DC Fast Charging Infrastructure for Electrified Road Trips

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CEC IEPR Workshop
August 6, 2020
● From the charging infrastructure standpoint, to electrify road trips in CA:

  1) **How many** charging stations (or plugs/ connectors) do we need?
  2) **Where** do we need those charging stations?
  3) What is the impact of charging load on **the electric grid**?

● To answer those questions, a new charging infrastructure simulation tool (EVI-Pro RoadTrip) has been developed:

  **EVI-Pro RoadTrip**
  – Focused on long-distance (100+ miles/day) travels.
  – Based on waypoint charging (stop to charge).

  **EVI-Pro**
  – Focused on short-distance travels.
  – Based on destination charging (charge when stop).

● **Scope:**
  - CA-bound/originated road trips
  - DC fast charging (DCFC)
  - Domestic (inter-state) & international
  - Personal light-duty BEVs (battery electric vehicles)
EVI-Pro RoadTrip: Overall Structure & Spatio-Temporal Resolution

Road Trip Volume and Pattern + BEV Energy Use and Charging Simulation + Station Design (Siting and Sizing) + Capacity Analysis

- Transportation
- Refueling Infrastructure
- Electric Grid

**Spatial resolution (default: longitude & latitude)**
- Coords. (origin, destination, trip simulation, etc.)
- 30m x 30m (land use type, etc.)
- TAZ (traffic analysis zone, capacity analysis, etc.)
- County (county-level aggregation)
- State (state-wide total number of stations, etc.)

**Temporal resolution (default: 1 minute)**
- Seconds (trip simulation, vehicular energy use, etc.)
- Minutes (charging time, detour to charging stations, etc.)
- Hours (intra-state road trip duration, etc.)
- Days (cross-country road trip duration, etc.)
- Years (infrastructure build-out, BEV adoption, etc.)
Volume & Pattern of Electrified Road Trips

- TAZ-by-TAZ* road trip activity: Caltrans (CA DOT) CSTDM* (V3)
- CA electrification projections: CEC Energy Assessments Division’s forecasts by 2030 (Low: 1.5M BEVs; Aggressive: 3.1M BEVs)
- Non-CA electrification projections: EIA and IEA forecasts

Long-Distance Travel (LDT) Volume (1,000s) in 2020, 2025, and 2030

- **TAZ**: Traffic analysis zone (commonly used in transportation planning) – adopted as a basic geographical entity for travel demand estimation in CSTDM.
- **CSTDM**: California Statewide Travel Demand Model

County-level characterization of electrified road trips (in millions) per day in 2030
Trip, Vehicle Energy Use, and Charging Simulation

- Three BEV types: SR (short range) Car, LR (long range) Car, and SUV.
- Leveraged NREL’s FASTSim (vehicle dynamic simulation tool).
- Detailed energy use and charging simulation for each road trip sample.

An example of simulated road trip (Southern border to SF; 520 miles; 5,200 data points)

Open Source Routing Machine (OSRM)

Aggregated Trip-by-Trip Energy Consumption Rate (kWh/mile)

- SR-Car (e.g., Nissan Leaf)
- LR-Car (e.g., Tesla Model S)
- SUV (e.g., Electrified Toyota Highlander)

DC Fast Charging Power (kW) as a function of Battery SOC (state-of-charge)

- 2020 SR-Car
- 2020 LR-Car
- 2020 SUV
- 2025 SR-Car
- 2025 LR-Car
- 2025 SUV
- 2030 SR-Car
- 2030 LR-Car
- 2030 SUV

Each dot/circle represents each trip.
● Locate stations in commercial areas & other preferred sites.
● CEC collected station developers’ input to prioritize candidate sites.
● Leveraged national land use data (NLUD, in 30m x 30m), as well as coordinate data of 6,000 gas stations in CA.

● Station sizing is based on station-by-station load profiles.
● The number of plugs: max simultaneous charging events.
● The number of plugs per station is capped at 10.

