Charging Infrastructure for Shared and Autonomous EVs

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***The Future of Electric Vehicle Infrastructure in the U.S.* Webinar**

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Idaho National Laboratory

…But first,

Relationship between charging infrastructure technology, cost, and the consumer

Today,

Cost to consumer = f(infrastructure cost & business model)

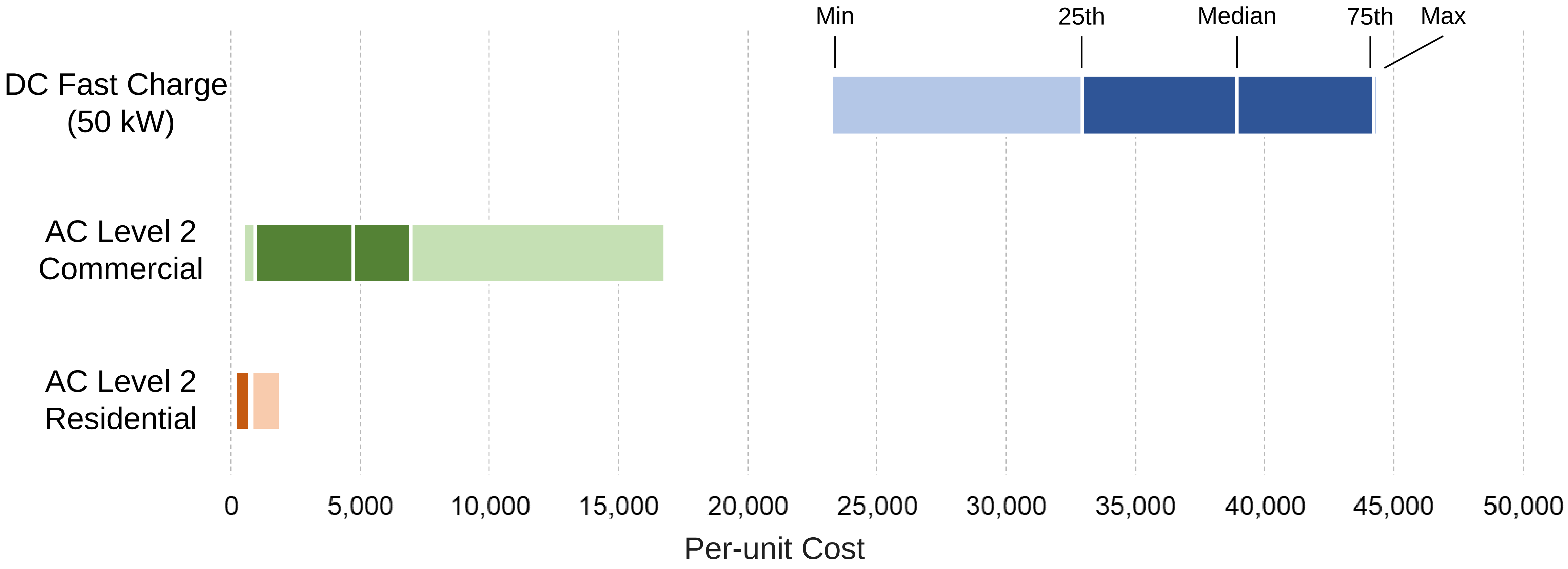
Cost of charging infrastructure is borne by

- Charging consumers
- Vehicle manufacturers (and consumers)
- Electric utility rate payers
- Tax payers
- Shareholders

Assume that in the long run,

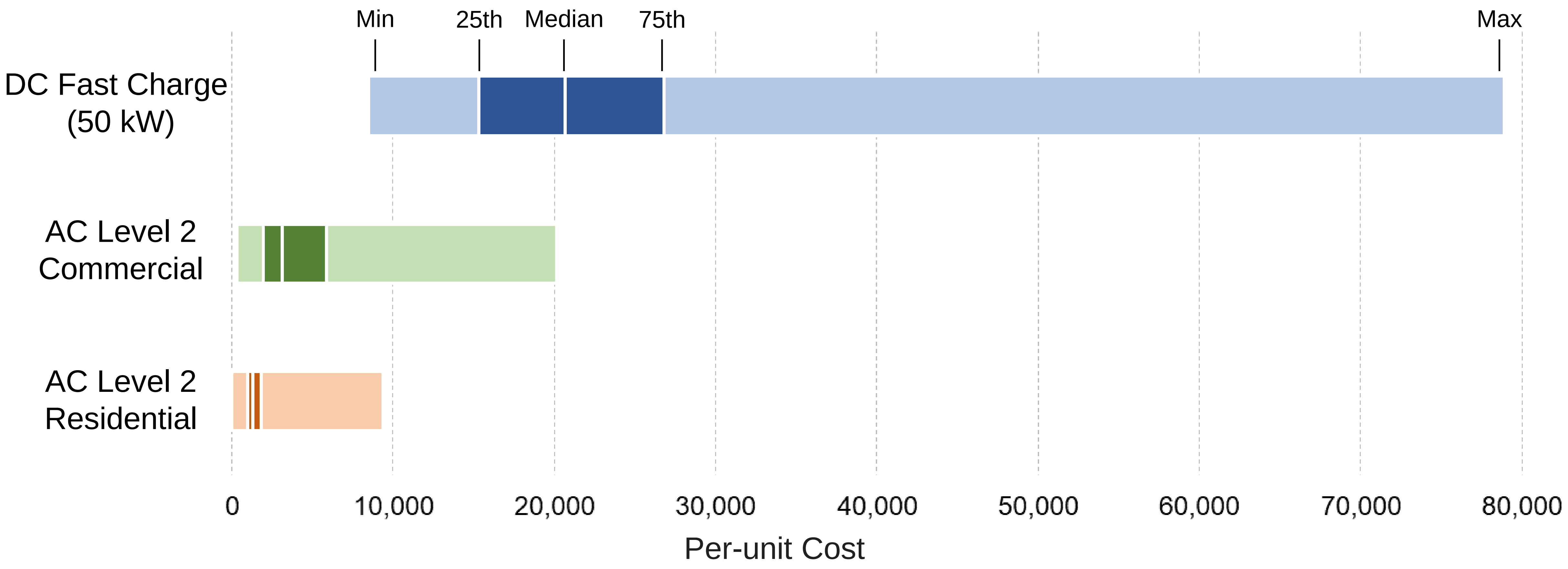
Cost of infrastructure $\longrightarrow$ Cost to the consumer

