ElectricFish

in collaboration with

Los Angeles Department of Water & Power

LKIC Pilot Project Report

December 2021 – March 2022

Introduction

The 350squared is ElectricFish's patented battery-integrated electric vehicle extreme-fast charging module. The unique product is a containerized solution that accelerates the deployment of flexible energy resources at sites to electrify help transportation without compromising the stability of the grid. These units could be the building blocks for a decentralized 'utility of the future'.

ElectricFish's 350squared charger for electric vehicles is designed to provide four key advantages over existing DCFC systems on market:

1. Fast, turn-key installation that eliminates the need for breaking ground, lowering the time and cost of deployments.
2. Top-of-the-line power output that delivers a true fast-charge experience regardless of time-of-day.
3. Lower site operation costs with the capability for peak-shaving and electricity demand shifting.
4. Resilience and reliability value to the electricity grid with grid services and back-up power capabilities.

The capabilities of the native 350squared module are enabled by its integrated 350 kWh Li-ion battery that has a single charging outlet with an output of up to 350kW. The system places limited demand on the utility service with its downsized interconnection of 40kW peak, through a single-phase 240 V/200 Amp connection. Using a transformer built into the system, the 350squared is also able to work with three-phase connections.

In December 2021, the Los Angeles Department of Water and Power (LADWP) hosted a three-month pilot through the end of March 2022 at the La Kretz Innovation Campus (LKIC) (*figure 1*). The deployed system comprised a 210 kWh NMC battery with a single EV charging outlet of 350kW peak output. A 10kW bi-directional connection through a single-phase, 240 V/30 Amp was installed.

Figure 1: ElectricFish pilot unit at the LKIC (December 2021)

Pilot objectives

The goal of the LKIC pilot was to demonstrate two of the manufacturer's key value propositions in its deployment model (*figure 2*). One significant objective for ElectricFish was to benchmark its implementation speed for 350 kW EV charging. Another key objective was to test the impact of the ElectricFish system on local grid feeder uptime with the site host in a grid-constrained location determined by its intelligence tool, CoReScore™.

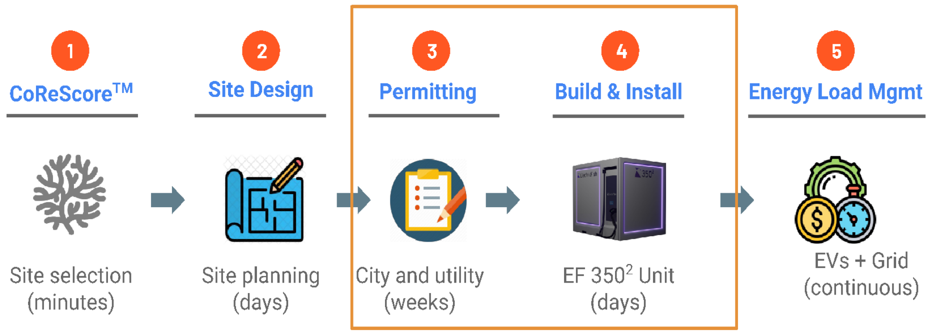


Figure 2: ElectricFish LKIC pilot demonstration objectives

Installation and set-up

As pictured in Figure 1, the pilot module was placed in an outdoor location on the parking lot of the LKIC in downtown Los Angeles, California. The unit weighs approximately 12,000 lbs (5,440 kg) with a footprint of approximately 10 X 8 ft (3.0 X 2.4 m) with a height of 8.5 ft (2.6 m), fitting two-thirds of a parking spot.
The device was laboratory-configured with a CCS-1 connector and an additional converter that couples to Tesla vehicles. A schematic of the pilot system is shown in Figure 3.

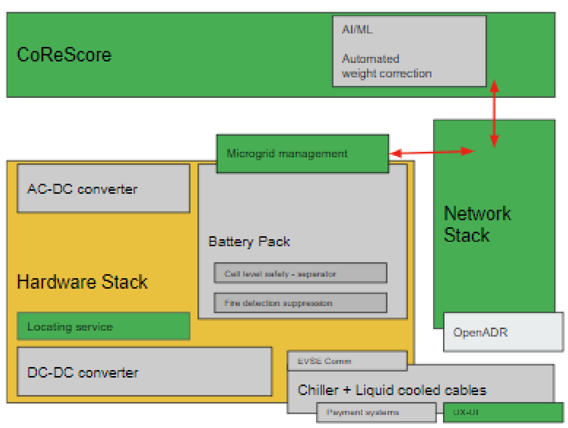


Figure 3: Schematic of system under test

A 16-26 GVW truck was used to transport the unit to site, with on-site hardware installation taking two (2) days. Installation costs totaled $6,900 - $3,000 for loading, $1,400 to ship from Fremont to DTLA, and $2,500 for unloading. The overall timeline for the pilot is summarized in the Gantt chart in Figure 4.

