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California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Advanced Battery-Electric Port Vehicles

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[1] BAE Systems https://www.baesystems.com/en/home
[2] Terminalift https://www.facebook.com/terminaliftllc

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the CEC to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance, and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued PON-14-605 to provide funding for medium- and heavy-duty advanced vehicle technology demonstration projects. In response to PON-14-605, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards March 24, 2015 and the agreement was executed as ARV-14-053 on May 20, 2015.

ABSTRACT

The TransPower's Advanced Battery-Electric Port Vehicles project was funded by the CEC to demonstrate the feasibility of utilizing battery-electric power to achieve routine operations of Class 8 yard tractors and drayage trucks in port applications and to retrofit an electric reach stacker with a new, experimental battery technology designed to increase operating range. Yard tractors and drayage trucks, each of which can haul loads of up to 59,000 kilograms, are commonly used at warehouses, distribution centers, ports, rail yards, and other commercial and industrial locations, are high consumers of petroleum and emit high levels of pollution. Because these sites are usually embedded within large populations or within disadvantaged communities, the tractors and trucks have a disproportionately negative effect on the health and welfare of thousands of individuals.

TransPower's Advanced Battery-Electric Port Vehicles battery-electric power is an electric drive system that Transportation Power, Inc. began developing in 2011. The Advanced Battery-Electric Port Vehicles project enabled Transportation Power, Inc. to make numerous improvements to its electric propulsion systems and to adapt them to yard tractors and to Class 8 drayage trucks. Transportation Power, Inc. converted and demonstrated two Kalmar battery-electric T2E yard tractors and two Navistar International ProStar battery-electric drayage trucks during the Advanced Battery-Electric Port Vehicles project.

Keywords: BAE Systems, ElecTruck, Transportation Power, Inc. (TransPower), TransPower's Advanced Battery-Electric Port Vehicles (TABEPV), Clean Transportation Program, yard tractor

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EXECUTIVE SUMMARY

Warehouses, distribution centers, seaports, rail yards, and other commercial and industrial locations around the world operate on-road and off-road vehicles such as yard tractors and Class 8 drayage trucks (capable of towing about 59,000 kilograms) and container handling equipment like a reach stacker. These tractors and trucks consume a lot of petroleum and emit large amounts of pollution. Because these sites are usually located within large populations or within disadvantaged communities, the trucks and tractors have a disproportionate negative effect on the health and welfare of tens of thousands of individuals.

This project, the TransPower's Advanced Battery-Electric Port Vehicles project addressed this problem by utilizing battery-electric drive systems to power two battery-electric yard tractors, two battery-electric drayage trucks, and a battery-electric reach stacker with a lifting capacity of 45,450 kilograms, thus eliminating petroleum consumption and tailpipe emissions. The TransPower's Advanced Battery-Electric Port Vehicles project showed that battery-electric power is an ideal solution for yard tractors, drayage trucks, and reach stackers; however, upgrading the reach stacker's original battery-electric drive system to a newer, high-energy lithium-ion battery technology was plagued with difficulties, for which TransPower was unable to find solutions by the agreement end date. The widespread use of battery-electric drive system in many different applications enabled the overall success of the TransPower's Advanced Battery-Electric Port Vehicles project in overcoming a variety of barriers, unresolved issues, and knowledge gaps in science and technology, marketing, and costs.

The primary objectives of the TransPower's Advanced Battery-Electric Port Vehicles project were to demonstrate:

- The reduced cost of manufacturing battery-electric tractors and trucks, measured by the number of labor hours required to manufacture the vehicles, average cost per hour, and material costs.
- A load-carrying capability equivalent to diesel yard tractors and trucks.
- An operating range of up to 150 miles for loaded drayage trucks, the ability for the yard tractors to complete two full shifts of 6.5 to 8 hours, and the reach stacker operational time increase from the original two hours to up to ten hours of continuous use.
- Availability levels and mean times between failures comparable to those of conventional diesel trucks and tractors.
- The energy cost savings, measured as the cost of electricity used to recharge the vehicles deducted from the cost of fuel, to do the same work with diesel tractors.
- Significant emissions benefits measured as the amount of greenhouse gases and criteria pollutants that would have been produced with diesel tractors performing equivalent work.
- A significant displacement of fossil fuels measured as the amount of fuel that would have been used by diesel tractors performing equivalent work.
- Progress toward commercializing the use of the ElecTruck.
- Overall customer satisfaction with the battery-electric drayage trucks, yard tractors, and reach stackers.

For the most part, the TransPower's Advanced Battery-Electric Port Vehicles project met all of these objectives. TransPower developed and installed a new battery-electric drive system for Kalmar's new T2E-model yard tractor, developed and installed a battery-electric drive system for the newest Navistar International ProStar model truck, and put all of them into service at the Port of San Diego for demonstration.

Key new technologies incorporated into these yard tractors and trucks include an advanced onboard alternating current fast charging capability and automated manual transmissions. In addition, TransPower replaced the lead-acid batteries on an experimental electric reach stacker with lithium-ion batteries.

During the project term, the two-yard tractors accumulated a total of more than 1,200 hours and 10,000 miles of service and the two drayage trucks accrued more than 950 hours and 1,800 miles of use, displacing about 5,300 gallons of diesel fuel combined and a reduction of nearly 54,000 kilograms of carbon dioxide. All of the tractors and trucks operated regularly until the end of the grant period and are expected to remain in commercial use until about 2025.

The reach stacker, however, did not have the same positive results. The new lithium-ion batteries failed repeatedly. After months of testing, engineers and technicians determined that the batteries were of poor quality. TransPower, though, did not detect these problems during the early laboratory testing that had given TransPower confidence in this technology. As a result, TransPower could not demonstrate the reach stacker during the data collection phase of the project.

Validation of the battery-electric vehicles in these fleets has demonstrated that electrification of yard tractors and drayage trucks are feasible and can deliver significant environmental and energy efficiency benefits. A parallel TransPower demonstration project funded under a separate CEC grant, the Heavy-Duty Electric Yard Tractor, manufactured five additional electric yard tractors using the same technology and placed them into service with companies throughout California. Due to the successes of the TransPower's Advanced Battery-Electric Port Vehicles project and Heavy-Duty Electric Yard Tractor projects, there was a commitment from other companies to purchase a total of 27 Peterbilt Class 8 battery-electric trucks powered by TransPower drive systems as well as Kalmar putting battery-electric yard tractors into full commercial production using the system developed by TransPower and naming the tractor the T2E.

CHAPTER 1: Project Background

Problem Statement

Yard tractors, drayage trucks, and reach stackers are pieces of heavy-duty cargo handling vehicles[3] that operate globally at thousands of ports, warehouses, distribution centers, farms, and other locations where heavy goods must be transported short distances on a continuous basis. Yard tractors and reach stackers are inefficient when operated on diesel fuel, due to their uneven duty cycles and high-power requirements that produce large amounts of toxic pollutants and greenhouse gases. Drayage trucks are also inefficient and polluting, and that is due to variables such as distances, speed limits, traffic, weather, and others that are associated with driving on public streets and highways.

Additionally, communities near the ports are most often disadvantaged communities, as determined by CalEnviroScreen 3.0,[4] and are more impacted by pollution than other communities are by having a higher risk for cardiovascular and pulmonary diseases.[5] TransPower is committed to reducing these harmful pollutants and greenhouse gases. TABEPV project utilized battery-electric drive systems to power two-yard tractors, two Class 8 drayage trucks[6], and a reach stacker that reduced petroleum consumption and tailpipe emissions in and around the Port of San Diego.

TABEPV Project Objectives

With the success of prior prototype battery-electric trucks and yard tractors by TransPower, investors and fleet operators were beginning to show interest. The recurring theme of these discussions, however, was that significant private investment in heavy duty battery-electric vehicles (BEV's) would only occur once private fleet operators start ordering such vehicles commercially. TransPower believed that the most effective way to make this happen was to get these heavy-duty BEV's into the hands of as many fleet operators as possible. The TABEPV project was designed to achieve this by delivering battery-electric Class 8 drayage trucks and yard tractors to three prominent fleet operators. This proved timely as the State of California placed a high priority on reducing emissions from goods movement activities, encouraged deployment of zero-emission trucks, yard tractors, and other heavy-duty cargo handling vehicles such as forklifts and reach stackers.

Around the same time that TransPower was designing the TABEPV, the Port of Long Beach and Port of Los Angeles implemented their Clean Air Action Plan[7], which detailed multi-year plans to achieve zero- and near-zero-emissions vehicles at the ports. The timing of the TABEPV project was ideal to help set the stage for larger public investments in expanding the deployment of drayage trucks, yard tractors, and other heavy-duty vehicles using

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[3] Vehicle Weight Classes https://afdc.energy.gov/data/10380
[4] CalEnviroScreen Website https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30
[5] United States Environmental Protection Agency https://www.epa.gov/air-research/research-near-roadway-and-other-near-source-air-pollution
[6] Class 8 Drayage Trucks https://blog.ballard.com/fuel-cell-drayage-trucks
[7] Clean Air Action Plan https://cleanairactionplan.org

TransPower's battery electric vehicle components. TransPower believes that continued investment in this technology will increase manufacturing, and then economies of scale will bring down the costs of the larger scale deployments. Small fleet demonstrations such as TABEPV, followed by larger demonstrations funded by the California Climate Investments, were expected to lead to substantial commercial interest by 2018. This was then expected to lead to substantial investor interest and to increase the amount of private capital to support large-scale adoption of heavy-duty battery-electric trucks, tractors, reach stackers, school buses, and other vehicles by the end of this decade.

Battery-electric power is an ideal solution for heavy duty drayage trucks, yard tractors, and cargo handling vehicles, but until recently a variety of barriers, unresolved issues, and knowledge gaps, hindered its widespread use in such applications. Most efforts to apply battery-electric propulsion to Class 8 on-road trucks and yard tractors resulted in prototype vehicles that failed to meet performance expectations when tested under real-world conditions with full loads. Even when augmented with hybrid propulsion systems, drayage truck and yard tractor demonstrations failed to match the performance of conventional diesel vehicles. Key shortcomings noted by truck and yard tractor operators included poor acceleration, insufficient operating range, and lack of reliability. The hybrid systems that were tested also failed to deliver sufficient fuel savings to merit an economic business case, typically reducing fuel consumption by only 10 percent to 30 percent.

TransPower took significant steps toward addressing these technical hurdles and developed a new generation of battery electric vehicle components that are custom designed for use in heavy duty trucks and yard tractors. These components include an inverter-charger unit, a battery management system, an automated manual transmission, and more. Prototype trucks and tractors that used these components had already started showing improvements in performance and reliability in demonstrations prior to the TABEPV project. The feasibility of operating Class 8 on-road trucks and yard tractors with battery-electric propulsion was validated in real-world demonstrations about a year before the TABEPV project started. These demonstrated vehicles included:

- Two battery-electric drayage trucks used by Total Transportation Services, Inc. and SA Recycling near the Port of Los Angeles and Port of Long Beach.
- A battery-electric yard tractor operated by IKEA at its main California distribution center.
- A battery-electric yard tractor operated by Total Transportation Services, Inc. at the Port of Los Angeles.
- A battery-electric yard tractor operated by Dole Fresh Fruit Company at the Port of San Diego.

These demonstrations attracted additional fleet interest in battery-electric heavy-duty trucks and yard tractors throughout California. Several of these fleet operators teamed up with TransPower to propose the TABEPV project demonstration. The demonstration proposition was intended to strengthen the scientific and technological foundation for battery-electric heavy-duty truck, yard tractor, and cargo handling vehicles deployments by enabling the evaluation of variety of different types of vehicles operating in close geographic proximity. A key feature of the TABEPV project was the demonstration of a promising new battery technology. TransPower believed that the new lithium iron phosphate battery technology that would be tested during the TABEPV would have the potential to increase vehicle operating range by 60 percent or reduce battery weight by one-third, or both. TransPower expected the TABEPV project to reach statistically valid conclusions about their overall performance and reliability, to accumulate enough miles of real-world use, and to demonstrate the heavy-duty trucks, yard tractors, and cargo handling equipment sufficiently enough to justify a higher purchase price until the economies of scale brings costs down.

TransPower expected these cost reductions to make heavy duty trucks, yard tractors, and cargo handling equipment more affordable to fleet operators and served as a catalyst for large-scale commercial adoption of heavy-duty BEV's in California and elsewhere. The involvement of major truck manufacturer Navistar International and yard tractor manufacturer Kalmar, along with three fleet operators (Dole Fresh Fruit Company, BAE Systems[8], and Terminalift), helped to provide a clear path-to-market for TransPower's the ElecTruck[9] products.

TransPower structured the TABEPV project to address market barriers by expanding the use of TransPower-manufactured battery electric vehicle components beyond those produced for small-scale medium- and heavy-duty demonstration projects. It enabled incremental improvements in the ElecTruck, system such as lower-cost battery monitoring boards and lighter-weight battery enclosures, which helped reduce the cost of key subsystems. Replacing the reach stacker's lead-acid batteries with lithium-ion batteries was projected to result in a 500 percent improvement in the reach stacker's operating range and would have opened up a significant niche market for the adaptation of TransPower technologies to be used in reach stackers.

A key goal of the TABEPV project was to help achieve a wider distribution of heavy-duty BEV's throughout California by increasing the number of battery-electric port vehicles at the Port of San Diego from one to five. This complemented the pre TABEPV deployments of TransPower vehicles in Los Angeles County and in the San Joaquin Valley and helped raise consumer awareness about the environmental benefits of heavy-duty BEV's.

Demonstrations of early hybrid diesel-electric on-road trucks and yard tractors prior to the TABEPV project showed improvements of only 10 percent to 30 percent in fuel savings. Since reductions in greenhouse gases are only proportional to reduced fuel use, the environmental benefits of this technology did little to justify their higher cost and reduced performance. The TABEPV project, on the other hand, enabled demonstration of an environmentally superior solution that eliminates all fuel use, thereby eliminating all greenhouse gases emissions and criteria pollutants at the point of operation. All five TABEPV vehicles were based at the Port of San Diego region, which is classified as a disadvantaged community that is disproportionately affected by diesel and other criteria pollutants.

The TABEPV project was also seen as critical for demonstrating the life cycle cost savings potential of battery-electric drayage trucks, yard tractors, and other cargo handling equipment when compared with diesel vehicles of the same type. Therefore, it was imperative to accurately calculate the total cost of owning and operating the vehicles using the ElecTruck. Although there is strong empirical evidence that electric vehicles (EV's) offered significant

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[8] BAE Systems https://www.heb.com/static-page/article-template/Green-Building
[9] Electric Truck System https://en.wikipedia.org/wiki/Electric_truck

economic advantages, there were few cost reductions (e.g., specific maintenance costs savings) that were proven in real world applications prior to TABEPV. During TABEPV, TransPower performed a total cost of ownership analysis to determine the cost-savings potential of electric truck, yard tractor, and other cargo handling equipment investments. This information would then be used to advise future users and help inform relevant market policies. It also provided critical hands-on experience for fleet operators and cost data was shared with the fleet sector. A fleet operator's most valuable source of information about new technologies is other fleet operators.

The TransPower Solution

TransPower first committed to reducing these harmful pollutants and greenhouse gases in 2011, when it initiated development of its first prototype electric truck and electric yard tractors. As an example of the emissions-reducing potential of these technologies, Table 1 shows the estimated fuel consumption and emissions from a typical yard tractor over the course of any given year.

