# Vehicle charging technology and electric vehicle supply equipment

ECI 189G: Lecture 6

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# Gasoline versus electric refueling

# Nomenclature

Charger/Electric Vehicle Supply Equipment (EVSE)

Connector/Plug

Charging Station

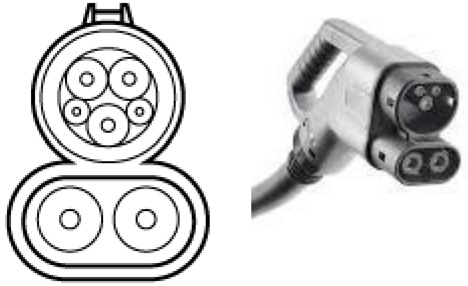
# Types of charging connectors

**Level 1 and 2**

J1772

**DC Fast**

CHAdeMO



CCS

Tesla

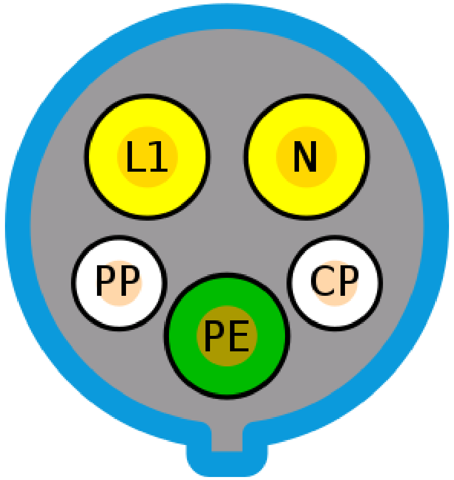
- Level 1: up to 1.1 kW – about **5-6 miles per hour**
- Level 2: up to 20 kW (but mainly 6, 6.6, or 7.2 kW) – about **25-30 miles per hour**
- DC fast charging: 50-400 kW (but mainly 50 kW or 120 kW) – between **150 to 300 miles per hour**

# Charging standards: SAE J1772

- The Society of Automotive Engineers (SAE) is a professional association and develops standards for a variety of equipment
- SAE J1772 is the interface standard for plugging into an electric vehicle
- Accommodates both Level 1 and Level 2 charging

# Level 1 and 2 (and 3)

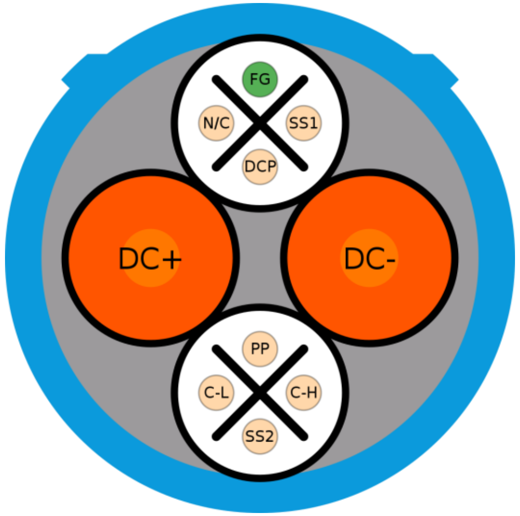
- L1 – AC Line 1
- N – Neutral for Level 1, AC Line 2 for Level 2
- PE – “Protective Earth” (ground)
- PP – “Proximity Pilot”, indicates that the plug is present (prevents vehicle from moving)
- CP – “Control Pilot”, communication between vehicle and EVSE

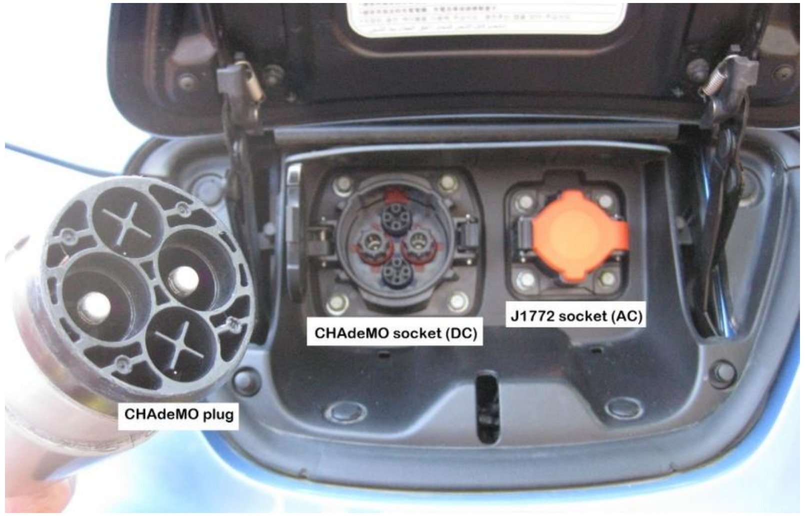



| Charge method | Voltage, AC (V) | Phase | Max. current, continuous (A) | Branch circuit breaker rating (A)[a] | Max. power (kW) |
|---|---|---|---|---|---|
| AC Level 1 | 120 | 1-phase | 12 or 16 | 15 or 20 | 1.44 or 1.92 |
| AC Level 2 | 208 or 240 | 1-phase | 24–80 | 30–100 | 5.0–19.2 |
| AC Level 3[b] | 208–600 | 3-phase | 63–160 | 80-200 | 22.7–166 |

# Charging standards: CHAdeMO

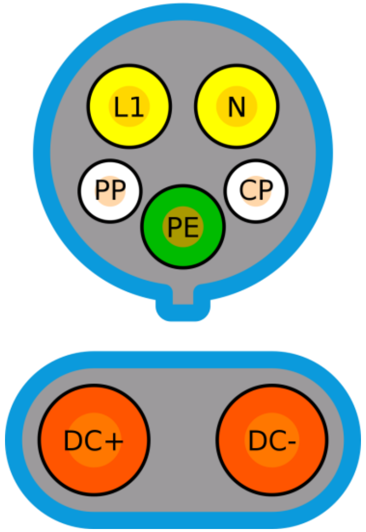
- CHAdeMO additional elements include:
  - FG: ground
  - SS1/SS2: start/stop charging signal sequence
  - N/C: not connected
  - DCP: vehicle grants permission to connect power
  - DC+/DC-: DC power flow
  - C-H/C-L: communication protocol between vehicle
- CHAdeMO is built to be capable of vehicle discharge (allowing vehicle-to-grid interactions)



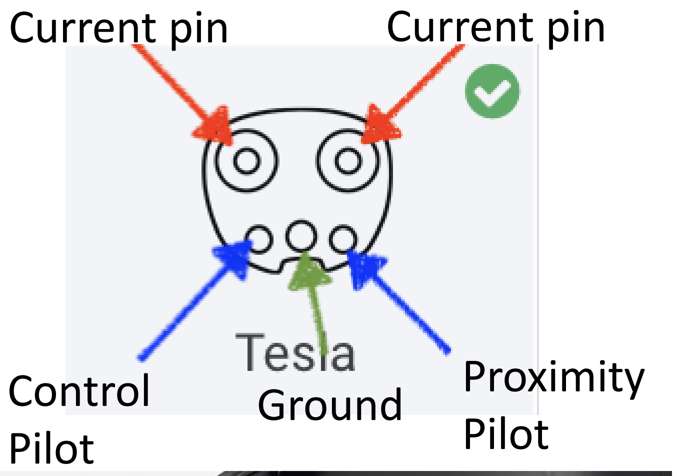
# Charging standards: CCS

- CCS stands for "Combined Charging System" since it is an extension of the J1772 Type 1/2 connectors
- CCS additional elements:
  - DC+/DC-: Electrical contacts for DC electricity flow




# Charging standards: Tesla

- Tesla vehicles have their own charging standard, uniquely capable of both AC or DC input current
- Adapters allow for Teslas to use the J1772 and CCS standards
- Some governments are requiring standardization, many Tesla stations now have CCS support




# DC Fast Charging





# Even faster DC fast charging



# How fast is a charger?  Your mileage may vary…

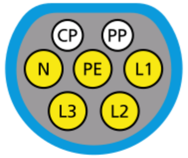
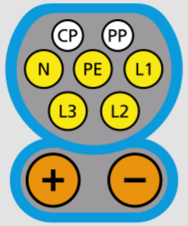
- A DC fast charger may not always operate at its full charging speed!
- For example: if you are at a 150kW charger at a station with 10 other chargers that are all occupied, other vehicles charging may affect your charging rate!
- The ability of EVSE to sustain its full charging capacity depends on the electric infrastructure upstream of it. Can the transformer maintain voltage and current demands?

