Wireless Extreme Fast Charging for Electric Trucks (WXFC-Trucks)

WAVE by Ideanomics

Principal Investigator, Michael Masquelier

Wireless Advanced Vehicle Electrification

June 24, 2021

Project ID: elt240

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WXFC-Trucks | Overview

Timeline

- Project start date: August 2018
- Project end date: June 2022
- Percent complete: 60%

Budget

- Total project funding: $9,838,240
  - DOE share: $4,292,137
  - Contractor Share: $5,546,103
- Funding for FY 2019: $1,249,762
- Funding for FY 2020: $3,603,179
- Funding for FY 2021: In-Progress

Barriers

- Meeting the window of time to deliver a medium voltage feed to the charge site
- Obtaining the necessary permits for the project
- Acclimating drivers to electric vehicles requires changing driver habits (or other personnel) for plugging in the vehicles and aligning the trucks over the wireless chargers

Partners

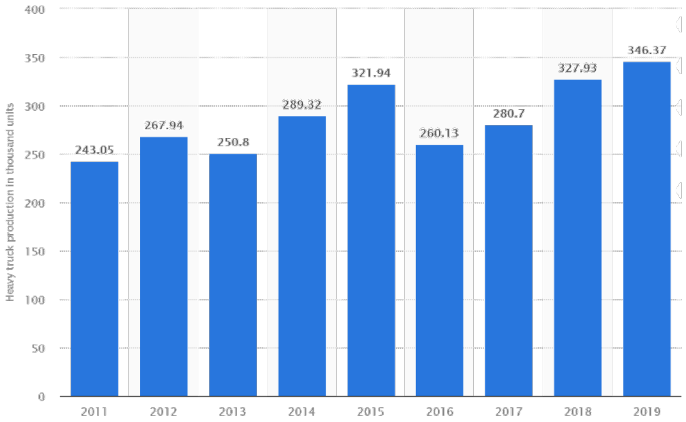
- WAVE, Inc. – Project Lead
- Cummins Inc. (Cummins)
- Schneider Electric (Schneider)
- Utah State University (USU)
- Port of Los Angeles (POLA)
- Total Transportation Services Inc. (TTSI)
- Los Angeles Department of Water & Power (LADWP)

WXFC-Trucks | Relevance

Impact

- The California Air Resource Board shows that 41% of all greenhouse gas emissions (429.5 $MMTCO_2e$ in California in 2016) is due to transportation
- 7.8% of all greenhouse gas emissions were from heavy duty trucks
- Enabler for this major pollution transportation sector to become all-electric
  - Fully charged vehicles in roughly 20-minutes means minimal down time to refuel and minimal impact on existing route planning
  - No cables means hands-free instant start of charging with no special personnel required
- Overcoming the charging time obstacle leads to a 3x to 4x reduction in actual fuel costs for vehicle operation
- Accelerate manufacturing and deployment of electric heavy-duty trucks

Heavy-Duty Truck Production in the US from 2011-2019



Objectives

- Wireless extreme fast charging
- MV grid to DC converter
- Extreme fast charging capable electric truck