Cost of Electric Vehicle Supply Equipment (EVSE)



Source: unpublished data from Smart Charge America (2016 – 2018) and WestSmartEV project (2016 – 2018)

EVSE Installation Cost



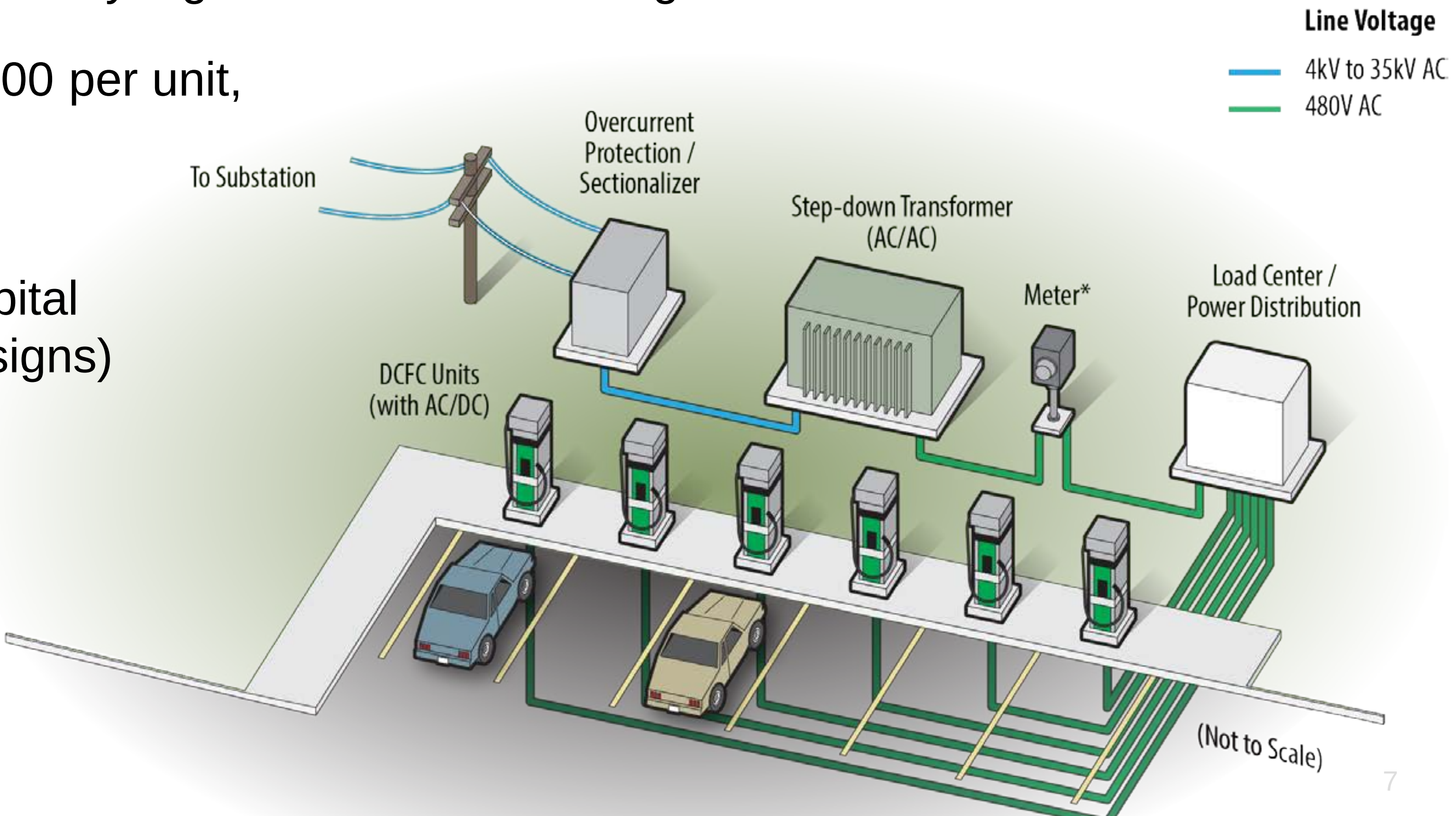
Source: unpublished data from Smart Charge America (2016 – 2018) and WestSmartEV project (2016 – 2018)