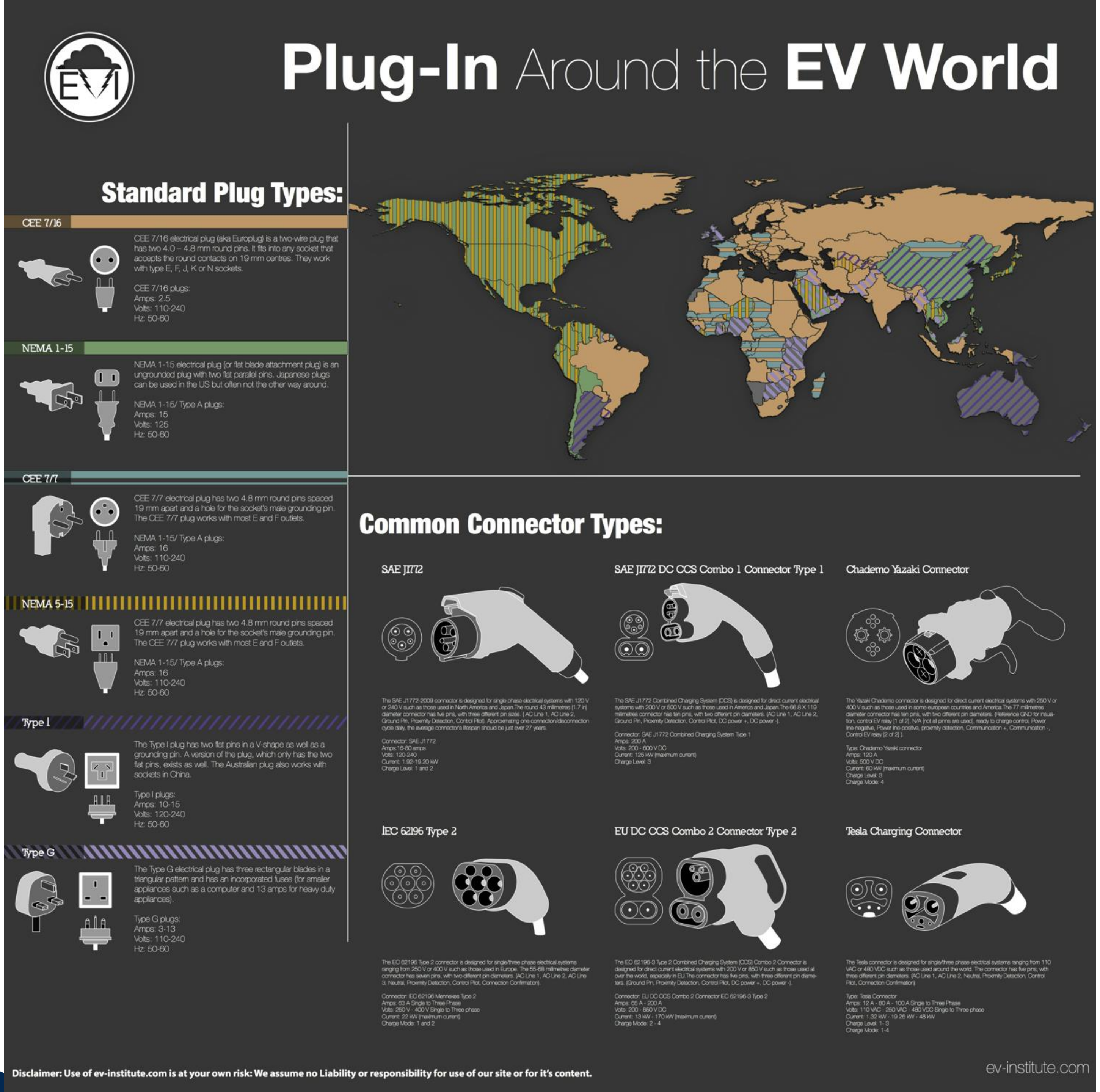

# Europe and Asia

# Charging standards: Type 2

- IEC 62196 Type 2 connector is the primary standard in the EU, it is the analogue of J1772 in the US
- Configurations allow for 3-phase power and lower DC power flow

AC & DC charging connector Type 2

| | | |
|---|---|---|
|  | AC<br>1- or<br>3-phase | max. 500V AC<br>3 x 63A<br>or 1 x 80A |
|  | AC<br>1- or<br>3-phase<br>DC-Low | max. 500V AC/DC<br>3 x 63A<br>or 1 x 70A DC<br>or 1 x 80A DC |
|  | DC-Mid | max. 500V DC<br>1 x 140A |
|  | DC-High | ≥ 500V DC<br>1 x 200A |


Plug-In Around the EV World
Standard Plug Types:
CEE 7/16
CEE 7/16 electrical plug (aka Europlug) is a two-wire plug that has two 4.0 – 4.8 mm round pins. It fits into any socket that accepts the round contacts on 19 mm centres. They work with type E, F, J, K or N sockets.
CEE 7/16 plugs:
Amps: 2.5
Volts: 110-240
Hz: 50-60
NEMA 1-15
NEMA 1-15 electrical plug (or flat blade attachment plug) is an ungrounded plug with two flat parallel pins. Japanese plugs can be used in the US but often not the other way around.
NEMA 1-15/ Type A plugs:
Amps: 15
Volts: 125
Hz: 50-60
CEE 7/7
CEE 7/7 electrical plug has two 4.8 mm round pins spaced 19 mm apart and a hole for the socket's male grounding pin. The CEE 7/7 plug works with most E and F outlets.
NEMA 1-15/ Type A plugs:
Amps: 16
Volts: 110-240
Hz: 50-60
NEMA 5-15
CEE 7/7 electrical plug has two 4.8 mm round pins spaced 19 mm apart and a hole for the socket's male grounding pin. The CEE 7/7 plug works with most E and F outlets.
NEMA 1-15/ Type A plugs:
Amps: 16
Volts: 110-240
Hz: 50-60
Type I
The Type I plug has two flat pins in a V-shape as well as a grounding pin. A version of the plug, which only has the two flat pins, exists as well. The Australian plug also works with sockets in China.
Type I plugs:
Amps: 10-15
Volts: 120-240
Hz: 50-60
Type G
The Type G electrical plug has three rectangular blades in a triangular pattern and has an incorporated fuses (for smaller appliances such as a computer and 13 amps for heavy duty appliances).
Type G plugs:
Amps: 3-13
Volts: 110-240
Hz: 50-60
Common Connector Types:
SAE J1772
The SAE J1772-2009 connector is designed for single phase electrical systems with 120 V or 240 V such as those used in North America and Japan.The round 43 millimetres (1.7 in) diameter connector has five pins, with three different pin sizes. ( AC Line 1, AC Line 2, Ground Pin, Proximity Detection, Control Pilot). Approximating one connection/disconnection cycle daily, the average connector's lifespan should be just over 27 years.
Connector: SAE J1772
Amps: 16-80 amps
Volts: 120-240
Current: 1.92-19.20 kW
Charge Level: 1 and 2
SAE J1772 DC CCS Combo 1 Connector Type 1
The SAE J1772 Combined Charging System (CCS) is designed for direct current electrical systems with 200 V or 500 V such as those used in America and Japan.The 66.8 X 119 millimetres connector has ten pins, with two different pin diameters. (AC Line 1, AC Line 2, Ground Pin, Proximity Detection, Control Pilot, DC power +, DC power -).
Connector: SAE J1772 Combined Charging System Type 1
Amps: 200 A
Volts: 200 - 600 V DC
Current: 125 kW (maximum current)
Charge Level: 3
Chademo Yazaki Connector
The Yazaki Chademo connector is designed for direct current electrical systems with 250 V or 400 V such as those used in some european countries and America.The 77 millimetres diameter connector has ten pins, with two different pin diameters. (Reference GND for insulation, control EV relay [1 of 2], N/A [not all pins are used], ready to charge control, Power line-negative, Power line-positive, proximity detection, Communication +, Communication -, Control EV relay [2 of 2] ).
Type: Chademo Yazaki connector
Amps: 120 A
Volts: 500 V DC
Current: 60 kW (maximum current)
Charge Level: 3
Charge Mode: 4
IEC 62196 Type 2
The IEC 62196 Type 2 connector is designed for single/three phase electrical systems ranging from 250 V or 400 V such as those used in Europe. The 55-68 millimetres diameter connector has seven pins, with two different pin diameters. (AC Line 1, AC Line 2, AC Line 3, Neutral, Proximity Detection, Control Pilot, Connection Confirmation).
Connector: IEC 62196 Mennekes Type 2
Amps: 63 A Single to Three Phase
Volts: 250 V - 400 V Single to Three phase
Current: 22 kW (maximum current)
Charge Mode: 1 and 2
EU DC CCS Combo 2 Connector Type 2
The IEC 62196-3 Type 2 Combined Charging System (CCS) Combo 2 Connector is designed for direct current electrical systems with 200 V or 850 V such as those used all over the world, especially in EU.The connector has five pins, with three different pin diameters. (Ground Pin, Proximity Detection, Control Pilot, DC power +, DC power -).
Connector: EU DC CCS Combo 2 Connector IEC 62196-3 Type 2
Amps: 65 A - 200 A
Volts: 200 - 850 V DC
Current: 13 kW - 170 kW (maximum current)
Charge Mode: 2 - 4
Tesla Charging Connector
The Tesla connector is designed for single/three phase electrical systems ranging from 110 VAC or 480 VDC such as those used around the world. The connector has five pins, with three different pin diameters. (AC Line 1, AC Line 2, Neutral, Proximity Detection, Control Pilot, Connection Confirmation).
Type: Tesla Connector
Amps: 12 A - 80 A - 100 A Single to Three Phase
Volts: 110 VAC - 250 VAC - 480 VDC Single to Three phase
Current: 1.32 kW - 19.26 kW - 48 kW
Charge Level: 1 - 3
Charge Mode: 1-4
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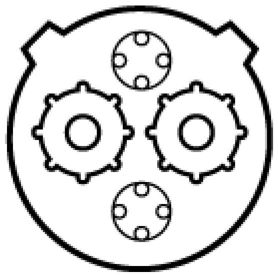
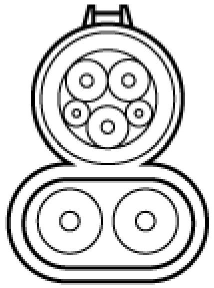
# Automakers and charging types

