Versatile Auxiliary Power System (VAPS) Field Integration Demonstration Results

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Technical Update, June 2023

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ABSTRACT

The versatile auxiliary power system (VAPS) was developed as a stand-alone lithium-ion battery based auxiliary power unit. Three types of VAPS with varying battery capacity and mobility were analyzed, all designed to displace internal combustion engine–driven generators. The demonstration of one VAPS—the Mobi EV—completed a total of 137 days to the Los Angeles District of Water and Power and was shown to be an effective source of AC power. The unit delivered an average of 2.3 kW of power a day, with 4.75 kWh of daily energy use. The estimated use per day was 10.2 hours. During this time, the VAPS was able to displace the fuel consumption and emissions generated by traditional internal combustion engine (ICE) generator systems. The VAPS was proven effective as a replacement for traditional gasoline or diesel-powered generators.

Keywords

Electric transportation
Fleet vehicles
Lithium energy storage
Medium- and heavy-duty vehicles
Vehicle auxiliary power
Versatile auxiliary power system (VAPS)

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PRIMARY AUDIENCE: South Coast Air Quality Management District (SCAQMD) customers, fleet managers, and generator end users

SECONDARY AUDIENCE: Internal combustion engine–based auxiliary power system manufacturers

KEY RESEARCH QUESTION

Can electric vehicle grade lithium energy storage be used in auxiliary power applications to displace gasoline and diesel engine–based auxiliary power systems?

RESEARCH OVERVIEW

The versatile auxiliary power system (VAPS) project included the development and design of power systems with lithium batteries and power conversion for auxiliary power applications.

KEY FINDINGS

- Initial technical hurdles during product maturation proves the need for robust hardware and software controls.
- Auxiliary mobile power is an effective means to displace traditional gasoline and diesel engine–based generators.

WHY THIS MATTERS

With tightening restrictions on gasoline and diesel fuel–based engines—particularly in states such as California—the effectiveness of lithium battery–based solutions to displace previous technology must be, and was, proven in the VAPS study. Like the fuel-based solutions, system robustness and reliability are crucial and were evaluated during laboratory testing in controlled environments. Fleet applications require resilience with auxiliary power because the dependency impacts business operations. Lithium-based technology such as VAPS require due diligence to prove its effectiveness in fleet applications.

HOW TO APPLY RESULTS

Data generated by the VAPS studies can be applied as justification for further design and integration studies by auxiliary power system manufacturers. Feedback from end users during field tests shall be useful for improvements in software control, user interface, and power management.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- The current generation VAPS units can be used in extended testing environments, including additional weather and climate changes, to better understand system performance for challenging operating environments.

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PROGRAM: Electric Transportation, P18 Supplemental

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BACKGROUND

Industry Overview

Fleet owners differ from the general consumer in that they own, manage, and operate multiple light duty (LD, < Class III), medium- and heavy-duty (MDHD, > Class III) vehicles including both passenger and work trucks. Fleets which carry a range of LD/MDHD vehicles are ones which support various industries and markets including power utilities, public service, telecom, shipping, material handling, and construction. Within each market and application are unique operations, duty cycles and methods by which the vehicles are leveraged to support cargo transport, personnel transport, and vocational equipment use. Utility fleet owners as an example, may operate MDHD vehicles equipped with articulating arms or "booms" to support overhead power lines. Public service may also use MDHD vehicles to support the cleanliness and safety of communities and cities. In markets including construction, both LD and MDHD vehicles can also be equipped with smaller internal combustion engine (ICE), gasoline or diesel, engine driven generators for AC power for tools, or DC power for chassis accessory support. While the general consumer uses a vehicle for on road transportation, fleets utilize and depend on LD and MDHD vehicles throughout the entire workday for both on road and off road transportation and to support various tools and jobs.

Fleet Operation Summary

Fleets with LD and MDHD trucks which support telecom, utility and public service markets generally use vocational equipment installed onto the vehicle by upfitters, for use during off-highway operations. When service crews are dispatched to any specific worksite, the fleet vehicle will be used to transport tools and crews using the engine for propulsion. When at worksite, the vocational equipment used for service is generally powered by the vehicle's engine as well, even though the vehicle is stationary. During worksite off-highway operations, the ICE is left to idle to support the vocational equipment loads. The engine can support cabin comfort for occupants with heating, ventilation, and air conditioning (HVAC) and cabin 12VDC loads including lights, sirens, safety, and communications equipment (radios, CB, GPS). The chassis ICE engine can also be coupled to a hydraulic power take off (PTO) which support hydraulically driven devices including booms or digging equipment. Smaller auxiliary power units or generators (APU/APG) equipped with ICE engines may also accompany the larger chassis ICE engine to support 120VAC/240VAC power hand tools, welding/fabrication equipment, or other accessories. In all instances, the ICE engine consumes either gasoline or diesel fuel while at idle and while driving.

To understand the inventory of fleet vehicles, a compilation of vehicle registrations within California was created by the Air Resources Board of California. The Emission Factor (EMFAC) tool and website[1] was used to quantify the inventory of Class IV to VIII vehicles in

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[1] Air Resources Board of California Emissions Factor (EMFAC) online resource, 2023: https://arb.ca.gov/emfac/fleet-db/84f4c29bb8d60b5d90d4270a1a586a1bd7306cff

the Los Angeles area alone in 2020 as 102,227 buses and trucks, out of 6,746,302 total registered ICE/EV and alternative fuel vehicles. When factoring in the remainder of California and nation, the impact of idle fuel consumption and emissions in the LD/MDHD truck category becomes a significant source of greenhouse gas emissions and pollutants. Within the index of emissions, an emphasis has been placed on the reduction of carbon dioxide, CO_2. Carbon dioxide remains as the basis for recent zero-emissions vehicle mandates (ZEV) and reaching net-zero goals. Recent International Energy Agency (IEA) studies[2] of the truck and bus markets in 2022 have recognized the growth of sales and interest in the MDHD markets, however, has shown that with the inclusion and adoption of hydrogen fuel cell and electric vehicles, CO_2 emissions are tapering towards 2030 goals, as shown in Figure 1-1.

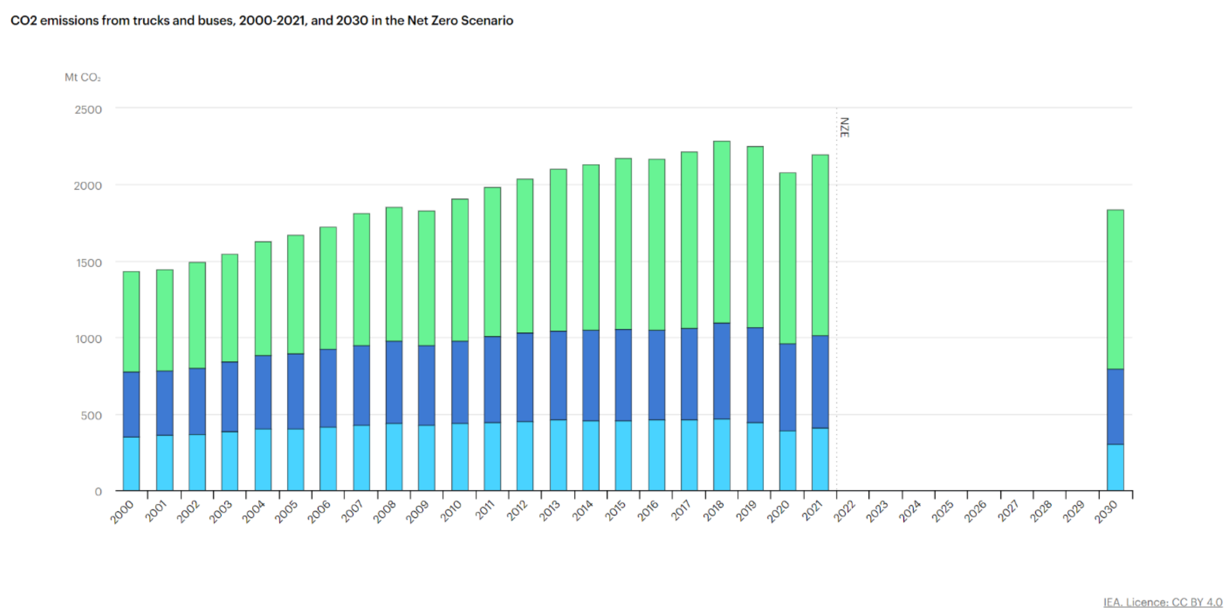

Figure 1-1
CO_2 emissions for truck and bus markets, 2000-2021 (source: https://www.iea.org/reports/trucks-and-buses)

Fleet Operation Challenges

Fleets are challenged to not only support the function of the fleet, but manage the operating costs associated with the vehicles. In all industry applications of LD and MDHD vehicles, the continual dependency on the ICE engine leads to increased maintenance and fuel consumed. ICE engines used for both on-highway propulsion and off-highway vocational tool support require significantly higher maintenance including inspections, oil changes, and tune-ups/adjustments involving both time and manpower resources. The lifespan and longevity of ICE engines in these applications also is reduced due to the continual use. Due to fluctuations in oil prices and transportation of fuel to fleet worksites, fuel continues to be a large cost for fleet expenses.