Cost of High-Power Charging

2017 INL study estimated cost of high-power fast charging stations

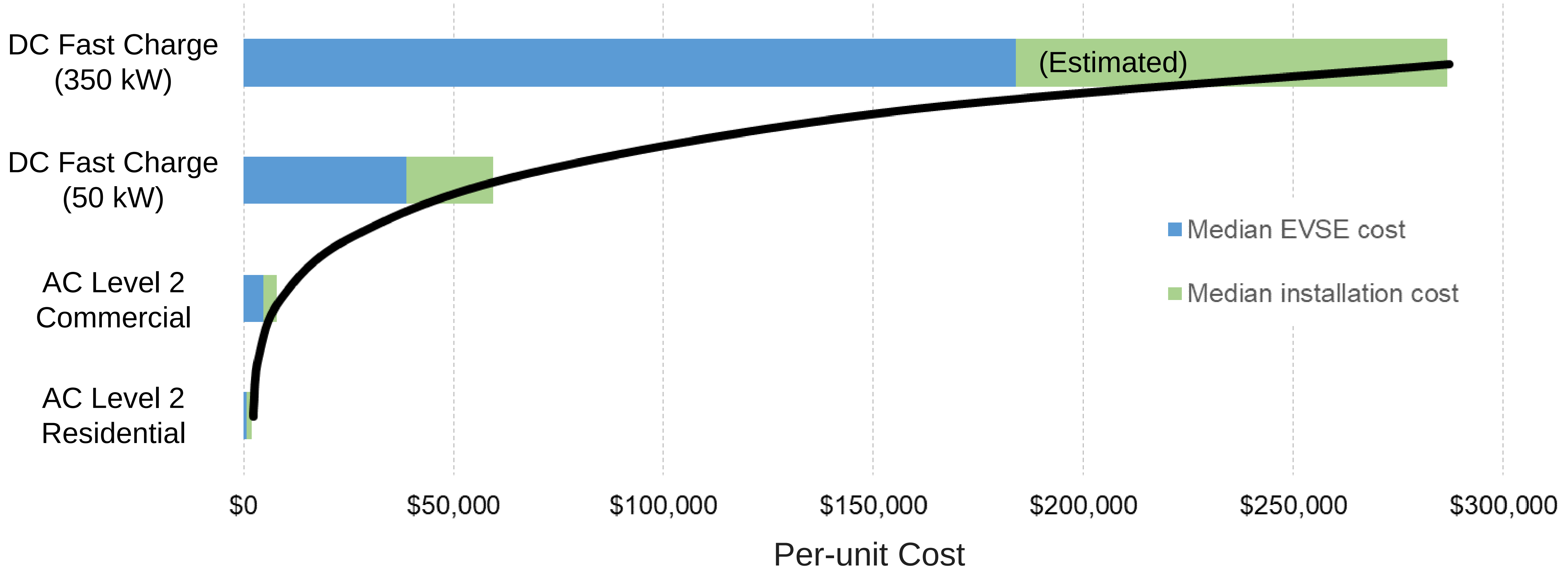
- $245,000 per 350-kW fast charger ($0.70 / W)
- Recent data suggests this is conservatively high – assume 2x too high
- Installation cost of $43,000 to $163,000 per unit, depending on site design

(Study highlighted trade-off between capital and operating costs for different site designs)