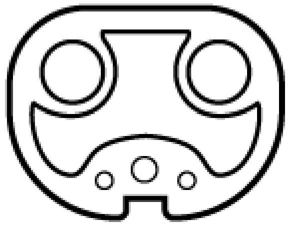
CHAdeMO



CCS



Tesla

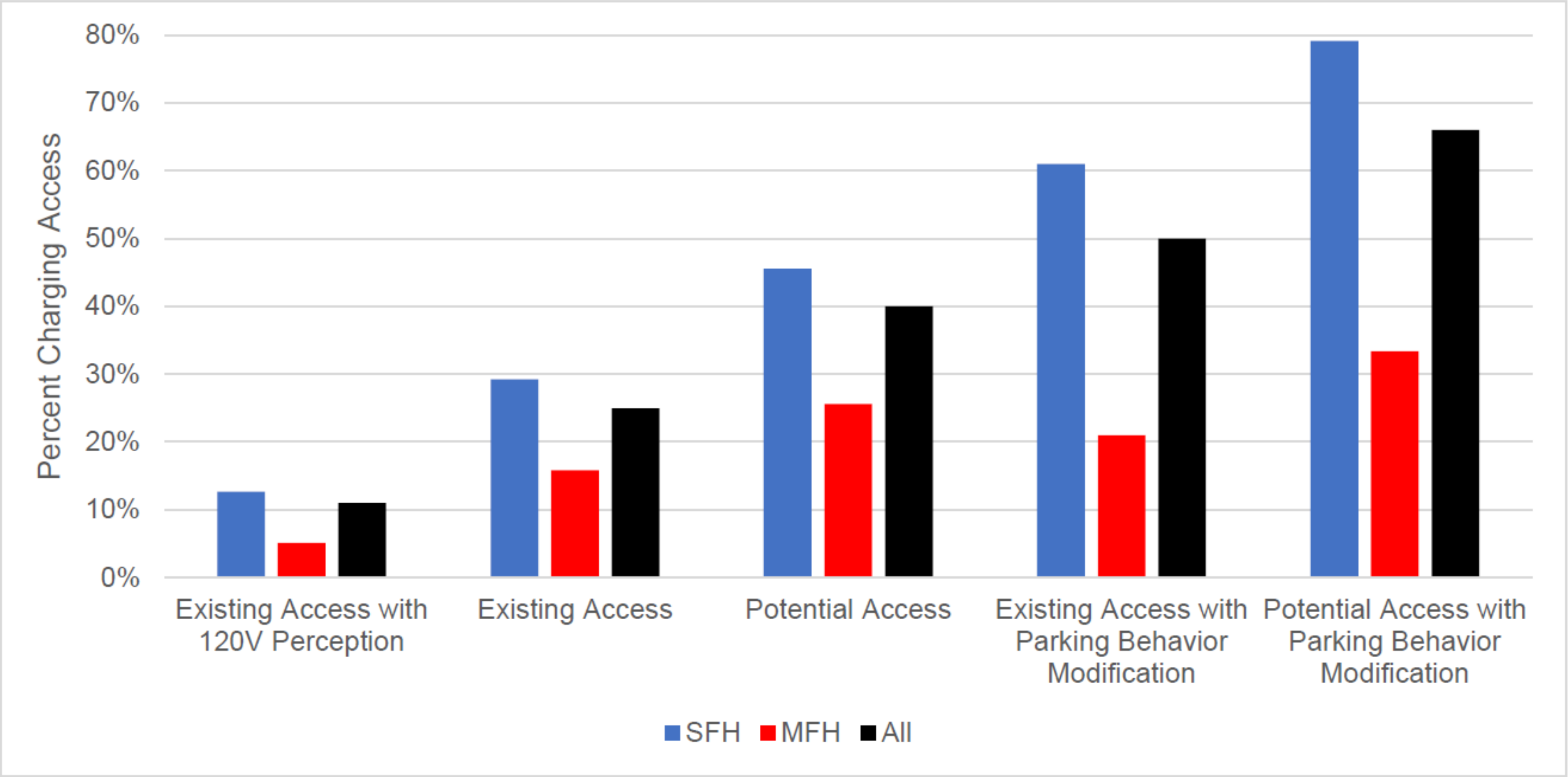


This looks skewed, but don't be deceived! Both Nissan and Tesla have both sold more EVs than most other automakers combined!

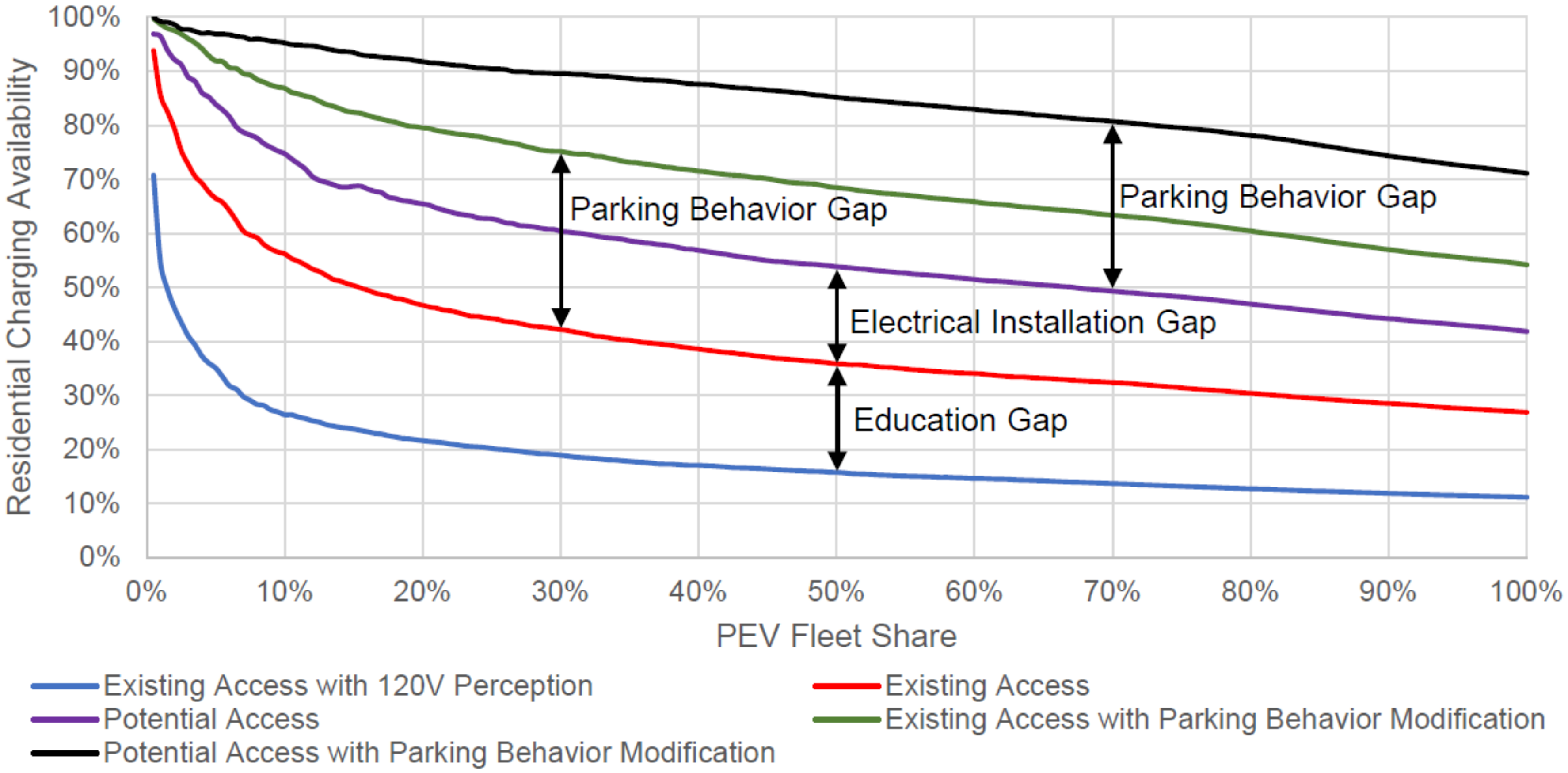
...But both Nissan and Tesla are moving towards CCS

# Infrastructure deployment: home


# How many homes can support charging?



# How might access change over time?



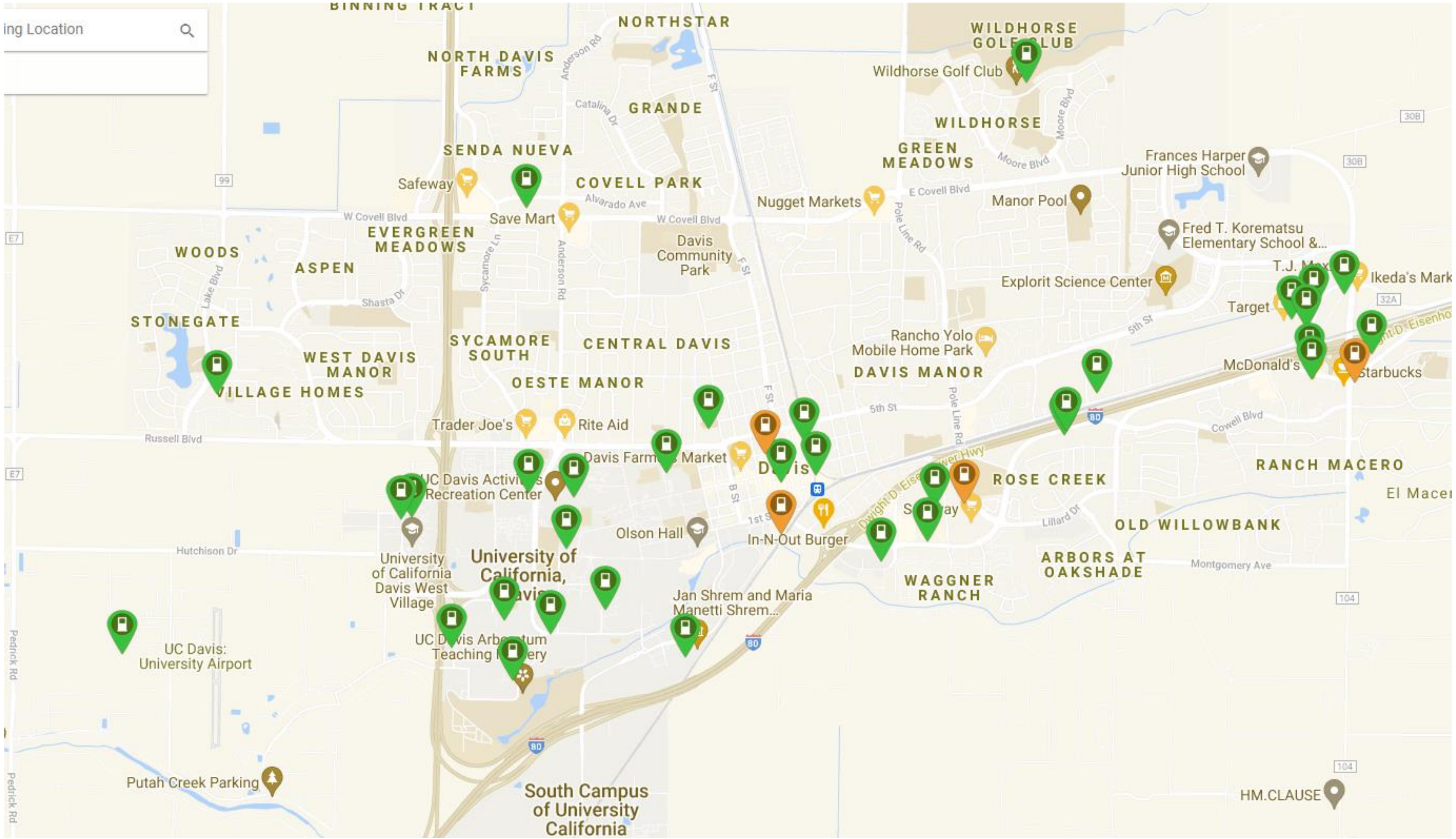
# Infrastructure deployment: work

- Companies have been providing workplace chargers as an employee incentive/benefit
- Sometimes requires interesting charging etiquette!

