Planning for Electric Vehicles and Strategies for Managing Charging

Douglas Black¹, Jason MacDonald¹, and Michael Kintner-Meyer²

¹Lawrence Berkeley National Lab and ²Pacific Northwest National Lab

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Introduction and outline

- Why transportation electrification is important to electricity system planning
- Overview of electric vehicle (EV) technologies and EV charging
- Considerations for EV charging infrastructure from a grid planning perspective
- Investments in charging infrastructure
- Forecasting methods and improvements underway
- Load forecasting tools for EV charging
- Example of utility planning for transportation electrification
- Questions states can ask their utilities to ensure adequate planning for transportation electrification
- Resources for more information
- Q&A
Why is transportation electrification important for electricity system planning?

- If the number of EVs needed to meet greenhouse gas (GHG) reduction targets reach the road, GW of load will be created to charge those EVs.
- Forecasting that load is much more difficult, both spatially and temporally, than other loads such as commercial, residential, and industrial.
- EVs represent a large potential source of flexible load in the future and can be an important source for grid services.
- EVs could be the single biggest end use in homes:
  - Demand (kW): level 2 (6-12 kW)
  - Energy (kWh): 25% to 45% of residential annual energy*
- EV charging differs from other types of load growth.
  - By definition, transportation equipment — i.e., EVs — are mobile and location of charging is not fixed.
  - Charge power and energy needed/delivered can vary greatly between EVs and with the same EV.
  - Value of flexibility to the grid (e.g., smart charging) must compete with the more critical value of EV providing mobility.

*Assuming 12,000 miles annual driving at 4 miles/kWh and average customer total electricity use — NW: 22,000 kWh and CA: 7,000 kWh
EV technologies and applications

► Light-duty (personal) vehicles (LDV)
  ■ Current--sedans and small SUVs (battery: 24-100 kWh); plug-in hybrids, an EV with small gas engine (battery: 4-16 kWh)
  ■ Near future--light-duty trucks and mini-vans (battery: 24-100 kWh)

► Medium-duty vehicles (MDV)
  ■ Delivery vans, work trucks (battery: 90-150 kWh); currently limited availability
  ■ Near future—recent order by Amazon for 100K electric delivery vans

► Heavy-duty vehicles (HDV)
  ■ Transit buses (battery: 200-450 kWh); currently available and operating in relatively small numbers
  ■ Long-haul semi-trucks (battery: 500+ kWh)

► Future considerations
  ■ Increasing LDV battery sizes lead to different charging patterns, e.g. once a week or very little non-residence charging.
  ■ Autonomous vehicles enable greater charging control and scheduling, but may have less flexibility due to shorter non-activity periods.
### EV charging configurations and locations

- **Residential**: single-family homes, multi-unit dwellings, street
- **Workplace**: industrial, office, and education; single building and campuses
- **Public**: Street, commercial, transit centers (e.g. rail, airports)
- **Possible future inductive and in roadway charging** (less efficient; change charging patterns at fixed locations)

<table>
<thead>
<tr>
<th>Type of Charger</th>
<th>Power Supply/Output</th>
<th>Typical Charging Time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
<td>Uses a standard 120 V AC electric circuit. Output: 12-16 amps; ~1.44 kW to ~1.92 kW</td>
<td>8-10 hours depending on model; used for home charging 2-5 miles of range per hour of charging</td>
</tr>
<tr>
<td><strong>Level 2</strong></td>
<td>Uses a 208/240 V AC electric circuit. Output: 15-80 amps; ~3.1 kW to ~19.2 kW</td>
<td>4-8 hours; available at home and publicly 10-20 miles of range per hour of charging</td>
</tr>
<tr>
<td><strong>Level 3 DC Fast Chargers (DCFC)</strong></td>
<td>Uses a three-phase 480V AC circuit converted to direct current (DC) to the vehicle. Output: Up to 500 amps; 50 kW up to 350 kW</td>
<td>30-60 minutes 60-80 miles of range per hour of charging²</td>
</tr>
<tr>
<td><strong>Next gen: Extreme Fast Chargers (XFC)</strong></td>
<td>800 V Output: 400 kW or more</td>
<td>Time to charge to 200-mile range: approximately 7.5 minutes</td>
</tr>
</tbody>
</table>