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[2] IEA (2022), Trucks and Buses, IEA, Paris https://www.iea.org/reports/trucks-and-buses, License: CC BY 4.0.

Alongside the management of operational costs, fleets are confronted with tightening restrictions on the use of the ICE engines. The largest source of ICE emissions is during idling, or when the vehicle is stationary, and the ICE engine is operating with minimal load. During stationary events when the ICE engine of MDHD trucks is on, but not used for propulsion, traditional utility truck operations may include the use of a hydraulic power take off (PTO). The PTO can support critical movements of boom articulation for utility bucket trucks, or continual loads for site operations using tools for drilling or pumps used for water evacuation of underground access points. In a stationary application, the use of large ICE for PTO use was shown to have higher emissions than while driving, as described by emissions data in Table 1-1 that was generated by the University of California, at Riverside (UCR) for Southern California Edison using emissions measurement devices and a heavy-duty chassis dynamometer to replicate road loads[3].

Table 1-1
SCE and UCR emissions data

Cycle	Average Emissions (g/bhp-hr)							Fuel use (kg/bhp-hr)	
	THC	CH4	NMHC	CO	NOx	CO2	PM	Carbon Balance	ECM
Boom	0.72	0.055	0.61	1.87	10.8	713	0.0816	0.227	0.205
Drill	1.15	0.095	0.96	2.82	18.0	941	0.0324	0.300	0.259
Hydraulic	0.63	0.033	0.54	1.36	12.0	645	0.0667	0.205	0.187
SCE Loop	0.10	0.008	0.08	2.19	3.3	654	0.0134	0.208	0.211
UDDS	0.11	0.020	0.08	2.94	3.4	678	0.0032	0.216	0.209
CILCC_CST*	0.28	0.008	0.27	2.13	5.4	731	0.0016	0.232	0.235

(yellow)	= Drive cycle
(blue)	= Stationary cycle

Source: University of California, at Riverside College of Engineering for Environmental Research and Technology

In this testing environment, the boom movements provided perspective on cycle-based PTO engagement, while the drill and hydraulic simulations provided details on loaded and unloaded continual PTO operation, respectively. The drive cycles include the heavy-duty urban dynamometer driving schedule (UDDS), which represents an average heavy duty truck duty cycle consisting of drive, and stationary idling. The SCE loop is similar to UDDS, with the inclusion of multiple stationary events in combination with both city and freeway driving. The combined international and local commuter cycle with correct speed trace is represented as CILCC_CST which averages both national and international drive cycles. In both UDDS and SCE loop cases, CO_2 emissions were lower than compared to boom and drilling operations where the PTO loads imparted onto the ICE are less than that while driving. While the main intention of MDHD trucks in this application is for stationary use, based on the emissions data, catalyst exhaust particulate management systems are not as effective in stationary use scenarios as compared to driving events.

[3] "Emissions from Three Driving Cycles and Three Power Take Off Cycles for a Southern California Edison Truck", prepared by University of California, at Riverside College of Engineering for Environmental Research and Technology, Riverside CA 92521, (2011).

Project Objectives

The versatile auxiliary power (VAP) system is a multifaceted approach to electrify both fleet vehicles and job sites. The core principle is to use lithium-ion battery energy storage with various types of export power systems to provide clean, electric work in place of a traditionally vehicle engine power source. The concept can be applied to vehicle systems such as cabin cooling through electric air conditioning and chassis electrical support for laptops, tool chargers and vehicle lights to perform varying degrees of job site electrification and engine idle free work operation.

The objective of this effort is to understand the benefits and impacts of electric auxiliary power on emissions and fuel usage by demonstration on various vehicle platforms. Members? can benefit from increased understanding of the options of the potential impacts over the life of the system. Converting fleets work site operation to electric power may also lead to increased grid reliability and increased safety, while stabilizing fleet operational costs.

2
TECHNOLOGY

Current Market Offerings

The passenger vehicle market has introduced many offerings to satisfy both fuel consumption and emissions reductions. The types of vehicles include fully electric vehicles (EV) which operate on battery energy storage and hybrid electric vehicles (HEV), which operate on both battery energy storage and ICE engine to either replenish battery energy or provide propulsion support. Additionally, plug-in hybrid electric vehicles (PHEV) are also available which captures grid energy to replenish the battery using grid energy along with the ICE engine. In these applications, the electric machinery (power electronics / motors) and battery energy storage used for propulsion have proven to provide sufficient performance, efficiency gains and fuel consumption improvements. With the advancement of energy storage chemistries, particularly with lithium-ion providing improvements in power delivery and storage capacity, electricity used as transportation fuel is estimated to be 20% of the cost of traditional gasoline or diesel fuel.

Original equipment manufacturers (OEM) have observed the benefits of EV/HEV technology and have adapted similar approaches with powertrain design into LD/MDHD trucks. By incorporating electric motor/batteries into the LD/MDHD market of trucks, ICE engine use in off-highway instances are drastically reduced as the energy dependency shifts from ICE engine to clean, quiet, battery energy.

Fleet Integration Challenges

The key to EV/HEV technology integration into fleet applications revolves around return on investment (ROI), or how the cost of the vehicle compares to the amount of utility the asset provides over its service life in return. While some state and local incentives may provide subsidies or financial benefits to procure EV/HEV technologies, the cost of updating or upgrading power utilities necessary to support plug in charging of EV/HEV vehicles is often left to the fleet to manage. While EV/HEV technologies are emerging into the MDHD space, the additional cost of the vehicle when compared to the ICE equivalent may be prohibitive for fleets who already have existing ICE engine-based vehicles that have service life remaining. With energy storage of MDHD trucks shared between the propulsion system and auxiliary systems, vehicle range and off-highway operational times can vary, requiring fleet owners to include additional time to charge or further changes in operations.

Versatile Auxiliary Power System

The versatile auxiliary power (VAP) system was developed as a portable energy storage device and a means to offset idle emissions and fuel consumption. The VAP system displaces the traditional small gasoline and diesel ICE engine with EV/HEV lithium-ion battery technology, providing clean, consistent, and noise-free electric power. The VAP system was designed to support vocational equipment in worksite operations by providing both 120VAC and 240VAC for power tools and accessories. The unit also provides 12VDC support to manage cabin loads including HVAC, radio equipment, lights, and sirens. The VAP system can power electric power take off units (ePTO) to provide hydraulic power. Within this project three VAP Systems were acquired.

VAPS #1 – Envoltz

Envoltz, LLC is a builder of electrified field equipment, including underground pullers, overhead tensioners, and export power packs all using lithium ion batteries. An export power unit was ordered to integrate onto a Southern California Edison (SCE) vehicle and perform field demos. It was designed to do underground vault work, fiber optics mobile splice lab, night work lights and tools. Our target customer for this technology is SCE work trucks.

Figure 2-1
Versatile auxiliary power (VAP) system by Envoltz, LLC

VAPS #2 – FreeWire Mobi Gen

A second VAP system was acquired, “Mobi Gen” by FreeWire. The Mobi-gen unit is transported by trailer. The Freewire Mobi Gen utilizes a second-use, or second life, battery, designed to provide up to 40kWh of energy. Second life batteries are ones that have reached the end of their automotive life but still have a residual capacity of about 70-80%. Our target customers are diesel generator users, such as: Utility jobsite electrification, City Parks departments, Landscaping, Food trucks, etc.

The FreeWire Mobi Gen VAP system allows for quick integration onto any platform by being mounted on a small utility trailer, as shown Figure 2-2.

Figure 2-2
Versatile auxiliary power (VAP) system by FreeWire, the Mobi Gen

By being mounted on a trailer, the VAP system can be transferred from any vehicle to another. It was designed to accompany the work truck from site to site, allowing the vehicles ICE engine to shut down. The electric loads from vocational operations can now be powered through VAPS, with no emissions or noise generated. Once the VAP System is depleted, the unit can be charged within 4-5 hours using a 30A SAE J1772 EV charging station. Idle reduction can now be accomplished on any existing fleet vehicle, without compromise of driving distance, auxiliary performance or have any additional fuel usage.

