EV Charging
Infrastructure Analysis

January 2022
Outline

• What’s all the fuss about?
• Better than gasoline
• Show me the money!
• Measure twice, cut once
• 30 x 30
• Heavy-duty electrification
• Challenges and opportunities remain
The U.S. Transportation Sector

- Light duty passenger vehicles cause 58% of sector emissions...
- While med/heavy duty trucks are 2nd highest at 20%
Increasing Demand for EVs

2021: ~2m EVs in operation

Source: DOE ANL, Green Car Reports

2030: 30m EVs in operation*

Source: DOE ANL, Green Car Reports
Vehicle Technology

BEV Sedan
BEV CUV/SUV
BEV Pickup
BEV Van

PHEV Sedan
PHEV CUV/SUV
PHEV Pickup
PHEV Van
FACT SHEET: The Bipartisan Infrastructure Deal Boosts Clean Energy Jobs, Strengthens Resilience, and Advances Environmental Justice
The Bipartisan Infrastructure Deal will invest $7.5 billion to build out the first-ever national network of EV chargers in the United States.

A critical element in the Biden-Harris Administration’s plan to accelerate the adoption of EVs to address the climate crisis and support domestic manufacturing jobs.

Provide funding for deployment of EV chargers along highway corridors to facilitate long-distance travel and within communities to provide convenient charging where people live, work, and shop.

Funding will have a particular focus on rural, disadvantaged, and hard-to-reach communities.
Sec. 11401 - Grants for Charging and Fueling Infrastructure for Corridors and Communities

- $2.5B for Alternative Fuels (EV, CNG, LNG, LPG, H2)

National Electric Vehicle Formula Program

- $5.0B for EV Corridors

Joint DOT/DOE Deployment Support Program to provide tools & technical assistance to funding recipients
Better than Gasoline

• Goals of a national charging network
  – Convenient, Affordable, Reliable, Equitable

• What should this network look like?
  – Lots of perspectives
    • Gas station scenario
    • EV happy hour
    • Home dominant

Key Stakeholders

- Current and Future EV drivers
  Understand and anticipate needs

- Auto OEMs
  Stimulate EV adoption

- EVSPs
  Support sustainable growth

- Site Hosts
  Enable charging as an amenity

- Electric Utilities
  Well-integrated with the grid
Charging Networks: Design Concepts

Coverage vs. Capacity
Establish coverage, then build capacity.

Terminology
Station = Charging Location
Port = Can Charge One EV at a Time
Connector = One or More per Port

Corridors vs. Communities
- Corridor needs are relatively small, but expensive and critical for adoption.

Home Charging is Foundational
- Today, most EVs do most of their charging at home.
- In the long-term, we expect the share of EVs without home charging to increase.
Charging Behavior Assumptions

- Traditional approach assumes a pyramid structure to charging behavior
  - Maximize use of charging at home/work and complement with public charging as necessary
  - Take advantage of long dwell time opportunities for inexpensive slow charging
  - Rely on expensive fast charging as necessary (long trips, emergencies, etc.)

**EVSE Terminology**

https://afdc.energy.gov/fuels/electricity_infrastructure.html

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**Charging Equipment**

Charging equipment for PEVs is classified by the rate at which the batteries are charged. Charging times vary based on how depleted the battery is, how much energy it holds, the type of battery, and the type of charging equipment (e.g., charging level and power output). The charging time can range from less than 20 minutes to 20 hours or more, depending on these factors. Charging the growing number of PEVs in use requires a robust network of stations for both consumers and fleets.

For information on currently available charging infrastructure models, see the Electric Drive Transportation Association's [GoElectricDrive website](https://goelectricdrive.org) and [Plug In America’s Get Equipped resource](https://pluginamerica.org), which include information on charging networks and service providers. When choosing equipment for a specific application, many factors, such as networking, payment capabilities, and operation and maintenance, should be considered.

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**Level 1 Charging**

- **2 to 5 miles of range per 1 hour of charging**
- J1772 connector
- *Alternating Current (AC) Level 1 equipment* (often referred to simply as Level 1) provides charging through a 120 volt (V) AC plug. Most, if not all, PEVs will come with a Level 1 cordset, so no additional charging equipment is required. On one end of the cord is a standard NEMA connector (for example, J1772) which is compatible with all Level 1 charging stations.