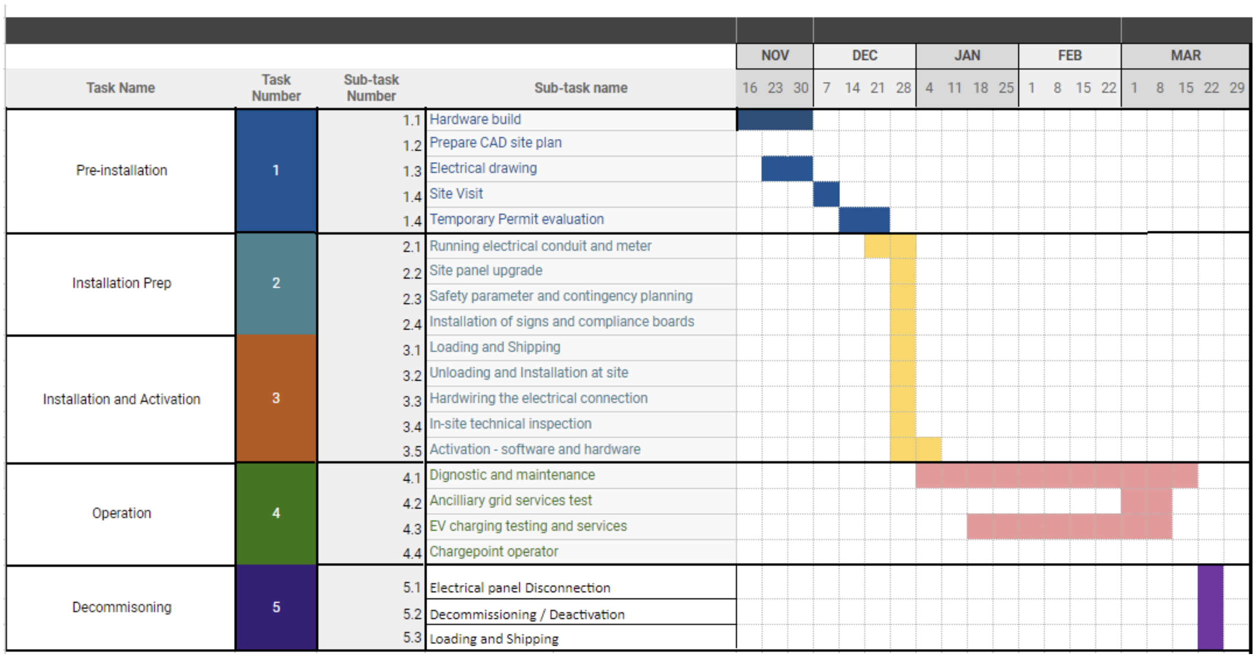


Figure 4: Pilot timeline

Characterization testing

Six operational modes were tested over the course of the pilot operation (*figure 5*). The testing and characterization results described are summarized in Table 1.

Mode 1: Unit off. ElectricFish observed the AC power input to the system while disconnected over time. The objective was to test power isolation in non-operation. The parameters of the system in this mode include AC-DC converter OFF, DC-DC converter OFF, grid circuit breaker OFF, with the high voltage subsystem, ambient cooling, and control circuit ON. In this mode, AC power consumption is maintained at 0 kW, with a maximum current signal of 1 Amp consumed by the Wi-Fi and system monitoring subsystems.

Mode 2: Standby. With the on-board battery fully charged, ElectricFish also observed the AC power input to the system in standby operation over time. The purpose of this test was to characterize the power requirement of housekeeping loads, including wireless communications, controller monitoring, cell leveling and thermal management.

The parameters of the system in this mode include AC-DC converter OFF, DC-DC converter OFF, high voltage subsystem OFF, with the grid circuit, ambient cooling, and control circuit ON. The baseline AC power input was 1.1 kW, with a current consumption of 2.7 Amp.

Mode 3: Grid charging. The input AC power to the grid-connected system 210 kWh battery at the benchmarked safe-operating SoC of ~20% was characterized with no vehicles attached. The single 10kW AC-DC converter system was tested at a maximum AC power draw of 5.1 kW, drawing current at 24.5 Amp. The power factor was maintained at approximately unity.