VAPS #3 – FreeWire Mobi EV

Our target customer for the Freewire Mobi EV unit is Electric Vehicles (EVs). The Mobi EV unit is designed to provide backup charge power for EVs within parking lots or other areas that do not have easily accessible grid power, providing to 80kWh of energy. Los Angeles Department of Water and Power (LADWP) was our utility partner, and they have this unit at the LaKretz Innovation Campus (LAIC). LADWP has discussed loaning this unit in the future for demonstration to the Los Angeles Police Department who have 100 EVs with no chargers, or Los Angeles Airport short-term parking. The sites themselves lack electrical infrastructure to support any EV charging, and they also do not have traditional parking spaces, making installing electrical infrastructure and fixed level 2 chargers difficult and costly. With this unit we were able to do a real world demonstration and understand the benefits and impacts of electric power availability on emissions and fuel usage.

Figure 2-3
Versatile auxiliary power (VAP) system by FreeWire, the Mobi EV

Laboratory Evaluation

Baseline testing was performed by Southern California Edison (SCE) in preparation for field demonstrations of the VAP systems. The three units are described in the table below:

Unit	Manufacturer	Specifications	Additional information
VAPS #1 Envoltz	Envoltz	6.6 kWh Battery Pack	Lab testing conducted by SCE
VAPS #2 Mobi Gen / Mobi-37	FreeWire	40kWh Mobi Gen 8kW continuous output	Lab testing conducted by SCE
VAPS #3 Mobi EV / Mobi-87	FreeWire	80kWh Mobi EV Charger 11kW continuous output	In-field testing conducted by LADWP at LAIC

The testing described below was conducted between July 2019 and March 2020. Due to limited access for resources responsible for the data acquisition, maintenance, and inspections of each unit during COVID, including the disbanding of SCE's Electric Vehicle Technical Center (EVTC), additional work was not completed beyond March 2020. When available, data from the battery units is provided in addition to a description of the testing procedures that were used.

VAPS #1 Envoltz Evaluation

The Envoltz unit is intended for installation on a utility truck with a focus on applications like cabin cooling, chassis electrical support, export power for light electric loads, etc. such as portable lights and cordless tool chargers. The battery was shipped to an SCE lab for testing prior to being used in field demonstrations. After arrival at the SCE lab, there was a delay prior to setting the unit up for lab testing. This delay likely led to the complete depletion of the battery which resulted in the battery being non-functional. Because of this, an Envoltz employee was dispatched to the SCE lab and used load banks to charge and discharge the Envoltz unit. During this testing, the Envoltz employee observed that the battery was short cycling, causing the unit to not discharge all the way. Under normal operation conditions, the Envoltz was expected to continue discharging until reaching 10% SOC, however testing revealed that the battery stopped discharging at approximately 40% SOC. The cause of the short cycling was determined to be the result of limitations on the inverter inside the unit. The entire unit was shipped back to the manufacturer and the inverter was replaced with an inverter that was more appropriately sized for full load performance and sent back to SCE.

VAPS #2 Mobi Gen Evaluation

Testing for the Mobi Gen unit was conducted in an SCE lab. Upon arrival at the SCE lab, the unit was set up immediately and it worked correctly for a few days. The Mobi Gen stopped functioning shortly thereafter. The unit was shipped back to the manufacturer to fix a disconnected breaker. This disconnection may have been the result of rough transportation between the manufacturing facility and the SCE lab. Ultimately, the unit was sent back to the manufacturer twice for minor hardware changes. Testing consisted primarily of cycling the battery daily to understand its reliability. This cycling was done by using the Mobi Gen to charge an electric vehicle. Results from this testing are shown in the figures below. Frequent use of the Mobi Gen revealed some performance problems. The unit had an issue with either the internal

24V batteries (which power the unit's screen and other utilities) or the software system which sometimes caused false warnings to appear on the unit's screen. Additionally, there were multiple occasions on which the unit's screen turned black so that the status of the unit could not be determined. This issue was solved by shutting the unit down and then turning it back on.

The Mobi Gen unit was in operation in the SCE lab from July 2019 to March 2020 at which point SCE lab operations were suspended due to COVID-19. After which, resources within SCE were no longer available to support the project. The plot below shows the Mobi's status over time during this 8-month period.

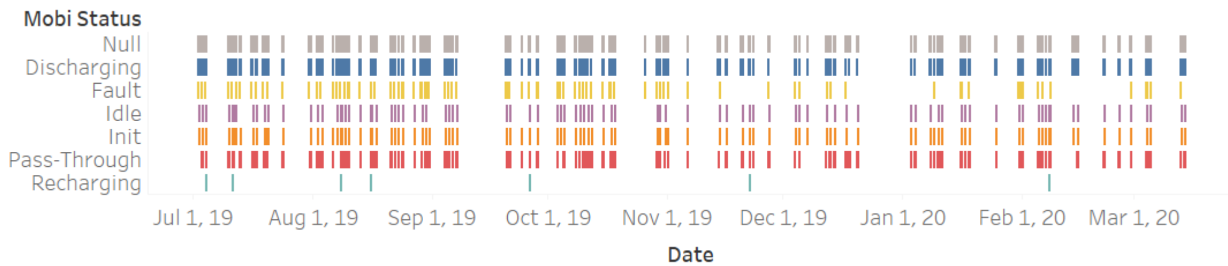

Figure 2-4
Mobi Gen status over time

The definitions of each status state shown in Figure 2-4 are elaborated below.

Definition of status states:

- Null: No defined status available.
- Discharging: The Mobi is actively discharging into an attached device (such as an EV, an electric scooter, a load bank, etc.)
- Fault: An error occurred (typically involving the Mobi's inverter) which caused a fault.
- Idle: The Mobi is neither charging nor discharging.
- Init: Another fault state typically indicating that the Mobi's computer system has malfunctioned.
- Pass-Through: The Mobi is connected to a power source and power is passing through the Mobi into an attached device (such as an EV, an electric scooter, a load bank, etc.) while the Mobi is also recharging its internal batteries.
- Recharging: The Mobi is pulling power from a power source to recharge its internal batteries. No devices are connected to the Mobi in this state.

Legend of status states:

Figure 2-5
Color legend of Mobi Gen status states

The state of charge of the Mobi Gen unit over time is shown below. In Figure 2-6 the status at each timestamp is null. This indicates that the Mobi Gen unit records either the SOC or the status at each time stamp, but not at the same time. Nevertheless, Figure 2-4 and Figure 2-6 show that the Mobi Gen was used regularly (generally at least once per week) throughout the entire 8-month period of testing.

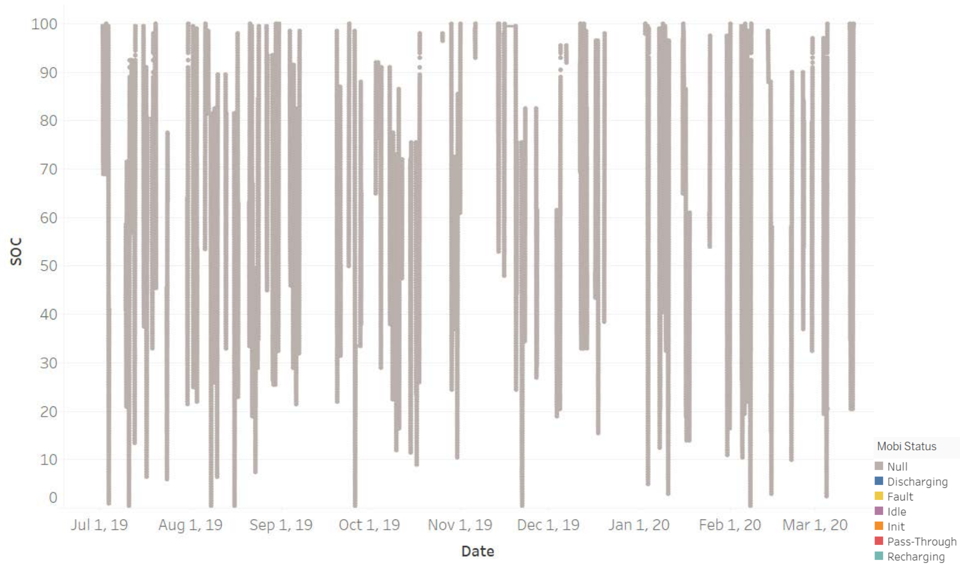

Figure 2-6
SOC over time of Mobi Gen. The legend for this plot is shown in Figure 1-2.

Figure 2-7 shows the instantaneous power in kW delivered by the Mobi Gen to the connected load (typically an electric vehicle). Power levels between 0 and 0.5 occur when the Mobi Gen is communicating or there is residual power pull but not when the unit is truly discharging. As shown, the maximum instantaneous power is about 8kW.