# Infrastructure deployment: public

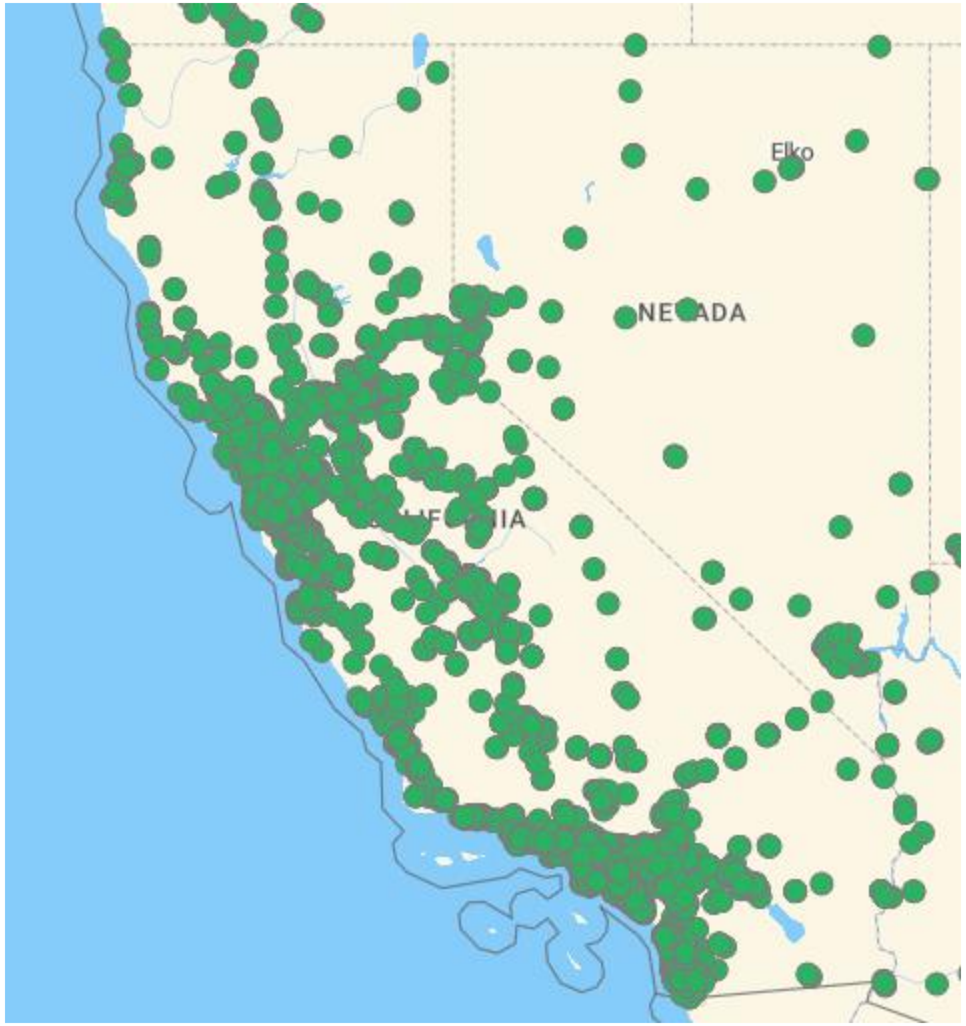



# Public Chargers in Davis

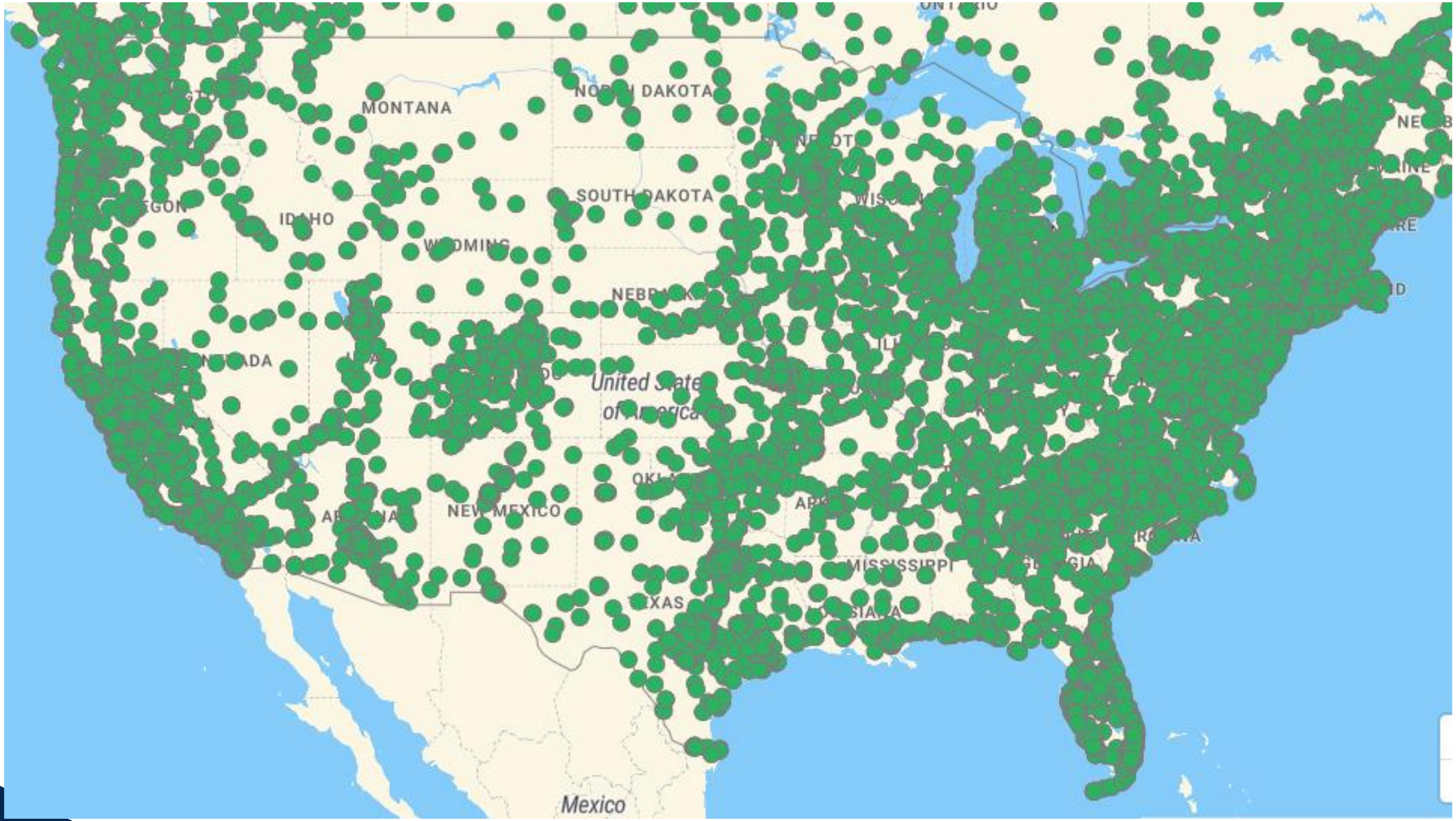


# Chargers in California

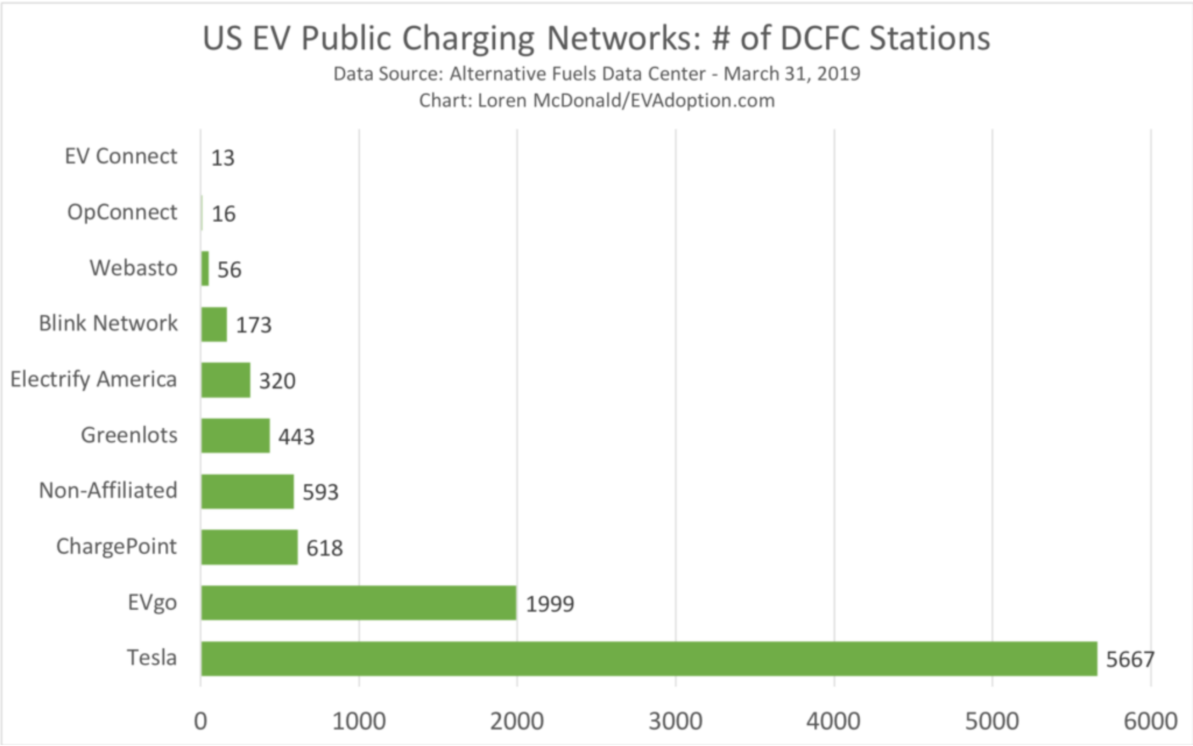
- >75,000 public chargers in California
- >10,000 DC Fast Chargers
- For reference: ~8,000 gas stations across the state