**Level 2 Charging**

- **10 to 20 miles of range per 1 hour of charging**
- J1772 connector
- AC Level 2 equipment (often referred to simply as Level 2) offers charging through 240 V (typical in residential applications) or 208 V (typical in commercial applications) electrical service. Most homes have 240 V service available, and because Level 2 equipment can charge a typical PEV battery to 90% state of charge (SOC) in 1.5 to 2 hours.

**DC Fast Charging**

- **60 to 80 miles of range per 20 minutes of charging**
- CCS connector, CHAdeMO connector, Tesla connector
- *Direct-current (DC) fast charging equipment* (typically 208/480 V AC three-phase input) enables rapid charging along heavy traffic corridors at installed stations. As of 2020, over 13% of public EVSE ports in the United States were DC fast chargers.
## Electric Vehicle Charging Standards

<table>
<thead>
<tr>
<th>Diagram</th>
<th>Standard</th>
<th>Maximum Output Power</th>
<th>Application Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="SAE%20J1772.png" alt="Diagram" /></td>
<td>SAE J1772</td>
<td>19.2 kW AC</td>
<td>Used for Level 1 and Level 2 charging in North America. Commonly found on home, workplace, and public chargers.</td>
</tr>
<tr>
<td><img src="CCS-1.png" alt="Diagram" /></td>
<td>CCS-1</td>
<td>450 kW DC</td>
<td>Used for DC fast charging most vehicle models in North America. Generally installed at public chargers.</td>
</tr>
<tr>
<td><img src="CHAdemo.png" alt="Diagram" /></td>
<td>CHAdeMO</td>
<td>400 kW DC</td>
<td>Used for DC fast charging select vehicles models in North America. Generally installed at public chargers.</td>
</tr>
<tr>
<td><img src="Tesla.png" alt="Diagram" /></td>
<td>Tesla</td>
<td>22 kW AC 250 kW DC</td>
<td>Used for both AC and DC fast charging for Tesla models only.</td>
</tr>
<tr>
<td><img src="J3068.png" alt="Diagram" /></td>
<td>J3068</td>
<td>166 kW AC 450 kW DC</td>
<td>Standard for both AC and DC charging utilizing the IEC 61851 ‘type 2’ connector for North America three-phase charging</td>
</tr>
<tr>
<td><img src="SAE%20J2954.png" alt="Diagram" /></td>
<td>SAE J2954</td>
<td>22 kW light-duty 200 kW heavy duty</td>
<td>Wireless power transfer. Standard for MD/HD vehicles is under development.</td>
</tr>
<tr>
<td><img src="SAE%20J3105.png" alt="Diagram" /></td>
<td>SAE J3105</td>
<td>&gt;1 MW</td>
<td>Automated connection device to charge MD/HD vehicles. Variants include pantograph up or down and pin-and-socket.</td>
</tr>
<tr>
<td><img src="Chaoji.png" alt="Diagram" /></td>
<td>Chaoji</td>
<td>900 kW DC</td>
<td>Conductive charging for sub-MW charging of LD/MD/HD vehicles in Asia. Standard is under development.</td>
</tr>
<tr>
<td><img src="CharIN%20MCS.png" alt="Diagram" /></td>
<td>CharIN MCS</td>
<td>4 MW</td>
<td>Conductive MW-level charging for MD/HD vehicles. Standard is under development.</td>
</tr>
</tbody>
</table>

Table modified from "Assembly Bill 2127 Electric Vehicle Charging Infrastructure Assessment (Staff Report), CEC 2021"
Existing US Deployment

<table>
<thead>
<tr>
<th>EVSE Type</th>
<th>Stations</th>
<th>EVSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public DCFC</td>
<td>4,105</td>
<td>8,048</td>
</tr>
<tr>
<td>Tesla DCFC</td>
<td>1,068</td>
<td>10,554</td>
</tr>
<tr>
<td>Total DCFC</td>
<td>5,173</td>
<td>18,602</td>
</tr>
<tr>
<td>Public L2</td>
<td>34,267</td>
<td>70,828</td>
</tr>
<tr>
<td>Tesla L2</td>
<td>4,439</td>
<td>14,686</td>
</tr>
<tr>
<td>Total L2</td>
<td>38,706</td>
<td>85,514</td>
</tr>
<tr>
<td>Total Overall</td>
<td>43,879</td>
<td>104,116</td>
</tr>
</tbody>
</table>