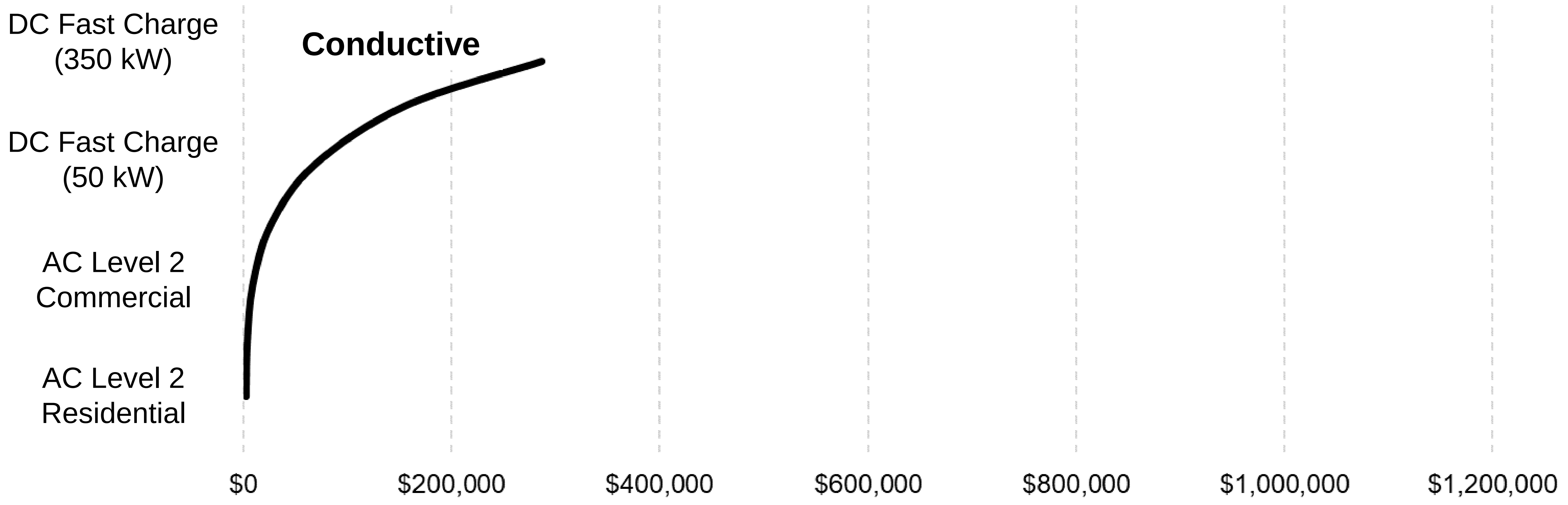


Francfort, J., Salisbury, S., Smart, J., Garetson, T., Karner, D., "Considerations for Corridor and Community DC Fast Charging Complex System Design," INL technical report INL/EXT-17-40829, May 2017, https://avt.inl.gov/sites/default/files/pdf/reports/DCFCChargingComplexSystemDesign.pdf

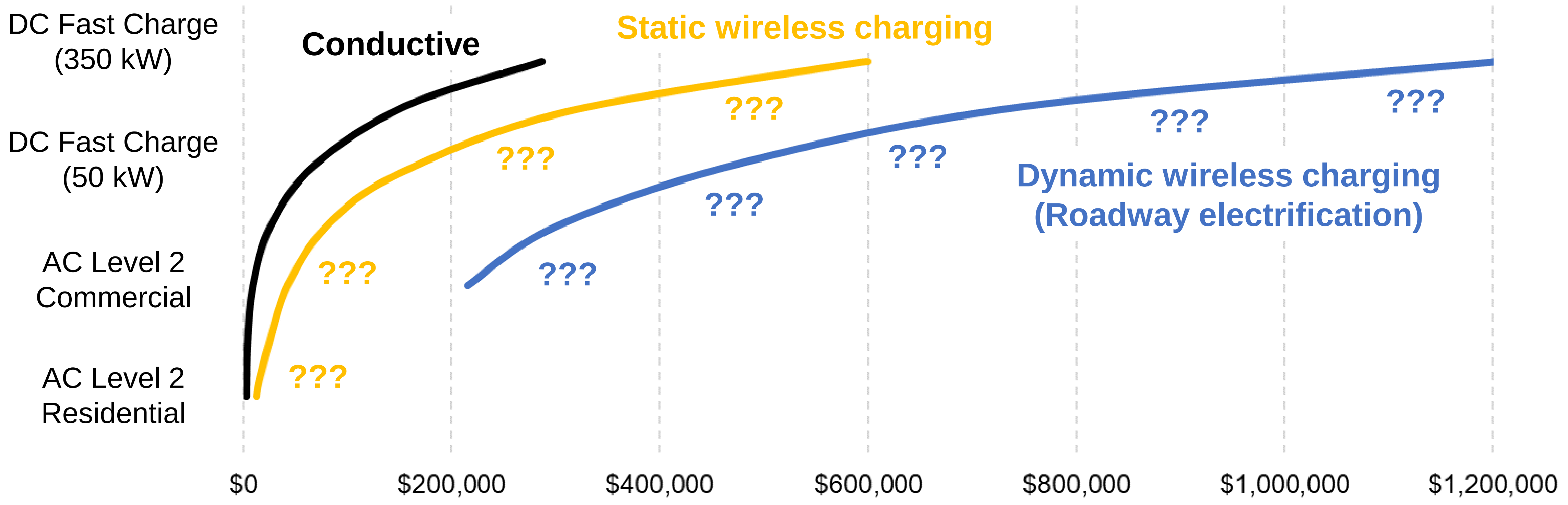
Total Capital Cost by EVSE Type



Total Capital Cost by EVSE Type



Total Capital Cost by EVSE Type



Other assumptions:

Total cost (capital + operating expenses) follows same trend

Costs will come down over time, but relationship stays the same

Conclusion:

The higher the power, the higher the cost

In the long run,

Cost of technology ⟶ Cost to the consumer

Cost of technology increases greatly with charging power

Focus should be on understanding consumer *willingness to pay* for charging power

What motivates consumer willingness to pay for charging?

Ample public charging opportunities?

"If there is a lot of charging infrastructure, I can charge whenever I need to."

Daily driving distance?

"Public charging infrastructure provides the range extension I need to take long trips."

Long EV range?

"If I have a long-range vehicle, I won't need to charge in public very often."

Yes, but these factors do not tell the whole story

What motivates consumer willingness to pay for charging?