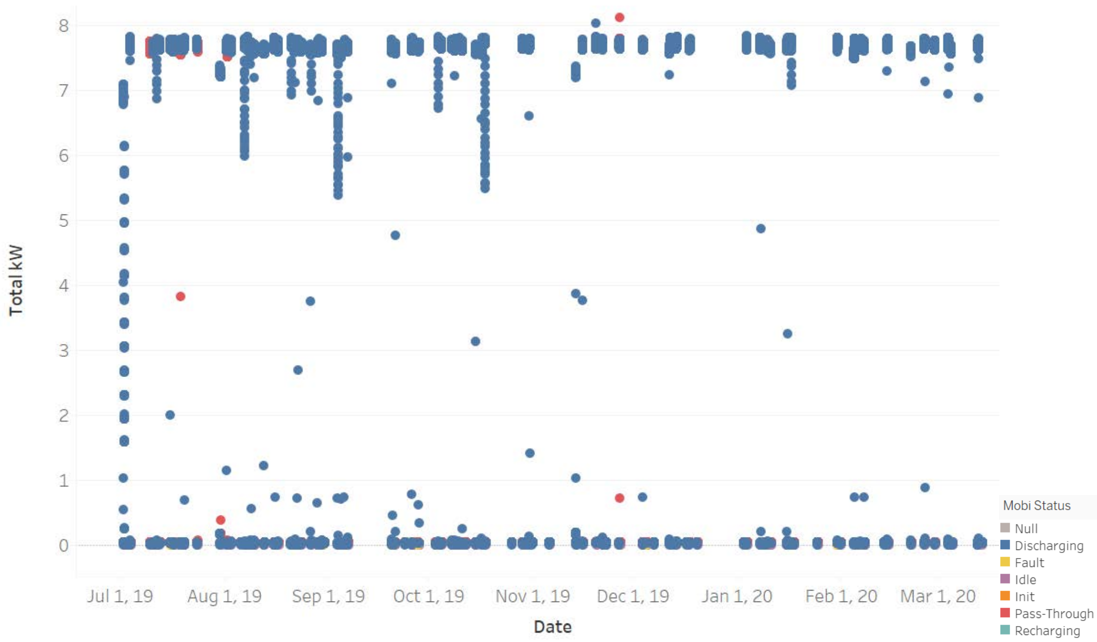

Figure 2-7
Instantaneous power (kW) delivered by the Mobi Gen over time. The legend for this plot is shown in Figure 2-5.

Figure 2-8 shows the total energy delivered by the Mobi Gen over time. Each vertical line on the plot shows a discharge session and the maximum value of each line is the total energy in kWh that was delivered during that discharge session. Pass through loads are important to recognize, as the unit was shown to be able to deliver power to connected devices while also being charged. In events where the unit placement and times of use cases are important, the recognition of pass-through functionality provides insight into the potential power delivery during off-peak charge times, rather than the unit being inactive for potential end users operating the unit in non-work day hours.

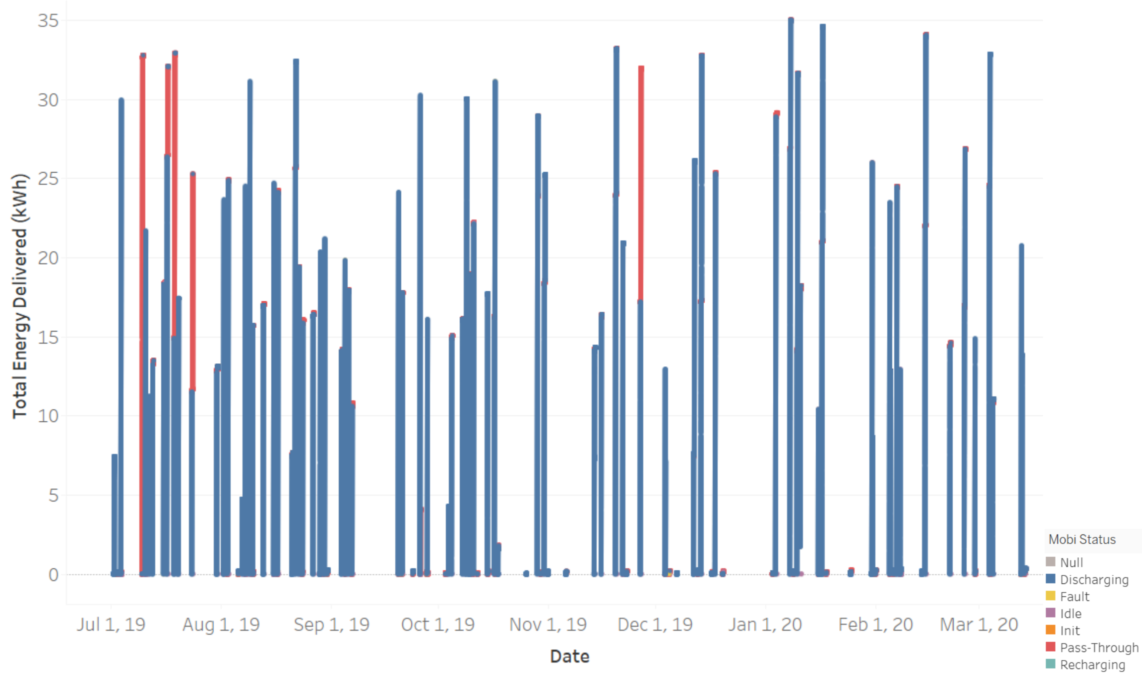

Figure 2-8
Total energy delivered (kWh) by the Mobi Gen over time. The legend for this plot is shown in Figure 2-5.

VAPS #3 Mobi EV Evaluation

The Mobi EV was demonstrated by LADWP at the Los Angeles Cleantech Incubator (LACI). For this unit, testing was not done in a controlled laboratory setting; instead, the unit was placed directly in the field and used to charge electric scooters in downtown Los Angeles. This relatively low risk application of the unit allowed data to be acquired from real usage. The figures below show results from the time period during which the Mobi EV was used to charge electric scooters. Specifications of a typical urban electric scooter are shown below. The Mobi EV unit has two J1772 EV charging ports. In some of the plots, information is shown for the two EVSE ports separately although both ports were used interchangeably. The two EVSE ports of the Mobi EV can be used simultaneously, however the plots below show that only one port was used at a time.

The Mobi EV unit was used to charge scooters between mid-September 2019 and early February 2020. The plot below shows the Mobi's status at every time stamp during this five-month period.

UNIT	*RANGE*	*BATTERY CAPACITY*	*MILES PER WH*
ELECTRIC SCOOTER	28 miles	374 Wh	.075

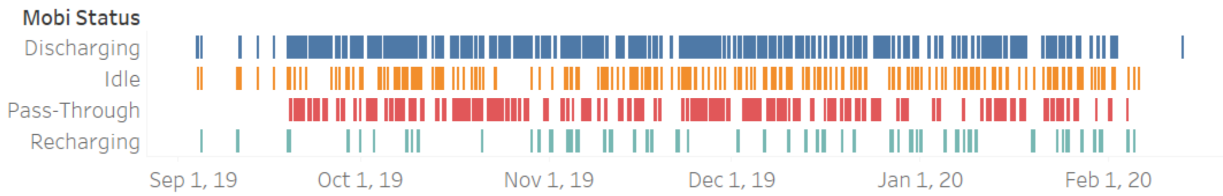

Figure 2-9
Mobi EV status over time

Definition of status states:

- Discharging: The Mobi is actively discharging into an attached device (such as an EV, an electric scooter, a load bank, etc.). Figure 2-9 shows that the unit was used for this application frequently and consistently.
- Idle: The Mobi is neither charging nor discharging. Idle time is shown to also be relevant and frequent in between discharging, allowing additional power management control strategies for capacity optimization control to follow in future designs.
- Pass-Through: The Mobi is connected to a power source and power is passing through the Mobi into an attached device (such as an EV, an electric scooter, a load bank, etc.) while the Mobi is also recharging its internal batteries. Pass through data is important, as simultaneous discharge and charging of the batteries can vary as a function of loads, battery condition, and temperature. It is important separate internal loads used for power management versus pass through loads to also understand thermal considerations and power used in these high pass through scenarios.
- Recharging: The Mobi is pulling power from a power source to recharge its internal batteries. The light blue colored segments which represent the unit charging in Figure 2-9 do not overlap any pass-through energy, representing that no devices are connected to the Mobi in this state. When compared to pass through and discharge loads, the recharging capacity can depict loads used to support the battery versus control and thermal loads to estimate capacity variances as a function of temperature or operating environment.