Table 1: Diesel-Powered Yard Tractor Consumption and Emissions Estimate

Fuel Used	12,080 gallons
Nitrogen Oxide Emissions	341.20 kg
Particulate Matter Emissions	12.30 kg
Total Hydrocarbon Emissions	18.60 kg
Carbon Dioxide Emissions	123,340.40 kg
Nitrogen Oxide Emission Factor (including deterioration and fuel correction factor) gram/boiler horsepower per hour	1.46 grams
Particulate Matter Emission Factor (including deterioration and fuel correction factor) gram/boiler horsepower per hour	0.05 grams
Total Hydrocarbon Emission Factor (including deterioration and fuel correction factor) gram/boiler horsepower per hour	0.08 grams

Photo Credit: California Air Resources Board

TransPower's first two-yard tractors were deployed in 2013 for a demonstration in San Antonio, Texas with major retailer HEB[10]. The HEB demonstration challenged these early prototype vehicles (which can be seen in Figure 1 below) to operate for at least 11 hours on a charge and at speeds up to 35 miles per hour.

[10] HEB Company Website https://www.heb.com/static-page/article-template/Green-Building

Figure 1: M1 and M2 at HEB, San Antonio, Texas

Photo Credit: TransPower

Later in 2013, TransPower delivered its first on-road Class 8 truck into test operations with a trucking fleet, a converted Navistar International truck that was operated by Total Transportation Services, Inc. near the Port of Los Angeles. As prototypes often do, these demonstrations showed strengths and weakness of the design. While the HEB tractors achieved unparalleled energy efficiency and range in hot summer conditions, several components demonstrated insufficient reliability. In Figure 2, the "Pilot Truck" delivered to Total Transportation Services, Inc. was able to demonstrate unprecedented power for an electric Class 8 truck, hauling loads up the steep bridges near the Port of Los Angeles , but this truck also showed a need for improved component reliability.

Figure 2: Pilot Truck Approaching the Vincent Thomas Bridge in February 2014

Photo Credit: TransPower

The HEB and Pilot Truck demonstrations also established the need for a more manufacturable and serviceable drive system design. In 2013-14, TransPower developed a second-generation electric drive system for yard tractors and trucks, and the updated design was featured in three new yard tractors and four new drayage trucks. Of these yard tractors, one was funded by the San Joaquin Air Pollution Control District for use by IKEA at its main California distribution center in Lebec and can be seen in Figure 3. Two were funded by the California Air Resources Board for use at the Port of Los Angeles which can be seen in Figure 4. In figure 5, the four drayage trucks were funded by the CEC under a prior grant with co-funding from the South Coast Air Quality Management District and were rolled out at a ceremony organized by the South Coast Air Quality Management District in March 2015, three months before the TABEPV project started.

Figure 3: Second-Generation Tractor at IKEA. Lebec, California

Photo Credit: TransPower

Figure 4: Port-Spec Tractor Testing at TransPower

Photo Credit: TransPower

Figure 5: Four Second-Generation Drayage Trucks, March 2015

Photo Credit: TransPower

To build on the successes of these early demonstration efforts, TransPower teamed up in early 2015 with three prominent California port fleet operators Dole, BAE Systems, and Terminalift to propose the TABEPV project. TABEPV was conceived to advance a key California policy goal—promoting zero emission goods movement, particularly in economically distressed areas.

TransPower's TABEPV team requested funding from the CEC to manufacture two new battery-electric yard tractors and two new battery-electric drayage trucks, which would then be demonstrated for two years in daily service in demanding port applications. The TABEPV project also funded the replacement of batteries on a reach stacker with a new type of lithium-ion battery that became available just before the project started. The two-yard tractors were used by Dole to move heavy refrigerated containers at its fruit terminal at the Port of San Diego. One truck was used by BAE Systems and the other by Terminalift to haul loads from the San Diego border region to their terminals at the Port of San Diego. The reach stacker would continue to be operated by Terminalift at the Port of San Diego.

The TABEPV project sought to build on the success of the earlier prototype yard tractor and drayage truck projects summarized above. TransPower's prototype tractors demonstrated increasing levels of productivity in the months leading up to the TABEPV project that started in June 2015. The TABEPV project aimed to further refine the technology used in yard tractors to the point where major yard tractor manufacturers such as Kalmar could confidently offer battery-electric models to their customers on a large-scale commercial basis and relying on TransPower to supply the drive system components. To help achieve this goal, TransPower persuaded Kalmar to support the TABEPV project by providing unpowered tractor gliders, which have only the frame, the cab, and the tires. Converting these gliders to battery-electric operation proved to be more challenging than expected, partly because Kalmar switched to a new yard tractor model, called the T2, shortly after the TABEPV project began, which forced TransPower to make numerous additional design changes. In addition, it took Kalmar and

TransPower several months to determine what base tractor parts needed to be kept in the glider package and which were not needed to support installation of the electric drive system.

The prototype tractors deployed by TransPower prior to the TABEPV project demonstrated superior performance and reliability as compared with competing electric tractors, and they provided a wealth of data to help guide the drive system refinements sought during the ABEPV project. Specific improvements pursued during the TABEPV project included reducing the weight and cost of the tractor battery subsystem by making design refinements and adopting more cost-effective manufacturing methods. The TABEPV project was able to achieve incremental improvements in the design of the TransPower drive system variant that was installed into the battery-electric port drayage trucks.

The TABEPV project demonstrated that heavy-duty yard tractors and drayage trucks using TransPower's battery-electric components can meet or exceed the performance standards of conventional diesel vehicles in long-term use, and that the technology can expand applications at California's vital port terminal operations sector. The TABEPV project also demonstrated measurable reductions in petroleum use and harmful emissions in disadvantaged communities, providing environmental and economic benefits where they are needed most urgently. The end goal of the project was to result in successful commercialization of TransPower's promising ElecTruck drive system products for yard tractors and drayage trucks. Metrics that were measured to validate the success of the TABEPV project included:

- Number of miles and hours of service achieved with the TABEPV tractors and trucks.
- Improvement in vehicle operating range and/or reductions in weight.
- Average reliability/availability of TABEPV tractors and trucks as compared with conventional tractors.
- Net reductions in petroleum use, greenhouse gas emissions, and criteria pollutant exhaust over the two-year term of the demonstration.
- Reductions in labor hours and total costs required to build electric tractors and drayage trucks.
- Number of commercial orders for ElecTruck tractors and trucks received during the project.

CHAPTER 2: Drive System Design

TABEPV Design Approach

Manufacturing reliable electric yard tractors and on-road trucks capable of hauling loads in excess of 45,000 kilograms (kg) is a formidable challenge, but one TransPower addressed effectively in early demonstration projects from 2011 through 2015. In Figure 6, TransPower's first electric yard tractor was deployed with HEB, a large Texas retailer in San Antonio in 2013. They displayed impressive power during the four months of operation but demonstrated the need for several improvements to achieve reliable long-term operation. Drawing on lessons learned from these first two tractors, TransPower improved its ElecTruck battery-electric drive system in 2014 and built three second generation prototype yard tractors. The first of these yard tractors was deployed at IKEA's main California distribution center in Lebec in September 2014, where it showed substantially improved reliability in the months leading up to the TABEPV project, accumulating more than 3,000 miles in its first six months of use. Two other yard tractors using TransPower's improved second generation system also achieved routine, daily, real-world service, one with Dole Fresh Fruit Company at the Port of San Diego and the other with a drayage firm near the Port of Los Angeles.

Figure 6: HEB Tractor in 2013

Photo Credit: TransPower

As discussed in the preceding chapter, a different variant of the ElecTruck drive system, tailored to the requirements of on-road Class 8 trucks, was also being developed in the months leading up to the TABEPV project. The "Pilot Truck" discussed previously demonstrated proof-of-concept of electric drayage trucks in late 2013 and led to the CEC-funded "Electric Drayage Demonstration" project, which produced the four trucks, shown previously in Figure 5, just before the TABEPV project was initiated. In fact, the TABEPV project was announced the day the four trucks were unveiled.

The successes of these early battery-electric yard tractors and drayage trucks provided the foundation for the TABEPV project, which focused on demonstrating refined yard tractor and truck drive systems suitable for commercial-scale manufacturing. The components to be used in the TABEPV vehicles were intended to be similar to those utilized in the earlier prototype vehicles, with improvements to reflect lessons learned from the earlier vehicles to improve reliability, reduce manufacturing costs, and improve serviceability.

TransPower First Generation Tractor and Truck Design

TransPower's first generation yard tractor and truck designs, as installed into the two HEB prototype tractors and the Navistar International Pilot Truck in 2013, provided a foundation for more than a decade of battery-electric yard tractor and on-road truck development by showing the potential for TransPower's proprietary motor-inverter drive combination to meet the performance requirements of demanding Class 8 tractor duty cycles. The first-generation yard tractor and truck combined permanent magnet motors manufactured by Jing-Jin Electric Company[11] with a custom-designed inverter-charger unit developed jointly with EPC Power, another California startup company. The CEC helped fund the inverter-charger unit during TransPower's first grant in 2011, which EPC Power supported as a major subcontractor.

In the first-generation drive system, the inverter-charger unit was shown to handle high power loads much more reliably than off-the-shelf inverters such as Quantum's electric vehicle inverters, which constantly failed when tested under high power in our first prototype truck. The inverter-charger unit also had the unique feature of combining the functions of the inverter, which controls the drive motors, and the battery charger, which recharges the vehicle's batteries while it is plugged in to a power source. The inverter-charger unit power section served the dual function of converting grid alternating current power to direct current power for the batteries and converting battery direct current power to alternating current power for use by the traction motors. Each inverter-charger unit delivered 150 kilowatts (kW) of continuous power to the drive motor and supports battery charging at up to 70 kilowatts. During the HEB demonstration in 2013, it was shown that one inverter-charger unit can meet the tractive power requirements of the heaviest yard tractors and recharge battery packs in two hours. The Pilot Truck demonstrated that the power requirements of on-road trucks can be met using two input capture units and two motors. In both the tractor and truck applications, the onboard inverter-charger units for battery charging eliminated the need for external battery chargers, which were large and expensive.

The first-generation yard tractor design incorporated two separate battery strings in the energy storage subsystem, providing 215 kilowatt-hours (kWh) of total energy storage capacity. This capacity was instrumental in achieving HEB's 11- to 13-hour operational requirements. To house this much energy storage, 14 battery modules were required, each consisting of 16 prismatic lithium iron phosphate batteries rated at 300 ampere-hours each. Accommodating this large battery subsystem required mounting of six modules under the tractor cab plus another eight modules outside the frame rails. This integration approach

[11] Jing-Jin Electric Company Website https://www.jjecn.com/en/

forced other components such as pumps, controller hardware, and power distribution systems to be mounted in various locations around the tractor, wherever they would fit. This resulted in numerous, drawbacks including:

- Difficulty servicing of the center mounted energy storage subsystem modules.
- Electrical interference with other low voltage components caused by stringing high voltage components about the vehicle.
- Partly due to the large weight of the battery subsystem, the tractors weighed almost 12,000 kg after integration, a significant increase over their production weight of 7,200 kg.

In addition to these issues, the first-generation design was limited by the selection of a Dana/Spicer gearbox using a shift actuator derived from the car racing industry. This first attempt by TransPower to utilize an automated manual transmission demonstrated the potential of this technology to improve vehicle operating efficiency; however, this particular automated manual transmission configuration was shown to be too frail to use in demanding yard tractor duty cycles, as the HEB tractors required frequent repairs of damage to the automated manual transmission shifting mechanism. The HEB tractors also required frequent replacement of battery management system sensors that were located in battery modules, and these modules were very difficult to access. These shortcomings pointed to the need for design improvements to significantly improve tractor reliability, robustness, and serviceability.

TransPower's first-generation drayage truck drive system, as manifested in the Pilot Truck design, was one of the first TransPower drive systems to use the heavier duty Eaton transmission instead of the Dana Spicer transmission used in the HEB tractors; however, it used the same basic motor and battery technologies as demonstrated in the HEB technologies, with the main difference being that, as discussed above, the Pilot Truck used two Jing-Jin Electric Company motors and two inverter-charger units to handle its higher power requirements. During the first few months of 2014, a sequence of progressively more demanding tests was performed with the Pilot Truck to characterize its performance. On February 14, 2014, the Pilot Truck performed its first loaded drayage service on the two major bridges in the Port of Long Beach area the Vincent Thomas Bridge and the Gerald Desmond Bridge. Figure 7 on the next page, is a photo of the truck crossing the Vincent Thomas Bridge with a container, bringing the fully loaded weight of the truck to nearly 28,000 kg.

Figure 7: Pilot Truck Crossing Vincent Thomas Bridge, 2014

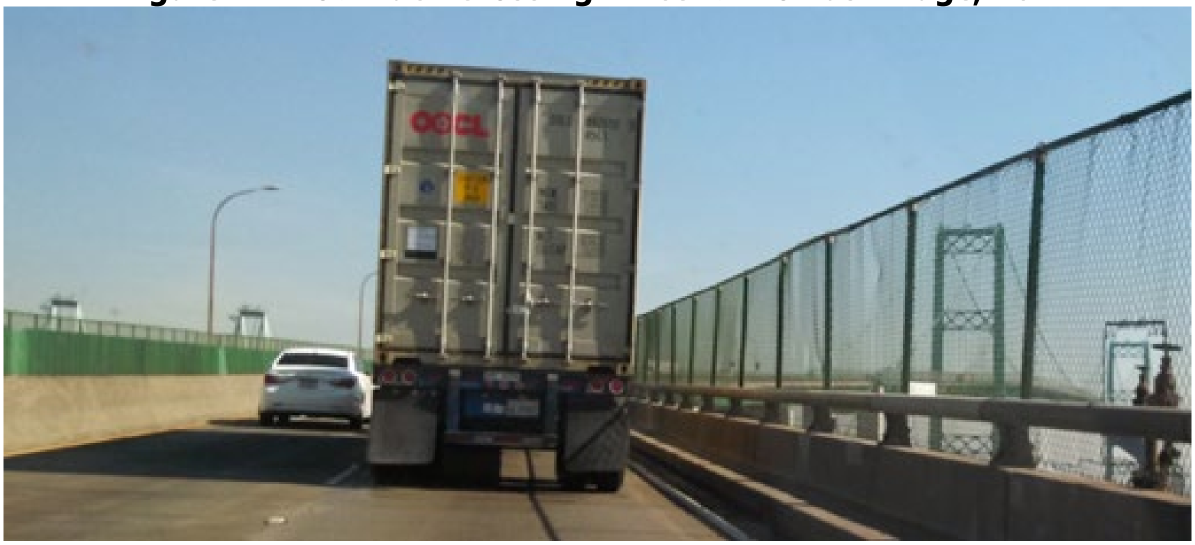

Photo Credit: TransPower

In subsequent tests in actual drayage service, the Pilot Truck consistently demonstrated sufficient road performance to handle all types of drayage operations, significantly exceeding the capabilities of previous electric trucks of this class. Problems with a few components, however, prevented the truck from being used reliably for significant lengths of time. By late summer 2014, the truck had accumulated approximately 4,400 total miles of testing and drayage service. The main source of continued difficulty was poor performance of the new battery management system boards, which TransPower had hoped would perform more reliably than the failure prone battery management system boards used on the HEB tractors. The battery management system boards on the Pilot Truck, however, also failed at unacceptable rates, demonstrating the need for a better solution.