- National Highway System
- FHWA Alt Fuel Corridor (EV Ready)
- Interstate System
- 4,105 Public DCFC Stations
- 1,068 Tesla Supercharger Stations*
  * Superchargers typically support 150-250kW per port

DOE AFDC Station Locator
(June 23, 2021)
Idaho: By the numbers

- ~2M LDVs
- ~1,000 gas stations
- ~6,000 PEVs
- ~100 public charging stations
- ~260 public charging ports

Source: DOE AFDC Station Locator (Jan 25, 2022)
Regression analysis was used to quantify the existing volume of infrastructure with respect to vehicle registration data.

Results indicate that L2 public charging is being installed at a rate of 40 ports per 1000 PEVs and public DCFC charging is being installed at a rate of 5 ports per 1000 BEVs.

Retail locations are the most common for public charging with 20-40% of public L2 installations and 60-70% of public DCFC installations occurring at retail facilities.

Supply of infrastructure tends to lead demand for public charging
Low-cost installations are tempting in the short-term, but not financially viable in the long-term

- Simulation study in Columbus, OH using data from the local electric utility (AEP)
- Priority should be placed on siting fast charging at locations with high potential utilization
- Such sites are likely to include urban cores, transit hubs, and airports
Utilization is key and it’s currently too low for profitability

- Charger station utilization data generally not available (company confidentiality concerns)
- Many networks at most public stations achieve only single digit utilization
- Electrify America average utilization on highways is less than 4%, or below 1 hour daily of EV charging!
- RMI* cites a utilization level of 30% before costs can be sufficiently amortized to realize profitability
- And yet, queuing is predicted to begin ~20% utilization rate** (or nearly 5 hours a day of charging)

* RMI study, DCFC Rate Design, 2019
** PWC, Electric vehicles and the charging infrastructure: a new mindset? 2021
Modern Fast Charging Stations can exceed $1M CapEx

- Equipment costs relatively predictable, but installations are very site-specific
- Future trends
  - Manufacturing scale
  - Installation learning curve
  - Site scarcity

<table>
<thead>
<tr>
<th>Charger Hardware</th>
<th>Unit cost per port</th>
<th>Installation cost per port</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2 commercial [7.2 kW]</td>
<td>low: $1,600 mid: $2,600 high: $4,100</td>
<td>low: $1,300 mid: $2,800 high: $4,800</td>
</tr>
<tr>
<td>DC 50 kW</td>
<td>low: $22,000 mid: $29,000 high: $36,400</td>
<td>low: $11,200 mid: $24,000 high: $39,800</td>
</tr>
<tr>
<td>DC 150 kW</td>
<td>low: $63,700 mid: $81,500 high: $100,000</td>
<td>low: $34,300 mid: $67,800 high: $131,100</td>
</tr>
<tr>
<td>DC 350 kW</td>
<td>low: $112,000 mid: $130,500 high: $142,000</td>
<td>low: $52,400 mid: $93,400 high: $135,500</td>
</tr>
</tbody>
</table>

Sources: NREL, RMI, BNEF, ICCT
The costs of permitting delays, lengthy utility interconnections, compliance with a mosaic of regulations, and the reengineering of projects because they were based on incorrect information...were frequently cited as more significant cost drivers than charging station hardware. These irregular and unplanned circumstances can add significant costs due to design rework, construction delays...

Electrify America’s Q2 2021 annual report to CARB cited:
- CA permits should take 15 days by law but average 79 days
- Utility interconnect process takes 273 days whereas site construction only assumes 21 – 28 days!

EV charging can benefit from installation streamlining, just as solar did a decade ago; soft costs comprised 64% of total deployment cost.

* 2019 RMI study – Reducing EV Infrastructure Costs, Chris Nelder & Emily Rogers
Charging deployment is often slowed by local permitting processes that vary widely

According to EVSE providers, the permitting process for DCFC stations is lengthy and fraught with delays due to unfamiliarity with the technology, protracted zoning reviews, and undefined requirements for permitting DCFC…In some extreme instances, station developers have withdrawn permit applications and found new charging station sites in neighboring towns.