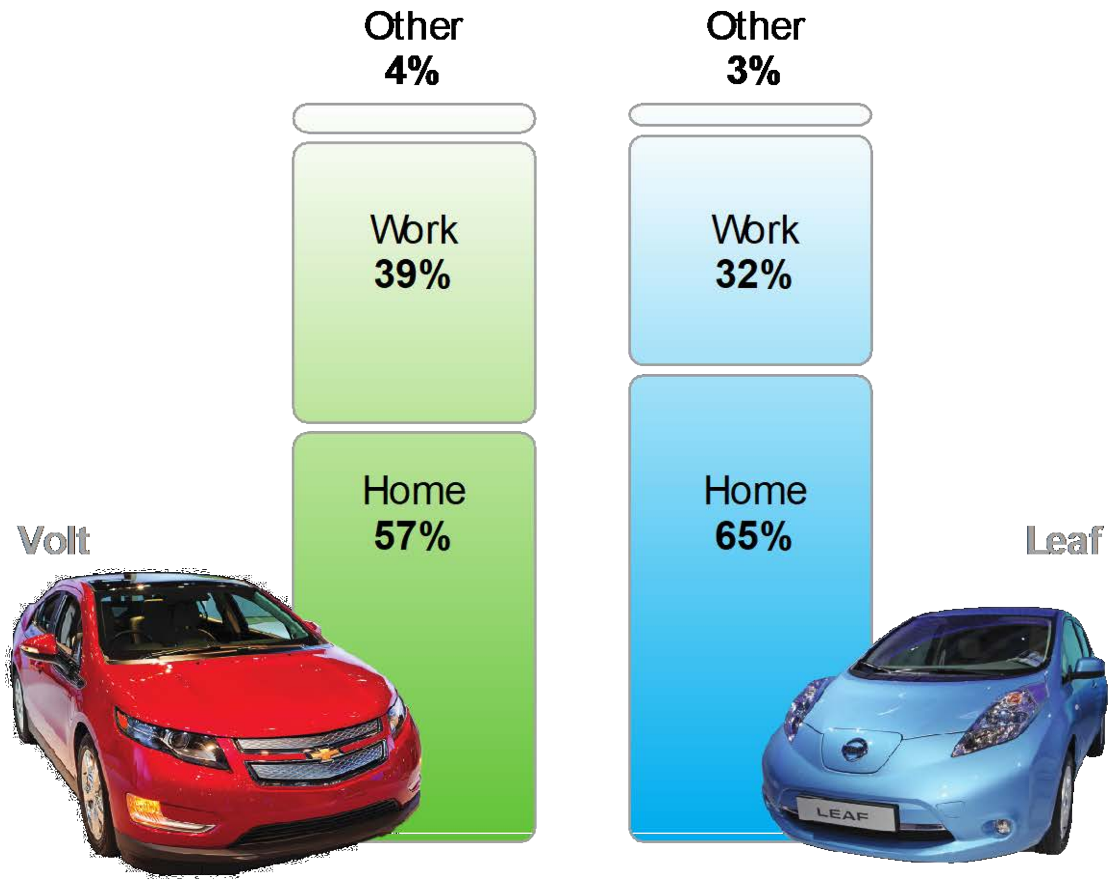
Willingness to pay is based on

Value of Charging Time

= opportunity cost of charging

It varies by market segment and consumer

Privately-owned Personal-use EVs



Most charging is done at home and work, where vehicles are parked for long periods of time

The value of charging time (VOCT) at these times is low, so slow charging is acceptable

Slow charging is inexpensive charging

Smart, J.,"Plugged In: How Americans Charge Their Electric Vehicles," INL technical report INL/EXT-15-35584, 2015, https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf

Shared Mobility: Privately-owned Ride-hailing EVs

The story changes when “time is money”

For ride-hailing drivers, VOCT is usually high for on-shift charging

How often is on-shift charging needed?

How fast is fast enough?

Source: INL

Two Lyft / Maven Gig drivers charging at mid-day. This EVgo fast charger site is in a Whole Foods parking lot in San Francisco. Both drivers were eating lunch during the 30+ minute charges.

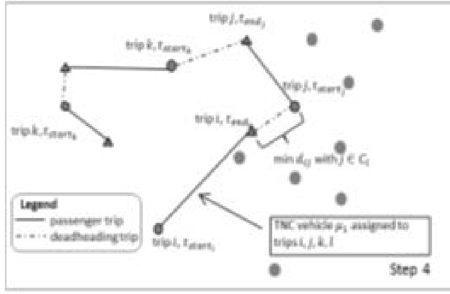
U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

The Advanced Fueling Infrastructure Pillar is focused on understanding the costs, benefits, and requirements for charging infrastructure to support energy efficient mobility systems of the future