## EV charging connectors and power ratings

<table>
<thead>
<tr>
<th>Connector Type</th>
<th>Power Rating</th>
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</thead>
<tbody>
<tr>
<td>SAE J1772 Type 1</td>
<td>1Ø 240V/7.68kW</td>
</tr>
<tr>
<td>IEC 62196-2 Type 2</td>
<td>3Ø 400V/12.8kW</td>
</tr>
<tr>
<td>GB/T 20234 AC</td>
<td>3Ø 380V/12.16kW</td>
</tr>
<tr>
<td>Tesla Supercharger</td>
<td>480V/140kW</td>
</tr>
<tr>
<td>GB/T 20234 DC</td>
<td>750V/187.5kW</td>
</tr>
<tr>
<td>CHAdeMO</td>
<td>500V/200kW</td>
</tr>
<tr>
<td>CCS Combo 1</td>
<td>600V/75kW</td>
</tr>
<tr>
<td>CCS Combo 2</td>
<td>1000V/200kW</td>
</tr>
</tbody>
</table>

[https://www.mdpi.com/1996-1073/12/19/3721/htm](https://www.mdpi.com/1996-1073/12/19/3721/htm)
Charging infrastructure ownership models

- **Funded**
  - Utility
  - Private
  - Public

- **Operated**
  - Utility
  - Private
  - Public
  - Private

- **Examples**
  - Duke Energy, CA Utilities
  - EVSE Rebate Program*
  - Utility-run RFPs
  - Automakers (Tesla, Volkswagen)
  - Charging Services/ EVSE OEMs
  - Office Buildings/Parks
  - Retail Chains
  - City/County Parking
  - Charging Services Company
  - Residential Pilot Programs*

*Rebate programs usually result in private ownership
States with approved utility ownership of EV infrastructure

U.S. utility filings on EV charging infrastructure

Source: BloombergNEF
Different ownership models for charging stations

► Utility-owned
  ■ **Pros:** speeds charger deployment, reduces installation costs, promotes equitable charger distribution and rates, minimizes negative grid impacts
  ■ **Cons:** can crowd out private investment, higher overall costs, slow to keep up with changing preferences

► “Make-ready” approach
  ■ Good compromise
  ■ Speed deployment
  ■ Increases electricity sales
  ■ Leverages private capital

Source: MJ Bradley & Associates and Georgetown Climate Center
Emerging ownership models for MDV/HDV applications

► Owned by fleet owner
► Leased from a third party
  ■ Charging station suppliers
  ■ Vehicle manufacturers
    • Tesla developing on-site Megacharger stations charged via solar
    • Chanje developing an "energy as a service" offering, providing a fully integrated EV infrastructure solution (used by FedEx)
    • Others include Rivian (used by Amazon) and Workhorse (used by UPS)
  ■ Vendors (e.g., Siemens, ABB, Amply)
    • Can step in with capital to manage part or all of charging system; create turn-key systems
    • Some specialize in optimizing charging which can be financially beneficial for fleets with little experience in this
  ■ Others
    • ChargePoint (nationwide network of chargers expanded to fleets)
    • eMotorWerks (SmartGrid-ready EV charging stations and grid management)
    • EVgo (EV fast charging stations for fleet partners)
EV infrastructure planning – Role of managed charging / utility rate design

- Utilities have implemented EV time-of-use (TOU) rates across U.S.
  - 43 utilities offer whole-home time-varying rates
  - 28 utilities offer EV-only rates using secondary meter
  - 5 utilities offer EV-only rate using submeter
  - 2 utilities use EV charger for submetering

- Example EV rates: PG&E EV-A
  - $0.13/kWh off-peak (12pm-7am)
  - $0.47/kWh on-peak (2pm-9pm)

  - Risk of significant EV loading spike at onset of off-peak → distribution system impacts. Staggering customers’ off-peak price can mitigate.

- PG&E Commercial EV rate replaces demand charges with a subscription

- Active Demand Response gives utility some direct control of charging when grid needs are dire, though few examples exist currently.
  - ~75% participation for early CA demand response pilots (opt-out)

Examples of effectiveness of TOU rates / managed charging

- **Maryland PC44**
  - Strain on local distribution systems from increased EV adoption mitigated by incentivizing off-peak charging through TOU rates or managed charging

- **Baltimore Gas & Electric EV TOU pilot (2015)**
  - Successfully shifted to off-peak charging

- **SDG&E’s EV-specific TOU pilot (2014)**
  - Shifted the majority of charging to “super off-peak” hours
  - Led the CPUC to mandate the state’s three IOUs to transition to default (or “opt-out”) TOU rates by 2019 or 2020