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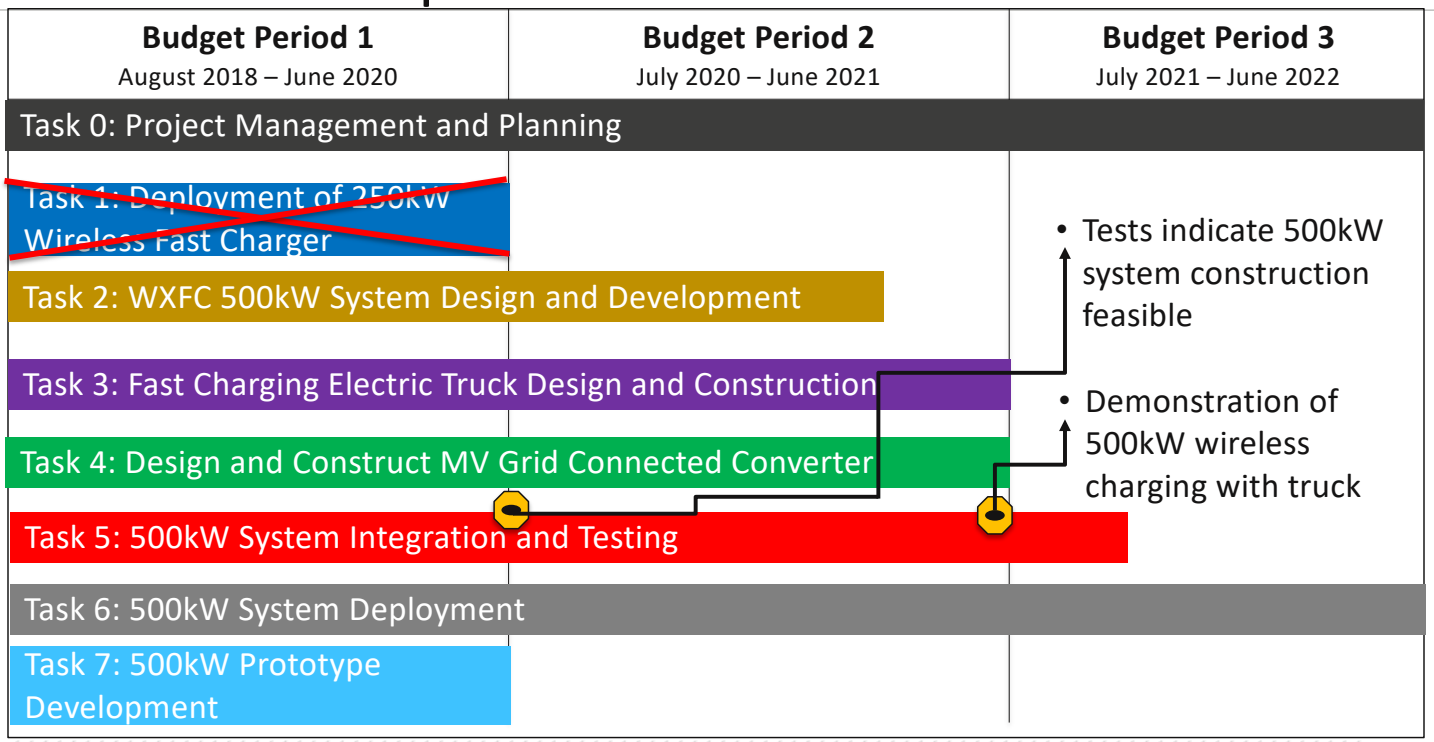
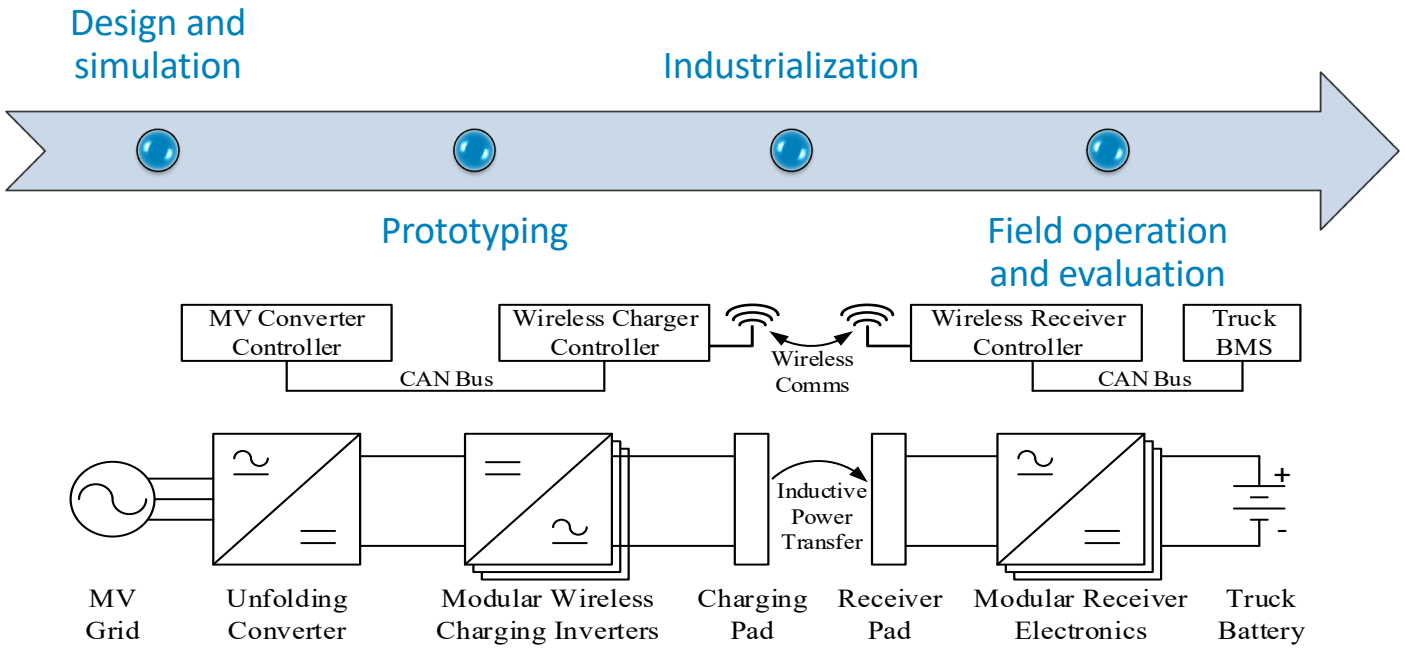
WXFC-Trucks | Relevance

