

Study Scope

- This study investigated the fast charging infrastructure needed by 2030 to enable seamless electrified road trips to and from national parks and monuments in seven western states: Washington, Oregon, Idaho, Wyoming, Utah, Nevada, and Arizona. It also estimated impacts to the electric grid.
- The research team investigated how on-route charging infrastructure projections change with different parameters or assumptions, as do related charging loads and grid impacts.
- NREL conducted the study in partnership with utility service provider PacifiCorp and Utah State University as part of the Western Smart Regional EV Adoption and Infrastructure at Scale project.


NREL

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Dong-Yeon Lee, Kaylyn Bopp, Matthew Moniot, and Alicen Kandt

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

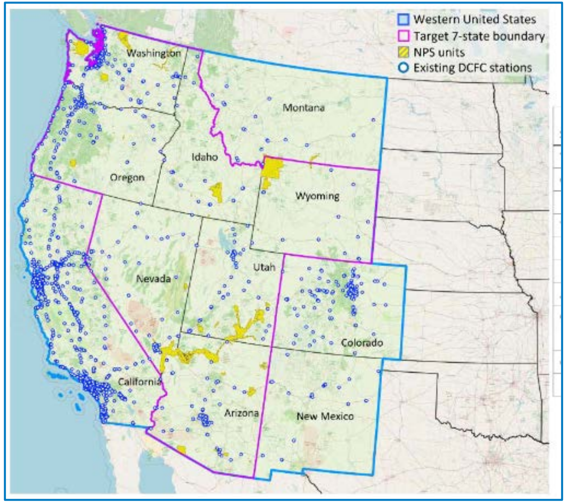
Technical Report
NREL/TP-5400-87100
September 2023

DCFC Focus

- When it comes to charging infrastructure for road trips (including those to and from NPS units), the most relevant charger type is direct current fast charging (DCFC) (Burnham et al 2017; Kampshoff et al. 2022). In the case of destination charging (e.g., overnight at home, workplace, parks, retail), EVs are parked for a few to several hours in one location (for reasons other than refueling), and thus they can be charged during that window of opportunity.
- For road trips, vehicles are constantly on the move most of the time (except overnight stays at hotels), and drivers would generally want to keep moving/driving while avoiding or minimizing time spent for refueling. In other words, unlike "opportunity charging" at home or a destination, on-route (or waypoint) charging is a time-sensitive activity where drivers typically seek to charge as quickly as possible.
  - For road trips and associated on-route (or waypoint) charging, other than overnight (opportunity) charging at hotels where Level 2 charging would be most relevant, DCFC should comprise most of the charging infrastructure.

Key Objectives

- Given the significance of the NPS units in the western United States, as well as the importance of EVs being capable of seamlessly traveling to and from the NPS units, it is crucial to develop and deploy sufficient charging infrastructure along the routes for those road trips.



Target study area

- We investigated three key aspects of fast charging infrastructure that will enable electrified road trips to and from NPS units in the western United States:
  - Where and how many on-route DCFC ports would be needed to support electrified road trips to and from the NPS units, focusing on seven western U.S. states (Washington, Oregon, Idaho, Wyoming, Utah, Nevada, and Arizona) where NPS units are most concentrated
  - How the on-route charging infrastructure projections might change with different assumptions around vehicle electrification rates, seasonal variations in the volume of the recreational road trips, and increased energy consumption for vehicles when towing trailers, among others
  - How many Level 2 chargers would be needed for opportunity charging at NPS units and overnight stays at lodging locations (e.g., hotels).

Methods

- EVI-RoadTrip is an on-route charging infrastructure simulation tool with a particular focus on on-road long-distance travel (road trips) that was originally developed by NREL. The four-step model includes:
  1. Road trip volume and pattern estimation
  2. EV energy use and charging simulation
  3. Charging station siting and sizing
  4. Electric grid capacity analysis.