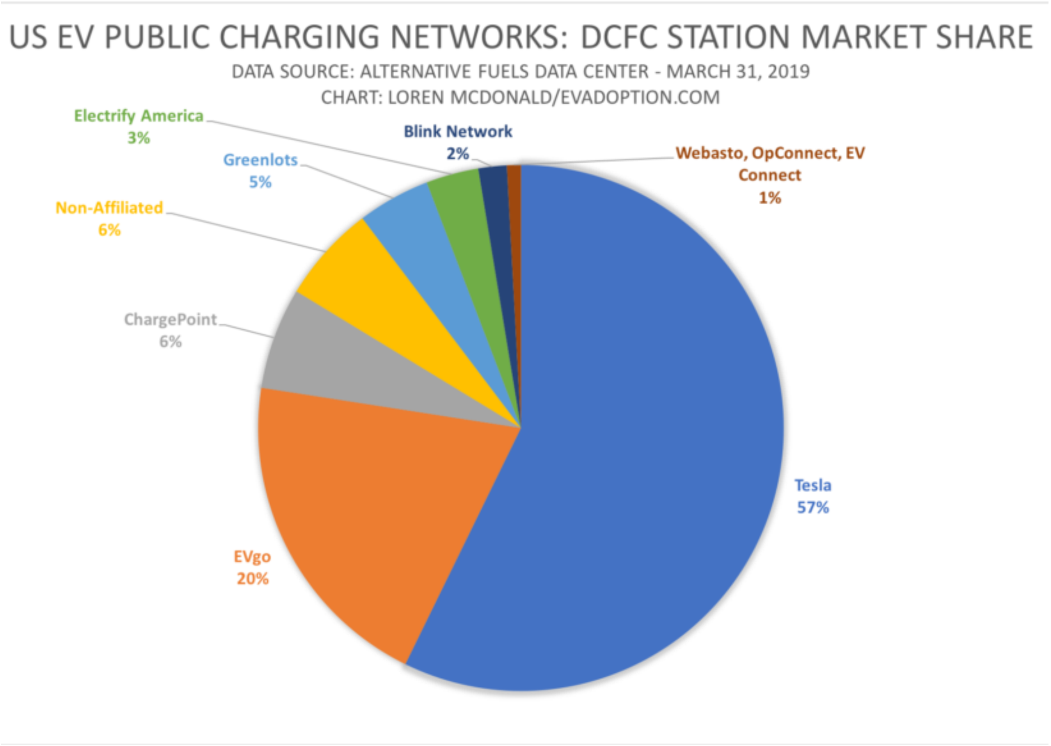


# Chargers in the US



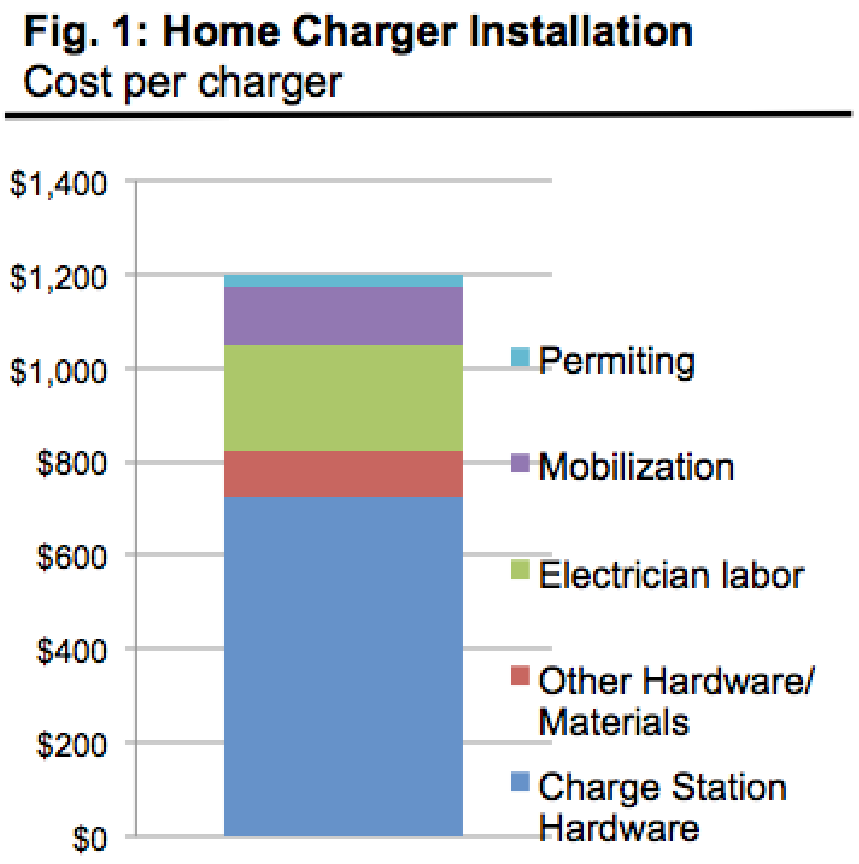
# Breakdown by network (old!)



# Infrastructure costs – Level 2 Home

- Usually the majority of the cost is related to the hardware (though many utilities actually cover this cost in CA!)
- There can be substantial variation in cost if a panel needs to be upgraded (20 Amp circuit to a 40 Amp or 50 Amp circuit)



# Infrastructure costs – Level 2 Public

**Fig 2: Parking Garage Installation**
Cost per charger, thousands USD

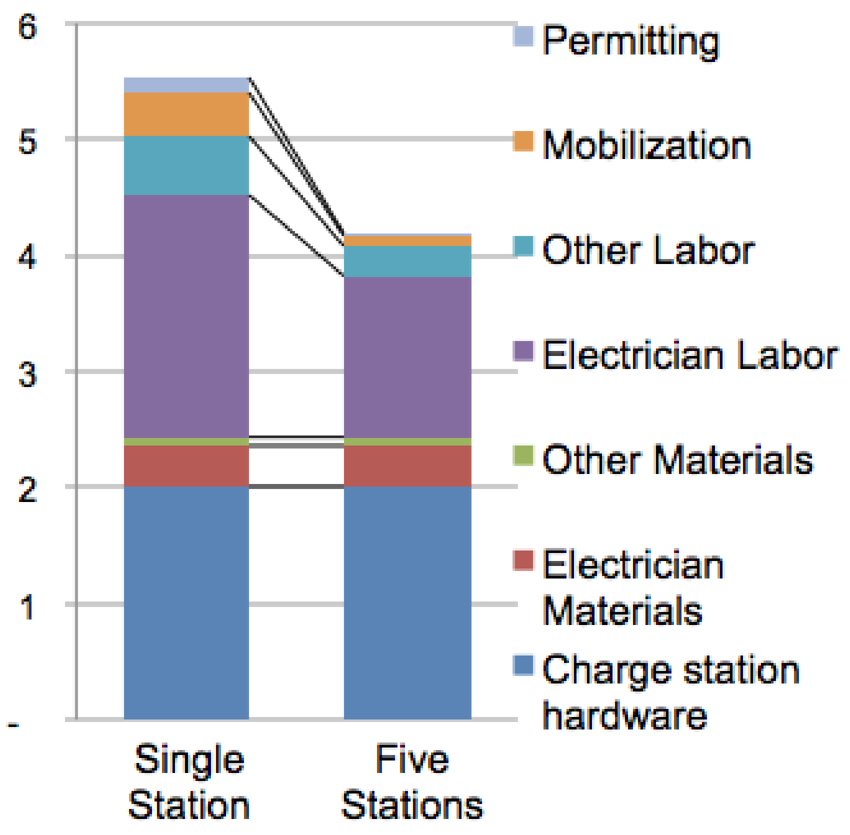
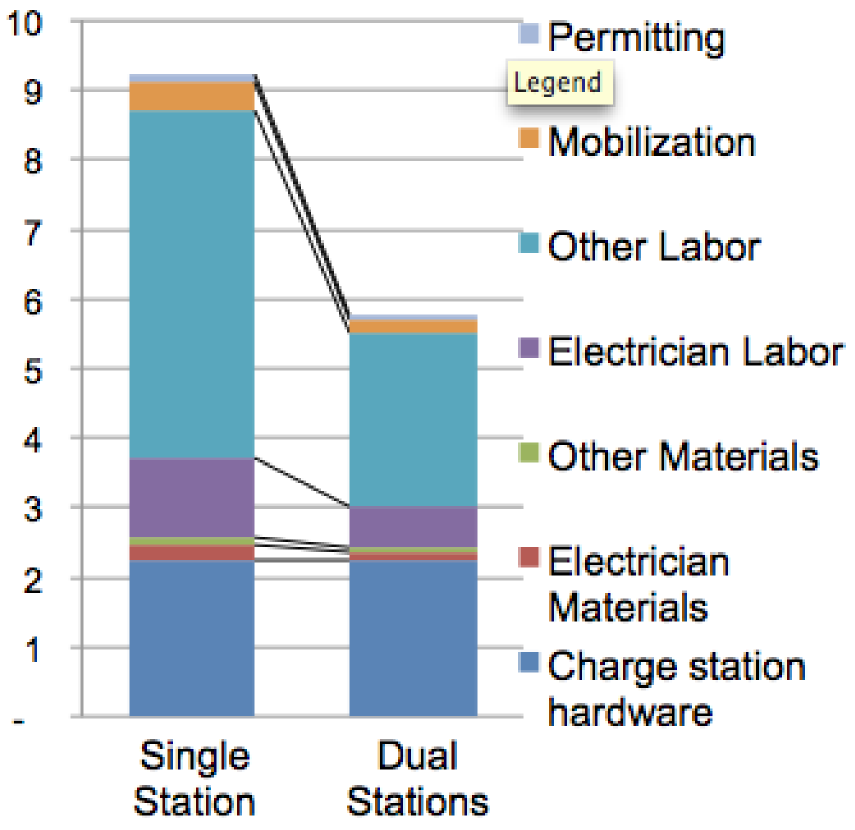