Legend of status states:

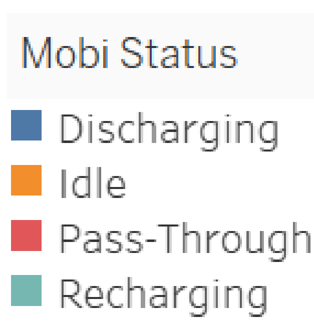

Figure 2-10
Color legend of Mobi EV status states

Figure 2-6 shows that the Mobi EV unit spent most of the time in either the discharging or pass-through state which indicates that the unit was heavily used during the five months. The figures below give a more granular view of how the Mobi EV was used daily by showing the SOC over time for each month. The color scheme in the figures below is based on the legend shown in Figure 2-10.

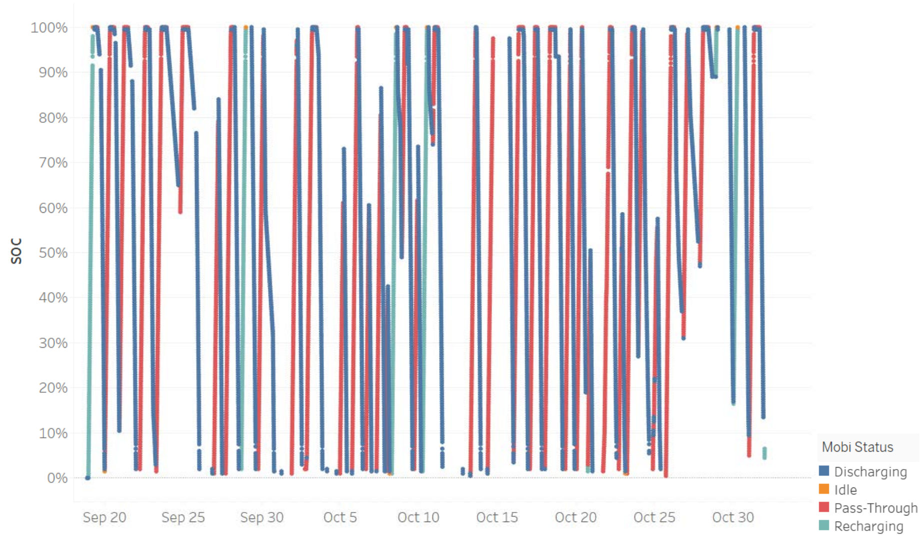

Figure 2-11
SOC over time of Mobi EV in September and October 2019

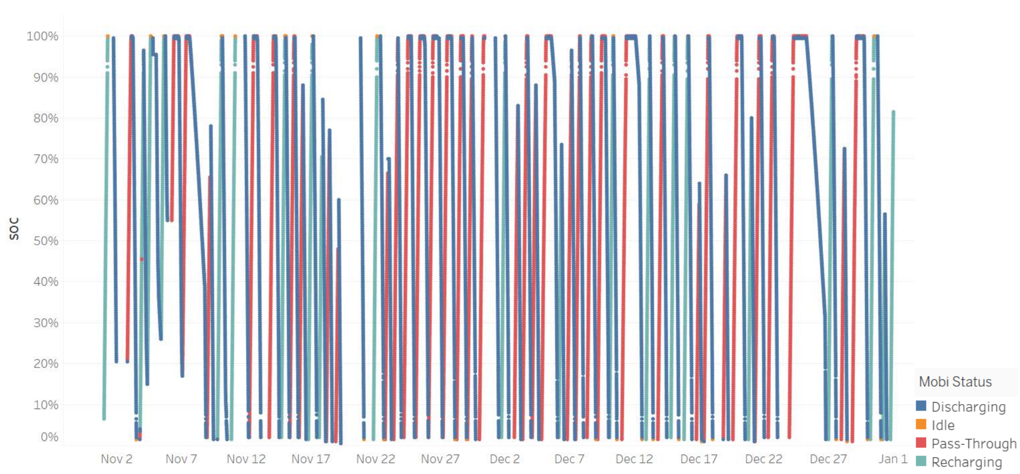

Figure 2-12
SOC over time of Mobi EV in November and December 2019

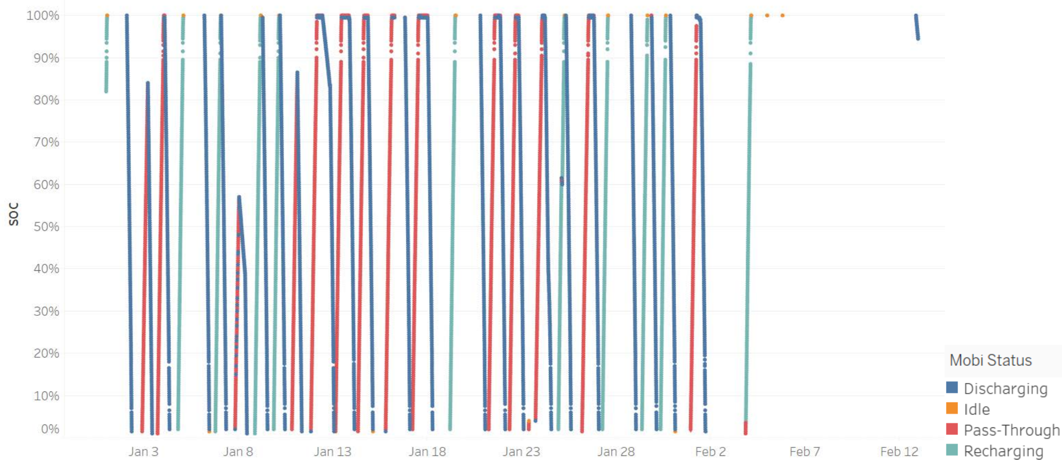

Figure 2-13
SOC over time of Mobi EV in January and February 2020

The instantaneous power of the Mobi EV as well as the total energy delivered are shown in the figures below. Figure 2-14 shows that the EVSE1 port was used from September until late October and then EVSE2 was used for the remaining time. Both ports are identical, so this behavioral preference is not indicative of underlying functionality of the Mobi EV. Power levels between 0 and 0.5 occur when the Mobi EV is communicating or there is residual power pull but not when the unit truly discharging. As shown, the maximum instantaneous power is slightly higher than 5kW.

Figure 2-14
Instantaneous power (kW) delivered by each port (EVSE1 and EVSE2) of the Mobi EV unit over time

Figure 2-15
Energy delivered by both ports (EVSE1 and EVSE2) of the Mobi EV over time

Figure 2-15 shows cumulative energy delivered over time for each discharge sessions (i.e. each vertical line on the plot shows a discharge session and the maximum value of the line is the total energy in kWh that was delivered during that discharge session). Preliminary calculations indicate that the Mobi EV powered more than 200,000+ miles of electric scooter transportation.

3 DEMONSTRATION

Field Evaluation

Two development VAP systems were developed and manufactured by Freewire Technologies, Inc, of San Leandro, CA. The development units consisted of one 5' x 8' (1.5m x 2.4m) trailer mounted battery auxiliary power unit and one mobile unit. The VAP system Mobi Gen consisted of 40kWh of total capacity, and 15kW of 120VAC/240VAC output power. The Mobi EV was deployed to the Los Angeles Department of Water & Power (LADWP).

The original scope of testing included field evaluations with deployment into the LADWP fleet. Due to COVID-19 lockdown restrictions, the VAP System was used between 9/1/2019 – 2/5/2020. A few select days in March, June, July, and August of evaluations were also completed.

Field Data

Data from the Mobi EV unit was recorded daily from 9/1/2019 to 2/5/2020, in an increment of 15 seconds. During which time, the state of charge (SOC), output power and energy were broadcast through the embedded telemetry system. A daily average of power, energy consumed, and hours of operation were measured for each month while the system was in service with LADWP. No charging information was available during the demonstration. The unit was described to have supported Level 2 opportunity charging of EV vehicles. Data from the days past February 2020 were shown to have insignificant usage. The usage data summary is shown in Table 3-1, with individual daily figures presented within the appendices.

Table 3-1
LADWP VAP system Mobi EV usage performance summary

	September 2019	October 2019	November 2019	December 2019	January 2020	February 2020	Total Average
Average Daily Power (kW)	1.57	1.60	1.83	1.68	1.64	5.47	2.30
Average Daily Energy Consumption (kWh)	2.78	4.48	5.58	4.80	4.82	6.07	4.75
Average Daily Usage (hr)	13.5	15.13	1.89	16.71	12.30	1.43	10.17

Based on the data in Table 3-1 usage shows general charge power rates representative of maximum power limits of Level 1 charging at 120Vac, as compared to a maximum of 19.2kW for Level 2 at 208Vac. At Level 2 output voltage of 208Vac, the low daily average to support maintenance loads of the vehicle being charged, which can include chassis 12Vdc chassis battery support or vehicle battery thermal loads consumed to maintain consistent battery temperature. The low daily power usage also reflects the state of charge of the vehicles being charged as high, where no bulk charge occurred.