TransPower Second Generation Yard Tractor and Truck Design

To address the issues experienced with TransPower's first-generation yard tractor and truck designs in 2013 and early 2014, a second-generation design was developed in 2014 for the yard tractor built for IKEA, two yard tractors built for the Port of Los Angeles, and the four electric drayage demonstration drayage trucks described previously. Key improvements featured in the second-generation design included:

- Accessories and supervisory controls were consolidated into one assembly called the power control and accessory subsystem which was configured to use the same space claim as a diesel engine.
    - Supervisory controls were consolidated into one enclosure dubbed the supervisory control module.
- The yard tractor's energy storage system was completely redesigned around a different lithium iron phosphate battery product from China Aviation Lithium Battery, and the energy storage subsystem for both the yard tractor and drayage truck was redesigned to use a smaller number of large battery modules.

- The powertrain, or motive drive subsystem was upgraded to an Eaton gearbox using TransPower controls designed into a dedicated powertrain control module.
- An automotive grade accessory inverter replaced the industrial inverters used on earlier tractors, which were not designed for vehicle use and thus failure prone.
- Controller area network-controlled automotive grade cooling pumps replaced the industrial pump.

One of the most important advances of the second-generation design was making the motive drive subsystem more rugged, which was achieved by adopting a heavier-duty Eaton manual transmission. This modification, first demonstrated on the earlier Pilot Truck, enabled TransPower to take advantage of an improved automated manual transmission product developed by Eaton over the preceding few years. The automated manual transmission advances the state of the art of transmitting torque from electric motors, combining rugged off-the-shelf manual transmissions with state-of-the art shifting controls and software. As discussed previously, TransPower's first-generation automated manual transmission used a shifting mechanism designed for racing cars and demonstrated the essential feasibility of an automated manual transmission but revealed that the racing car shift mechanism was not robust enough for heavy duty vehicles. To overcome this difficulty, TransPower teamed with transmission manufacturer Eaton in 2013 and upgraded the automated manual transmission to use Eaton's more robust shifting servomechanism. This device is visible near the bottom of the photo shown in Figure 8, mounted on top of the Eaton transmission.

Figure 8: Second-Generation Power Control and Accessory Subsystem and Motive Drive Subsystem Installed in the Yard Tractor

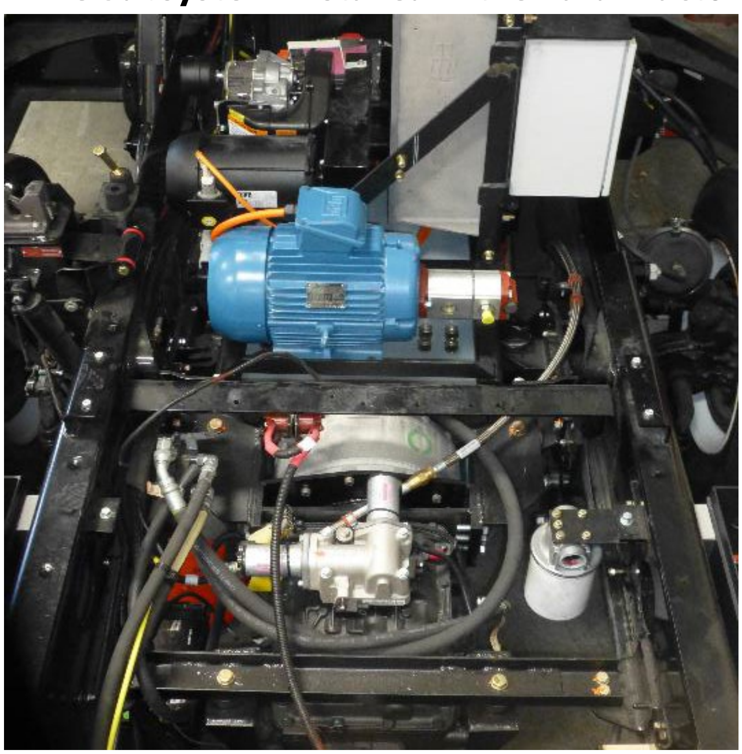

Photo Credit: TransPower

Most of the other EV's used direct drive between the electric motor and axle, which limited performance on automatic transmissions and relied on inefficient torque converters that sap valuable electric energy from the battery pack whenever the vehicle is running. The automated manual transmission provided improved performance at both high and low speeds, while enabling use of a more efficient manual transmission, which reduced energy consumption and increased operating range. The yard tractor variant of TransPower's automated manual transmission uses Eaton's medium-duty 6-speed transmission. For higher-power on-road Class 8 trucks, TransPower developed an automated manual transmission variant using Eaton's 10-speed transmission. All five yard tractors built during the TABEPV project used the Eaton-based automated manual transmission and the motive drive subsystem and TransPower continued fine-tuning the automated manual transmission shifting software throughout the TABEPV project as it acquired data from trucks and yard tractors in actual service.

Another key second-generation design improvement was the removal of battery modules from the area underneath the cab. This enabled TransPower to consolidate vehicle controls and accessories in this location, which gave rise to development of TransPower's power control and accessory subsystem, a new system integration concept to accommodate the major components used for vehicle control and electrically driven accessories, including the inverter-charger units previously discussed.

In the first-generation tractors, the inverter-charger units, power controllers, and accessory components were mounted directly to vehicles, spread around in various locations, and connected with cables. This required TransPower to develop and maintain dozens of different electrical, mechanical, and fluid interfaces with the base vehicle and made it difficult to access and service components once they were installed. Figure 9 shows the integrated power control and accessory subsystem concept installed into one of TransPower's second-generation prototype tractors.

Figure 9: First-Generation Tractor

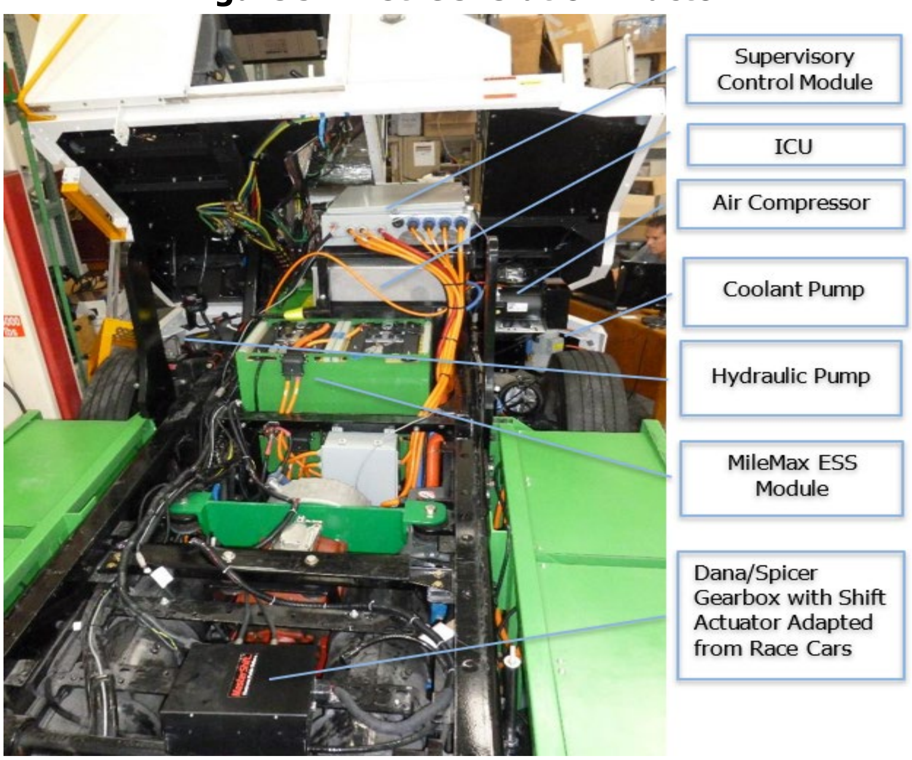

Photo Credit: TransPower

Another view of a second-generation power control and accessory subsystem assembly is shown in Figure 10.

Figure 10: Power Control and Accessory Subsystem Assembly Developed for Second-Generation Yard Tractor System

Photo Credit: TransPower

The power control and accessory subsystem components were pre-integrated into a specially designed structure and the many wiring and cooling connections between these components were completed before installation into the tractor. The entire power control and accessory subsystem assembly was then hoisted into the engine compartment as a single unit and connected to the tractor and the remainder of the drive system with minimal additional integration hardware and wiring.

The power control and accessory subsystem approach was also utilized in TransPower's second-generation on-road Class 8 truck drive system design, although in this case the power control and accessory subsystem had to accommodate two inverter-charger units, one for each of the two drive motors used in the on-road truck design. The first on-road Class 8 truck to use TransPower's power control and accessory subsystem approach was the electric drayage demonstration-1, the first of the four electric drayage demonstration trucks built under the CEC and South Coast Air Quality Management District project discussed previously. Figure 11 on the next page, is a photo of the power control and accessory subsystem after its installation into the truck's engine compartment.

Figure 11: Power Control and Accessory Subsystem After Installation into Electric Drayage Demonstration-1

Photo Credit: TransPower

The approach of pre-integrating all of the power control and accessory subsystem components into a single structure not only reduced TransPower's assembly time, but helped accelerate market acceptance of the ElecTruck system by forming the basis of drive system kits that are easy for established original equipment manufacturers to install into vehicles on their own assembly lines.

A key lesson learned during operation of the first-generation HEB tractors and the Pilot Truck was that the first-generation battery arrangement made it extremely difficult to service batteries or other components in the battery modules, such as battery management system sensors. TransPower also learned that installing 14 to 18 large battery modules into a vehicle is exceedingly complex. Hundreds of hours of labor were required to fabricate and wire these many different battery modules. The battery arrangement adopted for the second-generation yard tractor design consisted of just four battery modules—an upper and lower module on each side of the tractor. The second-generation on-road truck design, as reflected in electric drayage demonstration-1, initially utilized 18 battery modules, but was subsequently scaled down to use five much larger modules, similar to the approach taken with the second-generation yard tractor design. This greatly reduced the time required to install and service batteries on both yard tractors and drayage trucks using TransPower's second-generation drive system design.

TABEPV Design Approach

TransPower built on all of the design work described in the preceding subsections by making significant additional improvements to its yard tractor and drayage truck designs during the course of the TABEPV project. On June 24, 2015 a formal TABEPV project kick-off meeting was held at TransPower. TransPower met with representatives of Dole and BAE Systems to discuss continuing work to complete liability and other agreements needed for deployment of vehicles. This represented the beginning of TransPower efforts to familiarize deployment partner personnel with TransPower electric trucks and to understand the concerns of their organizations. Project partner SDG&E initiated a dialogue and provided the support equipment specified for drayage truck testing.

In addition, TransPower initiated a review of options for making incremental improvements to the drive systems in the TABEPV vehicles. The selected approach was to minimize changes to the drive system configurations and to focus instead on reducing costs through process improvements. The main exceptions to this were to be the upgrading of the reach stacker drive system to use the advanced Yinhe New Energy YHKAM batteries[12] and possible use of these cells in other TABEPV vehicles if experience testing them was positive.

YHKAM Battery Evaluation

While TransPower was generally satisfied with the prismatic lithium iron phosphate cells used on its most recent prototype vehicles prior to TABEPV, it was always searching for improved battery cell technologies that can increase operating range, reduce weight, or reduce costs. During the months leading up to the TABEPV project in late 2014 and early 2015, TransPower became acquainted with a new lithium iron phosphate cell product—a cell that stored 60 percent more energy than the cells previously used. An additional reason for switching to the new cells was a unique opportunity to manufacture these cells in the United States. The new higher energy cells were manufactured in China, but Yinhe signed an agreement giving TransPower rights to manufacture the cells in the United States.

Prior to the TABEPV project, TransPower tested several battery cells that were delivered to its battery test lab. These tests went well, confirming that the batteries offered higher energy storage than prior generation lithium iron phosphate cells and showing favorable cell balancing characteristics. By the time the TABEPV project began in June 2015, TransPower believed that the YHKAM battery might be the first battery technology since TransPower's formation in 2010 that offers significantly better performance than prismatic lithium iron phosphate cells without a significantly higher cost per kilowatt-hour. A major thrust of the TABEPV project was to determine whether this new battery product could be used reliably in the major vehicle types targeted: yard tractors, drayage trucks, and reach stackers.

Leveraging its prior investigations related to the battery product, TransPower was able to quickly complete the following activities upon commencement of the TABEPV project:

- Developed conceptual design for battery modules using these cells, compatible with TABEPV drayage trucks and yard tractors.
- Identified number of cells required for one test truck.

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[12] Yinhe New Energy Ltd http://en.yinhe.com/product

- Procured cells for one test truck from the supplier, Yinhe

Additional lab testing of these cells was performed after the start of the TABEPV project. Figure 12 is an example of data capture from tests performed during August 2015, showing ten cycles of charge and discharge behavior with voltage and temperature reported. This is a sample of the 300 test cycles that were eventually performed.

Figure 12: Data Capture from Lab Testing of YHKAM Cells

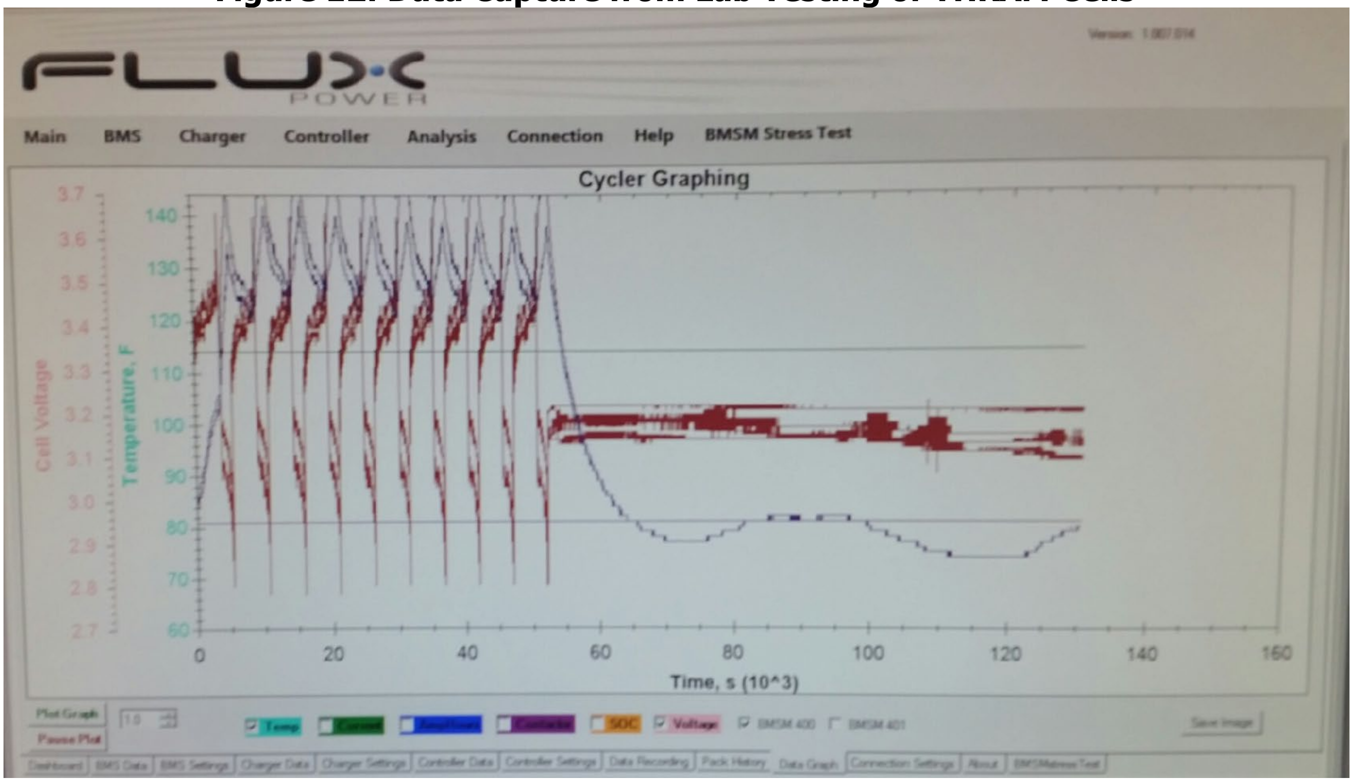


Photo Credit: TransPower

To further reduce risks to the vehicles to be built during TABEPV, it was decided to use the first of TransPower's current fleet of electric drayage trucks as a test bed for using these cells. For reasons to be discussed later in this report, this turned out to be a fortuitous choice. This test truck, electric drayage demonstration-1 was test operated from April 2014 until early 2015 but was unable to be used in consistent daily drayage service due to persistent problems with its original batteries and battery management system boards. While subsequent electric drayage trucks of the electric drayage demonstration design performed more reliably using higher quality battery cells and battery management system boards, electric drayage demonstration-1 remained idled due to its reliance on the older battery choice, so it was a logical vehicle to use as a testbed for the YHKAM battery. TransPower's goal was to complete the installation of these battery cells into electric drayage demonstration-1 by the end of the summer of 2015, which would enable sufficient drive testing to validate the cells by the end of 2015. This would enable TransPower to order additional battery cells for some or all of the TABEPV vehicles by the end of 2015, which would result in deliveries of these cells to TransPower in time for use in the TABEPV trucks and tractors.

