

# EV Charging

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U.S. DEPARTMENT OF  
**ENERGY**

# Oak Ridge National Laboratory

## ORNL's Mission

Deliver scientific discoveries and technical breakthroughs that will **accelerate the development and deployment of solutions** in clean energy and global security, and in doing so create economic opportunity for the nation

## Signature Strengths

Computational Science and Engineering  
Material Science and Engineering  
Neutron Science and Technology  
Nuclear Science and Technology



- DOE national laboratory (one of 17)
- >\$1.65B budget
- ~5,000 employees
- ~3,000 research guests annually



# Common Chargers today

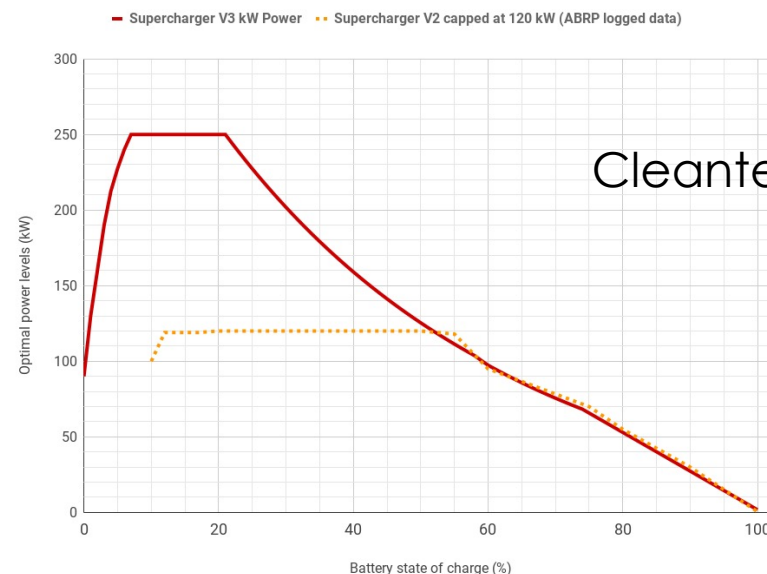
- Level 1 – 110V ~1.5kW: on board. No Power Electronics.
- Level 2 – 220V 3.3kW, 6.6kW, 11kW: on board. No Power Electronics
- DC Quick Chargers – 50kW
- Tesla – 150-250kW
- Electrify America – up to 350kW

# Range Anxiety

- EV range is increasing - >300 miles
- Range anxiety still exists
- More fast charging stations needed – 5-minute charging?

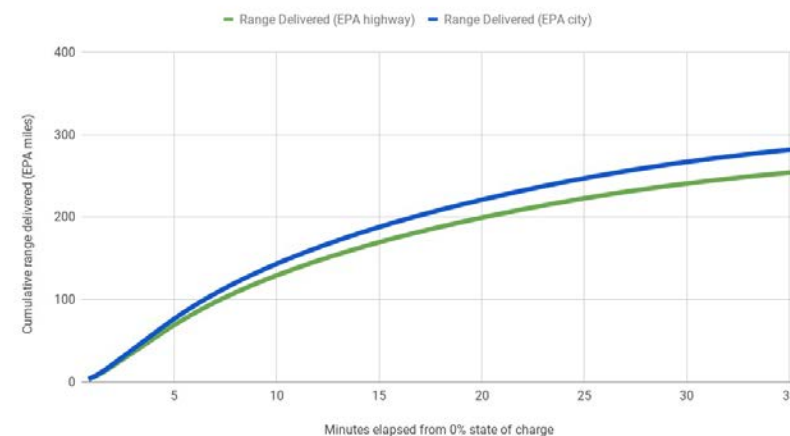
Tesla Model 3 Long Range on Supercharger V3 Beta - Estimated Charging Curve

Estimated charging power in optimal conditions, typical power will be lower, beta power levels may be modified for release version



Tesla Model 3 Long Range on Supercharger V3 - EPA Miles of Range Delivered vs. Charging Time

Estimated results in optimal conditions, typical miles delivered/time will be lower, beta results may be modified for release version