- **Arizona’s Salt River Project EV-specific TOU pilot (2018)**
  - TOU rates successfully pushed EV owners to charge during off-peak periods

- **SCE’s demand response program**
  - Customers received lower rates for slowing or stopping charging when demand hit a certain threshold, with curtailment events occurring up to 10 days a year
  - As a result, CPUC now requiring all new public Level 2 chargers built in CA to include demand response capabilities

- **PG&E and BMW’s i ChargeForward program (2015)**
  - Successfully curtailed on-peak charging and moved charging load to times that would help prevent curtailment of abundant renewable energy
EV infrastructure – Key issues for distribution planning

- WHEN (which year): EV adoption modeling
  - EV and EVSE cost and availability
  - Fuel prices
  - Local travel patterns / range anxiety
  - Sustainability (personal and public goals)
  - Neighbor-effect

- HOW MANY (which years): EV adoption modeling

- HOW (charging profiles): Some modeling
  - EVI-Pro (NREL)
  - PNNL (new for long-haul trucks)
  - Proprietary companies (for Tesla, Nissan)
  - Existing data from 10 years of historic data (how good are they for future profiles?)

- WHERE (in the service territory and in the distribution feeder):
  - Currently little available modeling; some survey (DTE)
EV adoption for personal vehicles

➤ EPRI (2017): projections from county level up using current trends
Regional distribution of EV sales in North America

Mostly due to strong sales in California

Passenger EV fleet over time

State share of total U.S. EV sales

EV outlook

Source: BloombergNEF, Marklines, Auto Alliance. Note: State sales breakdown based on 2018 market shares.
Subsidies are the most important policy driver in place right now

The federal tax credit is no longer available to Tesla or General Motors EV buyers.

State-level subsidies are less generous.

Source: BloombergNEF, Marklines, state governments
EV penetration projections and load forecasting (medium and heavy duty vehicles)

- California Air Resources Board’s Advanced Clean Trucks regulation requires an increasing share of trucks sold in the state to be zero emission starting in 2024, leading to a full transition to zero emission vehicles by 2045.

- CA banning new sales of gas cars by 2035*

- Assembly Bill 2127 calls for the California Energy Commission to project charging infrastructure needed to decarbonize trucking and to reduce the impact of diesel air pollution.


US EV forecast – all vehicle segments

Source: BloombergNEF. Note: Electric contains battery electric and plug-in hybrid. Fleet share values refer to 2040.
Load Profiling of EVs

- **LDV:** EVIPro (NREL: [https://afdc.energy.gov/evi-pro-lite](https://afdc.energy.gov/evi-pro-lite))
  - New research load profiling for EV shared mobility (US Davis)
- **MDV and HDV:** (PNNL: [https://www.pnnl.gov/news-media/influx-electric-vehicles-accelerates-need-grid-planning](https://www.pnnl.gov/news-media/influx-electric-vehicles-accelerates-need-grid-planning))

Source: NREL

**LDV Loadshapes at Ambient Temperatures of 25C**

**MDV**

- 1000 MDVs

**HDV**

- HLND: home – low – no delay
- HHND: home – high - no delay
- HHWD: home – high – with delay
- WLND: work – low – no delay
- WLWD: work – low – with delay

CAISO
Concepts of Charge Management

► Definition of flexibility
  ■ Temporal
  ■ Spatial

► Temporal methods to aggregate EVs (aggregator modeling)

Mobility planning impacts

- Mobility metrics* that can be applied to EV driving and charging activities
  - Energy consumption compared with traditional vehicles
  - Travel time with diverse route/charger selections
  - Cost associated with travel decisions, etc.

- Emerging trends of EV mobility planning
  - Coupling charging profiles with urban mobility*

*https://www.energy.gov/eere/articles/how-do-you-measure-mobility
*https://www.nrel.gov/docs/fy20osti/73579.pdf
*Planning for electric vehicle needs by coupling charging profiles with urban mobility, https://www.nature.com/articles/s41560-018-0136-x

Mobility patterns in the San Francisco bay area
Mobility planning impacts

- Emerging trends of EV mobility planning
  - **Optimize** whole-day travel/charging activities
Distribution planning for electrification of transportation

► **Key question:** When do I need to upgrade which circuit to which new load requirements, given all of the other changes in the distribution system (e.g., load growth, DER)?