Mode 4: Grid discharging. Similarly, the output DC power from the battery was characterized in this test mode. A maximum DC power output of 3.2 kW was supplied at 17.7 Amp.

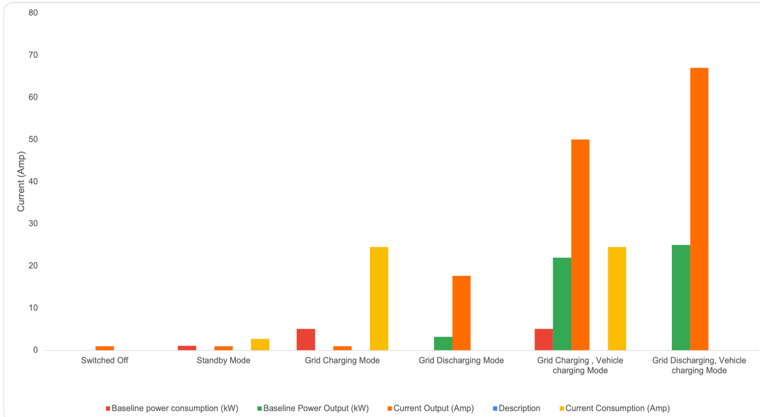


Figure 5: Test operation modes

Mode 5: Simultaneous grid and vehicle charging. The system was tested in this mode with the objective of characterizing the capacity of the system to serve EV charging output while the battery recharges from the grid. The parameters of the system in this mode include all of the AC-DC converter, DC-DC converter, high voltage subsystem, ambient cooling, and control circuit ON. The power input peaked at 5.1 kW, with a current consumption of 24.5 Amp while the system delivered 22 kW of EV charging at a current output of 50 Amp.

Mode 6: Simultaneous grid discharging and vehicle charging. The system was, lastly, tested to characterize its capacity to serve EV charging output and battery-to-grid discharge simultaneously. With all subsystems ON, the system delivered a total power output of 25 kW at 67 Amp.

Table 1: Summary of operability tests

S/N	Operating Mode	Description	Baseline power consumption (kW)	Current Consumption (Amp)	Baseline Power Output (kW)	Current Output (Amp)
1	Switched Off	System Disconnect a) AC-DC off b) DC-DC off c) High voltage subsystem - ON d) Ambient cooling -ON e) Control circuit - ON f) Grid breaker - OFF	0	0	0	1
2	Standby Mode	Basic powerup of system a) AC-DC - OFF b) DC-DC - OFF c) High voltage subsystem - OFF d) Ambient cooling -ON e) Control circuit - ON	1.1	2.7	0	1
3	Grid Charging Mode	Basic powerup of system a) AC-DC - ON b) DC-DC - OFF c) High voltage subsystem - ON d) Ambient cooling -ON e) Control circuit - ON	5.1	24.5	0	1
4	Grid Discharging Mode	Basic powerup of system a) AC-DC - ON b) DC-DC - OFF c) High voltage subsystem - ON d) Ambient cooling -ON e) Control circuit - ON	-	0.0	3.2	17.7
5	Grid Charging, Vehicle charging Mode	Basic powerup of system a) AC-DC - ON b) DC-DC - ON c) High voltage subsystem - ON d) Ambient cooling -ON e) Control circuit - ON	5.1	24.5	22	50
6	Grid Discharging, Vehicle charging Mode	Basic powerup of system a) AC-DC - ON b) DC-DC - ON c) High voltage subsystem - ON d) Ambient cooling -ON e) Control circuit - ON	0.0	0.0	25	67

Electric vehicle charging functional testing

Four main electric vehicles were used for functional EV charging tests (*table 3*), including interoperability tests, low- and high- voltage charging, vehicle charging self-termination, current up-ramp, and varying maximal voltage limit parameter for the charger. Table 2 summarizes the vehicle brands and models used in these and other tests, as well as manufacturer battery capacity and maximum charge rate specifications. Additionally, pre-charge and initialization tests (*figure 7*) were run on the Rivian and the Porsche Taycan.

Table 2: Electric vehicles available for charger testing

S/N	**Vehicle**	**Manufacturer specifications**	
		Battery Capacity (kWh)	Maximum Charge Rate (kW)
1	2020 Chevy Bolt	66	53
2	Hyundai Ioniq 6	77.4	232
3	2020 Polestar 2	78	150
4	Rivian R1T	128	180
5	Porsche Taycan	79	303
6	Genesis GV60	77.4	239

Given the nascent state of EV charging testing equipment that doesn't have all the requisite testing profile, our approach was to work directly with automakers, and available cars to check our compatibility with their charging initiation and stop, and then run long continuous tests with varying amparages. The table 3 summarizes a typical interoperability test, reaching a power delivery stage, and successful termination of the charge, without any payment or CPO authorization.