Station siting example
Station ID: 793
Coord: -122.872, 38.626
TAZ ID: 542
Charging events/day: 10
Plugs: 2
Land use type: commercial
Healdsburg, CA
Sonoma county

Simulated DCFC Station Locations by Land Use Type

Retail/shopping 57%
Recreation (parks) 28%
Gas stations 13%
Airports, 2%
Other, 1%

Charging demands along the routes

Individual Charging Load Profiles for a DCFC Station (ID: 235)

Simultaneous Charging Events for a DCFC Station (ID: 235)
68 charging events over the course of day
Peak simultaneous events: 10
Results: Stations and Plugs/Connectors

Required Number of DCFC Plugs for Electrified Road Trips
(Lower bound: 100% plug utilization rate
Upper bound: 25% plug utilization rate)

- 400 kW
- 300 kW
- 200 kW
- 100 kW

Snapshots for each simulation year (2020, 2025, and 2030) without the consideration of existing conditions from previous years.

Currently, existing stations are not considered in the process of station siting or network design in EVI-Pro RoadTrip.

TAZ-by-TAZ net deficit of DCFC plugs required
Year 2030
Aggressive BEV adoption
Lower bound (100% peak plug utilization rate)
Results: Load Profiles

- Network-wide total charging load reaches around 90 MW in peak hours in 2030 for Aggressive BEV adoption scenario (50 MW for Low scenario).
- Notable difference of load shapes between out-of-state inbound LDTs and the other types of LDTs (e.g., intra-state).
**Sensitivity Analysis: Charging Behavior & Technology**

- **Charging behavior** related to plug-out SOC:
  - TPM: Time penalty minimization (plug out at around 85% of SOC)
  - ATO: Always top off (plug out at 99% of SOC)

- **Charging technology** (speed, power, etc.) is still evolving.
- **What if Tesla V3-like kW-SOC curves are used?**

**DC Fast Charging Power (kW) as a Function of Battery SOC (state-of-charge): Baseline (Spread-out)**

**DC Fast Charging Power (kW) as a Function of Battery SOC (state-of-charge): Tesla V3-like**
Impact of Charging Behavior & Technology

● **Charging behavior (TPM vs. ATO):**
  - Significant impact on load profiles and plug counts.
  - Plug composition (power rating) is mostly the same.

- **Charging technology (kW-SOC curves):**
  - Less-than-significant impact on load profiles or plug counts.
  - Drastic difference in terms of plug composition (power rating).

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**Total Charging Load (MW) for Different Charging Behaviors (ATO vs. TPM)**

- 2030 TPM (time penalty min)
- 2030 ATO (always top off)

**Required Number of DCFC Plugs for Electrified Road Trips**

<table>
<thead>
<tr>
<th>Year</th>
<th>TPM</th>
<th>ATO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
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</tr>
</tbody>
</table>

- 400 kW
- 300 kW
- 200 kW
- 100 kW

**Total Charging Load (MW) for Different kW-SOC Curves**

- 2030 Baseline (spread-out)
- 2030 Tesla V3-like

**Required Number of DCFC Plugs for Electrified LDTs**

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline</th>
<th>Tesla V3-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 800 kW
- 700 kW
- 600 kW
- 500 kW
- 400 kW
- 300 kW
- 200 kW
- 100 kW
Results: Capacity Analysis – SCE (Southern California Edison) Case Study

- Required capacity by TAZ
- Available hosting capacity by TAZ
- Net capacity deficit by TAZ

- TAZ-by-TAZ capacity deficit ranges from 0 to 20 MW.
- Data quality of hosting capacity is to be improved.

Simulated location of charging station

Year 2030
Aggressive BEV adoption

Net capacity deficit (MW)
- < -2,000
- -2,000 – -1,000
- -1,000 – -500
- -500 – 0
- 0 (no remaining capacity)
- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 12

May require grid upgrade
1. **Need real world high-resolution data.**
   - Model usefulness depends on high quality input data that capture *real-world travel/driving behavior and charging session characteristics.*

2. **Enhance grid integration at all levels.**
   - DCFC loading (for electrified road trips) at the system-level *may align with solar power generation.*
   - Initial capacity analyses suggest that electrified road trips alone might be accommodated. However, when accounting for integrated electrical load (road trips, short distance travels, buildings, etc.), California should encourage efforts to *manage network over-build* ("turnover" pricing) and *proactively mitigate grid impacts.*

3. **Plan for RoadTrip stations as part of a holistic expansion of the network.**
   - Technology improvements *moderate the growth in the number of stations* and plugs needed to serve more BEVs in 2030, compared to 2025, highlighting the importance of *future proofing equipment and maximizing BEV-plug interoperability today.*
   - Integrating the RoadTrip analysis with EVI-Pro 2 can *optimize the network of stations.*
Limitations & Future Work

● “V1” of EVI-Pro RoadTrip (a model is a model).
● Need more realistic and rigorous methods and data for better characterization of driving & charging.
● Long-distance travels (or road trips): Traditionally under-researched area in transportation field.