FOA Objective	WXFC-Truck Expected Outcomes
Recharge battery in half the time	• New system with 500 kW wireless charging
Develop and verify vehicles equipped with XFC, charger installation and demonstration	• W-XFC system deployment and operation at POLA with two Class-8 trucks customized to support XFC. • Deployment in two stages. First early 250kW prototype charging and second final deployment at 500 kW • Combined, over two years of evaluation data and best practices
System design and grid infrastructure impact	• Direct MV 3-phase AC to DC single stage conversion solution to reduce grid integration costs, system size and weight, and improve efficiency.
Catalyze manufacturing and adoption of electric trucks	• Project goal targets key barrier to market adoption • One year of system hardware demonstration and evaluation are performed at one of the world's highest volume shipping ports at a critical time with zero emission requirements in place by 2035

WXFC-Trucks | Milestones



WXFC-Trucks | Approach



Block diagram of the WXFC system from MV grid to truck battery.

WXFC-Trucks | Approach

500kW MV Grid Connected AC/DC Supply Approach

- 3-phase unfolder with a soft DC bus two-level output
- Develop the 3-phase unfolder to achieve direct MV grid connection with switches commutating at the line frequency
- Design the series stacked isolated DC/DC converters to achieve the voltage step down function from MV naturally with near unity conversion ratio to obtain high efficiency

Extreme Fast Charging Capable Electric Truck Approach

- Investigate appropriate battery chemistry (LTO cells or NMC cells)
- Design custom thermal management for the cell to facilitate charging at 3C
- Select appropriate battery pack capacity and cell chemistry to integrate with electric powertrain applicable to Class 8 drayage applications

WXFC-Trucks | Approach

500kW Wireless Charging System Approach

- Leverage deployment experience with 250kW charger
- Use deployment experience to develop 500kW Prototype
- WAVE has experience integrating with different OEMs