Table 3: Vehicle tests run and charging output parameters

S/N	Vehicle Name and Test	Initial SOC	Final SOC	Peak charging rates (kW)	Time in mins	Miles Delivered
1	Chevy Bolt (high voltage 377V)	41%	42%	4.57	3	2.4
2	Hyundai Ioniq 6 (517V, 200 Amp ramp-up)	51%	52%	50	2	2.4
3	Polestar (high voltage 450V)	40%	43%	260	1	7.2
4	GV60 (600 V/85 Amp limit, 350 V/5 Amp precharge)	60%	65%	34	10	12

Further, we stress tested the system on what were the peak discharge rates of the system, reaching a peak of 625 A, and 850V for delivering charges to the vehicles. A comparative analysis of the delivered vehicle travel range with the pulse charging tests run are shown in Figure 6, the blue ones are representative charge sessions from table 5, and red data points reflect the charging rates at near realistic throughput rates for market vehicles like Hyundai Ioniq, and Porsche Taycan.

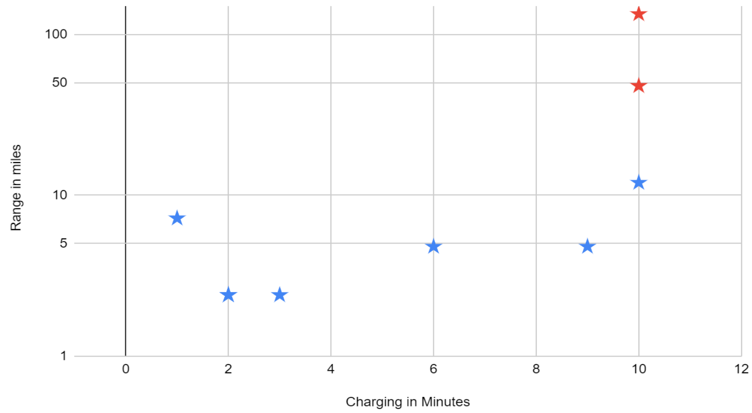
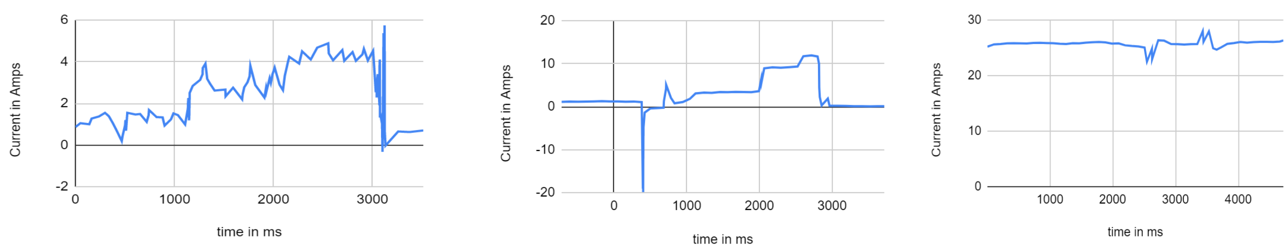


Figure 6: EV range delivered for interoperability (blue) and high power delivery (Red)

The development of a DC fast charger, there are 3 specific characteristic curves for the current delivery that need to be quantified for different vehicles, and fine tuned for an all-in interoperability. Figure 7, represents how the current profile looks like for our initial development of one of our development vehicles with a 400V system voltage.

The figure 7a signifies a power delivery from the charger when the charger goes to initial pre-charge mode, but fails in case of non- compliance with any of the metrics like the required precharge current, and the ripple in the current. In figure 7b, the charging sequence goes to a precharge, power delivery and normal shutdown, however, there is a surge of backflow in the current during the phase when the vehicle connects its batteries. Finally, in figure c, the continuous power delivery we see some surges in the current, that stem from a fluctuation in the requested voltage from the charging station.

Figure 8 represents the variables of the required pre-charge current, and our system's initial precharge voltage as we receive the vehicle's precharge request.