DCFC charging permitting problems

- Lack of knowledge or standardized process
- Subject to zoning and design reviews, even hearings oftentimes, when charging should be an accessory to the primary use of site
- EV charging parking doesn’t count in minimum needed by zoning
- Permit desk visit or mail in process required
- AHJs lack DCFC expertise, don’t have FAQs

Source: NESCAUM study, 2019

Even California, with more charging sites than any other state and AB1236 (which requires local jurisdictions to issue an EVSE permit within 15 days unless a health or safety violation is imminent) has had slow permitting approvals that can take 6 – 12 months or more.
Utility demand charges help balance grid supply, but load factor differences penalize DC fast charging

- Demand charges are a key tactic used by utilities to encourage consistent consumption and avoid peak power swings.
- Demand charges were initially developed for large and stable load consumers such as buildings and factories.

Consistent kw and kwh delivered with fewer spikes – demand charges more easily avoided

High kw and kwh delivered over shorter time period, intermittently – demand charges cannot be avoided!
Demand charges translate into staggering kwh costs and cannot be passed on to drivers

EVgo Utility Bill

Electrify America blended kwh gasoline equivalent costs

<table>
<thead>
<tr>
<th>Actual 2020 Bill Example</th>
<th>State</th>
<th>Cost per kWh, $</th>
<th>Equivalent gas cost, $/gal**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brigham City</td>
<td>UT</td>
<td>8.55</td>
<td>60.83</td>
</tr>
<tr>
<td>Kentucky Utilities</td>
<td>KY</td>
<td>3.36</td>
<td>23.91</td>
</tr>
<tr>
<td>Duck River</td>
<td>TN</td>
<td>2.85</td>
<td>20.29</td>
</tr>
<tr>
<td>PSEG</td>
<td>NJ</td>
<td>2.55</td>
<td>18.16</td>
</tr>
<tr>
<td>Oregon Trail Coop</td>
<td>OR</td>
<td>2.19</td>
<td>15.61</td>
</tr>
<tr>
<td>Toledo Edison</td>
<td>OH</td>
<td>2.04</td>
<td>14.50</td>
</tr>
<tr>
<td>Dominion</td>
<td>VA</td>
<td>2.02</td>
<td>14.35</td>
</tr>
<tr>
<td>Indianapolis P&amp;L</td>
<td>IN</td>
<td>1.65</td>
<td>11.76</td>
</tr>
</tbody>
</table>

Several studies cite concerns with demand charges and recommend rate reform...

EVgo’s monthly bill shows a kwh rate of 17.8 cents/kwh (compared with PG&E residential baseline rate of 11.9 cents) and a blended cost of $1.61/kwh!

Source: Electrify America and EVgo

As an alternative to demand charge elimination, utilities can consider incentivized storage* on/offsite (charging site operator either funds storage to peak shave and to provide grid services on site or taps into larger utility scale storage – both at lower price premium than demand charges)

* SMUD reference
Technology Solutions

Energy and demand charges as well as the technology recommendation vary geographically.

**Technology solutions** can be leveraged to reduce cost of electricity for stations that experience higher electricity costs:

- Energy storage (battery) can mitigate high **demand charges**
- Photovoltaic (PV) energy can mitigate high **energy charges**, even in areas with lower solar irradiance (e.g., Vermont)
EVI-X: Tools for Forward-Looking Analysis

Network Planning Tools
How many ports? What kind? Where?

Site Design Tools
Station sizing, on-site storage, load profiles

Network Planning

- EVI-Pro
  - Charging infrastructure projection based on typical daily travel
- EVI-OnDemand
  - Charging infrastructure demand modeling for ride-hailing services
- EVI-Pro Lite
  - Simplified version of EVI-Pro (free to use)
- EVI-RoadTrip
  - Charging infrastructure analysis for long-distance travel
- EVI-Equity
  - Charging infrastructure accessibility from environmental-justice perspective
- EVI-Pro HD
  - Depot and corridor charging infrastructure projection for commercial vehicles

Electric Vehicle Charging Infrastructure Analysis
NREL’s EVI-X Modeling Suite

- EVI-Fleet
  - Operational and economic analysis for fleet electrification
- EVI-InMotion
  - Dynamic and quasi-dynamic charging infrastructure design
- EVI-EnSite
  - Charging infrastructure energy estimation and site optimization
- EnStore
  - Techno-economic evaluation of behind-the-meter storage
- HEVII
  - Multi-fidelity telematics-enabled vehicle and infrastructure design

Network & Station Economics
Levelized cost of charging

Input Data Requirements
- Future EV Fleet Size Scenarios
- EV/EVSE Tech Attr & Cost
- Driver Demographics & Land Use
- Mobility Data or Scenarios (e.g., TEMPO)
- Residential Access & Charging Behavior
- Utility Rates & Local Hosting Capacity
NREL Charging Infrastructure Analysis Capabilities

... it’s all about the PEOPLE!