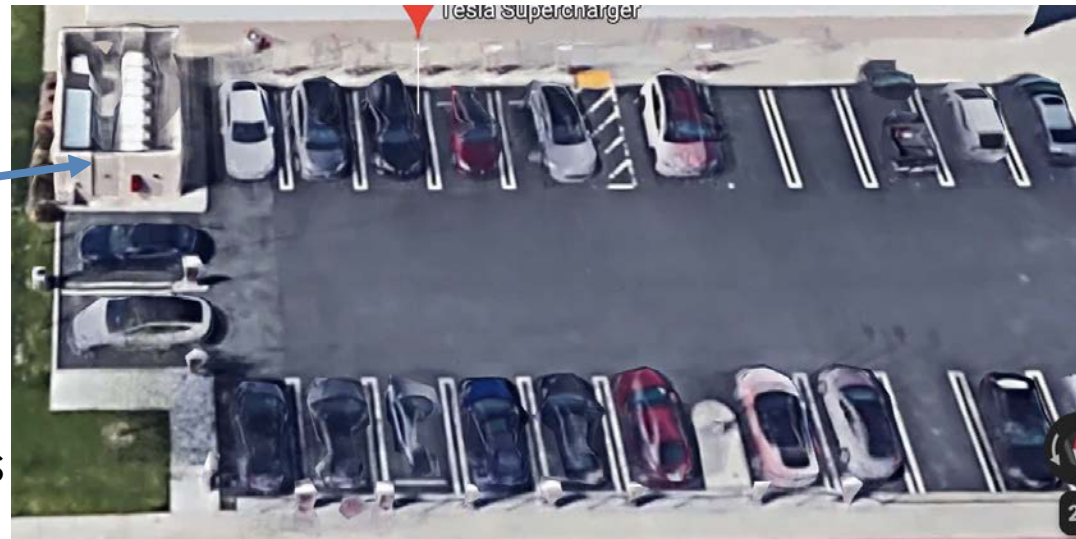
5 mins – 75 mile range

# Extreme Fast Charging (XFC)

- 350kW+ at 800V+ → the numbers will increase in the future
- 800V battery. 800V electric drive.
- Medium Voltage Connection
  - Transformer
  - Solid-state transformer



Tesla.com



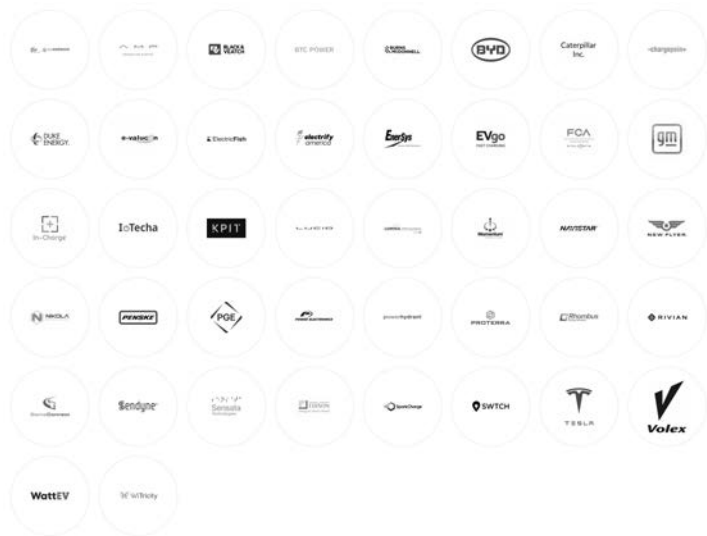
Transformer and PE

Google Maps  
Anaheim Superchargers

# CharIN

<https://www.charin.global>

- The standard focuses on Class 6, 7, & 8 commercial vehicles, but could easily be used for buses, aircrafts, or other large battery electric vehicles (BEVs) with huge battery packs and ability to accept a >1MW charge rate.



- Single conductive plug
- Max 1.250 volt & 3.000 ampere (DC)
- PLC + ISO/IEC 15118
- Touch Safe (UL2251)
- On-handle software-interpreted override switch
- Adheres to OSHA & ADA (& local equivalent) standards
- FCC Class A EMI (& local equivalent)
- Located on left side of the vehicle, roughly hip height
- Capable of being automated
- UL (NRTL) certified
- Cyber-Secure
- V2X (bi-directional)

<https://www.charin.global/technology/mcs/>



# Wired and Wireless Chargers



ORNL Wireless Charging animation  
<https://www.youtube.com/watch?v=Gw6XtzEOIyI>

# ORNL Wireless Charging Activities



Wireless power transfer (WPT) work at ORNL started in 2008



120kW WPT (2018)  
- 97% efficiency @ 6-inch gap  
- Fast charging for LD EV



300kW XFC (2021)  
- ORNL polyphase coil technology  
- Extreme fast charging for LD/MD