The selected battery module design, shown in Figure 13, was based on installing 90 cells into each module. TransPower calculated that yard tractors using this design could utilize either one or two such modules and on-road trucks could use either two or three modules, depending on range requirements. Using a single module, a yard tractor would have about two-thirds of the energy storage capacity of TransPower's previous battery-electric yard tractors. Using two modules, a yard tractor would have one-third more energy and an on-road truck would have about the same amount of usable energy as TransPower's current battery-electric on-road trucks. Using three YHKAM battery modules, on-road trucks would have about 50 percent more energy content than what was available for the TransPower electric trucks at the time.

Figure 13: Early Design of YHKAM Battery Module

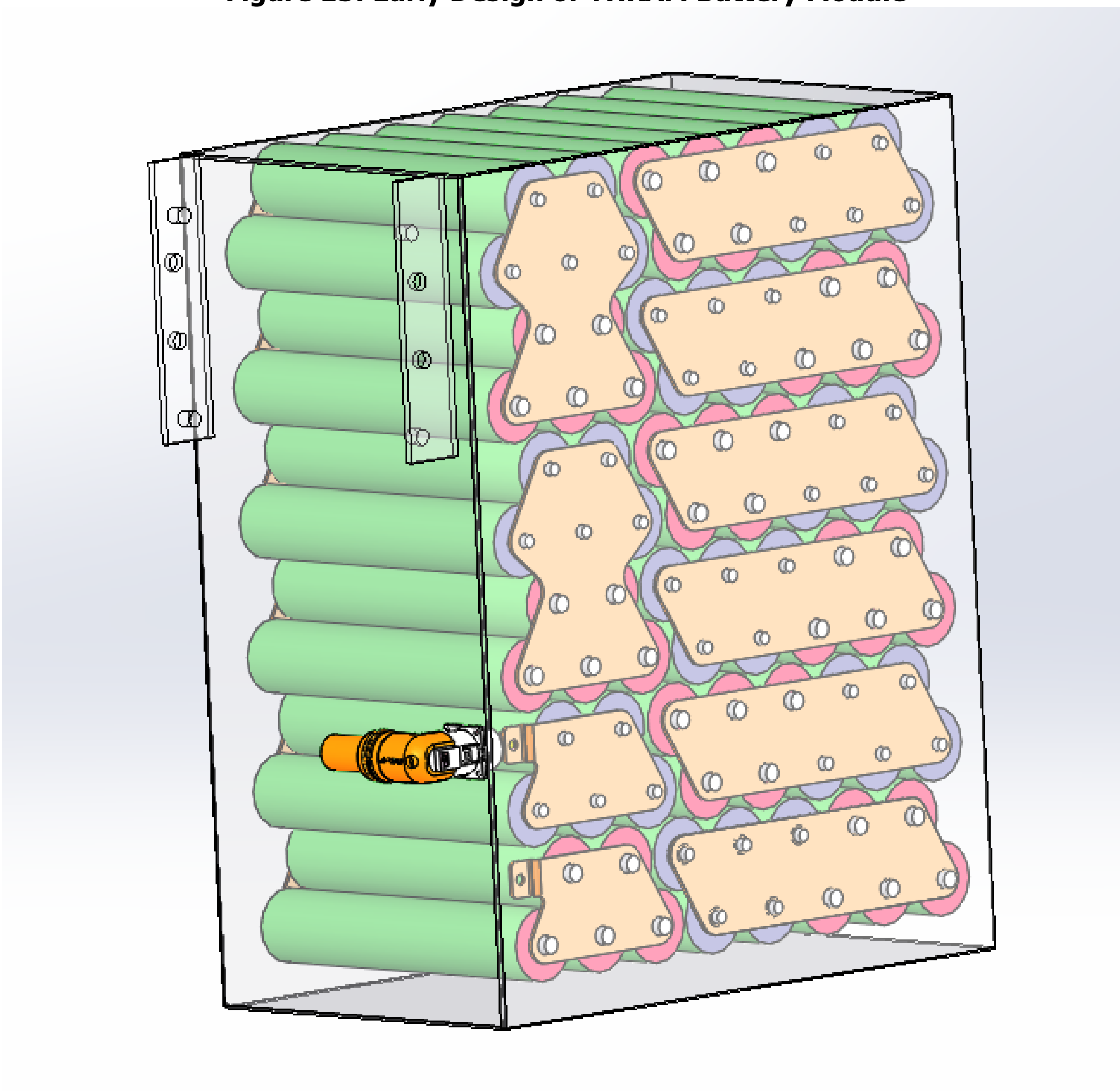


Photo Credit: TransPower

Another step to try to minimize the risk of migrating to this battery design, TABEPV project manager James Burns and commercialization lead Michael Simon traveled to the YHKAM battery manufacturing facility in Changsha, China in September 2015 and examined both the cell product and the process used to manufacture cells. Burns also visited a Yinhe facility in Shenzhen, China and motor supplier Jing-Jin Electric Company in Beijing, China. These visits were part of TransPower's due diligence aimed at validating the supply and quality of battery cells and drive motors prior to making final payments to Jing-Jin Electric Company for these important TABEPV components. The visits were very valuable in helping TransPower to understand the unique battery manufacturing processes.

The following month, TransPower received a shipment of 1,100 batteries, purchased under the TABEPV project for testing in the electric drayage demonstration-1 test truck. The plan was to integrate these batteries into 12 modules, each containing 90 cells as pictured in Figure 14 on the previous page. Each of these cells weighs approximately 2.4 pounds and stores approximately 270 watt-hours of electrical energy.

Unfortunately, the battery manufacturer Yinhe made a major mistake in the course of preparing this battery shipment. Believing that the batteries had to be shipped by air to meet TransPower's schedule, Yinhe discharged all the batteries to low states of charge to make them safe to fly. This action, taken without consulting TransPower, forced TransPower to expend significant resources in constructing a system to recharge all 1,100 batteries individually, a process that took far longer than it would have taken to ship the batteries to the United States by sea. Figure 14 is a photo of part of the apparatus built to charge and balance the Yinhe batteries.

Figure 14: Charging and Balancing the Discharged Batteries

Photo Credit: TransPower

Testing of the first YHKAM battery module in early 2016 yielded favorable electrical results, but also demonstrated that physical improvements to the module design were required. Figure 15 is the strengthened module that was developed in March 2016. The new design had features to improve the containment and protection of the cells, including development of a sturdy outer enclosure that would be mounted directly onto the frame rails of a truck.

Figure 15: Design of Strengthened YHKAM Battery Module

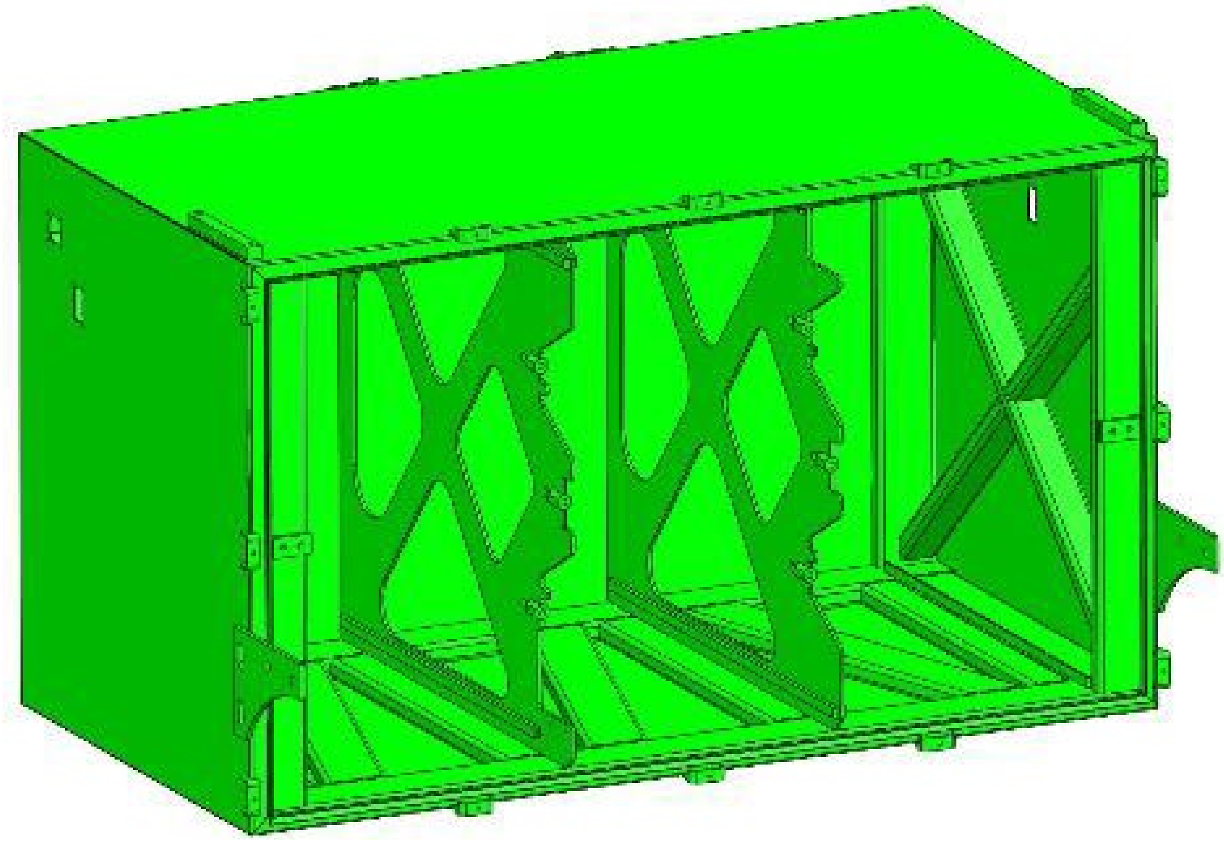


Photo Credit: TransPower

By July 2016, 12 battery modules using the new, strengthened design had been manufactured and lab tested, and final preparations were being made to install them into the electric drayage demonstration-1 test truck. Figure 16, shows the outer enclosure of one of these modules after being installed onto electric drayage demonstration-1 for a fit test. This photo shows that the outer enclosure consists of three segments, and each segment houses a 90-cell module that evolved from the initial concept shown previously in Figure 15. The outer enclosure therefore houses a total of 270 batteries. Four enclosures of this type were installed onto electric drayage demonstration 1, containing a total of 1,080 battery cells and providing approximately 300 kWh of total energy storage. This represented a substantial improvement over the previous battery system design as used in TransPower's electric drayage demonstration project trucks, which provided 215 kWh of total energy storage.

Figure 16: YHKAM Module Mounted to Electric Drayage Demonstration-1

Photo Credit: TransPower

TransPower hoped that the new battery system would increase the operating range of a fully loaded drayage truck from the 60-70-mile limitation of the electric drayage demonstration trucks to at least 100 miles. Drive testing of electric drayage demonstration-1 with the batteries began in August 2016. The drive testing was briefly halted after a few days, when it was discovered that incorrect fusing was installed in the pack. This was quickly corrected, and an additional 120 miles of drive testing of electric drayage demonstration-1 was accomplished in September 2016.

When the drive testing of electric drayage demonstration-1 resumed, early results indicated that the new pack had a lower than expected internal resistance, heightening hopes that the new YHKAM product would help improve operating efficiency and extend operating range. Figure 17 provides an example of the type of battery test data obtained from test driving the electric drayage demonstration-1 truck. Shown in this illustration is fuse temperature under hill climb on a maximum seven percent grade. Instrumentation of the fuse that failed during initial testing showed an 80 degrees Celsius rise in temperature that lowered the performance of the fuse, which caused premature opening.

Figure 17: Data Captured During Testing of YHKAM Batteries on Electric Drayage Demonstration-1

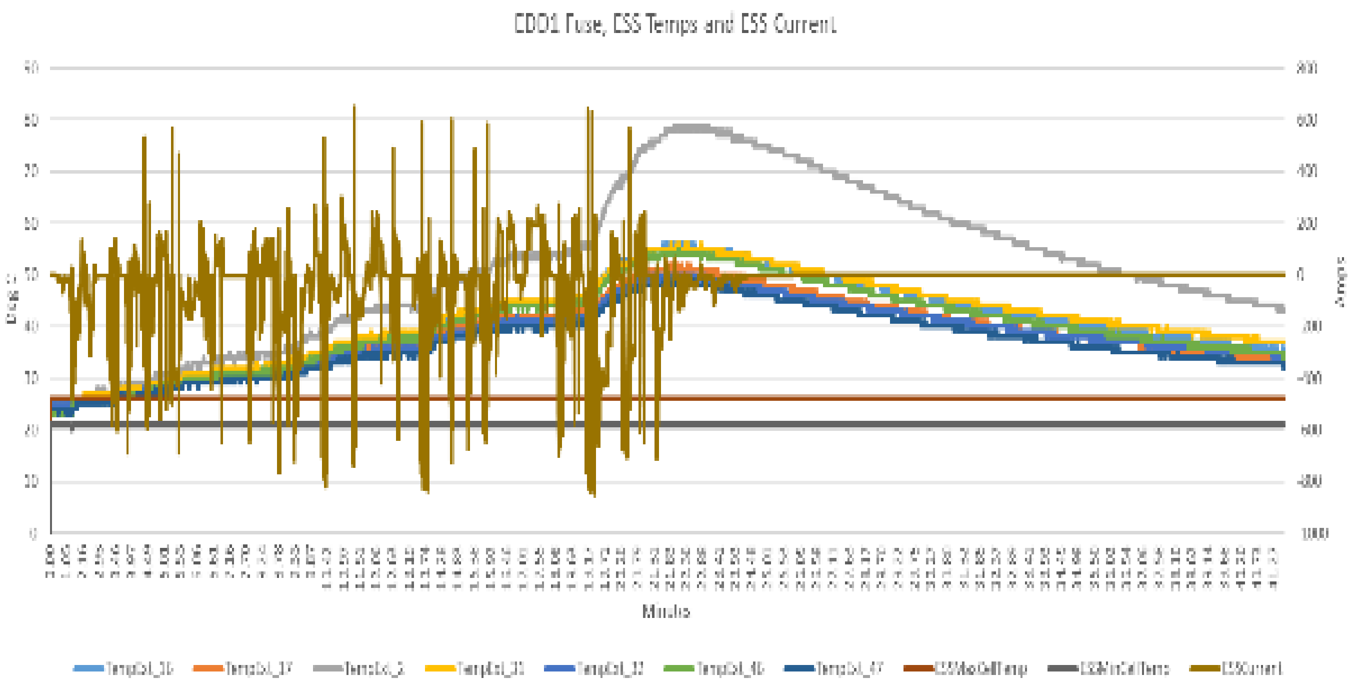


Photo Credit: TransPower

The energy storage subsystem fusing design for this battery subsystem was upgraded on the electric drayage demonstration 1 test truck to handle the new operational thermal loads within energy storage subsystem enclosures. Drive testing through October 2016 indicated that the new approach to fusing was effective in preventing premature fuse opening under load; however, continued drive testing led to the discovery of several defective battery management system boards. TransPower discovered damage to several cells under the control of these battery management system boards due to board failures. This required replacement of damaged cells and defective battery management system boards, which caused delays in fall 2016.