(a) Start-up to pre-charge current profile to go to power delivery phase, and then abandon charge

(b) Start-up to power delivery current profile to deliver power in delivery phase, and then abandon charge

(c) Continuous power delivery current profile to deliver power in delivery phase, and then abandon charge

Figure 7: Representative current profiles in various charging phases

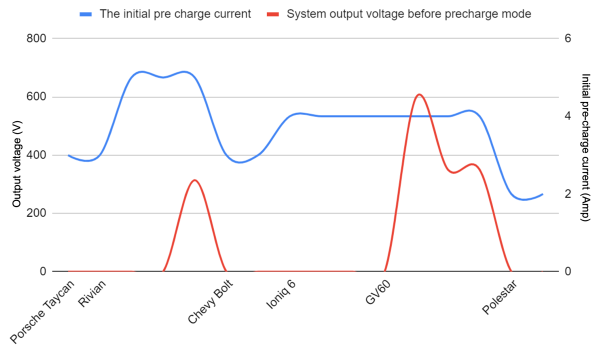


Figure 8: Vehicle visit initialization and pre-charge tests

Economics of installation

The deployment budget totaled $6,500 (including rigging, transport, and labor). This contrasts sharply with the costs of deploying a conventional 350kW, non-battery integrated DC Fast Charging system, which ranges from $40,000 to $70,000 for a single charger. Even lower-rated DCFCs serving 50kW typically cost $20,000 to $45,000 for installation.

Additionally, conventional battery-integrated DC Fast Charging systems, such as Freewire's Boost Charger, require some trenching to complete installation, according to the LADWP. Other conventional DCFCs require a primary dip of up to 30 meters from an existing distribution line, a secondary cable to the installation meter point, and three-phase transformer on a mounting pad. These system upgrade requirements are nullified with the turn-key ElectricFish technology.

For this temporary pilot installation, we did not seek permitting but would look to benchmark costs associated with the permitting process. Typical market permitting costs account for under 5% of installation costs for conventional DCFCs. For sites without ADA compliant markings, we would also seek to benchmark inclusion of the markings for future deployments.

Figure 9 references the breakdown of our pilot system's BOM cost which totaled $350,000. This initial cost is higher than the benchmarked cost of manufacturing, due to testing of components from different suppliers and slight oversizing on this first build. The power electronics and high-voltage battery system account for the bulk of costs, each constituting about 42% of total hardware BOM.

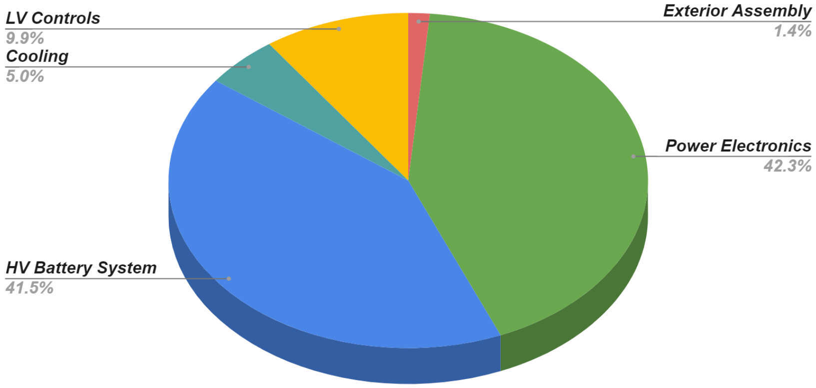


Figure 9: Hardware BOM cost breakdown

Decommissioning

The unit was decommissioned and derigged (*figure 10*) in a single-day, on March 22, 2022. Decommissioning costs totaled $8,000: $2,500 for loading, $2,500 to ship from Los Angeles back to Fremont, and $3,000 for unloading. The process itself only took 20 minutes for our electrical contractor to complete.

Figure 10: Unit decommissioning

Summary and conclusions

ElectricFish performed functional, interoperability and characterization tests on its pilot build of the 350squared at the La Kretz Innovation Center, in conjunction with the Los Angeles Department of Water and Power. The goal of the pilot was to test its fast, turn-key installation value proposition, to test its impact on the grid and local site host, to demonstrate its interoperability with existing battery electric vehicles from a range of OEMS, as well as to characterize the electrical system behavior of the unit in its various operating states.

The system demonstrated significant positive results in accelerating time-to-market and reducing implementation cost of critically needed resilient EV infrastructure. It placed a peak power demand of 5.1kW on the grid as constrained by the system design for the LKIC site. Also significant was the capability of the pilot unit to supply DC fast charge safely to an EV during battery-grid power exchange.

The LADWP testified to the success of the pilot demonstration, confirming that, unlike with their experience with the 50 kW EVgo, there was no impact to the peak power draw on the site electric meter, and thus, no impact to their electricity bill or site operation cost.