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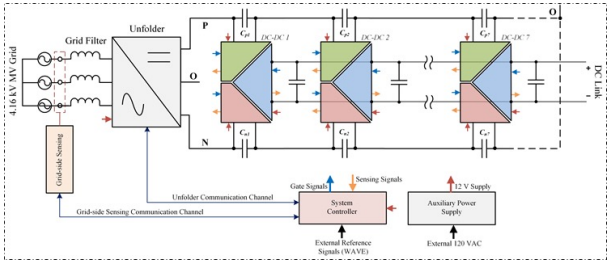
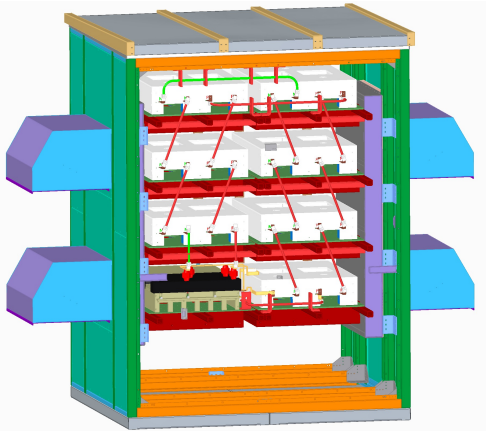
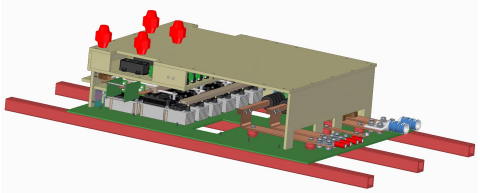
WXFC-Trucks | Technical Accomplishments & Progress

560 kW MV Grid Connected AC/DC Supply Progress

- Fully tested one 85 kW DC-DC converter electrically and thermally
- Updated fabrication packages for DC-DC modules based on testing
- Transformer fabrication package completed and external vendor has built the first sample
- Constructed and tested initial 560 kW 3-phase unfolder and updated the design considering UL feedback, and also integrated an EMI filter
- Coordinated with Schneider Electric to develop cooling and cabinet design – nearly completed
- Submitted initial documentation for UL to review
- Validated AC-DC module-level control design on low power prototype
- Simulated the proposed control strategy for the series-stacking of seven DC-DC modules



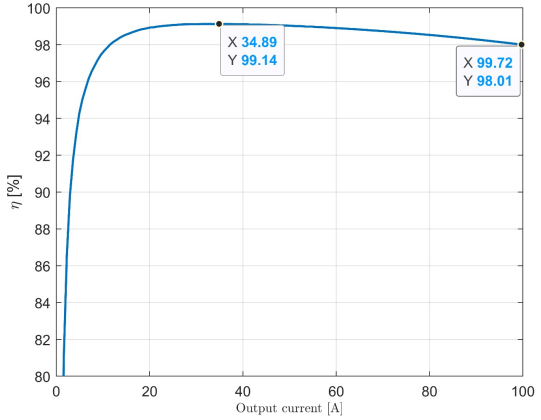




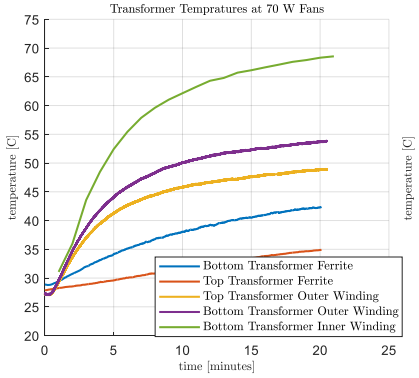
WXFC-Trucks | Technical Accomplishments & Progress

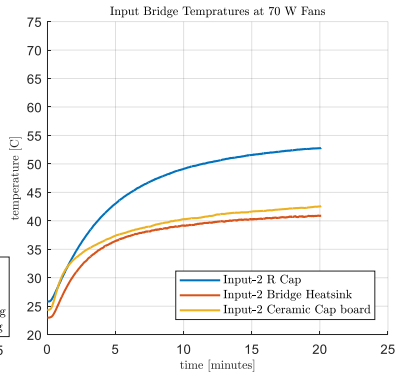
DC-DC Test Results:

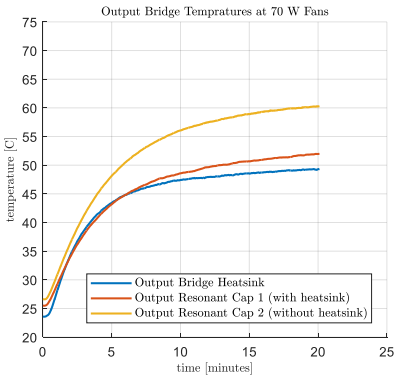
- Demonstrated the operation of the DC-DC module at multiple operating points at full power
- Performed efficiency sweep measurements across all load conditions



DC-DC 85 kW Thermal Testing Setup and Results:



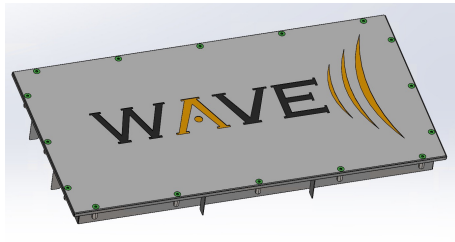




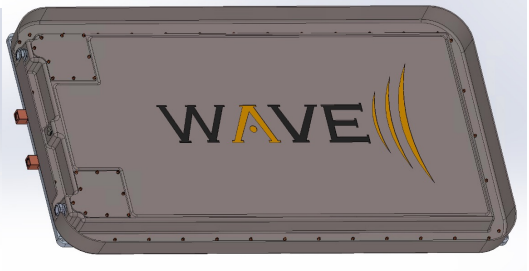
WXFC-Trucks | Technical Accomplishments & Progress

WAVE System Design Process

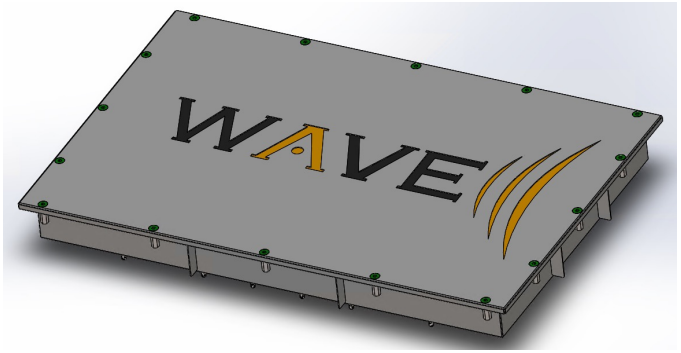
- WAVE has continued work on the extreme fast charger at 500kW with a focus on magnetics.
- Modular design approach will allow WAVE to deploy 2 X 250kW assemblies
- WAVE to meet weight, cooling requirements, and magnetic performance



WAVE 250kW Ground Side Pad



WAVE 250kW Receiver Pad



WAVE 250kW Ground Side Pad

WAVE System Design Process

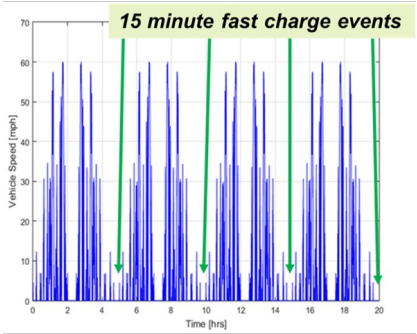
- Several Iterations were possible via simulation.
- Final design to have 25% weight reduction from original prototype.
- Production 500kW system design completed and on order
- During testing WAVE was able to transfer over 550kWh of energy during initial testing
- WAVE was able to run a 37 minute continuous charge during initial testing

WXFC-Trucks | Technical Accomplishments & Progress

Truck requirements

- Class 8 day cab based on TTSI's requirements
- Battery selected which supports 3C charging, 2C discharging

Key vehicle metrics	Target	As designed
Vehicle speed on 6% grade @ 82k lb GCVW	> 30 mph	32 mph
Charge power to 80% SOC (15 minutes)	495 kW	495 kW
Tractor weight	≤ 22.5k lb	22.8k lb
Vehicle range	45 miles	58 miles
Work-day duty cycle	20 hours 160+ miles	20 hours 200+ miles