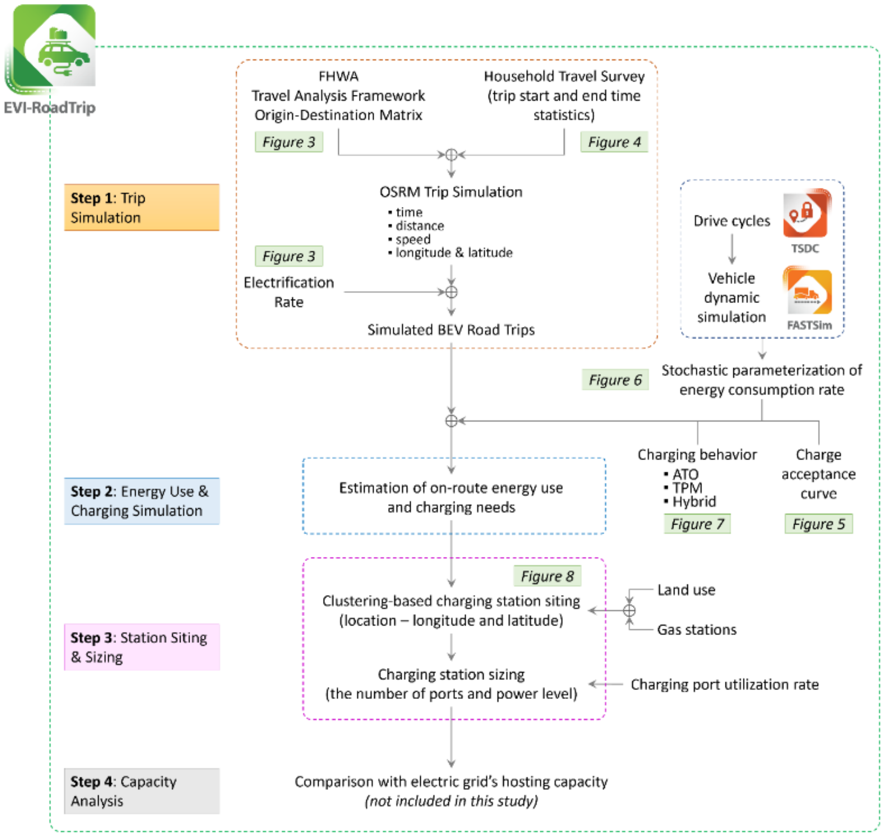


Figure 2. Schematic diagram of EVI-RoadTrip

Road Trip Volume and Pattern

- Used an origin-destination (O-D) matrix for passenger cars from the Federal Highway Administration's (FHWA's) "Traveler Analysis Framework" (2016). This includes road trips to, from, and through NPS units in addition to those that are not directly related to NPS units.
- Because the O-D matrix is for all types of road trips across the country, we selected O-D pairs that are only relevant to our study—those that originate from the study area of seven states, those for which the final destinations fall within the area, and those that pass through the area (e.g., from Los Angeles, California, to Houston, Texas).
- On a typical day, more than 30% of all road trips in the study area are directly associated with (i.e., originated from or destined to) NPS units (FHWA 2016). As such, the significance of NPS units in the overall road trip volume is rather unique in the western United States compared to other parts of the country.

Road Trip Simulation

- Each O-D pair in the “Traveler Analysis Framework” data provides geospatial information for the start and end of the trip. We simulate the trip between origin and destination using the Open Source Routing Machine (OSRM),[1] generating the traces (longitudes and latitudes) of vehicle movement from the origin to destination, which, in turn, translates into distance and speed for each time interval (1 minute is the default time interval in EVI-RoadTrip).
- Once the traces of vehicle movement in the space and time domain are set as such, we then pair each trip with one of the three types of battery EVs used in the Assembly Bill 2127 (CEC 2024) analysis: short-range cars (SR-Cars), long-range cars (LR-Cars), and sport utility vehicles or pickup trucks (SUVs/PUTs).
- After pairing one trip (O-D) with one vehicle, we assign a unique vehicle identification to that pair and track each vehicle’s minute-by-minute location (longitude and latitude), speed, energy consumption rate, charging demand, and charging power (when charging).

[1] OSRM is free, open source, and available under the very permissive (simplified) two-clause BSD license. See https://project-osrm.org/.

Energy Use and Charging Simulation

- Charging demand along the route of road trips mainly depends on the preferred initial departure or final arrival state of charge (SOC) as well as the evolution of on-route SOC between the origin and destination. This is affected by on-route vehicle energy efficiency and driving conditions (e.g., speed, temperature, terrain), among others.
- Trailers: two scenarios (all with and all without).