High Power DWPT (2021)  
- Partners: Hyundai and ACM  
- 200 kW @ 55 mph+



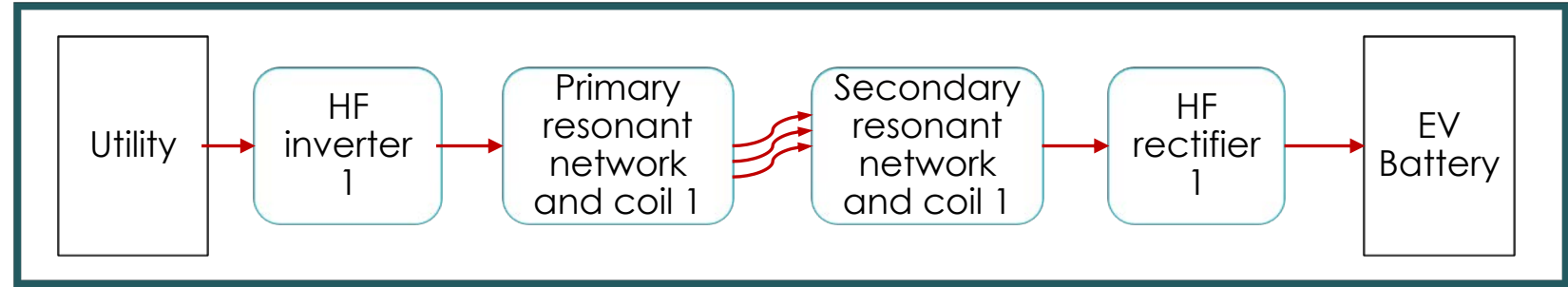
20 kW Bi-directional WPT (2020)  
- Partner: UPS  
- 20 kW Grid-to-EV  
- 6.6 kW EV-to-grid