Ahmed Mohamed  Nick Reinicke  Andrew Kotz  Catherine Ledna
Alicia Birky  Brennan Borlaug  Matteo Muratori  Partha Mishra  D-Y Lee  Eric Miller
Eric Wood  Steve Lommele  Chris Neuman  Johanna Levene  Andrew Meintz  Matt Moniot
The EV Infrastructure Projection Tool

Simulation model to:
• Estimate charging demand from EVs
• Design supply of infrastructure

Informed by real-world data and integrated with models of vehicle adoption, mobility, station economics, and the grid

Originally developed through collaboration with the California Energy Commission and since applied at the city-, state-, and national-level

Spatial distribution of demand in San Francisco (co-sim with LBNL BEAM)

2030 CA Statewide Charging Load (sim)
Travel Demand
Daily Driving

- Detailed driving data necessary to anticipate EV energy use and opportunities for charging
- Charging at home and work provide the most promising opportunities
  - Frequent visits for long durations
- Use of travel survey data assumes future PEV use conforms to historical precedent
  - Alternate vehicle use scenarios can be tested using sensitivity analysis

*Other includes:
- General errands
- Buy services
- Exercise
- Recreational activities
- Health care visit
- Religious or other community activities
- Work-related meeting / trip
- Volunteer activities (not paid)
- Work from home (paid)
- Attend school as a student
- Change type of transportation
- Attend child care
- Attend adult care
Driving / Charging Simulations

Travel Data

<table>
<thead>
<tr>
<th>Departure</th>
<th>Arrival</th>
<th>Destination</th>
<th>Driver A</th>
<th>Driver B</th>
<th>Driver C</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:00 AM</td>
<td>7:45 AM</td>
<td>Public</td>
<td>None</td>
<td>None</td>
<td>Public DCFC</td>
</tr>
<tr>
<td>9:30 AM</td>
<td>10:30 AM</td>
<td>Public</td>
<td>None</td>
<td>Public L2</td>
<td>None</td>
</tr>
<tr>
<td>12:45 PM</td>
<td>3:00 PM</td>
<td>Public</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>4:00 PM</td>
<td>5:00 PM</td>
<td>Home</td>
<td>Home L2</td>
<td>Home L2</td>
<td>None</td>
</tr>
</tbody>
</table>

Simulated Charge Events

Charging demand to satisfy travel

Sample Vehicle / Infra Assumptions:
- 250-mile BEV
- DCFC = 150kW
- L2 = 7.2kW

Sample Choice / Access Assumptions:
- Charge every night, home dominant
- Plug-in only if needed, even at home
- No home-charging, reliant on public infrastructure

Driving, Charging Simulations
• As electric vehicle adoption progresses, **residential charging access among electric vehicle owners is likely to decrease (as a %)** and become more uncertain.

• Residential access among **multi-family properties presents the greatest challenges**.

• Single family homes may dominate the light-duty vehicle stock, however residential access at these properties is not a given.

• Many opportunities exist for improving residential access across all property types.

• **Tradeoffs exist between residential and public infrastructure investments.**
Recent EVSE Utilization
Jan 2016 to March 2020

- EVSPs have provided NREL with event-level data from networked L2 and DCFC units across the U.S.
- Highly utilized DC stations currently serving more than 10 daily charge events

<table>
<thead>
<tr>
<th></th>
<th>U.S. (incl CA)</th>
<th>CA only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station Count</td>
<td>3,036</td>
<td>1,151</td>
</tr>
<tr>
<td>Plug Count</td>
<td>6,372</td>
<td>3,524</td>
</tr>
<tr>
<td>Unique ZIP Codes</td>
<td>1,703</td>
<td>529</td>
</tr>
<tr>
<td>Individual Charge Events</td>
<td>~7.2M</td>
<td>~5.2M</td>
</tr>
</tbody>
</table>

*2017 Q3 intentionally omitted (inconsistent reporting)
EVI-Pro Lite

Charging Need
Launched 2018

Load Profile
Launched 2020

afdc.energy.gov/evi-pro-lite
Objective: Make analytic capabilities of EVI-Pro model accessible to broad group of stakeholders for EVSE investment decisions.