Targeted work-day duty cycle

Electric Powertrain

- Cummins-developed 330 kW (continuous) central drive

Truck status

- Truck 1 undergoing validation; wireless charging demo in July
- Truck 2 starting validation testing
- Stand-alone battery test in Q3 2020 demonstrated 3C charging and met expected battery operation on target work-day duty cycle

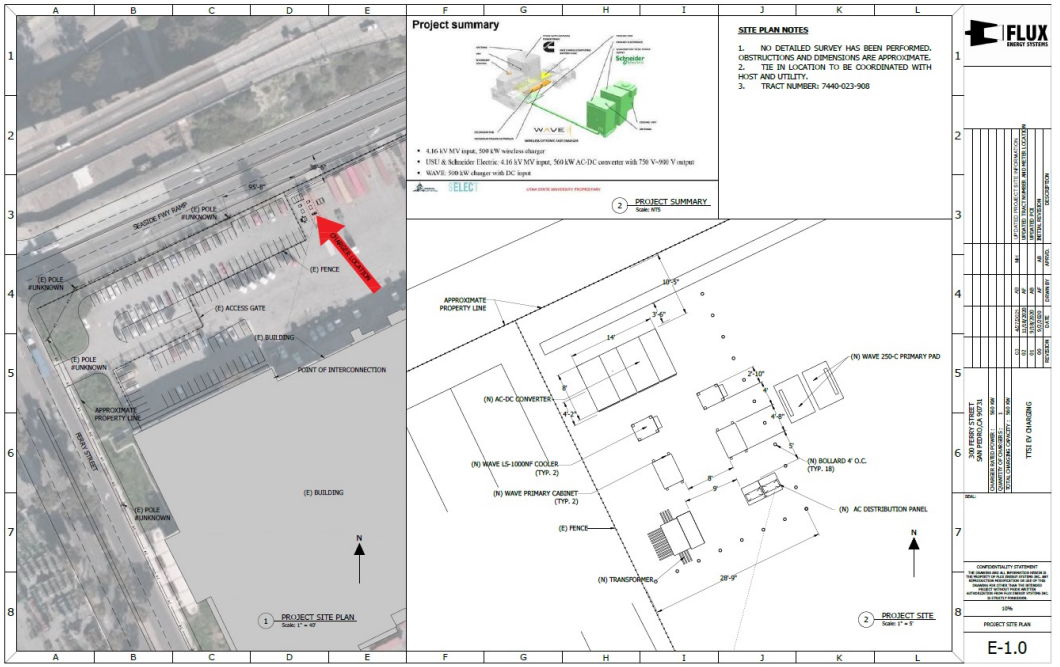
WXFC-Trucks | Technical Accomplishments & Progress

Challenges	Resolutions
Pivot back to Custom House POLA location	New site layout
LADWP Service Option - change in available service voltage	34.5kV lead time ~24 months, switch to 480V service with step-up transformer to medium voltage to simulate POC
Unfolder and power converter enclosure cooling – cooling requirements exceed standard solutions typically deployed	Increased enclosure size, working with vendors to increase air flow and routing through blowers and louvers
Surge protection – standard offer limited	Modification of existing offer to support requirements
EMI – ensuring adequate protection from model to build prototype	Continued modeling post prototype development
Isolation requirements – ensuring safe operating procedure through controls	Conditions map for isolation event from line-side contactor

WXFC-Trucks | Technical Accomplishments & Progress

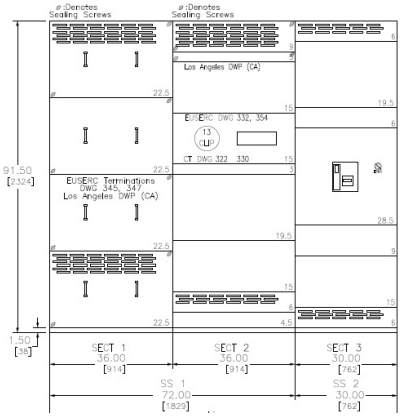
- Completed Custom House site design
- Completed LADWP service application
- Revise site design to reflect LADWP input from service application review
- Defined cooling load requirements and low-voltage circuit layout