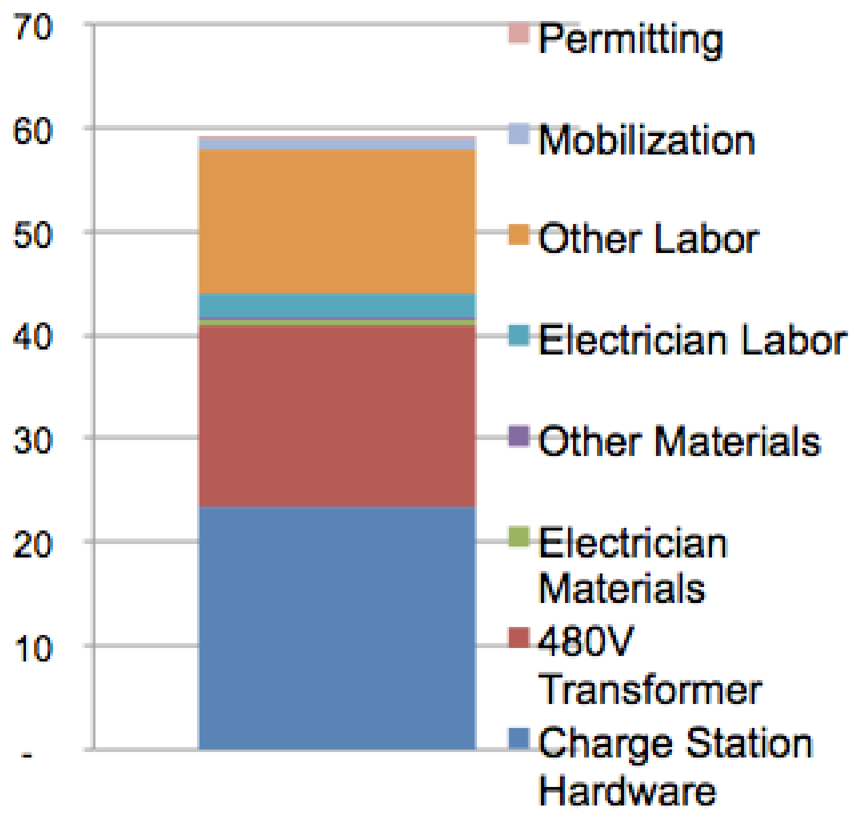

**Fig. 3: Curbside Installation**
Cost per charger, thousands USD



# Infrastructure costs – DC Fast Charger

- Infrastructure gets more expensive at higher charging speeds!
- DC fast charging requires an expensive, high-voltage transformer to transform AC power from the grid into DC power for the battery
- Substantial portion of the cost in installation (digging trenches for wiring)

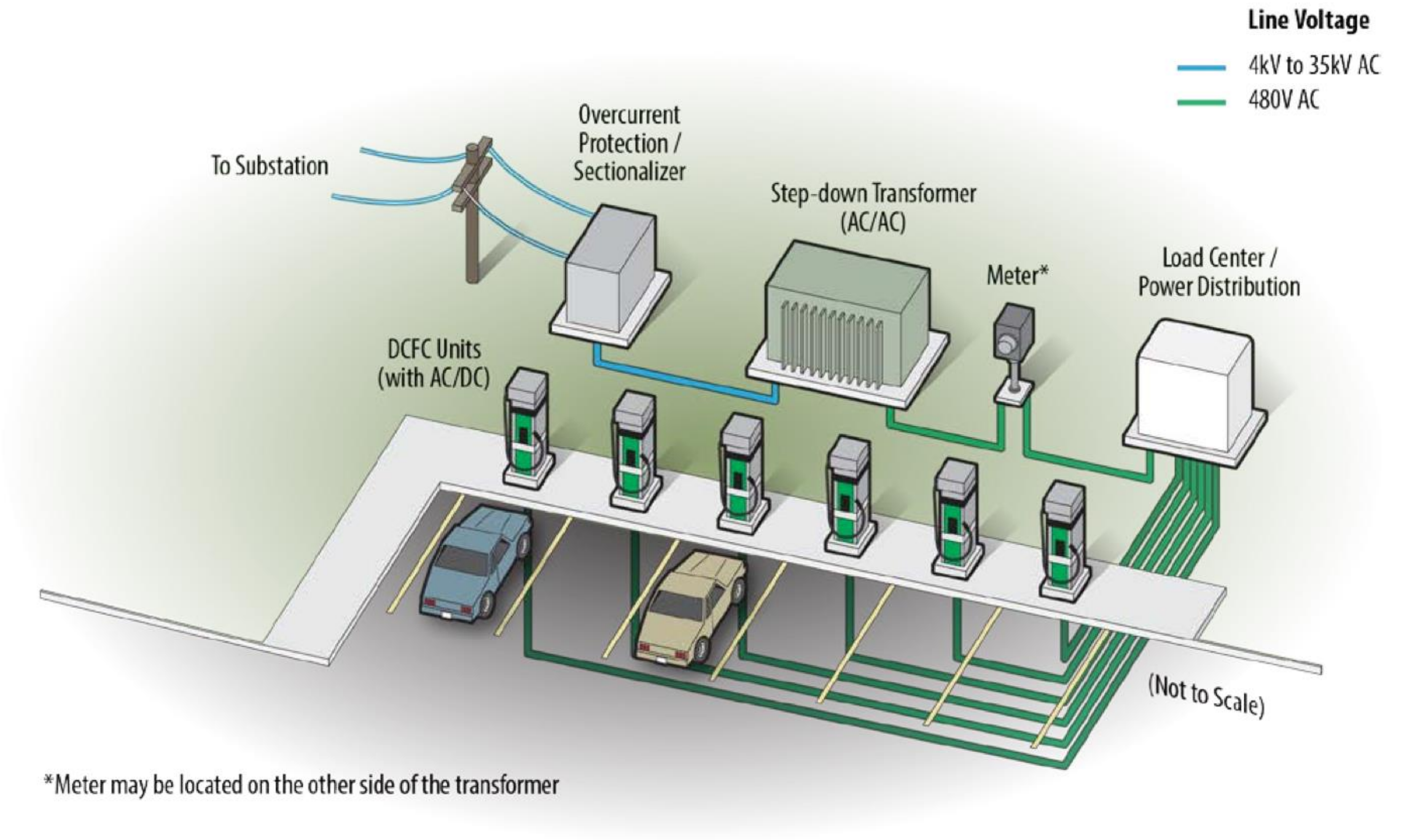
**Fig. 4: Curbside DC Fast Charger Installation**
Cost per charger, thousands USD



| | Level 2 Home | Level 2 Parking Garage | Level 2 Curb-side | DC Fast Charging | Description/Key Assumptions |
|---|---|---|---|---|---|
| Charge station hardware | $450–$1,000 | $1,500–$2,500 | $1,500–$3,000 | $12,000–$35,000 | |
| Electrician Materials | $50–$150 | $210–$510 | $150–$300 | $300–$600 | • $1.50–2.50/ft for conduit and wire, plus misc other materials<br>• $50–80/hour (per dist?)<br>• $500–1000 if new breaker is required<br>• Assume 2x electrical cost for level 3 |
| Electrician Labor | $100–$350 | $1,240–$2,940 | $800–$1,500 | $1,600–$3,000 | |
| Other Materials | | $50–$100 | $50–$150 | $100–$400 | • $25–100/ft for trenching/boring—depends on surface, soil, and underground complexity<br>• Mounting, signage, protection, and restoration also included here, but don't usually contribute more than a few hundred dollars |
| Other Labor | | $250–$750 | $2,500–$7,500 | $5,000–$15,000 | |
| Transformer | NA | NA | NA | $10,000–$25,000 | • 480V transformer installed by utility |
| Mobilization | $50–$200 | $250–$500 | $250–$500 | $600–$1,200 | • Home: 1–3 hours of electrician time for a home installation<br>• Public: $250–500 of time for 1–2 electricians and other labor. We found that the work could usually be completed in a single visit from each contractor. |
| Permitting | $0–$100 | $50–$200 | $50–$200 | $50–$200 | • Varies city to city, often a flat fee for one or several stations |

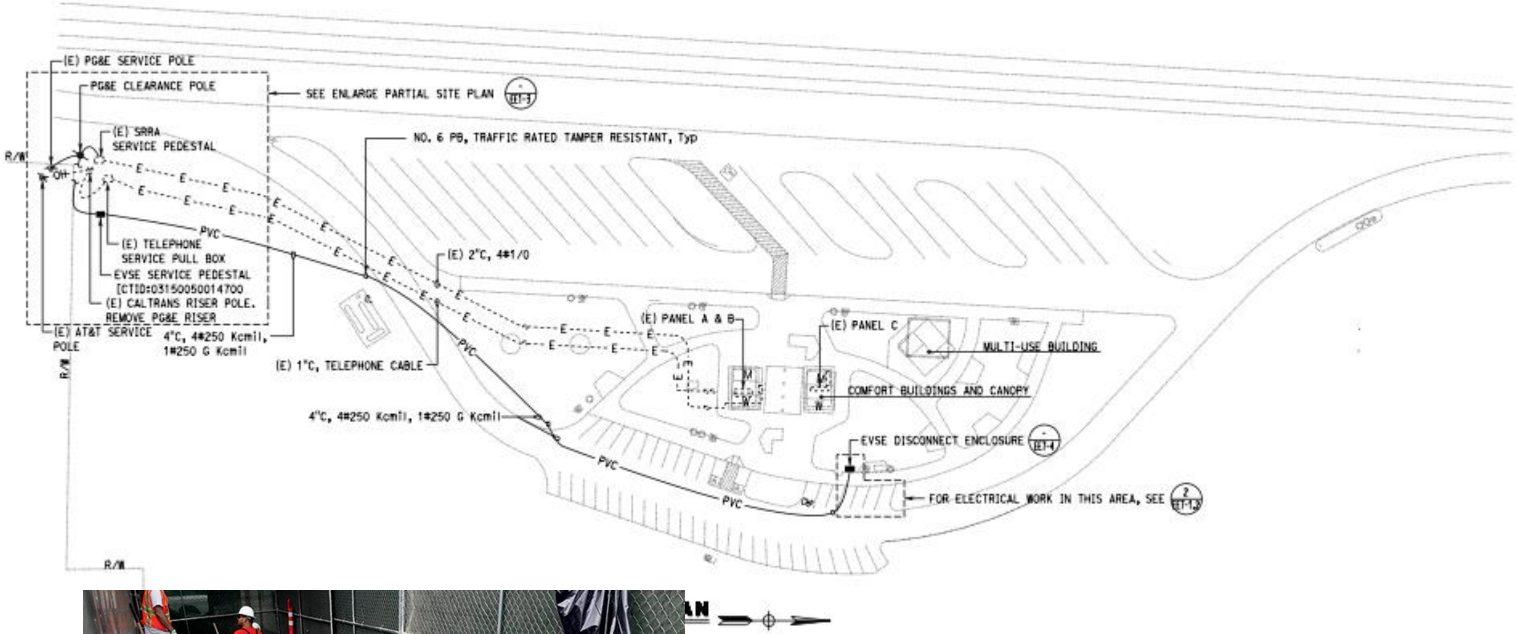
# “Make-ready” infrastructure

- “Make-ready” is a catch-all term for all of the infrastructure *upstream* of the EVSE unit
- May or may not count portions of the infrastructure paid for by utilities (depends who you talk to)
- Depending on the unique properties of the site, make-ready infrastructure may encompass different things