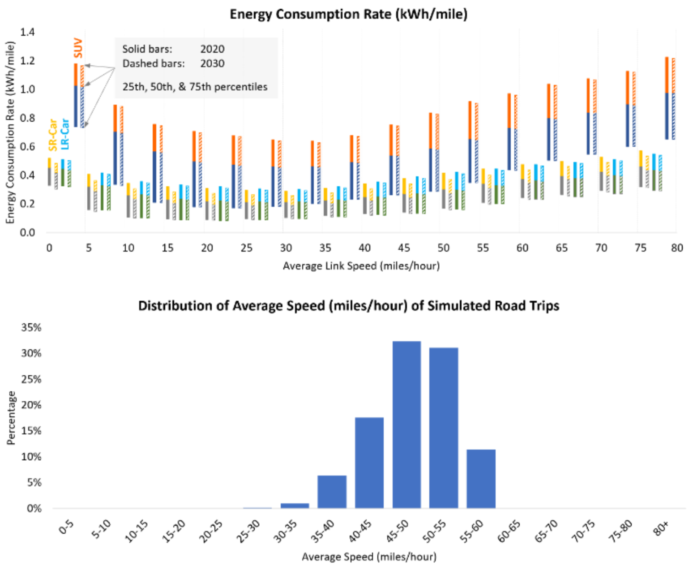


Figure 6. (Top) ECR (kWh/mile) for three different BEV types (SR-Car, LR-Car, and SUV/PUT) for different model years (2020 and 2030). (Bottom) Average speed (miles/hour) distribution for simulated road trips

Charging Station Sizing and Siting

- Based on the trip and charging simulation in the space (longitude and latitude) and time (minute-by-minute) domains described in the previous sections, we then aggregated the charging demands (points/locations where each vehicle requires charging, if any).
- We used the common k-means clustering method, which allows us to combine neighboring charging demand points within a certain radius that charging stations will serve. When combining charging demand in the proximity, we start with small clusters (e.g., groups of charging demand points within a 1-mile radius), and then we combine nearby smaller neighboring clusters (groups of charging demand points) to create larger clusters, depending on the desired cluster size (e.g., 5 miles). The final size of the clusters reflects the desired service area (e.g., 5 miles) in the analysis.
- This two-step clustering approach (starting with smaller clusters and aggregating them to build larger clusters as needed) provides flexibility in terms of evaluating different design values for a target service area of DCFC stations as well as the gaps between stations (e.g., 5 miles vs. 50 miles).

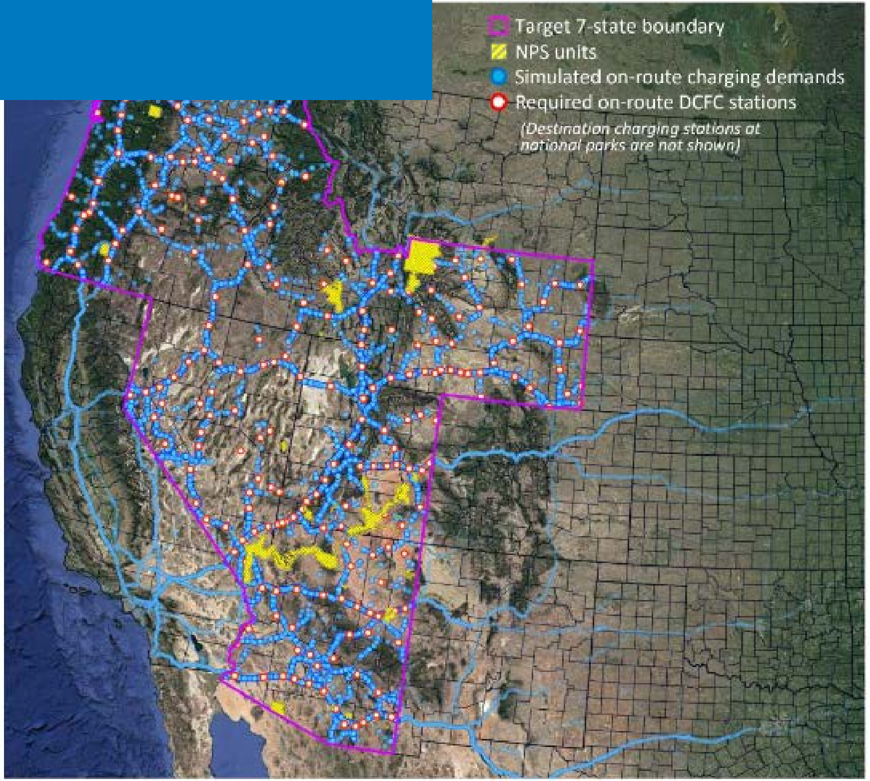
Charging Station Sizing and Siting (Continued)