Figure 18 illustrates the complexity of the work that was required to troubleshoot and fix problems with this battery system installed onto electric drayage demonstration 1.

Figure 18: Troubleshooting Battery Problems with Electric Drayage Demonstration1

Photo Credit: TransPower

On March 21, 2017, a YHKAM cell in one of the battery modules on electric drayage demonstration 1 ruptured shortly after a test drive using newly constituted modules and created a significant technological setback. The rupture of the cell, which occurred in TransPower's Escondido facility about two minutes into an attempted charging sequence, created a loud concussive sound and resulted in the release of smoke from the module, but did not cause a fire or any external damage to the module or test truck. Nonetheless, this cell failure was taken very seriously and TransPower performed months of exhaustive testing on the nearly 5,000 cells of this type that were purchased for several vehicles, including the Fantuzzi[13] reach stacker and two of the TABEPV drayage trucks. Figure 19 shows the damaged cell as installed into the module, and the arrow to the left of the photo points directly to the cell that ruptured.

[13] Fantuzzi Website https://ftmh.it

Figure 19: YHKAM Module with Ruptured Cell

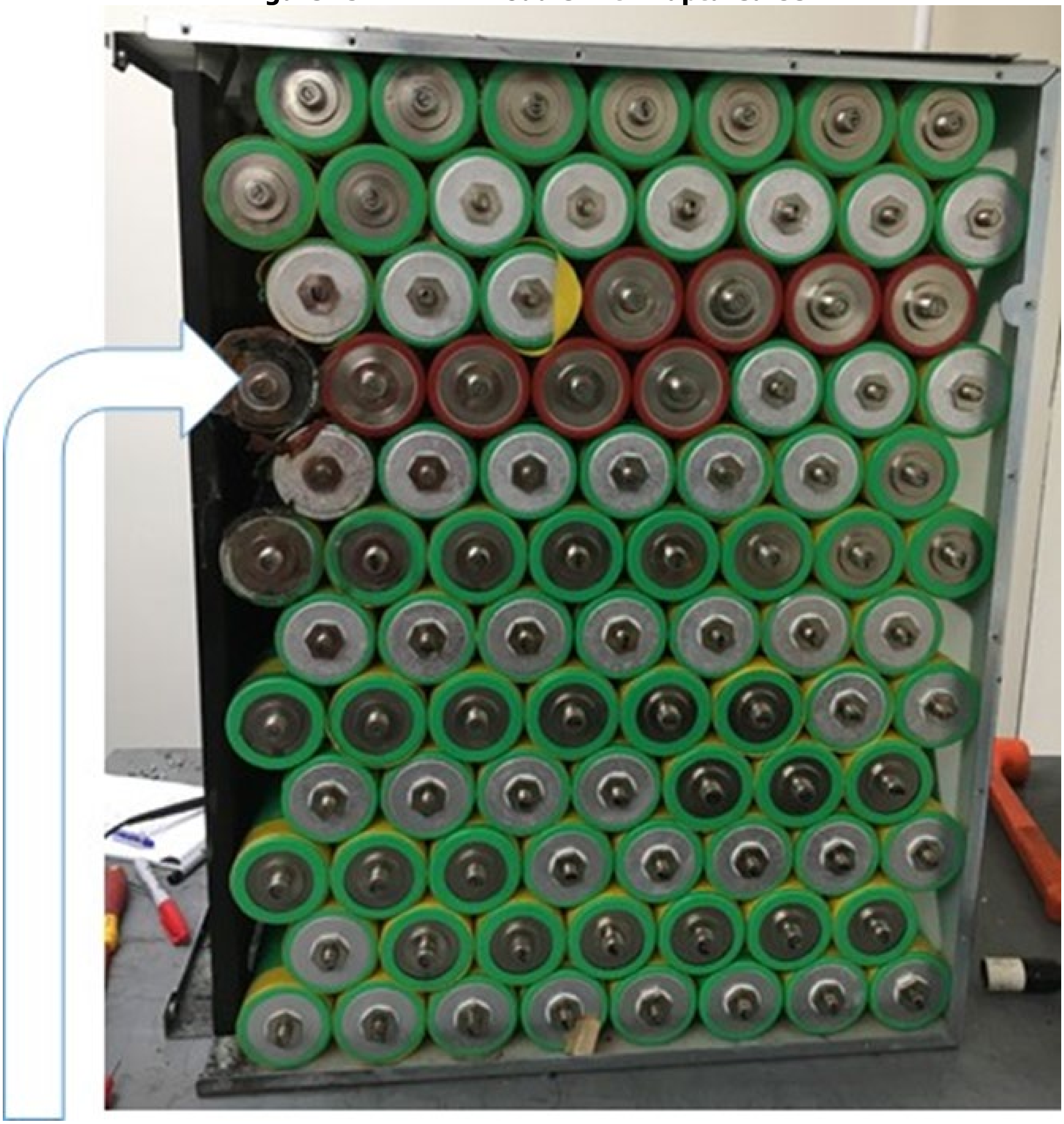


Photo Credit: TransPower

After using a battery tester to thoroughly re-test this module and the other 11 modules constituting the electric drayage demonstration-1 energy storage subsystem, TransPower developed a plan to replace the damaged cell in the module and resume testing of electric drayage demonstration-1. Once electric drayage demonstration-1 resumed test driving, however, the electric drayage demonstration truck experienced problems with other battery cells. While none of these cells ruptured in the same manner as the one that failed in March 2017, numerous cells did show signs of leaking, which is a hazardous condition.

By the end of the summer of 2017, TransPower made the decision to stop purchasing YHKAM batteries but to continue using its existing batteries in only three experimental vehicles: the Fantuzzi reach stacker and two experimental hybrid-electric drayage trucks. The reach stacker is operated only in a port environment with restricted access, so TransPower determined that even if a severe battery failure occurred, it would be unlikely to cause any collateral damage. In deciding not to use YHKAM batteries in the two TABEPV drayage trucks, however, TransPower incurred the cost of purchasing Voltronix batteries[14] for these two trucks after having already paid for 2,200 unusable batteries.

Other TABEPV Design Tasks

TransPower developed a variant of the YHKAM modules that were tested on electric drayage demonstration 1 for the Fantuzzi reach stacker in 2017. Developing this energy storage subsystem and integrating it into the Fantuzzi was the only other major design activity undertaken during TABEPV, because once TransPower made the decision to use Voltronix batteries in the two drayage trucks, nearly all other TABEPV subsystems were based on existing designs.

The design for the TABEPV yard tractors was based on the new drive system TransPower developed for Kalmar's new T2 tractor under a parallel Energy Commission grant, Heavy-Duty Electric Yard Tractors. Figure 20 shows the yard tractor design as developed early in the Heavy-Duty Electric Yard Tractor project in late 2015, highlighting in green the novel new energy storage subsystem design.

Figure 20: Yard Tractor Integration Concept

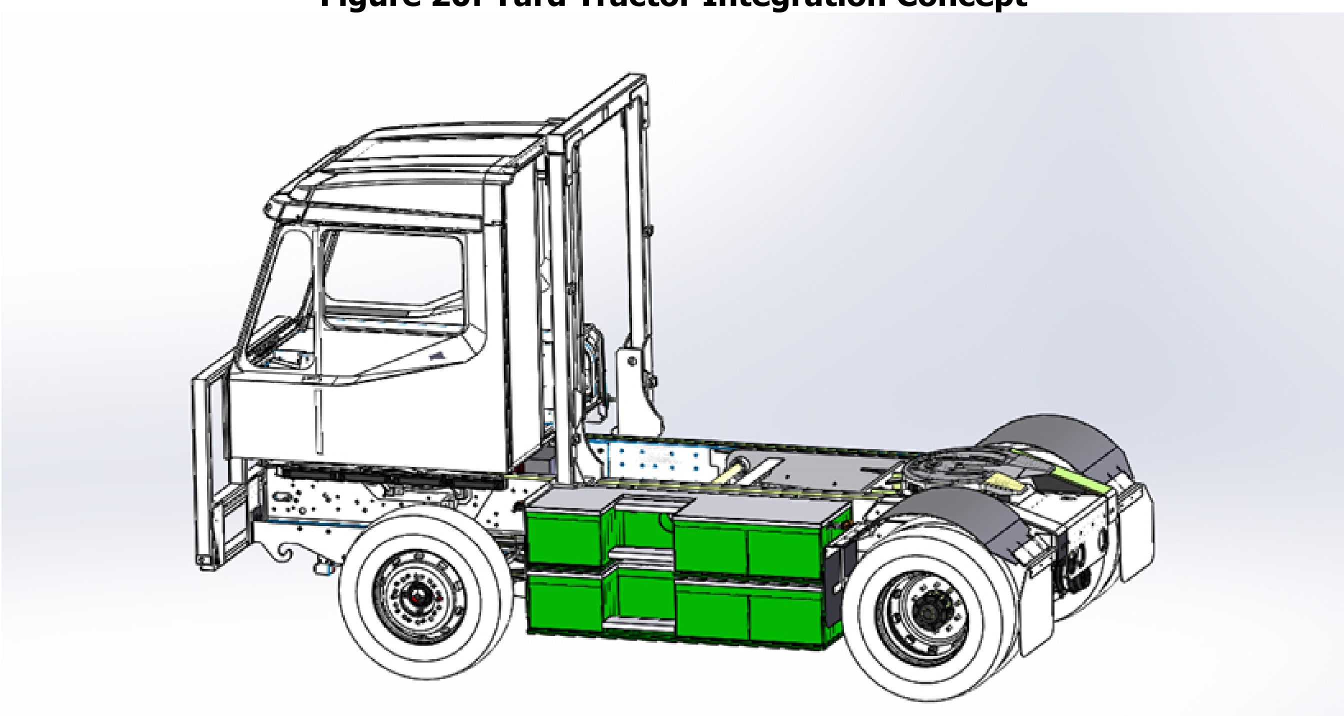


Photo Credit: TransPower

[14] Voltronix Website

The intricate design of the new battery enclosure design shown above took more than a year to fully develop. Figure 21 is computer model of the complete T2 yard tractor assembly with the new energy storage subsystem and power control and accessory subsystem installed. This more refined illustration shows the side steps incorporated into the design for easier and safer access to the rear deck. Both TABEPV yard tractors were designed to use 400 ampere-hour batteries manufactured by China Aviation Lithium Battery, the same type of battery used in five previous demonstration yard tractors built by TransPower in 2014 and early 2015. The two TABEPV yard tractors turned out to be among the last electric yard tractors built by TransPower using the China Aviation Lithium Battery batteries, because China Aviation Lithium Battery informed TransPower during the TABEPV project that it was discontinuing the manufacture of the 400 ampere-hour cells.

Figure 21: Refined Illustration of T2 with Drive System Installed

Photo Credit: TransPower

Ultimately, the design adopted for the two TABEPV drayage trucks was essentially the same as the latest design developed under a prior the CEC grant for the electric drayage demonstration project. As discussed previously, this prior grant resulted in production of four electric drayage demonstration trucks using the second-generation drive system design. Based on lessons learned during building and operating these four trucks, TransPower developed a third-generation drayage truck system design that incorporated a new RS-12 inverter, developed by EPC Power, to control one of the two main drive motors, as opposed to using an inverter-charger unit to control each motor. The RS-12 is smaller than the inverter-charger unit, as illustrated in Figure 22 on the next page, which shows the engine compartment of electric drayage demonstration-5 (the fifth truck in the electric drayage demonstration project) after installation of the inverter-charger unit and the RS-12. The RS-12, shown in the center of the photo with the EPC Power logo, is also less expensive than the inverter-charger unit.

Figure 22: Electric Drayage Demonstration-5 Engine Compartment, Showing RS-12

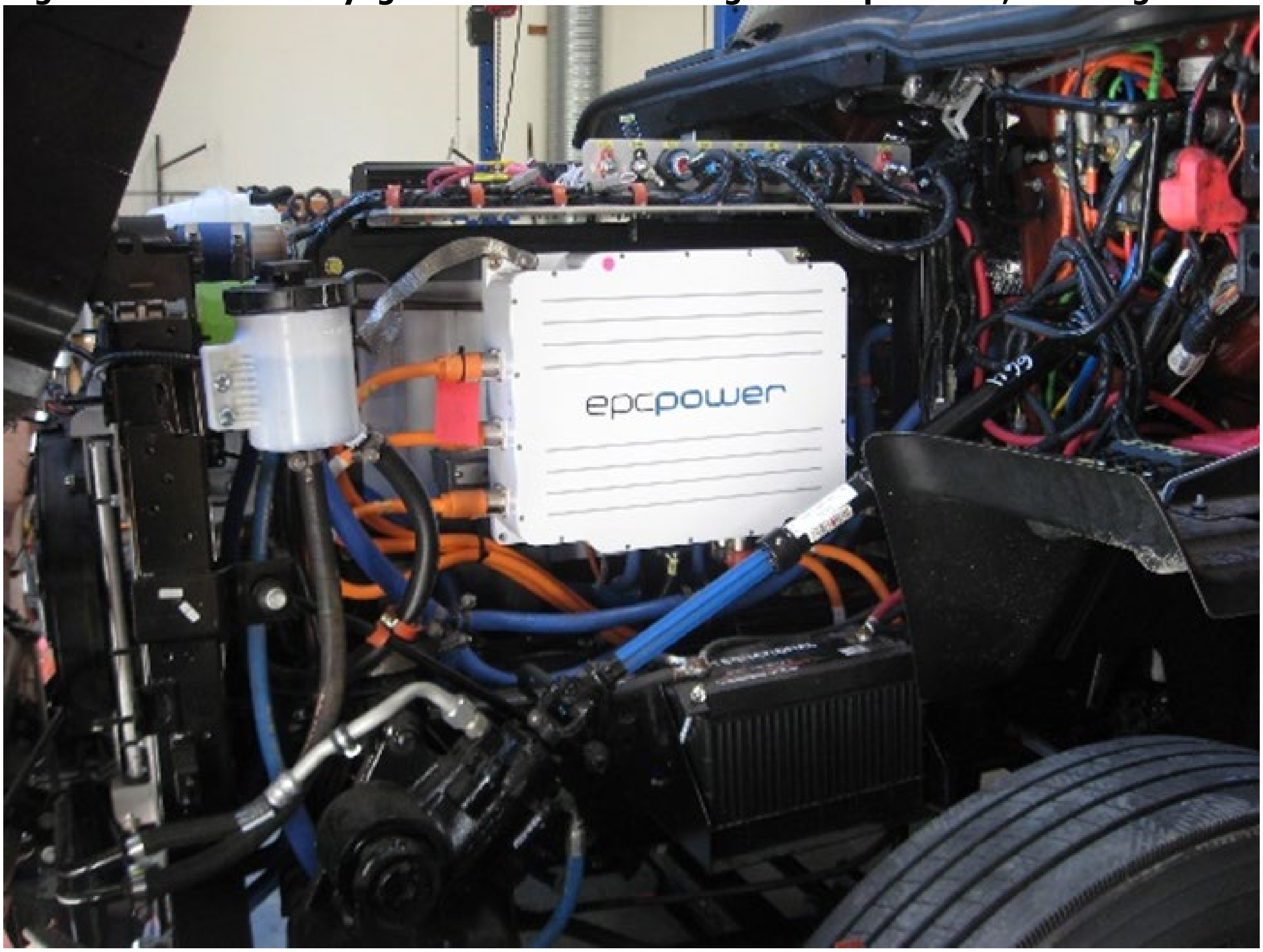


Photo Credit: TransPower

The third-generation Class 8 on-road truck design used in electric drayage demonstration-5, -6, and 7 also featured some improvements in the design of the five large battery modules used to house a total of 224 Voltronix batteries, along with numerous advanced integration methods and hardware. Successful demonstration of these last three electric drayage demonstration trucks in 2015 and 2016 provided a high level of confidence that this truck design could be used during the TABEPV project. It is unfortunate that the YHKAM battery product did not turn out to be of sufficient quality to use in the two TABEPV drayage trucks, but the third-generation electric drayage demonstration battery system design was the original choice for these trucks and it turned out to be the most viable energy storage subsystem option.