Wireless EV Charging to Enable Electrified Transportation

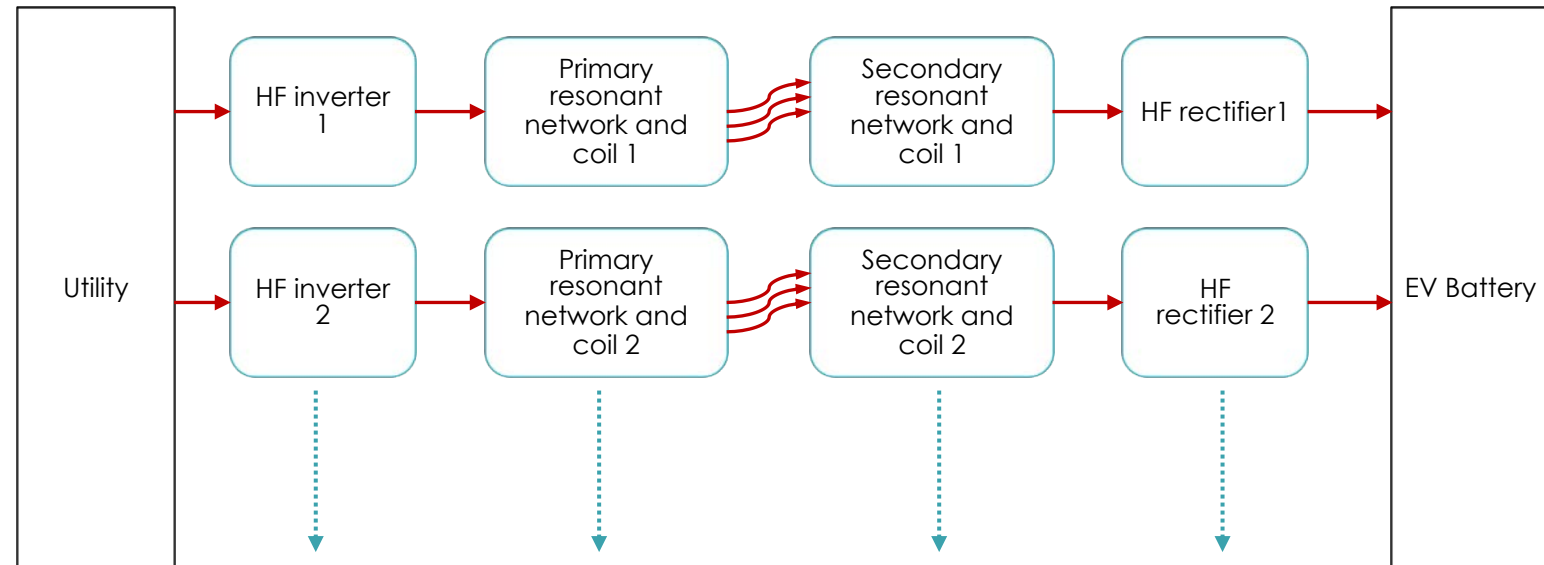


# ORNL's Wireless Power Transfer Approach

Single line power flow



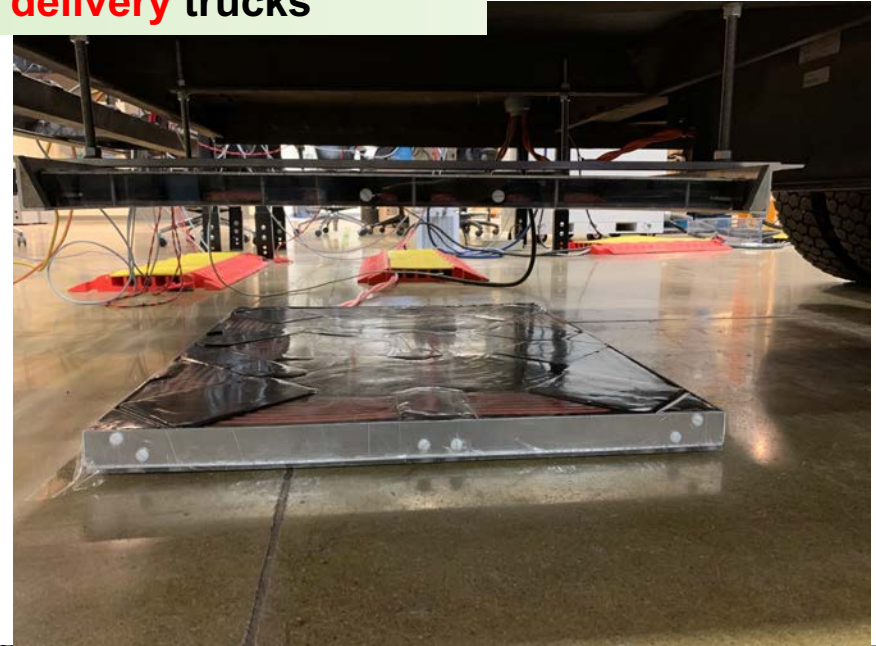
Not a paralleled approach



# Bi-Directional Wireless Charging – UPS Demonstration

Developing high-power, bidirectional wireless charging for electric **delivery** trucks

- **Target:** Design, model, simulate, build, integrate, and test a bi-directional wireless power transfer (BWPT) system for medium duty delivery trucks
  - A vehicle integrated  $\geq 20$  kW wireless power transfer system with bi-directional operation
  - High-efficiency with a nominal magnetic airgap of **11 inches**
  - Vehicle-to-grid mode wireless power transfer to building or grid loads (grid support or ancillary services)
- **Demonstrated:**
  - **Grid-to-Vehicle:** 20.36 kW at 93% efficiency
  - **Vehicle-to-Grid:** 12.8 kW to 480V power grid at 89.1% efficiency
- Vehicle and charging system will be deployed at a UPS facility in Roswell, GA for 6 months of data collection and evaluation