Privately-owned Ride-hailing EVs



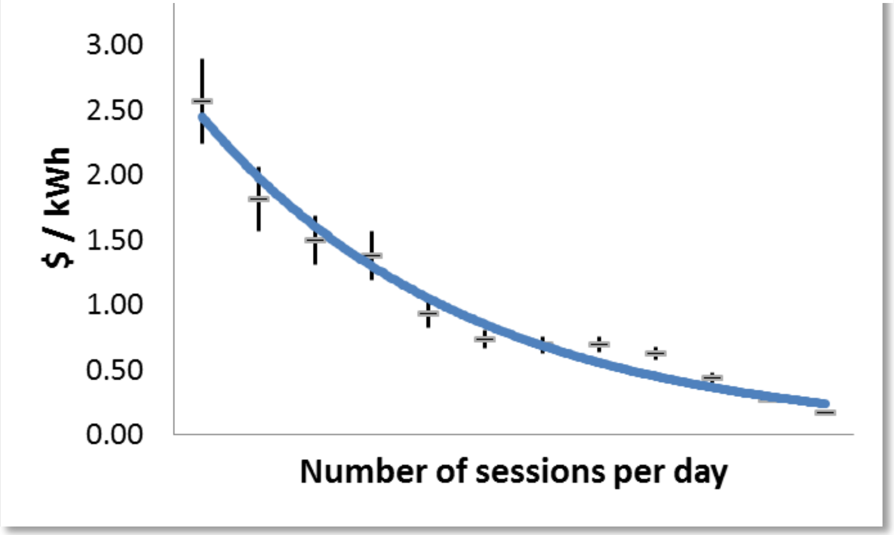
NREL compared travel in 5,000 real personal-use vehicles vs. same travel in simulated ride-hailing EVs

Shared EVs:

- Drove 29% more daily miles
- Needed 2x more fast chargers
- Used fast chargers 3.5x more
- 50-kW fast charging usually sufficed*

*with perfect knowledge of the future. In real life, drivers may be anxious to charge more quickly to avoid missing fares

High fast charger utilization helps EV charger economics



Wood, E., Rames, C., Kontou, E., Motoaki, Y., Smart, J., Zhou, Z. "Analysis of Fast Charging Station Network for Electrified Ride-Hailing Services." SAE Technical Paper 2018-01-0667, doi:10.4271/2018-01-0667.

Commercial Car-sharing EVs

ReachNow

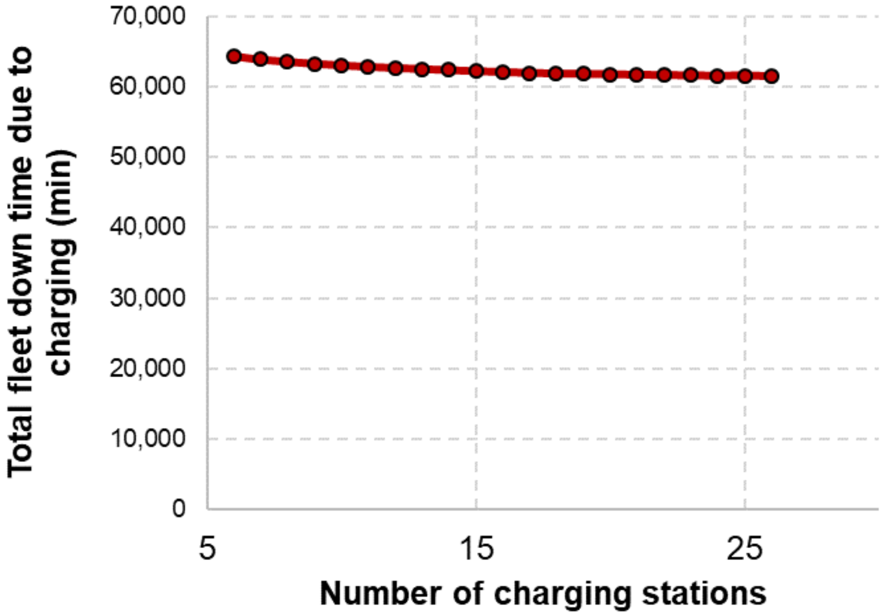
Source: www.reachnow.com

Free-floating car-sharing service relies on fast charging network for EVs

INL used data-driven optimization to site new charging stations to reduce downtime due to charging

Commercial Car-sharing EVs

Adding 20 strategically-placed fast chargers reduced travel time to chargers by 49%



But overall marginal benefit was small because charging time is the dominant component of vehicle downtime

Better to increase charge power than to install more chargers

Roni, M.S., Yi, Z., & Smart, J. (2019). "Optimal Charging Management and Infrastructure Planning for Free-floating Shared Electric Vehicles." Submitted to Transportation Research Part D

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

Commercial Automated Ride-hailing EVs

LBNL simulated automated ride-hailing fleet in San Francisco Bay Area

Used siting algorithms to design widespread charging network

Varied fleet size, EV range, charge power

Zhang, H., Shepard, C., Lipman, T., Zeng, T. & Moura, S. (2019). “Charging Infrastructure Demands of Shared-Use Autonomous Electric Vehicles in Urban Areas.” Submitted to Transportation Research Part D.