- Once we generate the clusters (service areas of charging stations containing individual charging demands that those stations absorb), we reassign the centroid of each cluster to the nearest point of interest using National Land Use Data (Theobald 2014)—30-m by 30-m land use characteristics (e.g., retail, airport, highway). In addition, we use the location information for gas stations from OpenStreetMap (2023).
- After we determine the location of the station for each cluster containing a group of charging demand points for different vehicles/trips, we estimate the size of the station in terms of the number of charging ports.
  - We overlay all charging profiles (minute-by-minute charging events and power) for all charging demands within each cluster.
  - We then determine the peak hour that has the most charging activities during the course of the day. Based on the number of simultaneous charging events during that peak hour in that station, we estimate the minimum required number of ports.
- As for DCFC station sizing, EVI-RoadTrip estimates the number of stations and ports as well as the power ratings of those ports.

Findings

- The high-resolution spatial and temporal analysis showed that the requisite number of DCFC charging ports varies greatly—ranging from 1,200 to 22,000—depending on key assumptions.
- The study also examined electrical load profiles for fast charging infrastructure to inform electric grid operations and planning and found that the load varies greatly, ranging from 70 MW to 400 MW.
- As illustrated in the report, these large ranges hinge on key assumptions, such as EV adoption (number and types of vehicles), charging behavior, average distance between charging stations, station utilization, and whether vehicles tow trailers.

Quantity of DCFC Ports



Required Number of On-Route DCFC Ports in 2030
(Scenario: High BEV penetration; Hybrid charging behavior; 50-mile gap between stations)

	Lower	Upper
Total	2,350	4,620
Washington	140	270
Oregon	245	470
Idaho	140	290
Wyoming	205	400
Nevada	440	860
Utah	540	1,060
Arizona	640	1,270

Number of On-Route DCFC Stations by State

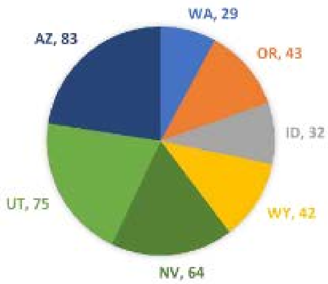


Figure 10. (Left) Simulated network of on-route DCFC stations in the seven states in 2030. (Right) The required number of DCFC ports (lower [100% utilization rate] and upper [50% utilization rate] estimates) and stations by state for one scenario (high BEV penetration, hybrid charging behavior, and 50-mile average gap between DCFC stations)