► **Light-duty Vehicles**
  - Step 1: EV adoption projections on the map (e.g., understanding locational demographics and technology choices)
    - Outcome: number of vehicles and where they may be charged (default: home charging)
  - Step 2: Load profiling
  - Step 3: Power flow analysis
    - Input: new EV load, DER
    - Output: voltage violations, thermal load exceedance
  - Step 4: Mitigation strategies
    - EV flexibility (temporal, spatial)
    - DER (PV, storage, smart inverter)
    - Distribution upgrades (transformers, voltage controller/regulators, conductors)
Distribution planning for electrification of transportation (continued)

► MDV/HDV

■ Step 1: Survey by likely commercial/industrial EV adopters
  • Transit
  • Delivery (U.S. Postal Service, UPS, FedEx, etc.)
  • Any commercial/industrial with fleets

■ Step 2: Simple calculations of additional peak loads based on use-cases
  • Night charging at depot
  • Night charging somewhere
  • Day charging at Hubs

■ Step 3: Power flow analysis (same as for LDV)
  • Input: new EV load, DER
  • Output: voltage violations, thermal load exceedance

■ Step 4: Mitigation strategies
  • EV flexibility (temporal, spatial)
  • DER (PV, storage, smart inverter)
  • Distribution upgrades (transformers, voltage controller/regulators, conductors)
Questions States Can Ask (1)

Assuming that EVs are in your load forecast projections, how do you project growth of EVs for the following vehicle classes?

- **Light-Duty Vehicles [LDV] (cars, SUVs, vans, pick-up trucks)**
  - Based on state’s zero emission vehicle requirements, if they exist in your state?
  - Based on high, medium, low projections by industry organizations, consultants, government reports (e.g., EPRI, Bloomberg, EIA).
  - Based on your own or your consultants’ EV adoption modeling

- **Medium/Heavy-Duty Vehicles [M/HDV] (commercial truck and bus fleets)**
  - Based on industry report (e.g., Bloomberg)
  - Based on your surveys of selected customers with truck and bus fleets
  - Electric trucks/buses are NOT included in load projections. If not, why? Too difficult and/or not relevant?

What are your assumptions for the EV charging infrastructure and load profiles?

- **For LDV:**
  - Level 2 (6.6 kW or 12 kW) charging at home
  - Level 2 (12 kW) charging at work, public charging urban, or along corridors
  - Level 3 (50 kW+) charging at public charging stations

- **For M/HDV:**
  - Level 3 (50 kW DC): at fleet yard
  - DC charging (150 kW, 350 kW, 1+ MW) at fleet yard or along corridors
Questions States Can Ask (2)

► Given the choice of projected EV charging infrastructure, how might you estimate the additional EV load?
  ■ We use published charging profiles based on charging infrastructure projections
  ■ We are using only home charging
  ■ We estimate based on current and expected tariff structures
  ■ For fleet vehicles, we assume i) a fixed day/night schedule or ii) night-charging only

► For the distribution system planning process, how do utilities treat EV load?
  ■ EV loads are added to other load growth and DER assumptions (e.g., IRP projections).
  ■ Utilities develop several scenarios to address uncertainties in EV load growth (when and where it will occur) and smart charging management.
    ■ Near term planning (e.g., 5-10 year) considers trajectories to meet long-term (e.g., 30-year) policy goals.

► What are the key drivers for utility investment in EV infrastructure?
  ■ Utilities can rate-base investments in charging infrastructure.
  ■ EVs will increase kWh sales and utility revenue, potentially keeping down volumetric rates.
  ■ EVs will provide new opportunities for grid flexibility and renewable integration.
Resources for More Information


► NREL EV Load profiles: https://afdc.energy.gov/evi-pro-lite


► Department of Energy Alternative Fuels Data Center, https://afdc.energy.gov/fuels/electricity.html
  - Overview of EV and EVSE technologies, costs, benefits, incentives, and research

  - Compilation of CPUC’s work supporting EV and EVSE adoption, including that with IOUs
### States that have approved utility ownership of EV infrastructure