● **Future work** (not exhaustive):
  - Consider infrastructure co-utilization by entire LDV fleet (short-distance travels, TNC, etc.).
  - Internalize existing charging infrastructure in the overall station network design.
  - More integrated and advanced analysis (decision-making) of driving (drivers) and charging (infrastructure).
  - Account for dynamic aspects of the refueling network (e.g., coordinated charging, station congestion).
  - More realistic method for DCFC station siting and sizing (e.g., by reaching out to relevant stakeholders).
  - Stochastic approach for key parameters (e.g., heterogeneity of charging behavior).
  - State-wide capacity analysis (beyond the SCE area).
Thank You

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NREL/PR-5400-77634
Appendix
Road Trip Electrification Projections

- Road trip electrification is based on general light-duty vehicle electrification projections (BEV adoption).
  - California: 10% by 2030 (based on the forecasts made by CEC’s Energy Assessments Division)
  - Non-CA states: 2.5% by 2030 (based on EIA AEO – see next slide)
  - Mexico: 0.05% by 2030 (based on IEA projections)

- BEV adoption scenarios:
  - Baseline/aggressive (3.1M BEVs by 2030): Business as usual
  - Low (1.5M BEVs by 2030): Potential aftermath (e.g., slower electrification) of the ongoing pandemic (COVID-19)

<table>
<thead>
<tr>
<th></th>
<th>Baseline (Aggressive) BEV Adoption</th>
<th>Low BEV Adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intra-state</td>
<td>External</td>
</tr>
<tr>
<td>2020 CSTDM (All)</td>
<td>215,151</td>
<td>344,058</td>
</tr>
<tr>
<td>RoadTrip (Electrified)</td>
<td>4,226</td>
<td>3,762</td>
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<tr>
<td>2025 CSTDM (All)</td>
<td>211,684</td>
<td>363,005</td>
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<tr>
<td>RoadTrip (Electrified)</td>
<td>12,332</td>
<td>11,810</td>
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<tr>
<td>2030 CSTDM (All)</td>
<td>210,844</td>
<td>372,856</td>
</tr>
<tr>
<td>RoadTrip (Electrified)</td>
<td>20,425</td>
<td>20,323</td>
</tr>
</tbody>
</table>
BEV Adoption in Non-CA States

- EIA AEO 2020 projection: 2–4% of total LDV (light-duty vehicle) stock in the U.S. will be BEVs by 2030.
- The range reflects 23 different scenarios EIA evaluated.

Data source: EIA AEO 2020
TAZs (Traffic Analysis Zones) & Gateways in CSTDM

- **5,454 internal TAZs**
  - Used for short-distance (SHT) and long-distance (LNG) travel volume

- **53 external TAZs (gateways)**
  - 3 ports (Port of Oakland, POLA, & POLB)
  - 50 roadways crossing CA boundary
  - Used for external (EXT) travel volume

**CSTDM TAZ Area Distribution**
(80% TAZs < 5 square miles)
Seed Coordinates for Origins and Destinations: CHTS + NLUD

**CHTS** (California Household Travel Survey):
About 0.2 million unique coordinates as reference points for origins/destinations; the spatial density is correlated with population centers.

**NLUD** (National Land Use Data):
Down-sampled for residential and commercial spots (30m x 30m)
Breakdown of Origin and Destination Coordinates by Sources/Types

- Replaced centroids (used when no CHTS coordinates are available) with NLUD coordinates.
- Reduced duplicate CHTS samples.
- In the final input data (trips) for simulation, NLUD coordinates account for about 11%.
Travel volume increases over time, but the overall spatial pattern of road trips remains similar.
BEV Type, Population, and Specifications


BEV specification example: Battery size (kWh)
Model Year (MY) Distribution (adapted from CEC EAD data)

Baseline (Aggressive) BEV Adoption

<table>
<thead>
<tr>
<th>Model Year</th>
<th>SR-Car (2030)</th>
<th>LR-Car (2030)</th>
<th>SUV (2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>6%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>2020</td>
<td>22%</td>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td>2025</td>
<td>39%</td>
<td>44%</td>
<td>43%</td>
</tr>
<tr>
<td>2030</td>
<td>33%</td>
<td>27%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Low BEV Adoption