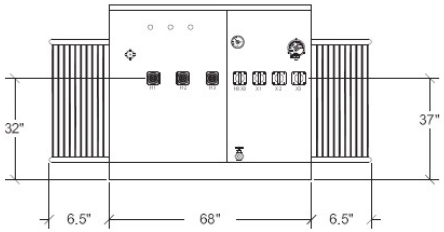
Updated Site Plan

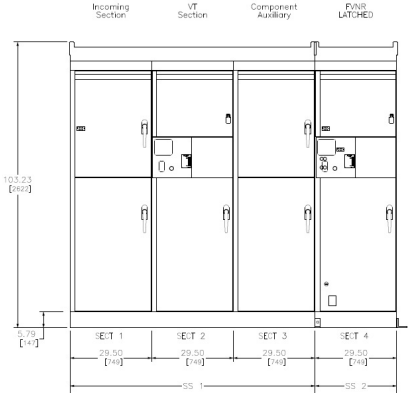


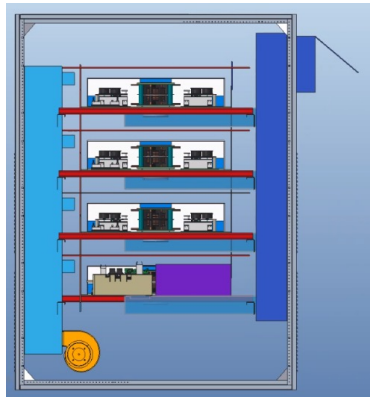
WXFC-Trucks | Technical Accomplishments & Progress

- **New switchboard for LADWP metering**
- **Step-up transformer to medium voltage**
- **Primary contactor**
- **Custom design for unfolder cabinet**









WXFC-Trucks | Response to Previous Reviewer Comments

Approach:

Reviewer: "The planned approach was sound, but the re-scoped project still focuses on a 500-kW wireless extreme fast-charging (WXFC) unit that has not been fully developed and the project in nearly halfway complete. The team is still making substantial changes to 500 kW hardware. The new plan of moving the 500-kW testing to the third period raises the risk for completion of major milestones."

Response: The 250kWx2 module is now fully developed, tested, ready to scale to 500kW, integration with Cummins truck completed, ready to install on truck arriving at WAVE in July.

Technical Accomplishments & Progress:

Reviewer: *"Recognition of the lack of progress of a 3C-capable large energy storage system (ESS) pack suitable for a HD application is not a sufficient plan to ensure a properly developed vehicle will be available for testing required to show system capability."*

Response: 3C charging rate for BESS has been tested at Cummins, will be demonstrated on truck in operation at POLA.

Collaboration & Coordination Across Project Team:

Reviewer: *"There appeared to be some issues with the primary site partner; however, that has been addressed and moved to a new Carson location. This is not without issue as it will entail facility modifications; however, the team appears ready to tackle this barrier."*

Response: Strong, frequent, structured communication continues amongst all team members (WAVE, Cummins, USU, Schneider Electric, TTSI, SCE). Confirmed return to original site which will be more convenient and accessible for normal drayage truck operations.

Proposed Future Research:

Reviewer: *"The difficulties in getting the site ready for a pilot project should be identified as a barrier that needs better understanding within the future work."*

Response: Completed Custom House site design and LADWP service application. Revised site design to reflect LADWP input from service application review.