#### U.S. utility filings on EV charging infrastructure

<table>
<thead>
<tr>
<th>State</th>
<th>Utility</th>
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<tbody>
<tr>
<td>California</td>
<td>Liberty utilities</td>
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<tr>
<td></td>
<td>Pacific Gas and Electric Company (PG&amp;E)</td>
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<td></td>
<td>San Diego Gas &amp; Electric (SDG&amp;E)</td>
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<td></td>
<td>Southern California Edison (SCE)</td>
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<tr>
<td>Delaware</td>
<td>Delmarva Power &amp; Light Company</td>
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<tr>
<td>Florida</td>
<td>Duke Energy</td>
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<tr>
<td>Hawaii</td>
<td>Hawaiian Electric (HECO)</td>
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<tr>
<td>Kansas</td>
<td>Kansas City Power and Light Company (KCP&amp;L)</td>
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<tr>
<td>Kentucky</td>
<td>Louisville Gas and Electric Company and Kentucky Utilities Company (LG&amp;E and KU)</td>
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<tr>
<td>Maryland</td>
<td>Baltimore Gas and Electric Company (BGE)</td>
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<td></td>
<td>Delmarva Power &amp; Light Company</td>
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<td>Potomac Electric Power Company (PEPCO)</td>
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<td>Southern Maryland Electric Cooperative (SMECO)</td>
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<td>The Potomac Edison Company (PE)</td>
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<td>Massachusetts</td>
<td>Eversource Energy</td>
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<td>DTE Energy company</td>
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<td>Minnesota</td>
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<td>National Grid</td>
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<td>Orange and Rockland Utilities (O&amp;R)</td>
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<td>Rocky Mountain Power</td>
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<td>Washington</td>
<td>Avista</td>
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<tr>
<td></td>
<td>Potomac Electric Power Company (PEPCO)</td>
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</tbody>
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Source: BloombergNEF
EV adoption models

1) Simple modified exponential

\[ X(t) = X - X_0\left(1 - e^{-bt}\right) \]

Where:
- \( t \) is time,
- \( X \) is a measure of market penetration at time \( t \),
- \( X_0 \) is the saturation level,
- \( b \) is a growth function, and
- \( b \) is a shape function.

2) Logistic

\[ X(t) = \frac{a}{1 + e^{-bt}} \]

3) Gompertz

\[ X(t) = a e^{-b(e^{-ct})} \]

4) Bass

\[ N(t) = N_0 + \left(\frac{q}{m}\right) M(t) \]

\( p \) is the coefficient of innovation,
\( q \) is the coefficient of imitation,
\( M \) is maximum penetration,
\( N \) is cumulative sales in time, \( t \).
EV market trends: U.S.

Source: www.atlasevhub.com
Future of policies are uncertain

States supporting California’s zero-emission vehicle mandate

Source: BloombergNEF.

Share of total passenger vehicle sales in Zero-Emission Vehicle Mandate states

- ZEV states: 31%
- Potential ZEV states: 67%
- Other states: 2%

17 million vehicles sold.
New EV models drive growth

Source: BloombergNEF. Marklines
Electric vehicle charging outlets by state

Source: https://afdc.energy.gov/data/10366
## Truck classification

### Class 7/8 Tractors

- **Over the Road**
  - Younger Trucks; High Annual VMT
  - Mostly higher average speed, highway driving

- **Short Haul/Regional**
  - Between cities; Drayage; Day Cabs
  - Includes second use trucks; trucks with smaller engines

### Class 3-8 Vocational Work Trucks

- **Urban**
  - Cargo, freight, delivery collection
  - Lower VMT; Lower Average speed; Lots of stop start

- **Rural/Intracity**
  - Cargo, freight, delivery collection
  - Higher VMT; Higher Avg speed; Combined urban/highway

- **Work site support**
  - Utility trucks, construction, etc.
  - Lots of idle time; Lots of PTO use

### Class 2B/3

- **Pickups/Vans**
  - Commercial use; Automotive OEMs & volumes

Reference: California Hybrid, Efficient and Advanced Truck Research Center (CalHEAT) (2013). CalHEAT Research and Market Transformation Roadmap For Medium-And Heavy-Duty Trucks
Operator/aggregator communication and control methods

- **Aggregator objectives**
  - Ancillary service markets (regulation up & down) from California Independent System Operator
  - Proxy demand resources (PDR) market integration
  - Time-of-use (TOU) program with energy charge and demand charge
  - Peak-day pricing (PDP) program
  - Demand bid program (DBP)

- **Individual EV constraints**
  - Energy constraint
  - Time schedule constraint

- **Distributed control strategies**
  - Allocate day-ahead bids to each EV in a distributed fashion
  - Preserve privacy among EV drivers

https://www.sciencedirect.com/science/article/pii/B978012816457000165