CHAPTER 3: TABEPV Manufacturing

Component Manufacturing

In December 2015, six months after initiating the TABEPV project, TransPower formalized its commitment to purchase two Class 8 Navistar International ProStar trucks[15] that were to serve as the TABEPV drayage trucks. These trucks were in addition to the pre-existing electrified ProStar truck that was used as a test bed for evaluating the new batteries. As discussed in the preceding chapter, use of the pre-existing ProStar trucks enabled an early evaluation of YHKAM technology and allowed TransPower to gain valuable experience with these batteries before deciding whether to use them in the new TABEPV drayage trucks. TransPower also committed to the purchase of two Kalmar yard tractors for TABEPV in late 2015. With these long-lead items ordered, early project manufacturing efforts were allowed to focus on component manufacturing.

Battery Pack Manufacturing

To enable testing of these batteries as early as possible, fabrication of the first YHKAM battery module was initiated before the end of 2015. Figure 23 is a photo of the outer housing of the module during fabrication.

Figure 23: YHKAM Battery Module Housing

Photo Credit: TransPower

[15] ProStar International Trucks https://www.internationaltrucks.com/en/trucks/prostar

Figure 24 shows the interior of this battery enclosure after the installation of these batteries in January 2016.

Figure 24: Interior of YHKAM Battery Module with Cells

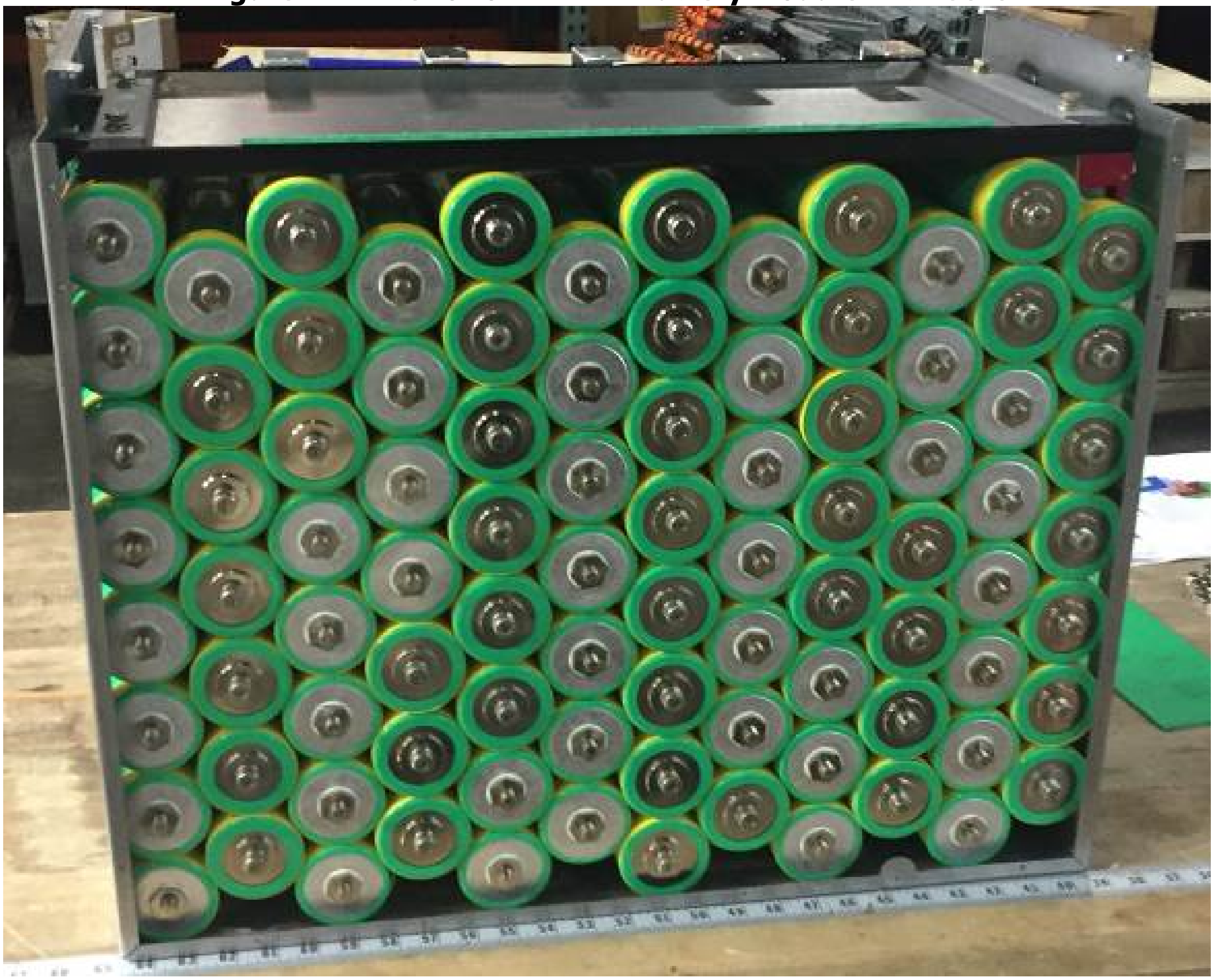


Photo Credit: TransPower

Initial lab testing of this first module yielded positive results. Figure 25 on the next page, is a depiction of the charge/discharge test results for this module, showing a very tight distribution of cell group voltages that indicated a very uniform internal resistance during cell discharge. A capacity of over 803 ampere-hours was measured between 3.7 volts of direct current and 3.0 volts of direct current per cell.

Figure 25: Data from Testing of YHKAM Battery Module

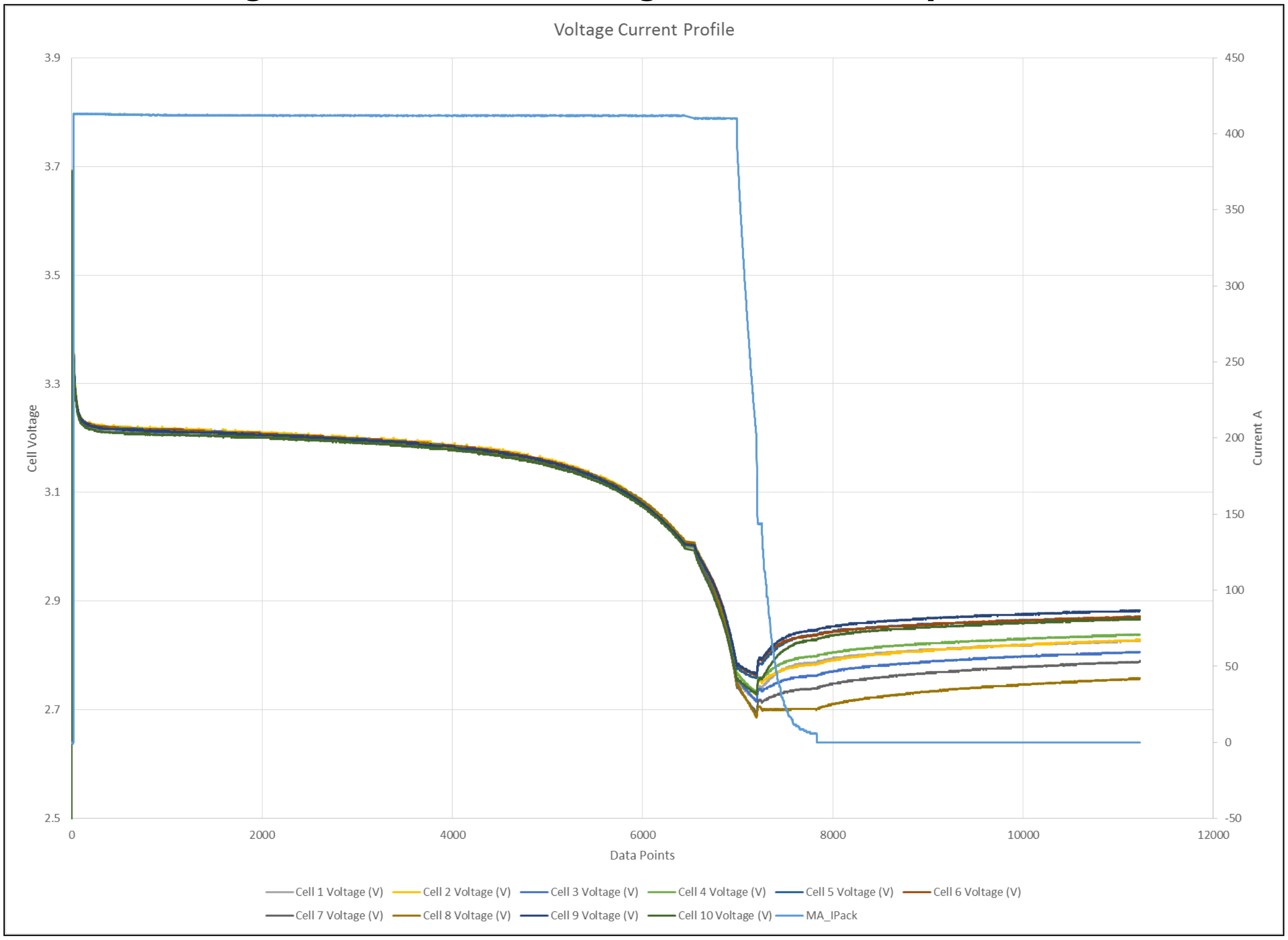


Photo Credit: TransPower

Completion of these battery modules required development of a new battery management system board, custom-designed by TransPower and its battery management system development partner EPC Power to fit within the unique cell arrangement in the module. Figure 26 on the next page, is a photo of the first YHKAM module after installation of the battery management system boards in April 2016.

Figure 26: Battery Module Showing Battery Management System Boards

Photo Credit: TransPower

As discussed in Chapter 2, 12 YHKAM modules of the type pictured above were installed into the electric drayage demonstration-1 truck and tested during the testing of this truck starting in August 2016. A second large order of these battery cells was received in January 2017, which included 2,200 cells that were intended to be used in the two TABEPV drayage trucks. Some unexpected physical changes were noted in the cells received, which included the use of a coating (rather than a polymer film) on the exterior face of the cell as well as a slightly thicker spacer in of the polarity-indicating end cap. The new cell coating did not appear to be as robust as the original film, and numerous cells were received with damage to that coating sufficient enough to expose the conductive case of the cell. Figure 27 is a close-up view of one of these cells received during this second large shipment.

Figure 27: Close-up of YHKAM Battery Cell

Photo Credit: TransPower

Motive Drive Subsystem Manufacturing

Consistent with the goal of using as much pre-existing battery-electric vehicle hardware as possible, TransPower elected to use the same motive drive subsystems in the TABEPV yard tractors and drayage trucks as used in preceding EV's of these types, which consisted of Jing-Jin Electric Company motors, Eaton transmissions, and automated manual transmission shifters. The yard tractor variant consisted of one Jing-Jin Electric Company motor and an Eaton 6-speed transmission and the drayage truck version used two Jing-Jin Electric Company motors and an Eaton ten-speed transmission. Figure 28 is a photo of the motive drive subsystem assembled for the first TABEPV yard tractor in mid-2016.

Figure 28: Motive Drive Subsystem for TABEPV Yard Tractor

Photo Credit: TransPower

Despite the use of existing motive drive subsystem designs, new lots of Jing-Jin Electric Company motors arrived with unexpected characteristics. Jing-Jin Electric Company claimed the new motor had the same characteristics, but early operation on other vehicles proved that was not the case, and that the motor was significantly less efficient and less powerful when paired with inverter control firmware developed for the original motor. Performance was substantially lower and subject to inverter control loop faulting, especially at higher revolutions per minute values used during upshifting of the transmission. The data in Figure 29 illustrates this degradation of performance.

Figure 29: Data Showing Reduced Performance at Higher Revolution Per Minutes

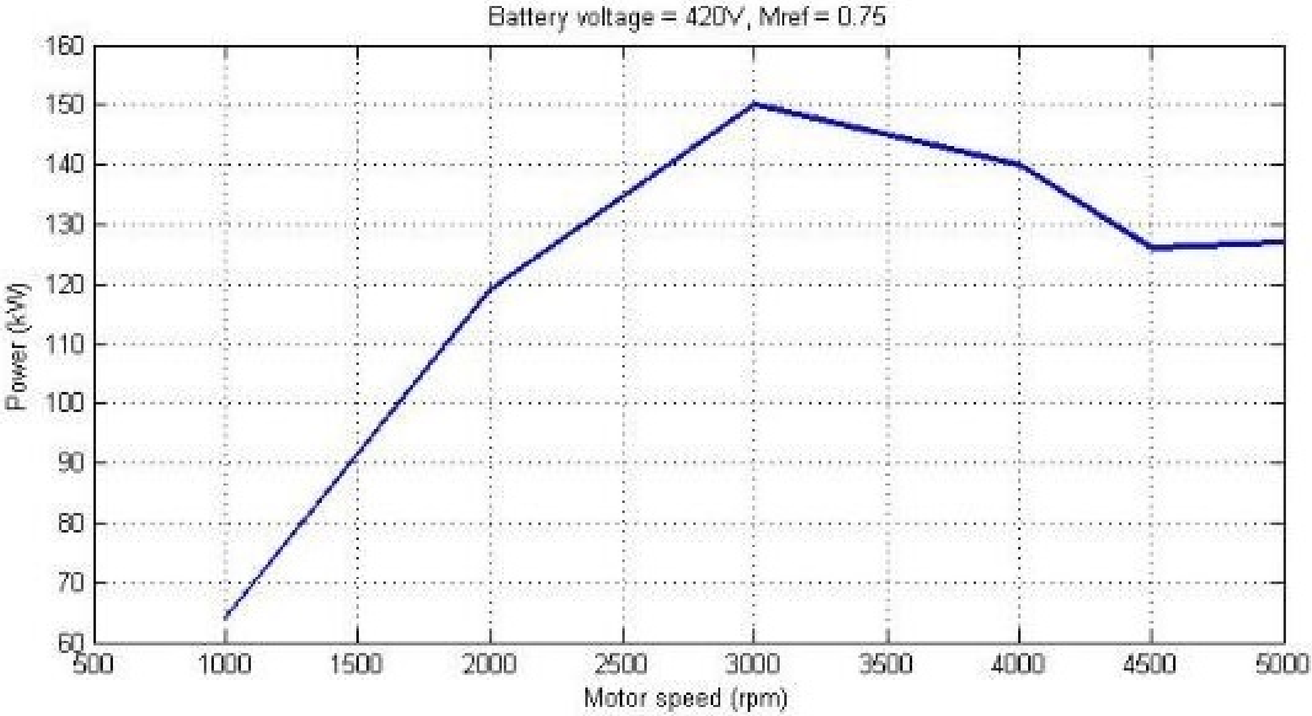


Photo Credit: TransPower

This situation forced TransPower and EPC Power to conduct a lengthy process similar to what is required to match a new motor product with an inverter. This included characterization of performance on an electric dynamometer, followed by refinement of firmware's parametric model of motor electrical characteristics, and then control rule modifications for safety and stability, all the while targeting levels of performance and efficiency on par with the previous motor-inverter matching. After some effort new firmware was developed that allowed the inverter-motor pair to supply equivalent performance to prior products. The new inverter-motor pair was first used in the two-yard tractors and two drayage trucks built under TABEPV.