Approach: Develop a simplified, web-based interface for EVI-Pro that gives users access to a limited number of critical input variables.

Significance & Impact

• EVI-Pro “unlocks” an unlimited number of scenarios for planners to explore regarding EV charging infrastructure requirements.

• Since its launch, 6,000 users have viewed 14,000 pages on the tool, spending almost 4 minutes per visit.

afdc.energy.gov/evi-pro-lite
Waymo starts to open driverless ride-hailing service to the public

Kirsten Korosec  @kirstenkorosec  /  10:31 AM MDT • October 8, 2020

Waymo

Waymo
“30 by 30”
Charging Infrastructure Supporting 30M Electric Vehicles by 2030

Brennan Borlaug, Dong-Yeon (D-Y) Lee, Matt Moniot, Fan Yang, Yanbo Ge, and Eric Wood
PEV Registration Shares – 2030 Scenario w/ 30M PEVs

Ranges from 1.1% -> 47.8% PEVs

Bubble size and color represent the PEV share of LDVs per core-based statistical area (CBSA); State color represents the PEV share of LDVs in state rural areas.
2030 Typical daily road trips: 2,354,000

2030 Typical daily BEV road trips: 268,000 (about 1% of the BEV fleet)
# EVI-X Modeling for Idaho (preliminary results)

## 2025
- **Total PEVs:** 20,231 (currently 5,980 in ID)
- **PHEV share of PEVs:** 37% (currently 41% in ID)
- **PEV share of veh regs:** 1.2% (currently 0.3% in ID; simulated 2025 U.S. share: 2.8%)
- **Share of PEV owners w/ access to home charging:** 98% (simulated 2025 U.S. avg.: 93%)

- **Total 2025 EVSE Ports (work L2; public L2; public DCFC):** 1,123 (354; 282; 487)
- **Share of 2025 EVSE ports in Boise, ID:** 39% (54% of PEVs located here)

## 2030
- **Total PEVs:** 149,825
- **PHEV share of PEVs:** 12% (simulated 2030 U.S. share: 10%)
- **PEV share of veh regs:** 7.8% (simulated 2030 U.S. share: 11.5%)
- **Share of PEV owners w/ access to home charging:** 91% (simulated 2025 U.S. avg.: 83%)

- **Total 2030 EVSE Ports (work L2; public L2; public DCFC):** 4,253 (2,398; 559; 1,296)
- **Share of 2030 EVSE ports in Boise, ID:** 48% (47% of PEVs located here)
Transit Bus Electrification

- Transit authorities have been early adopters of heavy-duty EVs
- High-VMT, fixed route operation tends to be ideal for electrification
- Allows fleets to take advantage of EV low operating costs
- Predictable schedule alleviate the need for fast charging
NREL-Hosted Event Supports Industry Development of Megawatt Charging System Connectors
Oct. 12, 2020

Tesla Semi prototype spotted in Chicago, IL
Tesla is deploying the first Megacharger to charge its Tesla Semi electric truck

Fred Lambert - Oct. 12th 2021 2:05 pm PT @FredericLambert
• Simulations used to estimate future demand for heavy-duty charging
  • Includes mix of slow charging at overnight locations and fast charging along freight corridors

• Investment needed per port expected to far exceed that of light-duty vehicles
  • Potential for significant grid impacts at depots and travel centers
“This is about more than just up-time. Charging standards are such that compliant vehicles and infrastructure can still be inoperable. This is where Tesla has a real advantage. They control both sides of the handshake.”

“Driver tolerance for inconvenience is very low. Even one negative experience waiting in line or finding a broken charger can sour the user experience.”

“If someone struggles to charge and they can't - they blame us (auto OEM). Success rate of a customer plugging in at a public station today is abysmal. Auto OEMs cannot play this role long term.”
Interoperability

- **Interoperability** refers to the ability to use a charging network membership at other networks’ stations (“roaming”). Although every major charging network signaled interoperability intent before 2020, it is only enabled through two agreements which may become consolidated “soon”.