Ideal charger locations to serve fleet of 15,000 automated electric taxis

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Commercial Automated Ride-hailing EVs

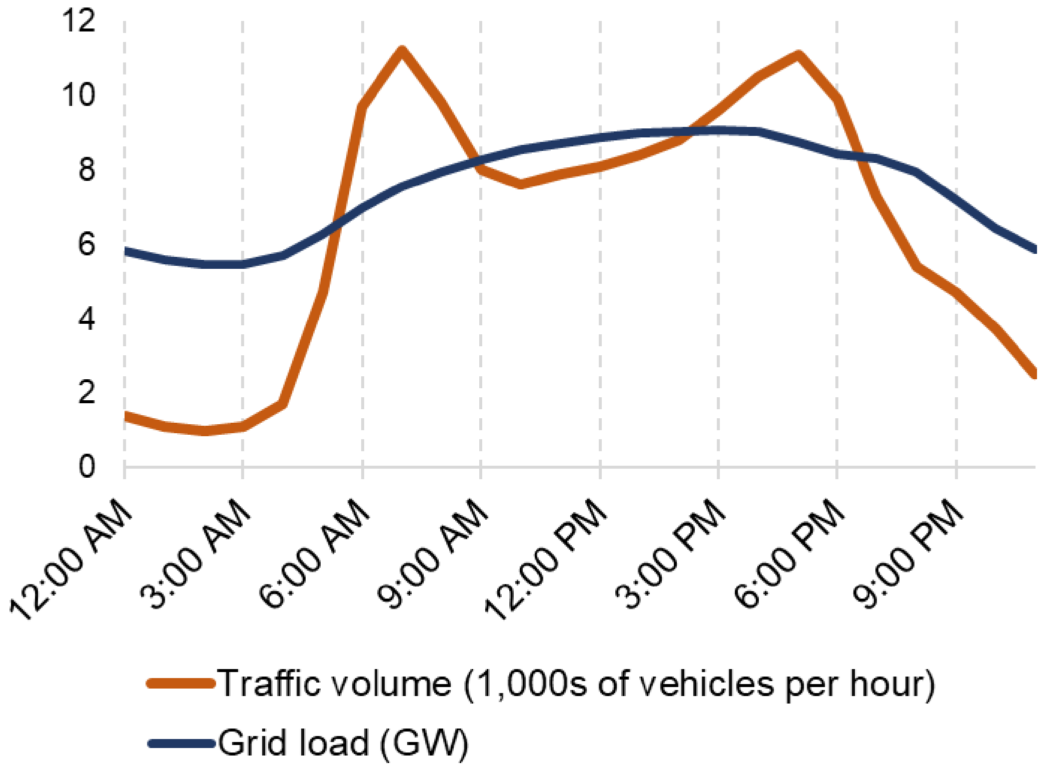
Larger fleets of AEVs can serve travel demand with lower per-mile cost

Fleet operation is more economical with 50-kW chargers than with 250-kW chargers

A fleet of 150-mile range vehicles slightly out-performs 75-mile range vehicles

Zhang, H., Shepard, C., Lipman, T., Zeng, T. & Moura, S. (2019). “Charging Infrastructure Demands of Shared-Use Autonomous Electric Vehicles in Urban Areas.” Submitted to Transportation Research Part D.

Important Future Work: Commercial Automated Ride-hailing EVs



VOCT is not constant because ride-hailing demand is not constant

Charging cost may not be constant (time-of-use or dynamic pricing)

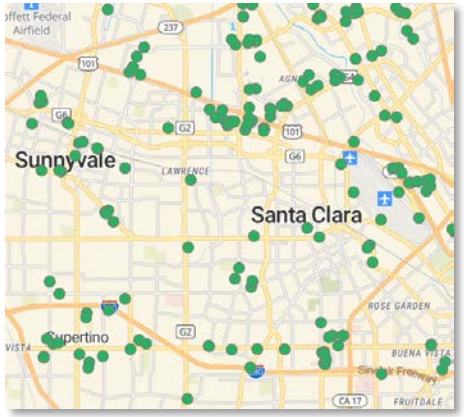
Predictive analytics and complex optimization are needed for fleet management and charging network design

Example traffic volume data from FHWA Office of Operations, https://ops.fhwa.dot.gov/freewaymgmt/publications/documents/nrpc0610/workshop_materials/hov_to_hot/tabletop_poster.htm
Example utility load data from ISO New England, https://www.iso-ne.com/isoexpress/web/reports/load-and-demand