Fantuzzi Charger Manufacturing

While TransPower's design approach for TABEPV was to maximize use of existing, proven battery-electric vehicle components, upgrading and replacing the existing batteries on the reach stacker required the development of a new, high-power onboard charger compatible with the 600 volt of direct current architecture of the Fantuzzi drive system. The new charger in the Fantuzzi reach stacker was developed by EPC Power, which was able to cost-effectively leverage the designs of previous chargers that were developed by EPC Power for other TransPower applications. EPC Power used castings for this project that were repurposed from one of TransPower's stationary energy storage project. These castings, previously used to house stationary 250-kilowatt chargers, were well suited to the task of housing the 110-kilowatt on-board charger required for the Fantuzzi.

Yard Tractor Conversion

Since the design of the battery-electric drive system for the two TABEPV yard tractors was largely developed on the heavy-duty ERT project previously mentioned, conversion of the two TABEPV yard tractors was delayed until after the design had been validated on the first Heavy-Duty Electric Yard Tractor project yard tractor. The only significant difference was that the

TABEPV yard tractors would use Kalmar's port-specific yard tractors, which had a few features to prevent salt corrosion that the Heavy-Duty Electric Yard Tractor project yard tractors did not require. The two-yard tractor gliders for the TABEPV project were ordered during the summer of 2016 and Kalmar specified a delivery date of January 23, 2017. This was later than had been hoped, but building gliders was a new process for Kalmar, so they proceeded slowly.

During final assembly of the first Heavy-Duty Electric Yard Tractor project yard tractor during the fourth quarter of 2016, TransPower completed the move from its Poway, California, location to its new and larger headquarters in Escondido, California. This move provided a 40 percent increase in work area for TransPower's growing team, but it caused some additional disruption and delay to the first Heavy-Duty Electric Yard Tractor project yard tractor, which was not completed until March 2017. Figure 30 is a photo showing the first Heavy-Duty Electric Yard Tractor project yard tractor nearing completion in TransPower's new facility, and Figure 31 on the next page is a photo of the first Heavy-Duty Electric Yard Tractor project yard tractor during its initial test driving in the parking lot of TransPower's facility.

Figure 30: TABEPV Tractor Nearing Completion at New Escondido Facility

Photo Credit: TransPower

Figure 31: First Kalmar Tractor During Initial Test Drives

Photo Credit: TransPower

As work on the first Heavy-Duty Electric Yard Tractor project yard tractor was nearing a conclusion in February 2017, TransPower received the two Kalmar gliders for the TABEPV yard tractors. Figure 32 is a photo of the first TABEPV yard tractor glider being prepared for the installation of its drive system in April 2017. By this time, most of the major subsystems for both TABEPV yard tractors had already been built and were ready to be installed into the two Kalmar gliders.

Figure 32: First TABEPV Tractor Glider Awaiting Drive System Installation

Photo Credit: TransPower

The need to redesign the battery mounting brackets to avoid stress failures caused a final delay in completing the two TABEPV yard tractors. This was a problem experienced with the first Heavy-Duty Electric Yard Tractor project yard tractor after it was subjected to one or two months of heavy use in May and June 2017. By September 2017, both TABEPV yard tractors were nearing completion, as shown in Figure 33. Commissioning of high and low voltage equipment was nearing completion, with only the energy storage subsystem requiring a new mounting structure, which had been redesigned to resist fatigue.

Figure 33: TABEPV Tractors Nearing Completion, September 2017

Photo Credit: TransPower

The first TABEPV yard tractor was completed, test driven, and ready to be delivered to its intended fleet operator, Dole Fresh Fruits at the Port of San Diego, by November 2017. Figure 34 on the next page, is a photo of the yard tractor taken shortly before delivery. The second TABEPV yard tractor, which can be seen in Figure 35 was completed in February 2018, but the delivery of both tractors to Dole was delayed for several weeks due electromagnetic interference issues which began showing up with the first tractor during test drives at TransPower in early 2018. This interference resulted in the yard tractors not being able to completely charge to full capacity. In March 2018, the first yard tractor was placed into limited operation with Dole and the second tractor was being used as a testbed for a new feature designed to address the interference issues experienced on the first tractor.

By May 2018, the interference issues with the first yard tractor were resolved and the tractor was being used regularly by Dole, with the second tractor being used in limited service. By June 2018, both of the battery electric T2E yard tractors were in continuous operation with Dole. Information on Dole's operating experience with these tractors is provided in Chapter 4.

Figure 34: First TABEPV Yard Tractor, Awaiting Delivery to Dole

Photo Credit: TransPower

Figure 35: Second TABEPV Yard Tractor

Photo Credit: TransPower

Drayage Truck Conversion

Conversion of the first TABEPV drayage truck began in May 2016. Figure 36 is a photo of the truck at TransPower's old manufacturing facility in Poway, California while undergoing initial preparations for installation of its electric drive system.

Figure 36: First ProStar Truck Readied for Conversion to Ele6ctric Drive

Photo Credit: TransPower

By June 2016, TransPower completed manufacturing and procurement of several of the major components required for completion of the two TABEPV drayage trucks. One of these components was the new RS-12 inverter developed by EPC Power. It provides the power necessary to control one Jing-Jin Electric Company motor but does not contain the hardware used in the EPC Power inverter-charger unit for battery charging. The reduced the size and cost of the RS-12 allowed TransPower to utilize only one inverter-charger unit and one RS-12, rather than two inverter-charger units. The inverter-charger unit/RS-12 design was carried over to the TABEPV project, and a photo of the RS-12s used in the two TABEPV drayage trucks is provided in Figure 37.

Figure 37: RS-12s for TABEPV Drayage Trucks

Photo Credit: TransPower

Shortly after initiating conversion of the first TABEPV drayage truck, the supplier of the lithium iron phosphate batteries used in its drayage trucks, Voltronix, informed TransPower of a supply shortage. In response to concerns that the shortage of Voltronix batteries would prevent the drayage trucks from being completed, TransPower purchased an additional 2,200 YHKAM batteries for the two TABEPV drayage trucks in June 2016, despite the fact that testing of these batteries on the electric drayage demonstration-1 test truck had not yet begun. As previously mentioned, testing these batteries in the electric drayage demonstration-1 revealed major defects in this battery, causing TransPower to revert to use of the Voltronix batteries, which by then were once again available.

By September 2016, two of the three major ElecTruck subsystems the motive drive subsystem and power control and accessory subsystem– were installed into the first drayage truck and were awaiting installation in the second drayage truck. TransPower hired two part-time fabricators to accelerate the remaining welding and fabrication tasks for both drayage trucks' energy storage subsystem structures. Unfortunately, around the same time, Yinhe advised TransPower of a quality problem that it had detected in its latest production run of cells, which delayed the shipment of cells for the first TABEPV drayage truck and reach stacker to the end of 2016.

TransPower's move to its new facility resulted in additional delays but offered a chance to reorganize around new production processes to produce multiple vehicle products simultaneously while effectively managing the preparation and control of inventory in different stages of assembly. The two TABEPV drayage trucks would be among the first vehicles completed at the new facility. Integration of the two trucks, however, continued on through much of 2017, largely due to the unplanned need to switch back to using the Voltronix batteries. The first TABEPV drayage truck was finally completed in October 2017. Figure 38 shows this truck charging outside TransPower's Escondido facility shortly after it was completed.

Figure 38: First TABEPV ProStar Drayage Truck

Photo Credit: TransPower

Conversion of the second drayage truck proceeded very rapidly once all of the subsystems for both trucks were built, with the second truck completed by January 2018. Around that time frame, the first drayage truck was delivered to Terminalift to be operated at the Port of San Diego, and the second drayage truck was delivered to BAE Systems at the Port of San Diego in

March 2018. By April 2018, both drayage trucks were in limited service, following BAE Systems' installation of their charging equipment. Chapter 4 provides information on the operation of these trucks at these terminals.

Fantuzzi Battery Upgrade

In early 2017, TransPower removed the existing energy storage subsystem racking from the Fantuzzi reach stacker and transported to TransPower. The racking was used as a base feature in the redesign and mock-up for the new version of the racking. This was done to ensure that the new racks would be capable of securing the KAM-based battery modules that were to be installed on the reach stacker. The existing steel structure was used so it would align with the existing attachment points, would fit within the original dimensions, and match up with the other constraints that were present in the vehicle. Building of a mock-up allowed the team to make progress on the new energy storage subsystem structures without the need for a digital model of the vehicle, its energy storage subsystem racking, or bringing the huge Fantuzzi vehicle 30 miles to TransPower. Figure 39 shows the mockup of a YHKAM battery module mounted on top of the existing energy storage subsystem racking hardware.

Figure 39: YHKAM Battery Module Mock-up

Photo Credit: TransPower

The old steel racking was too small to accommodate the new modules, but the attachment point and volume of the old structures provided constrains for the new design. It appeared that three of the new modules would fit within the longitudinal boundaries of the Fantuzzi side-by-side, thus requiring only four assemblies to complete the new energy storage subsystem structure. Additional reach-stacker components, such as a steel shroud, could be used with the old racking to assure a fit in mock-up, prior to transport to the Port of San Diego and integration into the vehicle on site.

By June 2017, the final plan for upgrading of the battery subsystem on the Fantuzzi reach stacker was completed. Figure 40 shows the reach stacker with an overlaid sketch illustration of the notional placements for the major new subsystem component. It shows the location of one of the enclosures that will contain nine lithium iron phosphate battery modules in the vehicle recess that was initially devoted to the previously used lead-acid batteries. It also shows the rear deck area planned for the mounting of two smaller lithium iron phosphate module enclosures that will contain three modules each. This much-enhanced lithium iron phosphate battery capacity was expected to deliver up to half a shift of operation. With the planned 120 kilowatt charging capability, an extended midday charging was expected to permit an additional partial shift of operation relatively quickly.

Figure 40: Reach Stacker with Sketches of Component Placement

Photo Credit: TransPower

Test fitting of new components on the reach stacker was initiated in July 2017. Figure 41 is a photo showing the test fitting of a battery module onto the vehicle. By August 2017, the reach stacker enclosures and support structure designs were finalized. First, the articles were fabricated. Then other items were test fitted to the reach stacker on-site at the Port of San Diego. Battery management cabling and connectors were specified and purchased. Additionally, the first portion of infrastructure was completed for the vehicle’s charger. This consisted of power vault modifications and the siting and connection of a transformer to prepare for the installation of the charger that was supplied by TransPower.

Figure 41: Test Fitting Battery Hardware on the Reach Stacker

Photo Credit: TransPower

Test fitting of a completed energy storage subsystem module on the Fantuzzi, shown in Figure 42 on the next page, was achieved for the first time in August 2017.

Figure 42: Test Fitting of the Completed Battery Module on the Reach Stacker

Photo Credit: TransPower

In September 2017, reach stacker enclosures and support structure designs were verified and fabricated, and test fitting of the battery modules, battery management system units, and peripheral parts completed verification. All energy storage subsystem enclosures were complete and were either finished or at the powder-coating service. By October 2017, the reach stacker enclosures and support structures were all complete and the battery modules, battery management system units, and peripheral parts were integrated. All energy storage subsystem elements were completed and tested, and the first two enclosures were shipped to the integration site at the Port of San Diego. By February 2018, all major system components for the Fantuzzi except for a single newly designed safety device were installed on the vehicle. Harnessing and other support elements were largely in place and commissioning was initiated. Figure 43 shows the completed reach stacker vehicle in February 2018.

Figure 43: Completed Reach Stacker

Photo Credit: TransPower

Unfortunately, after the conversion of the Fantuzzi was complete, progress in commissioning the vehicle was greatly slowed due to the exit of a former employee that had led the original reach-stacker system. This employee was working as a local consultant but advised TransPower that he would not be able to support the Fantuzzi project for several months. This forced TransPower's own software engineers to learn the Fantuzzi system and gradually take over the responsibilities the former employee had held. Among other challenges, the Fantuzzi charging process required the generation of special software. This would enable the existing inverter/charger (that was developed for use in lower-voltage vehicles) to be used at a higher alternating current input voltage and higher direct current output voltage of the upgraded battery pack of the Fantuzzi. Figure 44 is a photo of one of TransPower's newer software engineers taking over the commissioning duties.

Figure 44: TransPower Engineer Commissioning the Reach Stacker

Photo Credit: TransPower

CHAPTER 4: Operational Testing and Evaluation

Vehicle Deployment Sites

All TABEPV project vehicles were deployed at the Port of San Diego. One of the two drayage trucks was deployed with BAE Systems, the second drayage truck was deployed with Terminalift, and the two TABEPV project yard tractors were deployed with Dole Fresh Fruit. The reach stacker remained with its original operator, Terminalift.

BAE Systems

BAE Systems is an advanced defense technology company, operating across 40 countries with over 85,000 employees. Its technologies are used in air, space, maritime, land, and cyber space. BAE Systems performs maritime, ship work, and logistics using drayage trucks at their Port of San Diego facilities. Figure 45 shows the deployment route taken by one of the TABEPV project battery-electric drayage trucks operated by BAE Systems and, Figure 46 is a snapshot of the telemetry tracking on the truck.