- The benefit of interoperability is the reduced need for multiple plastic charging cards or charging apps (a frequent and longstanding complaint by EV drivers).

- Until such time interoperability becomes ubiquitous, other approaches such as credit card readers, like gas station, are likely needed.

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**Current Agreements**

- Greenlots
- EV Connect
- ChargePoint
- EVgo

**Coming Soon?**

- Sema Connect
- Electrify America
- Blink
- Greenlots
- EV Connect
- FLO
- ChargePoint
- EVgo

Notes: Largest networks in **bold**
- Electrify America absent
- Blink absent
Even the top DC fast charging networks need big quality improvements

“If EVs are to replace fossil-fuel vehicles, they need to be able to make long highway trips, which means that DC fast charging needs to be reliable, convenient, affordable and ubiquitous...[but] the user experience often leaves much to be desired...”

<table>
<thead>
<tr>
<th>Category</th>
<th>Electrify America</th>
<th>EVgo</th>
<th>ChargePoint</th>
<th>EVconnect</th>
</tr>
</thead>
<tbody>
<tr>
<td>App &amp; Website</td>
<td></td>
<td></td>
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<td>Website</td>
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<td>App Operation</td>
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<td>105</td>
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<td>App Functionality</td>
<td>97</td>
<td>83</td>
<td>98</td>
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<td>Price &amp; Payment</td>
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<td>89</td>
<td>97</td>
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<td>Sub–Total</td>
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<td>338</td>
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<td>Charging Location</td>
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<tr>
<td>Environment</td>
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<td>Charging Station</td>
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<td>Service</td>
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<td>61</td>
<td>65</td>
<td>47</td>
</tr>
<tr>
<td>Access &amp; Payment</td>
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<td>38</td>
<td>36</td>
<td>58</td>
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<tr>
<td>Sub–Total</td>
<td><strong>347</strong></td>
<td>285</td>
<td>266</td>
<td><strong>303</strong></td>
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<tr>
<td>Total Score (Out of 1000)</td>
<td><strong>691</strong></td>
<td><strong>610</strong></td>
<td><strong>604</strong></td>
<td><strong>566</strong></td>
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</table>

Although Electrify America won this 202 test with 691 points/1000 (C-score?), key customer issues include:
- Relatively high prices
- Starting problems and interruptions
- No QR code scanning for station ID
- Short cables make it difficult to reach EV charging ports
- Site designs don’t accommodate large vehicles

Source: Charged EV Magazine, Dec 2020
Site Design Best Practices

• Location, location, location
• Consider need for “future proofing”
• Anticipate technology evolution
• Use on-site storage/generation to mitigate operating costs
• Provide multiple, interoperable payment options
• Incentivize data sharing to help grow the network
• Emphasize importance of reliability
Neighborhood-Level Analysis: Refueling Infrastructure

Greater Chicago Area

Broader context: IL is one of the top 10 states that have the worst equity of refueling infrastructure and PEV adoption in terms of income and race.

Income and race maps are overlayed. If you see red areas, they are the ones with low-income and/or (higher share of) people of color.

- Public DCFC
- Public L2
- Gas station
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- **HH Income**
  - High
  - Low

- **People of Color**
  - Low
  - High

**Maps Symbols**:
- Public DCFC
- Public L2
- Gas station
Decarbonization of the power sector means EVs keep getting greener as they age.

Managed charging is an enabling technology to help the grid operate efficiently and lower the carbon intensity of EV charging.
Growing a Charging Network from the Ground Up

Charging Network of the Future

The Roots: Home Charging
(single family, apartments, curbside)

The Trunk: Fast Charging
(corridors and retail)

The Branches: Destination Charging
(right speeding at offices, recreation, dining, etc.)

Yesterday
Today

Public Network
Private Network
EV Analysis Takeaways

1. Data, Data, Data
2. Understand Coverage Needs
3. Bridge the “Valley of Death”
4. Evaluate the Potential for Residential Charging
5. Value of “Lite” Tools
6. Emerging Mobility Options (short term)
7. Role of Automation (long term)
Thanks! Questions?

www.nrel.gov