4

ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS

Fleet Effectiveness Study

The Mobi EV VAP System has shown to be useful throughout the demonstration periods as a mobile opportunity charge solution for EVs, between September 2019 to February 2020. The total was 137 days' worth of usage data. During which, the Mobi EV VAP System was shown to provide consistent power for extended periods beyond the traditional 8-hour workday period. There was no record of any performance or physical issues that occurred during deployment of the Mobi EV unit, as compared to the remaining VAP units which were shown to have technical challenges that limited operation and validation testing.

It was observed in Table 3-1 that the average power draw per day was 2.3kW, which when connected to either a 120VAC at 19A, or 208VAC at 11A. No data was observed as to which outlets or which power draw voltage level was used during the evaluation.

While the loads on the Mobi EV unit included mainly charging EV batteries, general loads on gasoline or diesel engine based Auxiliary Power Generators (APG) units include those used in the construction and the utility space. The loads can be categorized as plug in inductive loads (motor driven power tools including drills, or saws, pumps) or resistive loads (heat guns, space heaters), or high frequency / high current welding equipment in construction environments, to smaller loads including cellphone or cordless tool battery chargers. A summary of potential average 120/208-240VAC loads commonly used for gasoline or diesel engine-based generators for utility or construction fleet tools is shown in Table 4-1.

Table 4-1
Commonly used 120 / 208-240VAC loads on vocational ICE APG systems

Manufacturer	Tool	Function	Input Voltage (AC)	Maximum Current Draw (A)
Milwaukee	Corded Drill	Drilling, boring	120	15
	Sawzall	Reciprocating saw for cutting	120	15
	Cordless battery charger	Recharge cordless tool battery	120	2.1
Miller	Millermatic 200 MIG Welder	Mig welding for mild steel/fencing	120	24.5
		Heavier duty steel (>1/4")	208 / 240	31.3
Bosch	4-1/2" Grinder	Light duty grinding	120	12
		Heavy duty grinding	120	16

Based on the current draw average, any combination of hand tools could have been used during the demonstration instead of mobile EV charging. Larger loads from equipment like welders were not observed to be used in this demonstration, however, could be powered by the VAP System for smaller duty cycles.

Emissions Savings

When work trucks are operated, emissions are generated from drive cycles to and from worksites, as well as when stationed for vocational work. During the off-highway stationary portion, the ICE engine based APG can produce emissions that also aren't filtered through catalytic converters or exhaust additives (i.e. diesel emissions fluid) as automotive engines would during on-highway transport. The result of APG operation are higher emissions and noise.

The APG can also come in the form of smaller engines which can power various tools outside of the ones specified in Table 4-1. In such cases, engine driven components are required to support hydraulic or hydro powered equipment including pumps and power take off units. The commercial markets also utilize small ICE engines to drive equipment including pressure washers and welders, each of which have electric equivalents that can leverage the quiet, emissions free AC output of a VAP System. The following table generated by previous EPRI analysis of EPA MOVES data shows emissions generated by specific functions of ICE driven tools and equipment.

Table 4-2
EPA MOVES emissions data per vocational operation

	CO_2 g/hr	NOX g/hr	PM10 µg/m^3	PM2.5 µg/m	SO_2 g/hr	VOC g/hr
Air Compressors	10.7000	0.0315	0.0011	0.0011	0.0001	0.0057
Gas Compressors	214.0000	0.4304	0.0209	0.0203	0.0015	0.0104
Generator Sets	3.0000	0.0278	0.0003	0.0003	0.0000	0.0046
Hydro-power Units	5.1000	0.0196	0.0014	0.0014	0.0001	0.0160
Light Commercial Air Compressors	9.6000	0.0462	0.0030	0.0029	0.0001	0.0136
Light Commercial Gas Compressors	307.2000	0.6587	0.0405	0.0405	0.0017	0.3174
Light Commercial Generator Set	0.9000	0.0022	0.0001	0.0001	0.0000	0.0068
Light Commercial Generator Sets	4.5000	0.0343	0.0025	0.0024	0.0000	0.0046
Light Commercial Pressure Wash	0.9000	0.0019	0.0002	0.0001	0.0000	0.0061
Light Commercial Pressure Washer	2.0000	0.0155	0.0010	0.0010	0.0000	0.0017
Light Commercial Pumps	1.4000	0.0062	0.0013	0.0012	0.0000	0.0116
Light Commercial Welders	4.9000	0.0217	0.0027	0.0026	0.0001	0.0176
Pressure Washers	2.4000	0.0154	0.0002	0.0002	0.0000	0.0033
Pumps	4.4000	0.0248	0.0004	0.0004	0.0000	0.0049
Welders	11.3000	0.0341	0.0012	0.0012	0.0001	0.0062

With the estimated average daily hourly usage extracted from the VAP System telemetry, the following table represents estimated emissions savings.

Table 4-3
Estimated emissions savings using daily average hours of VAP system use

	CO_2 (g)	NOX (g)	SO_2 (g)
Air Compressors	114.4900	0.3367	0.0006
Gas Compressors	2289.8000	4.6050	0.0157
Generator Sets	32.1000	0.2971	0.0002
Hydro-power Units	54.5700	0.2093	0.0007
Light Commercial Air Compressors	102.7200	0.4943	0.0010
Light Commercial Gas Compressors	3287.0400	7.0479	0.0184
Light Commercial Generator Set	9.6300	0.0234	0.0002
Light Commercial Generator Sets	48.1500	0.3673	0.0004
Light Commercial Pressure Wash	9.6300	0.0201	0.0002
Light Commercial Pressure Washer	21.4000	0.1659	0.0002
Light Commercial Pumps	14.9800	0.0659	0.0002
Light Commercial Welders	52.4300	0.2324	0.0007
Pressure Washers	25.6800	0.1648	0.0001
Pumps	47.0800	0.2657	0.0002

Although electrically driven versions of the tools specified Table 4-2 may not provide sufficient performance as compared to the ICE equivalents, the AC powered versions can still be operated using the VAP System to displace ICE engine drives equivalent systems. The following table describes the same tool lists as Table 4-2, with estimated run times in a traditional workday of 8 hours. For applications of “trouble-trucks” as an example which operate daily with 2-3 stops per day. These applications utilize trucks equipped with 20-40’ extension booms and hydraulic tool circuits or ICE driven APGs. The estimated power draw or power generated by each system was assumed, using average values of products on the market for purchasing.

Table 4-4
Estimated energy consumption or generation

	Hours / day	AC Equivalent Source / Load Power (kW)	Daily Energy Consumed or produced (kWh)
Air Compressors	5	1.4	7
Generator Sets	8	2	16
Hydro-power Units	3	2	6
Light Commercial Air Compressors	2	1.65	3.3
Light Commercial Pressure Washer	3	1.5	4.5
Light Commercial Pumps (~1 hp well pump)	3	2.5	7.5
Light Commercial Welders	2	12	24
Charging (Level 1 max) 32 kWh useable capacity (estimated)	16.67	1.92	32.00
Charging (Level 2 max) 32 kWh of useable capacity (estimated)	1.67	19.2	32.06

With 40 kWh of total energy storage, a portion of that capacity of the deployed VAP System is considered "useable" versus total. The usable capacity may range from 75-80% of the total capacity. With this assumption, 30-32 kWh of capacity is available for daily use, which was shown to be sufficient for the demonstration and daily use. Using a level 2 J1772 charging with a maximum of 19.2 kW of power, or 1.92kW for maximum level 1 charging, the table includes an assumption of estimated charge times.

Future Studies

To gain perspective of battery degradation performance, the charging data over the period of the field evaluation would have been required. The differences in energy capacity in, while charging, and out, while used throughout the day, along with SOC percentage could be captured through telemetry. The data can be charted and analyzed for decay rates based on cycle counts or calendar life.

While one of the solutions was trailer mounted and designed as a mobile unit, further studies may be required to understand the performance impact of trailer towing versus mounting on suitable chassis', in comparison to the unloaded vehicle. Fuel efficiency and consumption may impact vehicle return on investment or cost of ownership metrics. With added weight or trailer load however, drivability/maneuverability, as well as remaining payload capacity continue may contribute to additional safety risks.

Additional data correlating internal and external ambient and system temperatures and battery management / monitoring system temperatures would also provide useful information on performance differences due to thermal constraints. For colder environments which may require resistive or liquid heating, to higher temperature areas which may limit output power, the energy throughput would be analyzed and charted for performance impact due to temperature.