<table>
<thead>
<tr>
<th>Model Year</th>
<th>SR-Car (2030)</th>
<th>LR-Car (2030)</th>
<th>SUV (2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>20%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>2020</td>
<td>24%</td>
<td>27%</td>
<td>21%</td>
</tr>
<tr>
<td>2025</td>
<td>28%</td>
<td>38%</td>
<td>43%</td>
</tr>
<tr>
<td>2030</td>
<td>28%</td>
<td>27%</td>
<td>21%</td>
</tr>
</tbody>
</table>
Road Trip Distance Statistics

Total Driving Distance (miles) - 2030, Baseline BEV Adoption
(Average: 260 miles)
Trip Initialization

- CHTS-LDT (long-distance travel) indicates that trip start/departure time centers around 10–11 am.
- CHTS-LDT start time distribution (below) is used as reference for departure time.
Generic energy consumption rate (kWh/mile) was developed from NREL’s FASTSim simulation with CEC/CARB/NREL vehicle specifications and millions of real-world drive cycles.
Departure and Entry SOC (State-of-Charge)

- Departure SOC for intra-state road trips: FleetCarma NE data.
- Entry SOC for out-of-state inbound road trips: SOC at the point of entering the state (CA) boundary.
- Run EVI-Pro RoadTrip with FHWA TAF (Traffic Analysis Framework) O-D matrix (for 2040).

Estimating Entry SOC for “External Inbound” Trips

- FHWA TAF O-D (county-by-county LDT) + EVI-Pro RoadTrip

![Travel Distance (miles) Distribution](image)

![Total Driving Time (hours) Distribution](image)

![Total Charging Events Distribution](image)
Plug-In and Plug-Out SOC (State-of-Charge)

Charging Power as a Function of SOC

- 2020 Car - SR
- 2020 Car - LR
- 2020 SUV
- 2025 Car - SR
- 2025 Car - LR
- 2025 SUV
- 2030 Car - SR
- 2030 Car - LR
- 2030 SUV

First bending point
Second bending point (reference plug-out SOC)

Plug-in SOC
- 100% SOC
- Driving
- 0% SOC

Time to plug in
5 mile
5%

0-100% SOC
Charging Power (kW)
0 50 100 150 200 250 300 350
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

5 mile Plug-in SOC

Time to plug in
5%
0% SOC
Example Energy and Charging Simulation: External Trip

- Trip ID: 38212
- Traveling from the southern border to SF
- Approximately 520 miles
- Average MPH: 52 (excluding charging)
- Simulation year: 2030
- Vehicle: LR-Car
- MY: 2030

ATO (always top off); 1 rounds of charging for 30 minutes

TPM (time penalty minimization); 2 rounds of charging for 22 minutes
Example Energy and Charging Simulation: Intra-State Trip

- Trip ID: 7148
- Traveling from Joaquin to San Diego
- Approximately 470 miles
- Average MPH: 52 (excluding charging)
- Simulation year: 2030
- Vehicle: SR-Car
- MY: 2030

ATO (always top off);
3 rounds of charging for 57 minutes

TPM (time penalty minimization);
3 rounds of charging for 34 minutes
## Prioritized Preferred Sites for DCFC Stations

<table>
<thead>
<tr>
<th>Priority Group</th>
<th>Land Use Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Retail/shopping</td>
</tr>
<tr>
<td></td>
<td>Gas stations</td>
</tr>
<tr>
<td></td>
<td>Lodge</td>
</tr>
<tr>
<td>2</td>
<td>Airports</td>
</tr>
<tr>
<td></td>
<td>Port, train station</td>
</tr>
<tr>
<td>3</td>
<td>Urban park</td>
</tr>
<tr>
<td></td>
<td>General Park</td>
</tr>
<tr>
<td></td>
<td>Natural park</td>
</tr>
<tr>
<td></td>
<td>Off-highway vehicle staging area/trailhead</td>
</tr>
<tr>
<td></td>
<td>Motorized park</td>
</tr>
<tr>
<td></td>
<td>Entertainment (stadiums)</td>
</tr>
<tr>
<td></td>
<td>Designated recreation area</td>
</tr>
<tr>
<td></td>
<td>Campground/ranger station</td>
</tr>
<tr>
<td></td>
<td>Marina</td>
</tr>
<tr>
<td></td>
<td>Resort/ski area</td>
</tr>
<tr>
<td></td>
<td>Picnic/trailhead</td>
</tr>
</tbody>
</table>
Sensitivity Analysis Cases