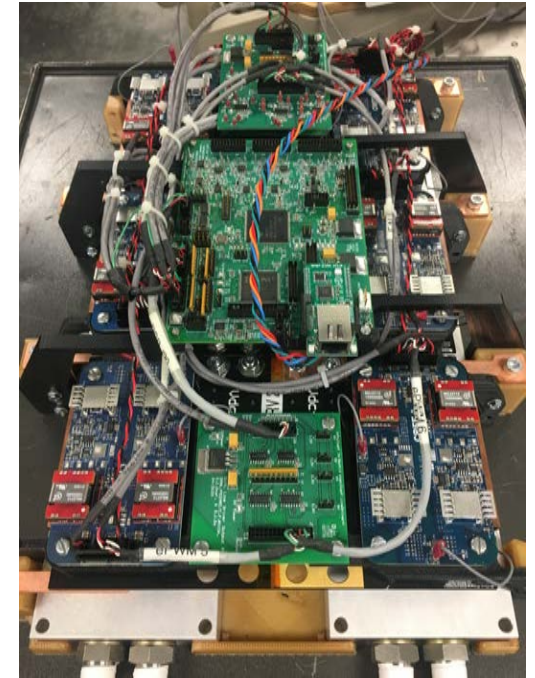




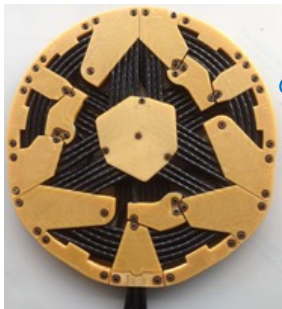
# Wireless Extreme Fast Charging (XFC): 270 kW

100kW and 270kW power transfer (50% increase in SOC in 10 minutes) with 90% efficiency (end-to-end)

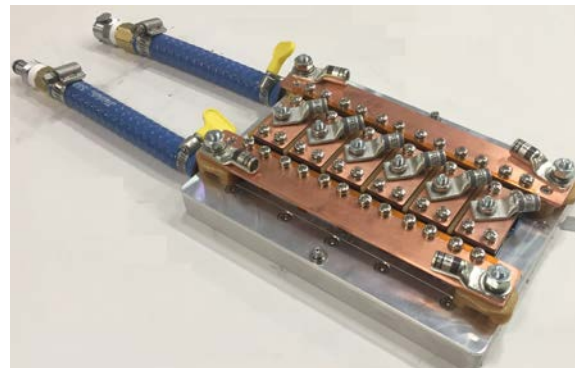
- Partnering with Hyundai-Kia North America Technical Center (HATCI) and VW Innovation Hub
- Targeting 3C charge rates
- Hyundai KONA EV (100 kW power transfer) and Porsche Taycan (270 kW power transfer) research vehicles
- Achieved 0.905 and 1.53 MW/m<sup>2</sup> surface power density with 100 kW and 270 kW receivers
- Open-ended winding dual three-phase inverter design for the primary side,
  - 500 kW design, 9.16 liters, ~55 kW/liter specific power



Primary-side  
high-frequency  
inverter  
– 500 kW peak  
power



Laboratory  
development of the 100-  
kW receiver for Kona EV  
(375 mm diameter)



100-kW HF open-  
ended winding  
rectifier for Kona  
EV

Laboratory  
development of the  
100/300-kW  
interoperable ground  
coupler (750 mm  
diameter)





# High Power and Dynamic Wireless Charging of Electric Vehicles

## Relevance

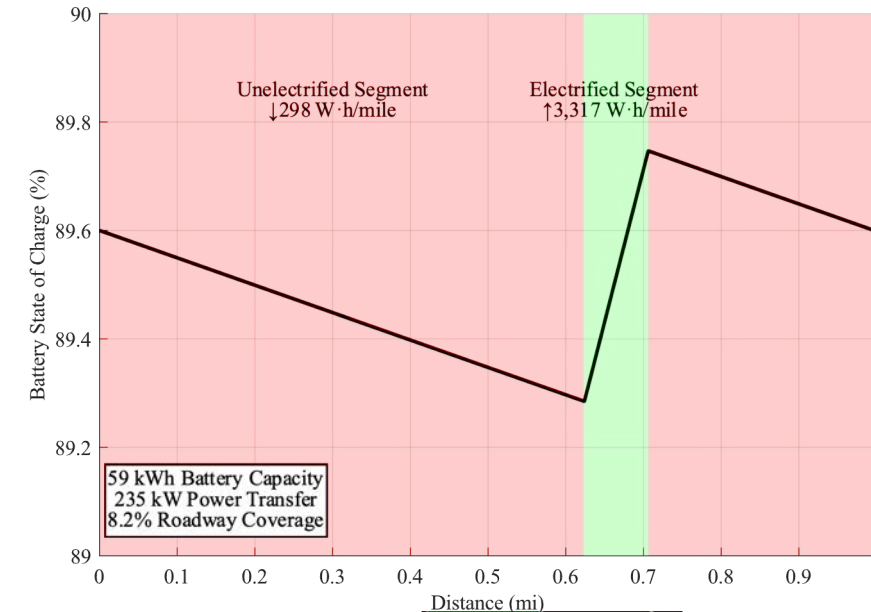
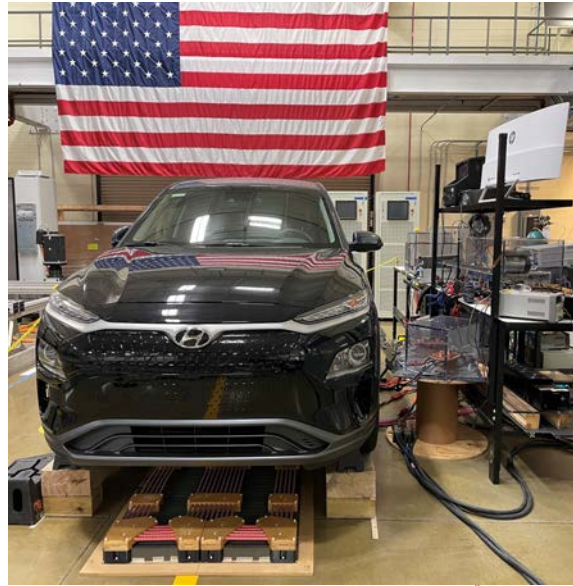
- Dynamic EV charging can significantly alleviate range anxiety and concurrently reduce the on-board battery requirement (weight and cost reduction)