Relevance:

Reviewer: *"This is the first project that goes from charger design to site deployment, thereby demonstrating the practical reality of this technology leading to its adoption."*

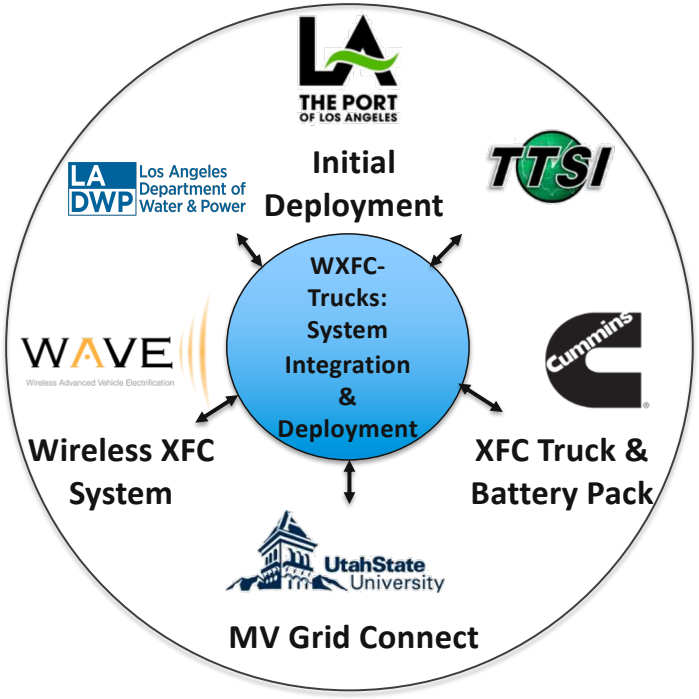
Response: This effort has already spawned commercialization discussions with TTSI about additional 500kW chargers and E-Trucks at additional sites.

Resources:

Reviewer: *"The technology scope of this project is broad and therefore there is more opportunity for unanticipated development costs."*

Response: The broad scope of the project has contributed to some delays; however, additional resources have been added. Truck anticipated to be running at POLA in Q3.

WXFC-Trucks | Collaboration & Coordination with Other Institutions



- **The Port of Los Angeles** – Deployment Partner
- **Los Angeles Department of Water & Power** – Deployment Partner
- **Total Transportation Services Inc.** – Port Trucks Partner
- **Cummins** – Truck Integration and Electric Drivetrain Partner
- **Utah State University** – Research Partner
- **Schneider Electric** – Electrical Supplier, Industrialization Partner

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WXFC-Trucks |Remaining Challenges & Barriers

LADWP UGPS agreement finalization:

- Determining capacity at existing circuit
- Final LADWP approval for interconnection at existing gear

UL process:

- Ambiguity due to lack of existing standards for primary-fed DC conversion equipment
- Logistics – build and test location sites geographically dispersed

WAVE System:

- Control integration with MV-Grid converter
- Truck Integration
- Control leakage to surrounding environment

Truck Design:

- Ensuring adequate thermal management of battery and WAVE components during charging under range of environmental conditions

WXFC-Trucks | Proposed Future Research

Future Research Opportunities:

- Battery: To improve long-term commercial viability, industry needs to develop a low-cost, higher energy density 3C charge (continuous) capable battery
- Grid Feed: Optimize MV-to-DC Converter for various electric utility MV voltages available.
- Thermal: Minimization of heat generated and novel thermal materials.
- Operator Cost: Addition of stationary storage to offset demand and TOU charges.
- System: Overall improved system-level efficiency.

Any proposed future work is subject to change based on funding levels

WXFC-Trucks |Summary

This project brings together all three critical components needed to solve the barrier for adoption of electric heavy-duty vehicles:

- High-efficiency MV grid supply to lower energy costs and reduce total footprint of equipment
- High-efficiency, high-energy density wireless extreme fast charger
- An all-electric vehicle capable of high C-rate charging and equipped to handle a wireless charging system

This project's overall system approach is driving research that will result in a highly cost-effective solution that will make adoption of all-electric fleets not only viable, but very compelling.

Critical success factors include:

- Development of a 500kW wireless charging system
- Development of a Class-8 truck powertrain with a battery pack capable of reliably and repeatedly charging at a greater than 3C-rate up to 500kW
- Development of a modular direct MV 3-phase AC to DC power converter
- Achieve system MV grid to vehicle battery efficiency of 92%