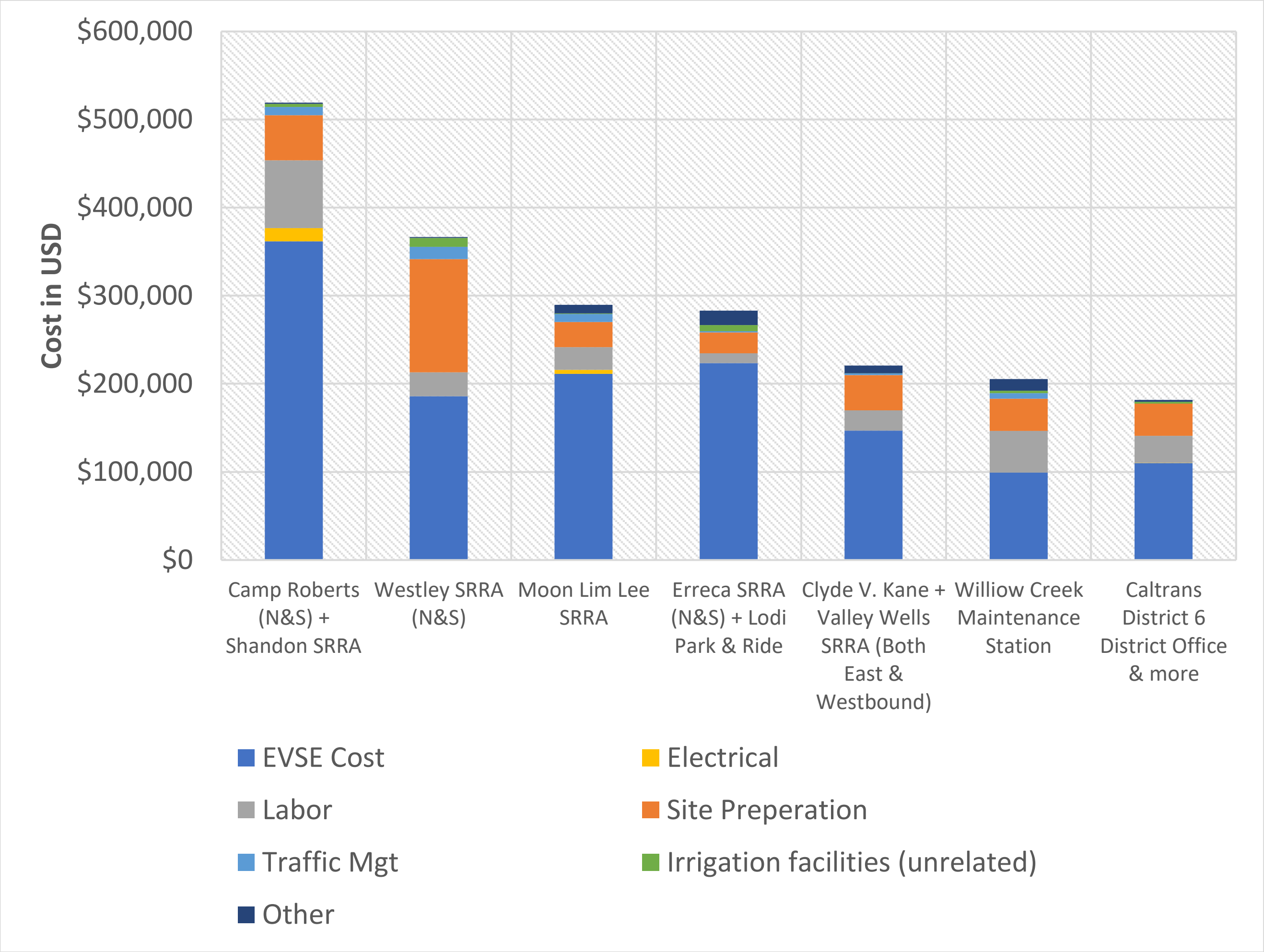
# Installing EVSE

- Trenching, conduit, pipeline, wiring costs (construction and material costs) can be a substantial proportion of total costs
- In an example rest stop, distance from transformer to EVSE meant a **huge** increase in costs



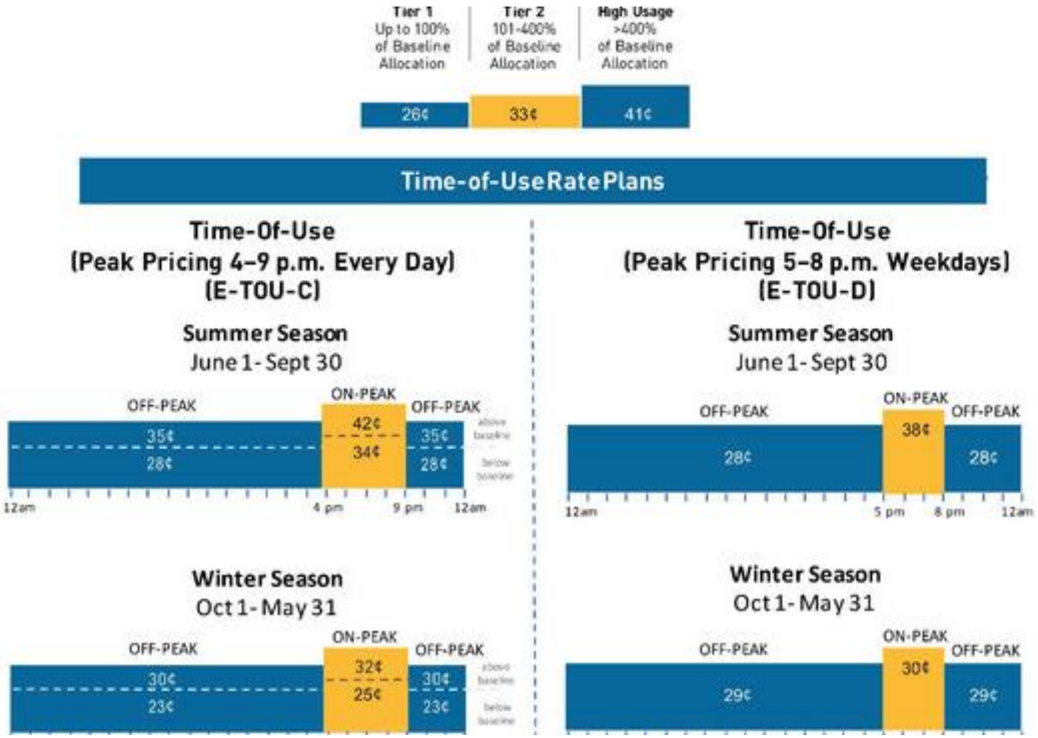

# A case study of installation costs at CA rest stops

- Estimates of costs shown earlier tend to be a lower bound—but they can reach as high as hundreds of thousands of dollars
- Why are these costs important to estimate from a policy perspective?