## Objective

- Design, develop, build, and validate vehicle integrated **200 kW** dynamic wireless electric vehicle (EV) charging
- Charge sustaining mode of operation
- **8.2%** roadway coverage

## Status

- **186 kW**, **93.3%** efficient, in-lab wireless power transfer validated;
- Field demonstration planned for **Spring 2022** at American Center for Mobility in Michigan



# Integrating Dynamic Wireless Power Transfer Systems in Roadways

Validate technologies and solutions to transition high-power dynamic wireless (HPDW) charging of electric vehicles (EVs) from an early-stage proof-of-concept system to a practical roadway-integrated dynamic wireless power transfer (DWPT) system suitable for deployment at-scale.

- Characterize HPDW charging system both **in the lab and on the road at ACM.**
- Analyze the power transfer characteristics including
  - efficiency, power & energy profiles,
  - misalignment tolerance,
  - thermal profiles,
  - emissions and shielding,
  - impact of different vehicle classes,
  - impact on the grid,
  - use cases,
  - scalability, and
  - **environmental factors.**
- Identify and develop solutions to challenges of **roadway integration of high power DWPT** components and different **roadway materials.**
- Perform system-level cost study and analysis of deployable scenarios for integration of DWPT system for **light-, medium-, and heavy-duty EVs**



Laboratory development of 200 kW, 20 MPH dynamic wireless charging emulator

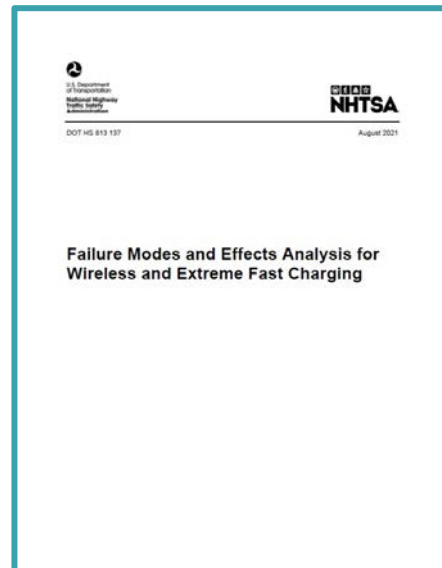


ACM deployment of 200 kW DWPT system with 4 roadway integrated transmitters and roadside equipment



# Failure Modes and Effects Analysis for Wireless and Extreme Fast Charging

- NHTSA funded FMEA report
- Review of wired and wireless charging technologies in a 230-page report along with conceptual FMEA for different charging levels
- 3 different charging levels (3.3-22kW, 22-120kW, 120-350kW) with wired and wireless charging were considered for conceptual FMEA study



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<https://rosap.ntl.bts.gov/view/dot/57152>

Gurpinar, E., Mohammad, M., Kavimandan, U., Asa, E., Galigekere, V. P., Ozpineci, B., Mukherjee, S., Tolbert, L., Bai, H., & Liu, Y. (2021, August). Failure modes and effects analysis for wireless and extreme fast charging (Report No. DOT HS 813 137). National Highway Traffic Safety Administration.



# Questions