Important Future Work: Commercial Automated Ride-hailing EVs

Infrastructure siting strategy

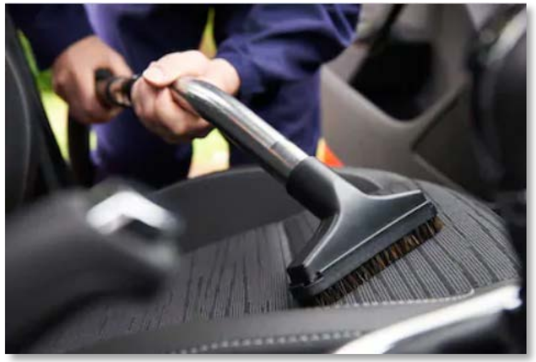
3rd party distributed charging network



Source: www.afdc.energy.gov

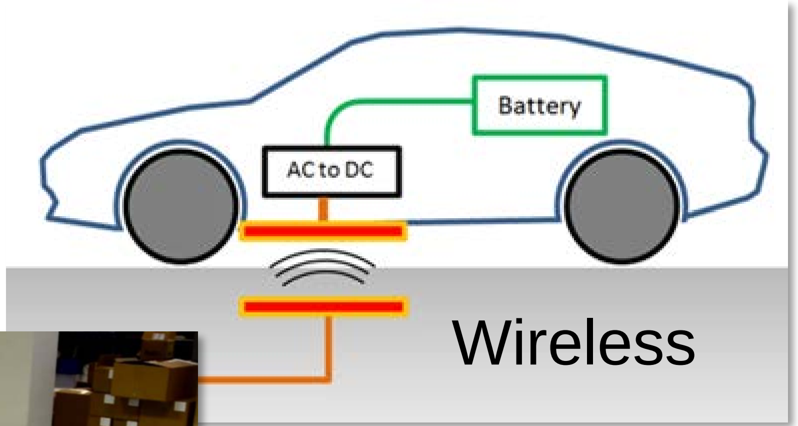
and/or

Charging in centralized depots



Source:shutterstock.com

Technology required to automate charging adds cost



Source: INL

Robotic conductive

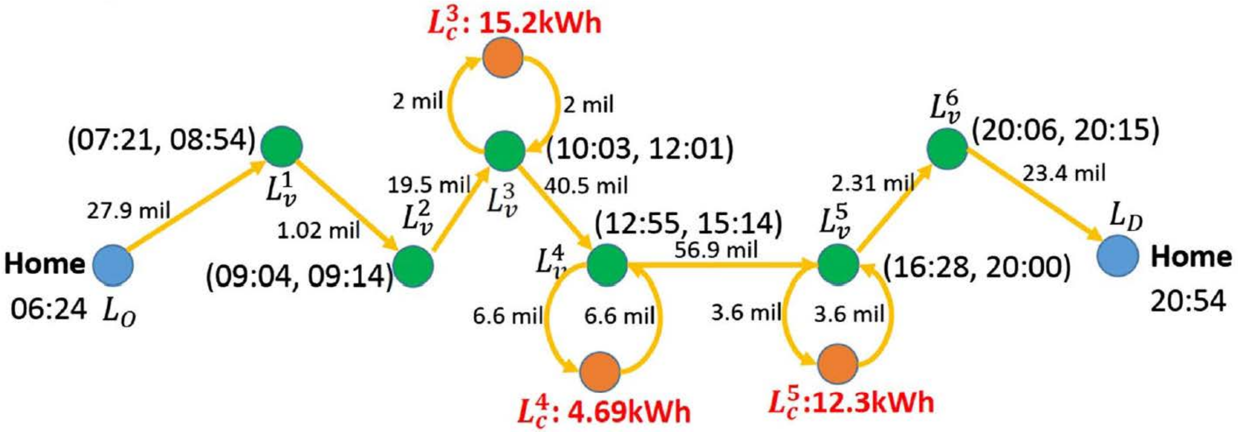
Source: twitter.com/tesla

Privately-owned, Personal-use Automated EVs

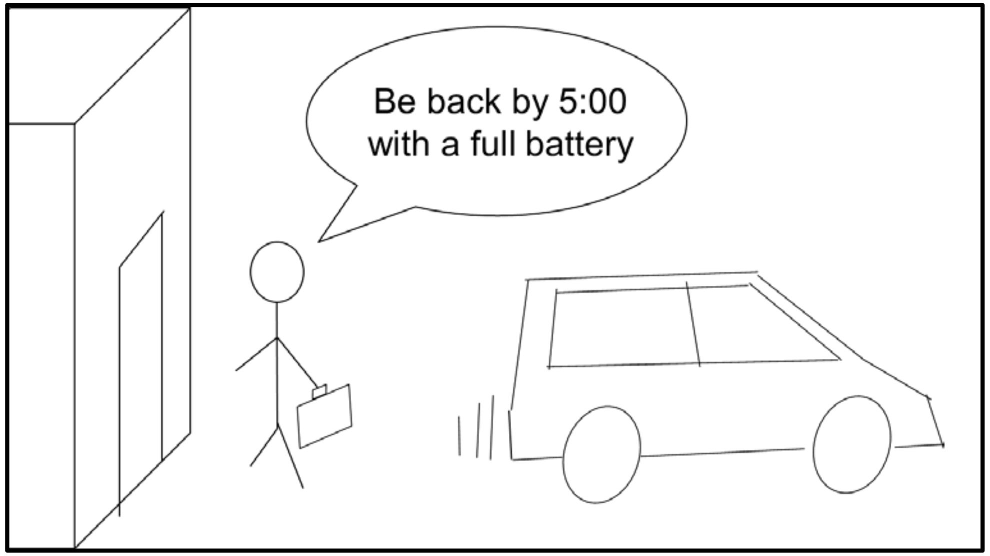
Valet charging as needed at any destination

Enabled by vehicle-to-cloud communication, predictive analytics and machine learning

Makes charging possible when VOCT is low



Yi, Z., Shirk, M. "Data-driven optimal charging decision making for connected and automated electric vehicles: A personal usage scenario." Transportation Research Part C: Emerging Technologies 86 (2018): 37-58.



Source: INL

Conclusion

Consumers will bear the cost of charging infrastructure in the long run

Cost increases with charging power

Focus should be on understanding consumers' willingness to pay in terms of how they value charging time

Understand how this varies by market segment

- Private vs. commercial
- Personal vs. shared use
- Human-driven vs. automated

Take advantage of vehicle automation, connectivity, and artificial intelligence to enable vehicles to charge themselves when the value of charging time and cost are low