A
AVERAGE DAILY POWER AND ENERGY CHARTS

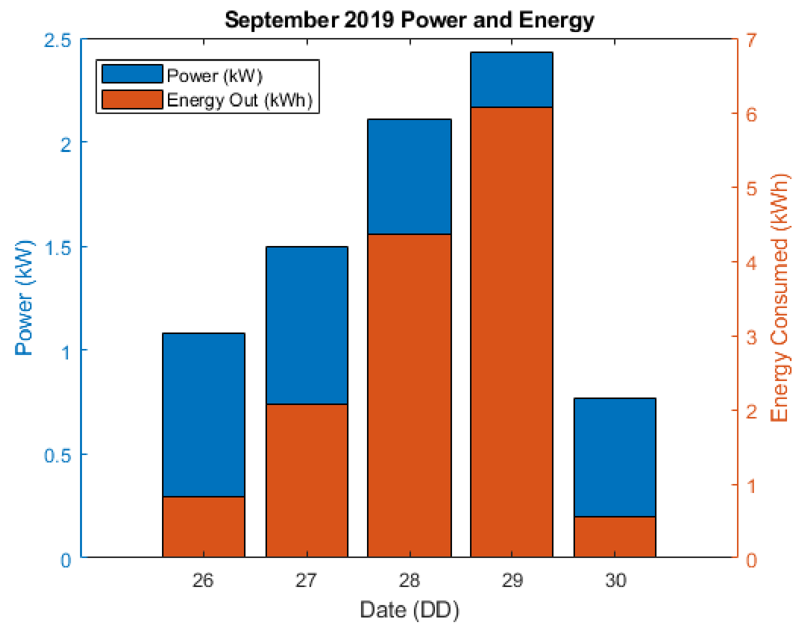

Figure A-1
LADWP VAP system daily average power and energy consumption, September 2019

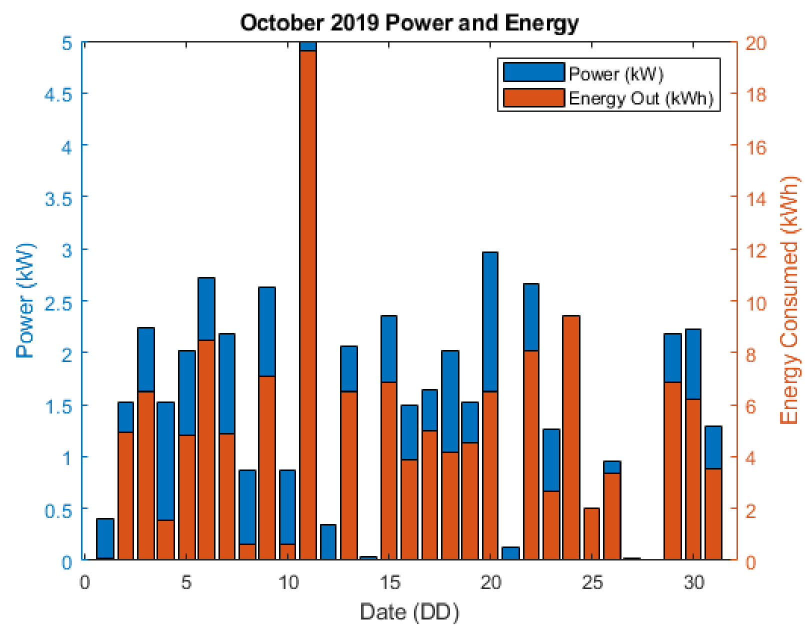

Figure A-2
LADWP VAP system daily average power and energy consumption, October 2019

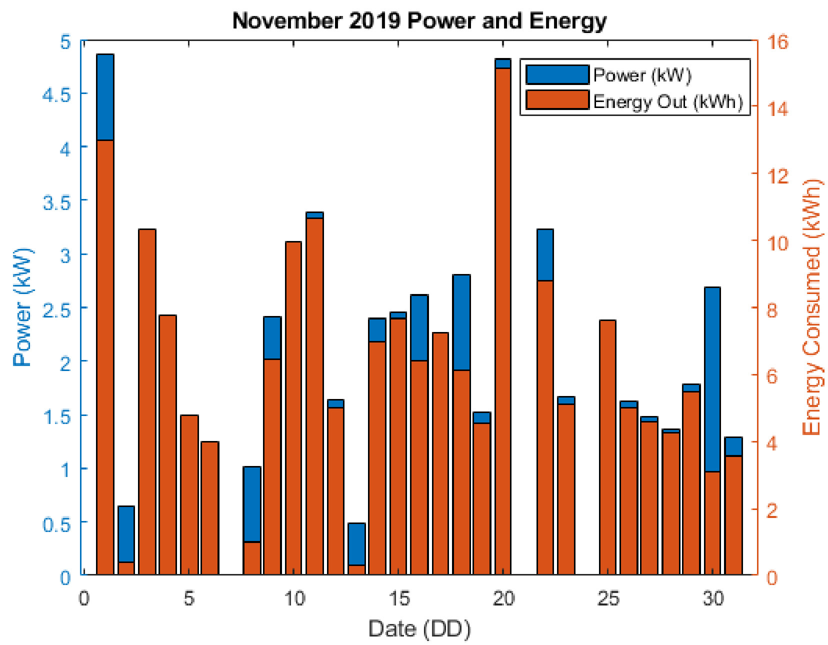

Figure A-3
LADWP VAP system daily average power and energy consumption, November 2019

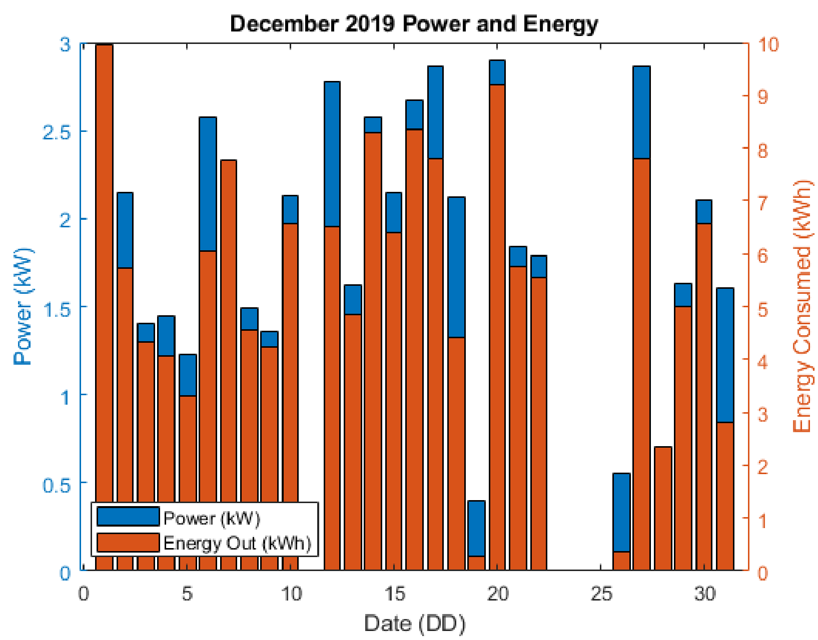

Figure A-4
LADWP VAP system daily average power and energy consumption, December 2019