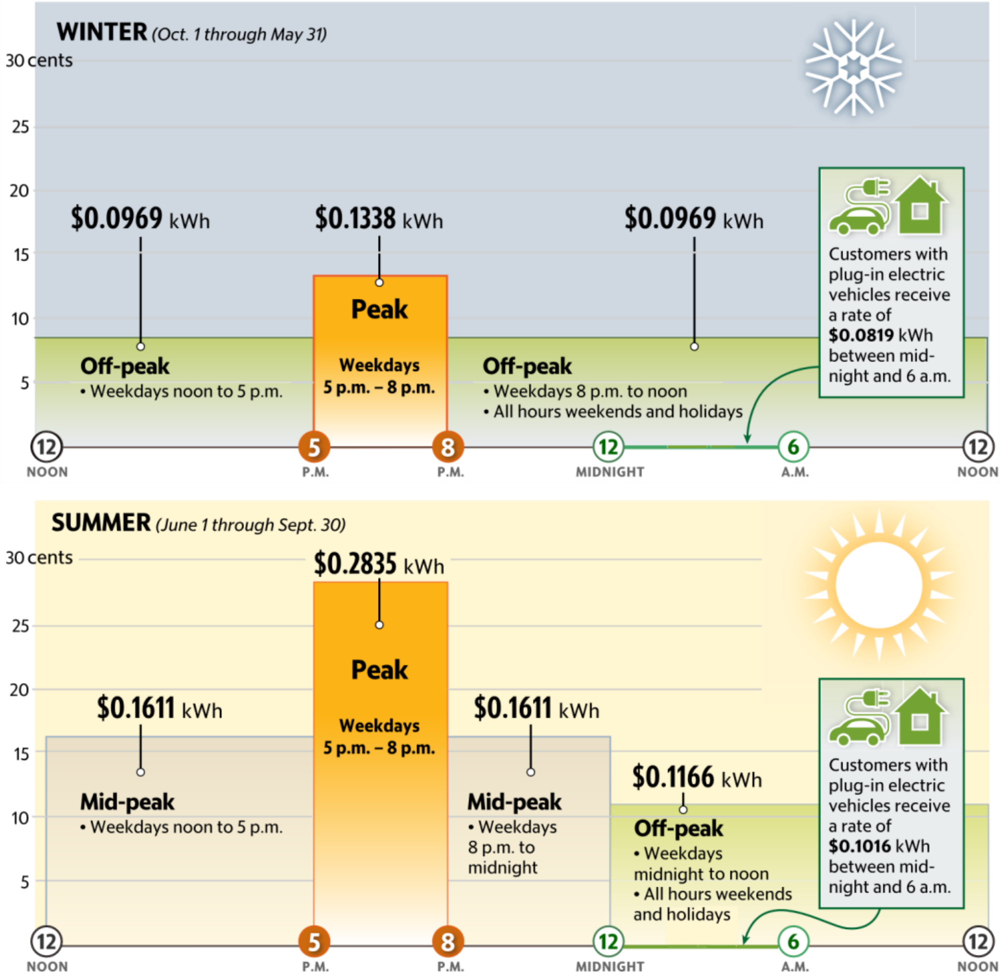


# Residential electricity rates

Pacific Gas and Electric Company®




SMUD®

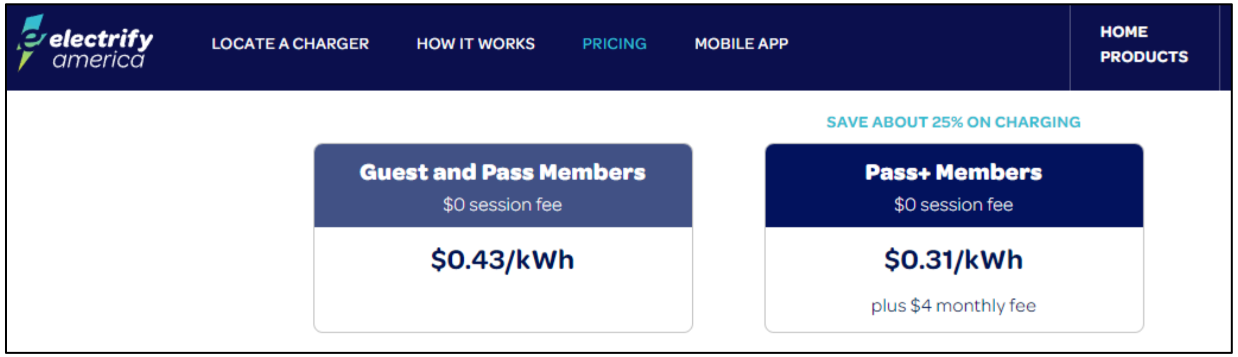


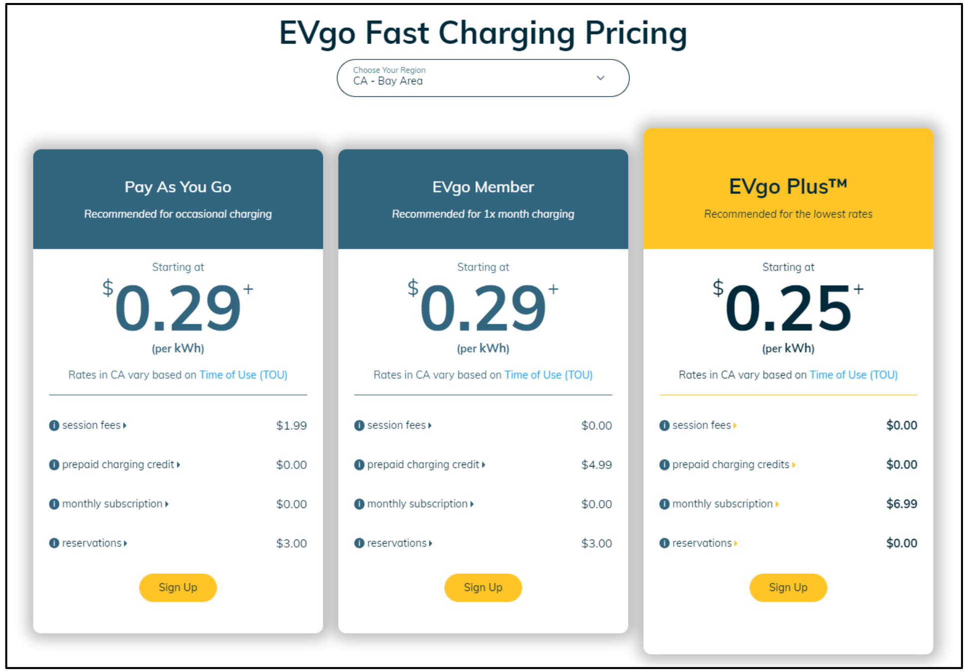
# Public charging rates

| Tier 1 | Tier 2 | Tier 3 | Tier 4 |
|---|---|---|---|
| Charging at or below 60 kW | Charging above 60 kW, at or below 100 kW | Charging above 100 kW, at or below 180 kW | Charging above 180 kW |
| Lowest price per minute | Second-lowest price per minute | Second-highest price per minute | Highest price per minute |

| | | | |
|---|---|---|---|
| $0.17/min | $0.45/min | $0.84/min | $1.35/min |
| @60kW: | @100kW: | @180kW: | @250kW: |
| $0.17/kWh | $0.27/kWh | $0.28/kWh | $0.324/kWh |

| Country | Currency | Idle fee (per minute) | Idle fee (per minute) when the station is 100% occupied |
|---|---|---|---|
| United States | USD | $0.50 | $1.00 |
| Canada | CAD | $0.50 | $1.00 |



# What is the business case for EV chargers?

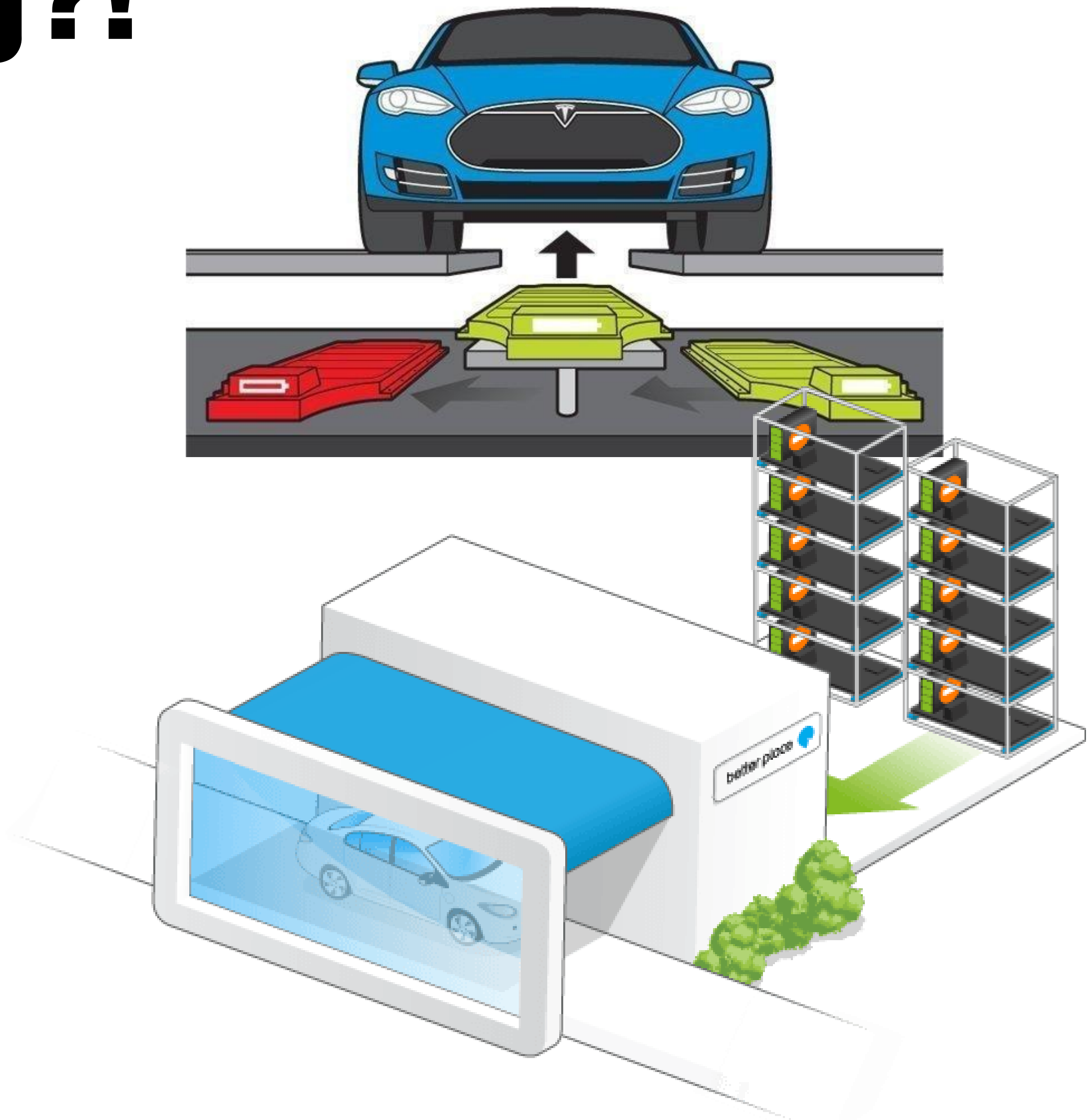
- Let’s assume that businesses want a 3 to 5-year payback period for any investment they are making.  How do EV chargers fare?
- Consider a $100,000 charger that makes $0.30/kWh selling its electricity, how often would the charger need to be occupied to make its payback?

# Wireless charging?

- Wireless (or inductive charging) uses electromagnetic induction to generate electricity through inductive coupling
    - Magnetic field is create that creates in AC current in the vehicle's induction coil
- Not a theoretical technology, it already exists!  However, there are many challenges:
    - More expensive than comparable chargers
    - Gap to vehicle leads to low capacitance
    - Generally inefficient

# Battery swapping?!

- Solves issues related to charging time—likely similar to the gas station model
- Many challenges remain:
  - Many studies point to issues with achieving positive economics (needs more batteries to handle flow, but more batteries = $$$)
  - Standardization of battery types
  - Must have specific vehicle designs



# Autonomous charging?!?