- BEV type share (e.g., SUV-dominant).
- Battery size.
- Energy consumption rate (kWh/mile).
- Plug-in SOC (related to the radius of station service area or coverage).
- Plug-out SOC.
- kW-SOC curves.
- Ambient temperature and corresponding accessory load (e.g., heating).
- Potential sites for DCFC stations (e.g., gas station-centric).
- Station sizing – peak-hour plug utilization rate (e.g., 100% vs. 25%).
(What-If) Alternative Station Siting Strategy: Gas Station-Centric

- Existing gas stations can absorb/host around 70% of DCFC stations needed.
- Forcing gas stations for potential sites transforms the overall structure as well - for example, see how the share of retail/shopping centers changes.

**Final Station Sites by Land Use Types**

**Default Station Siting Strategy**

- Gas Stations
- Retail/shopping centers
- Natural park
- General park
- Highways, railways
- Airports (developed)
- Urban park
- Areas of Critical Env. Concern, Research Natural Area
- Campground/ranger station

**Gas Station-Centric Siting Strategy**

- Gas Stations
- Retail/shopping centers
- Natural park
- General park
- Highways, railways
- Airports (developed)
- Urban park
- Areas of Critical Env. Concern, Research Natural Area
- Campground/ranger station
Network-Wide Load Profiles (for Electrified Road Trips)

Network-wide Charging Load (MW) Profiles

- 2030 Baseline TPM
- 2030 Low TPM
- 2030 Baseline ATO
- 2030 Baseline TPM - BEV Range
- 2030 Baseline TPM - BEV Share (Equal)
- 2030 Baseline TPM - BEV Share (LDV Fleet)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Baseline TPM - Buffer (10 miles)
- 2030 Baseline TPM - ECR (High)
- 2030 Baseline TPM - ECR (Low)
- 2030 Baseline TPM - HVAC (@30F)
- 2030 Tesla V3-like

Preliminary results. Subject to review/change.
Load Profiles: Difference relative to 2030 Baseline TPM

Network-wide Charging Load (MW) Profiles: Difference (relative to 2030 Baseline TPM)

- 2030 Low TPM
- 2030 Baseline ATO
- 2030 Baseline TPM - BEV Range
- 2030 Baseline TPM - BEV Share (Equal)
- 2030 Baseline TPM - BEV Share (LDV Fleet)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Baseline TPM - Buffer (10 miles)
- 2030 Baseline TPM - ECR (High)
- 2030 Baseline TPM - ECR (Low)
- 2030 Baseline TPM - HVAC (@30F)
- 2030 Tesla V3-like

Preliminary results. Subject to review/change.
Load Profiles: Intra-Hour Variation

Intra-Hour Variation of Network-wide Charging Load (MW) Profiles

- 2030 Baseline TPM
- 2030 Low TPM
- 2030 Baseline ATO
- 2030 Baseline TPM - BEV Range
- 2030 Baseline TPM - BEV Share (Equal)
- 2030 Baseline TPM - BEV Share (LDV Fleet)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Baseline TPM - Buffer (10 miles)
- 2030 Baseline TPM - ECR (High)
- 2030 Baseline TPM - ECR (Low)
- 2030 Baseline TPM - HVAC (@30F)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Tesla V3-like

Preliminary results. Subject to review/change.
Load Profiles: Intra-Hour Variation (scaled by the first hour)

Intra-Hour Variation (scaled by the first hour) of Network-wide Charging Load (MW) Profiles

- 2030 Baseline TPM
- 2030 Low TPM
- 2030 Baseline ATO
- 2030 Baseline TPM - BEV Range
- 2030 Baseline TPM - BEV Share (Equal)
- 2030 Baseline TPM - BEV Share (LDV Fleet)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Baseline TPM - Buffer (10 miles)
- 2030 Baseline TPM - Buffer (10 miles)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Baseline TPM - Buffer (2 miles)
- 2030 Baseline TPM - ECR (High)
- 2030 Baseline TPM - ECR (Low)
- 2030 Baseline TPM - HVAC (@30F)
- 2030 Tesla V3-like

Preliminary results. Subject to review/change.
Required Number of Connectors for Electrified Road Trips by 2030
(Lower bound, based on 100% peak-hour plug utilization rate)

Preliminary results. Subject to review/change.