Siting of DCFC Stations

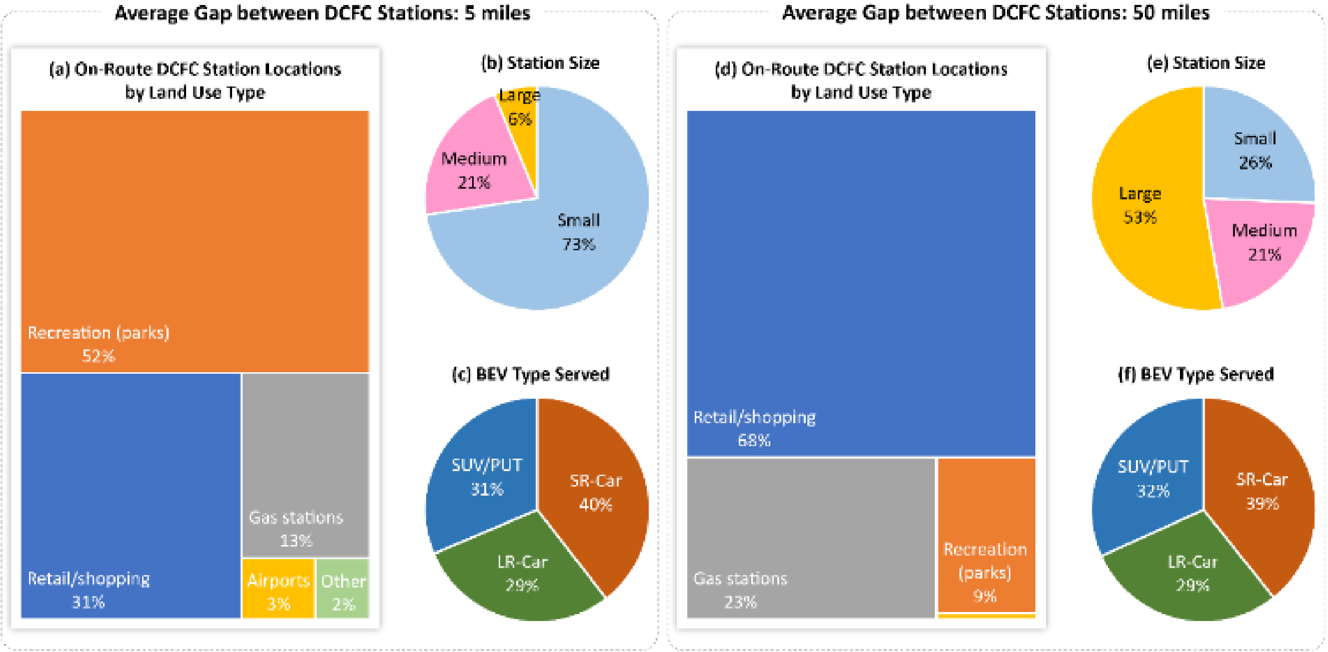


Figure 15. Land use type, station size, and BEV type served for two different settings for the average gap between stations—5 miles (left: a, b, and c) vs. 50 miles (right: d, e, and f)—for the simulated network of on-route DCFC stations in the seven states in 2030 (Figure 10)

Charging Load Profiles

- Most DCFC charging events occur in the afternoon, and the least occur between midnight and early morning.
  - The station total charging load profile peaks around 3 p.m., and the peak load is approximately 1.5 MW.
- We repeat the estimation of the load profile and charging events for each station in the study area by assembling individual vehicles' charging activities for the station. When we aggregate the values for all stations, we get area-wide load profiles and charging events that both peak around 4 p.m.
- The peak network-wide on-route DCFC load is estimated to be approximately 140 MW, and the total number of charging events during the peak hour (4 p.m.) is approximately 800. The area-wide peak on-route DCFC load of 140 MW is roughly equivalent to 0.5% of the current electrical load for the entire northwest (35 GW on average) (EIA 2020).

Conclusions

- The required number of fast charging ports for on-route charging infrastructure ranges from 1,200 to 22,000, depending on different assumptions of key input parameters—vehicle electrification rate, charging behavior, average gap between charging stations, port utilization rate, and whether the vehicle is towing a trailer.
- Electrical load for on-route fast charging infrastructure would peak in the afternoon, ranging from 70 MW–400 MW, varying with the key input parameters.
- This study illustrates how different input parameters result in different degrees of impact on various aspects of the charging infrastructure, illuminating the complexities that planners or decision makers would need to navigate when designing charging infrastructure for electrified road trips.
- The study also clearly exemplifies the importance of comprehensively accounting for road trips that are directly and indirectly related to the study area when evaluating on-route charging infrastructure needs.

Opportunities for Future Work

- This study makes projections for 2030, but a longer-term analysis (e.g., up to 2050) would be helpful for multidecade infrastructure planning that requires long-term insights.
- Future work could consider equity elements and investigate how to ensure an equitable transition when building out charging infrastructure and supporting vehicle electrification. For this, energy justice/equity tools and models such as Electric Vehicle Infrastructure for Equity (EVI-Equity) (NREL 2023) could be integrated with EVI-RoadTrip to holistically assess the equity implications of electrified road trips and the corresponding charging infrastructure.
- A future study would need to be based on more detailed empirical data that can characterize people's behavior while on road trips for driving, taking breaks, refueling, and so on. Such data are currently scant in the field of long-distance travel research.

Using the Right Tools for the Job

The analysis leveraged NREL's Electric Vehicle Infrastructure for Road Trips (EVI-RoadTrip) tool, a computational model that estimates on-route EV charging infrastructure needs for long-distance travel. EVI-RoadTrip is part of the lab's EVI-X suite of EV charging infrastructure analysis tools, which informs the planning and development of EV charging infrastructure—from the regional, state, and national levels to site and facility operations.

How EVI-RoadTrip Works

EVI-RoadTrip simulates individual road trips from origins to destinations at a high spatial (longitude and latitude) and temporal (minute-by-minute) resolution, identifies charging needs along routes, and aggregates charging demands within a certain radius to estimate charging station placement, sizing, and utilization.

By repeating this process for all road trips in a given study area, EVI-RoadTrip develops a proposed network of fast-charging stations that provide sufficient coverage and capacity. It also estimates electricity needs based on the projected charging station locations and characteristics.

The analysis also tapped into drive cycle data from NREL's Transportation Secure Data Center as well as the vehicle simulation capabilities of NREL's Future Automotive Systems Technology Simulator.

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Thank you!

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. Support for the work was also provided by PacifiCorp under WestSmart's EV@Scale project. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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