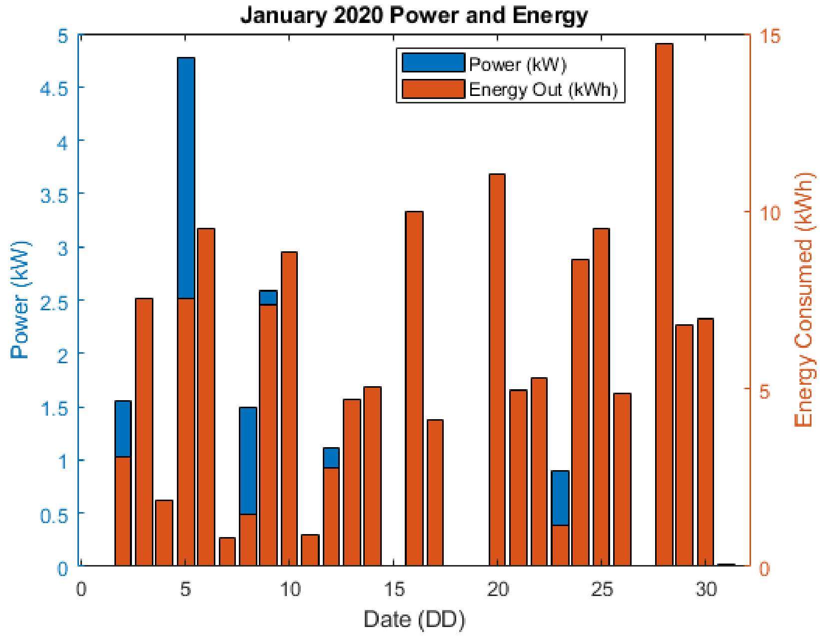

Figure A-5
LADWP VAP system daily power and energy consumption, January 2020

B
VAP SYSTEM HOURS OF USE PER DAY

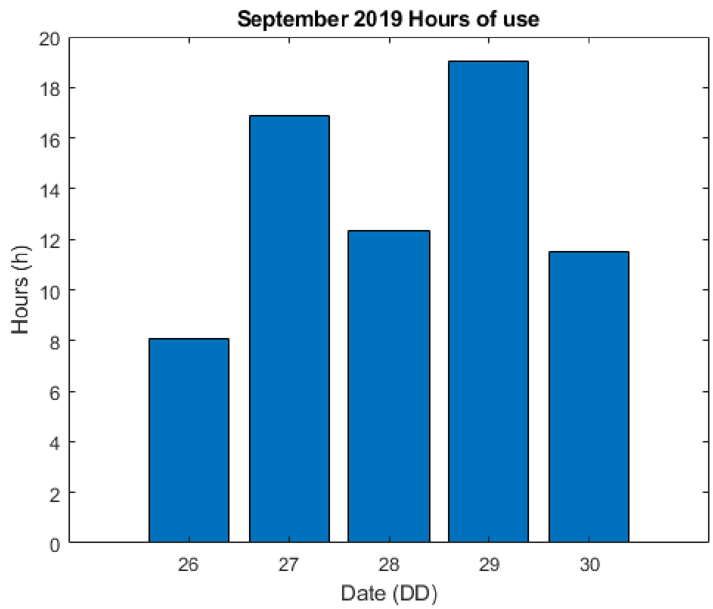

Figure B-1
LADWP hours of service per day, September 2019

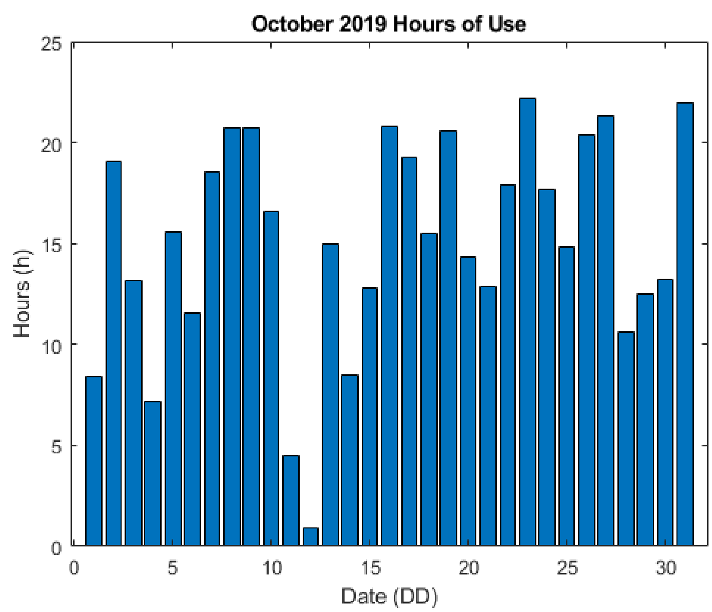

Figure B-2
LADWP hours of service per day, October 2019

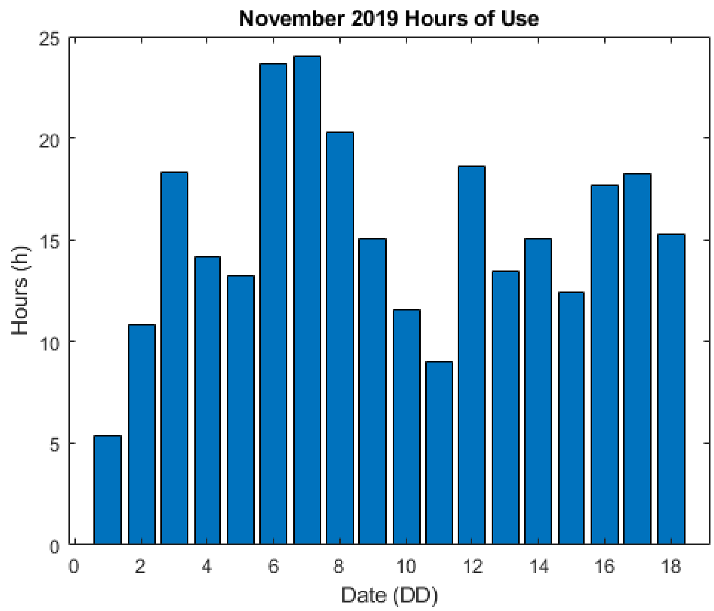

Figure B-3
LADWP hours of service per day, November 2019

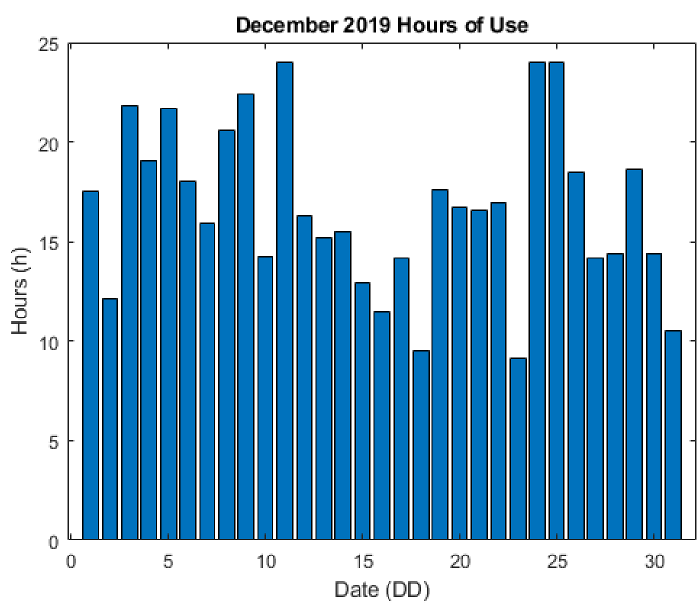

Figure B-4
LADWP hours of service per day, December 2019

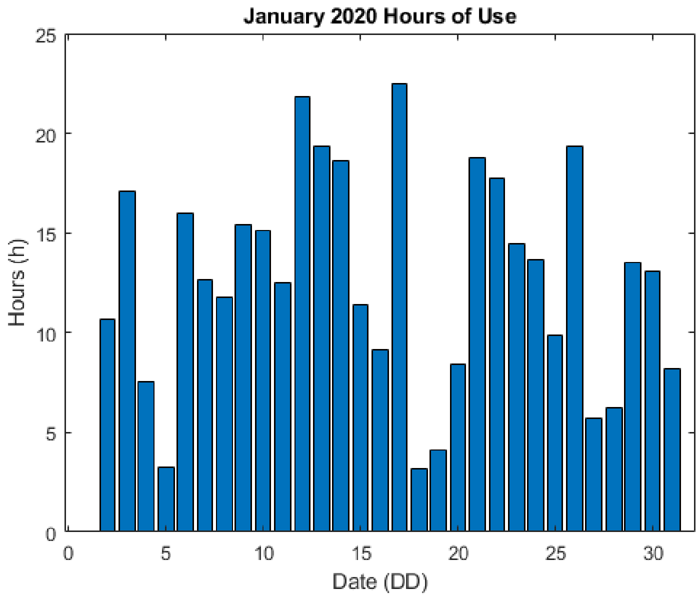

Figure B-5
LADWP hours of service per day, January 2020

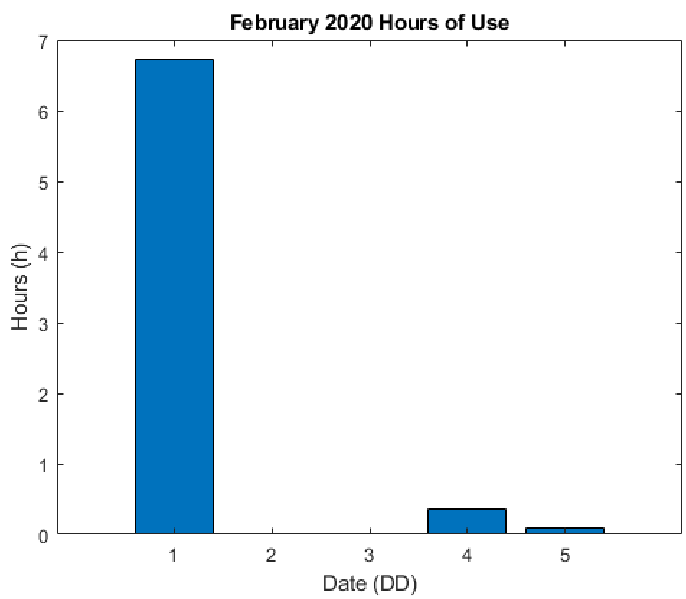

Figure B-6
LADWP hours of service per day, February 2020

About EPRI

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