Figure 45: BAE Systems Truck Route

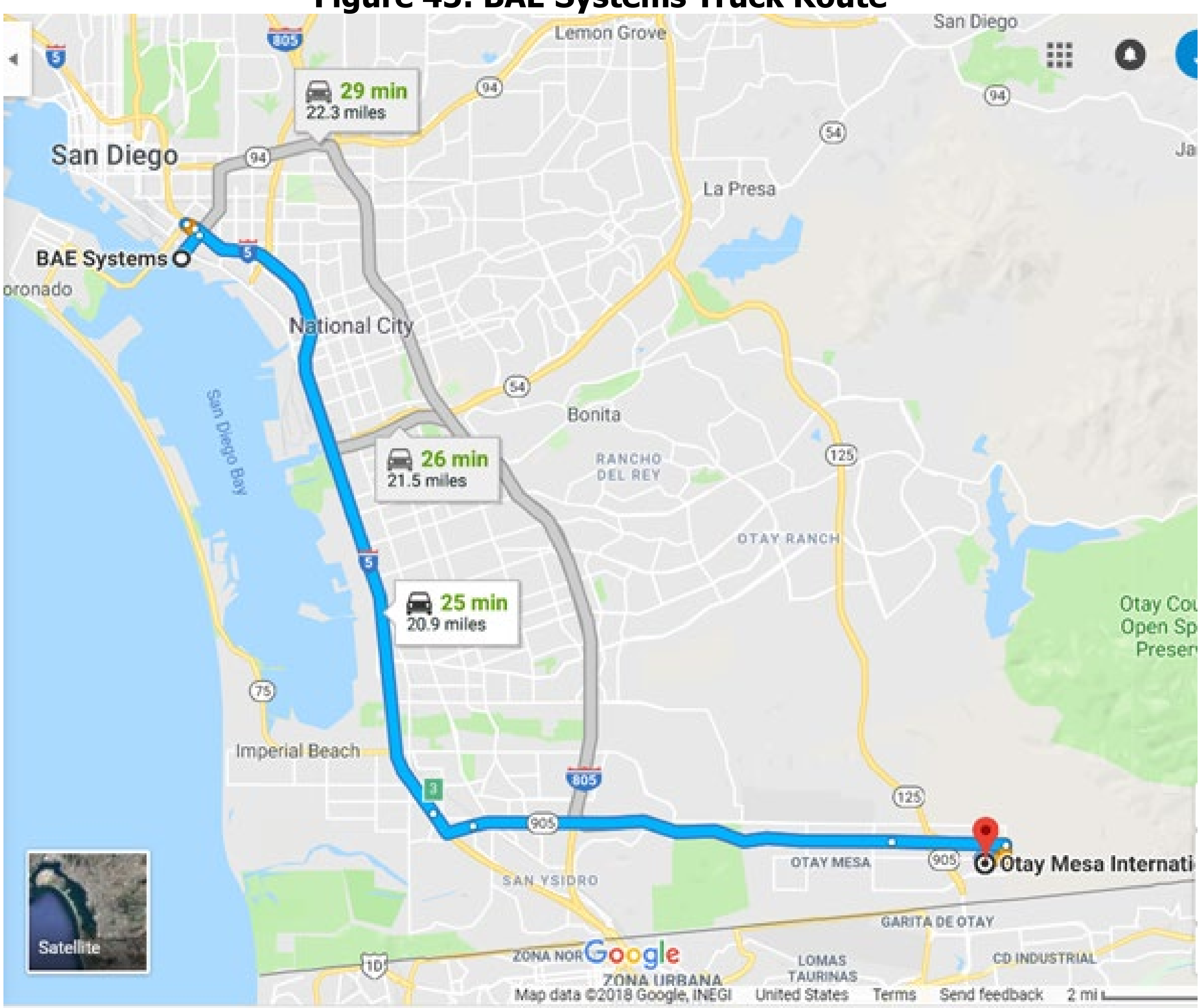


Photo Credit: Google Maps

Figure 46: Telemetry Data of the BAE Systems Drayage Truck

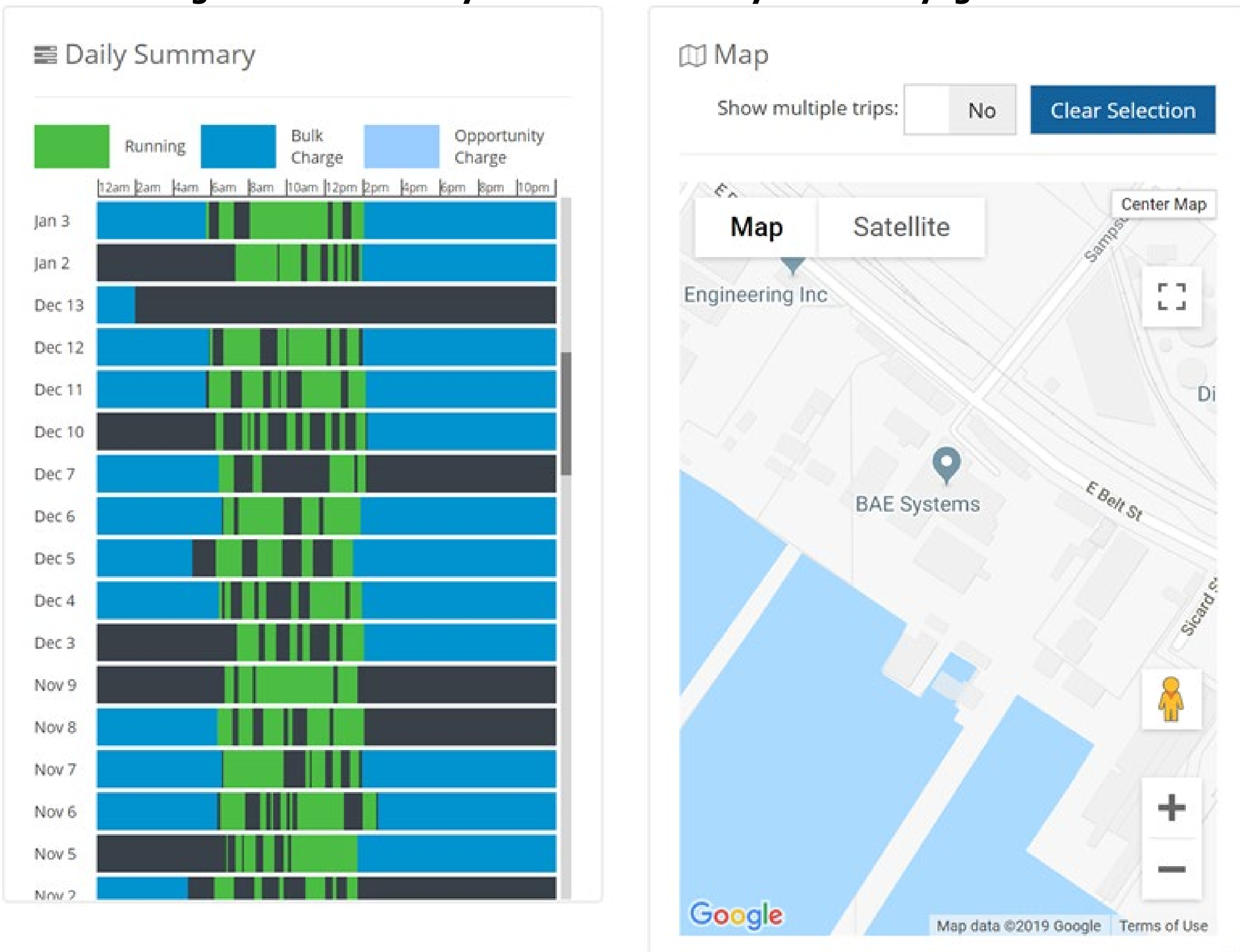


Photo Credit: TransPower

BAE Systems placed this truck into service and operated it between their National City and Otay Mesa facilities. The company reported 542 hours of driver operation of the drayage truck from September 2018 to January 2019, averaging about 108 hours per month.

The duty cycles for BAE Systems produced the following statistics:

- Average distance per day: 7.0 miles.
- Maximum distance per day: 41.0 miles.
- Average energy consumption: 2.0 kWh per mile.
- Average moves per day: 2.
- Average speed: 6.0 miles per hour.
- Percent time driving versus idling: 50 percent.
- Total battery electric vehicle miles: 1,572.0.

Dole Fresh Fruit

Dole is one of the world's largest producer of fresh fruit and vegetable products, with produce grown in over 23 countries and employing over 70,000 people through 300 different product lines. Dole ships to retailers, wholesalers, schools, restaurants, hotels, and food providers across North America, Europe, and Asia. Headquartered in Westlake Village, California, Dole Food Inc. has operated as a Port of San Diego tenant since 2002. Dole Fresh Fruit brings approximately 30,000 containers of produce, including 27 million boxes of bananas through the port annually. In 2012, Dole renewed their lease for an addition 24 years with the Port of San Diego, ensuring long-term local operations.

Dole received two battery-electric yard tractors, which totaled 1,130 combined hours of driver time between October 2018 and February 2019. Each truck was operated for about 141 hours per month. Figures 47 and 48 on the next page are snapshots of daily usage and routes for both tractors. The duty cycles for these yard tractors were not intense and produced the following statistics:

Tractor 1:

- Average distance per day: 11.0 miles.
- Maximum distance per day: 57.0 miles.
- Average energy consumption: 0.70 kWh /mile.
- Average moves per day: 4.
- Average speed: 4.0 miles per hour.
- Percent time driving versus idling: 52 percent.
- Total battery electric vehicle miles: 5,073.0.

Tractor 2:

- Average distance per day: 5.0 miles.
- Maximum distance per day: 18.0 miles.
- Average energy consumption: 2.5 kWh /mile.
- Average moves per day: 2.
- Average speed: 4.0 miles per hour.
- Percent time driving versus idling: 51 percent.
- Total battery electric vehicle miles: 1,347.0.

Dole's demonstration of the two battery-electric yard tractors was a success for Dole, TransPower, the Port of San Diego, and surrounding communities. As a result of this positive demonstration, Dole led a proposal to the CEC for 10 electric Kalmar-TransPower yard tractors in 2016. While Dole's proposal was ranked among the six finalists, their proposal was not ultimately funded. TransPower anticipates a continuing relationship and potential deployment of further EV's with Dole at the Port of San Diego.

Figure 47: Telemetry Data of Dole's Battery-Electric Yard Tractor 1

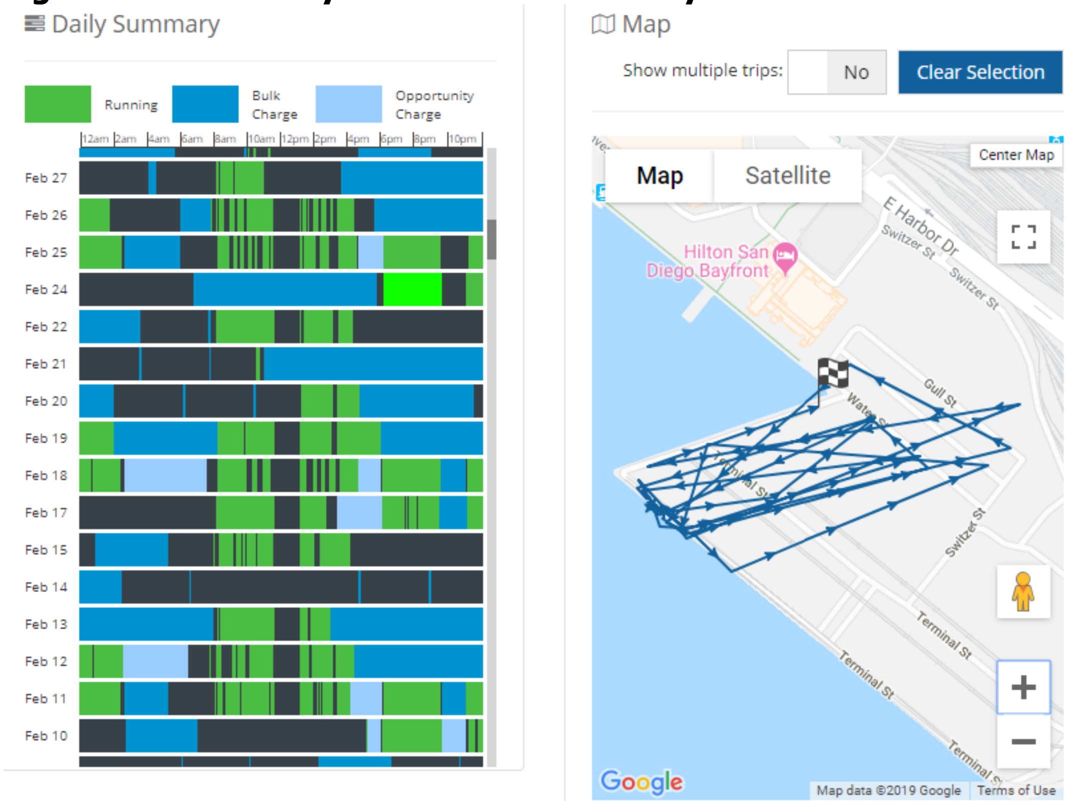


Photo Credit: TransPower

Figure 48: Telemetry Data of Dole's Battery-Electric Yard Tractor 2

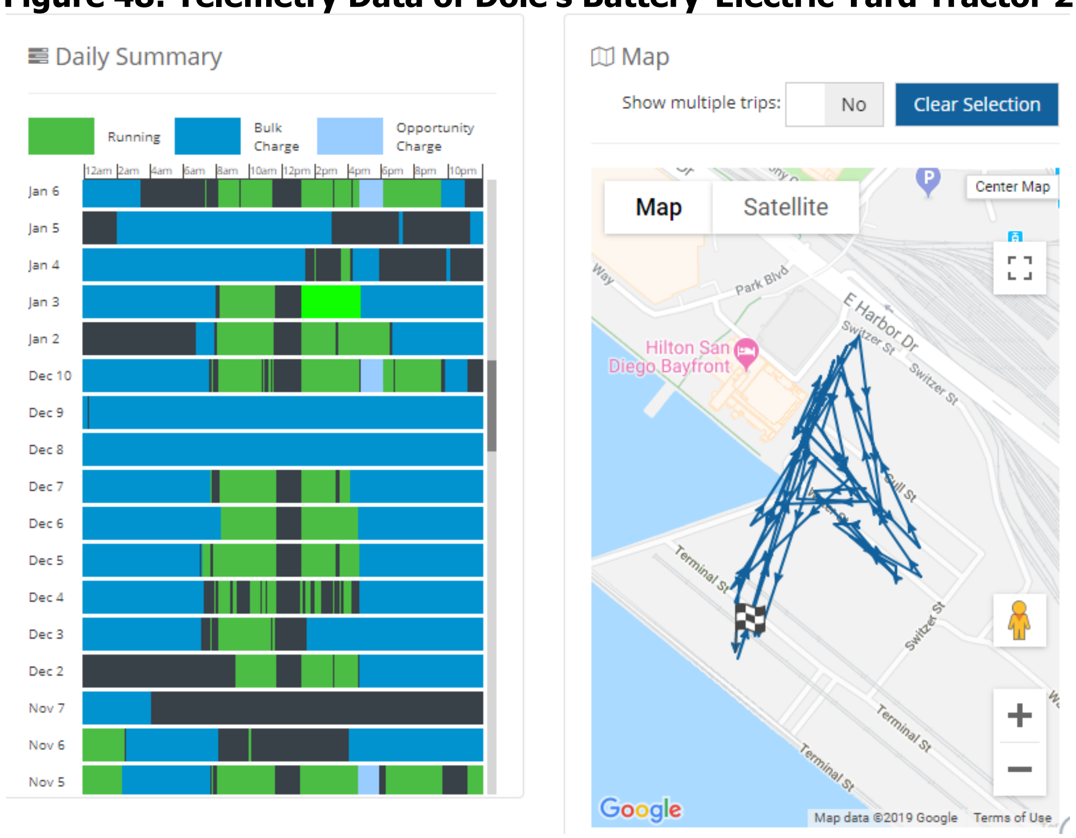


Photo Credit: TransPower

Terminalift

Terminalift is a freight shipping and trucking company based in Santee, California. Terminalift operates trucks between its marine terminal at the Port of San Diego to other locations, commonly traveling through disadvantaged communities including San Diego’s Barrio Logan. The Fantuzzi reach stacker and a battery-electric Class 8 drayage truck were delivered to Terminalift as pictured in Figure 49. For the drayage truck, Terminalift reported 136 driver-operated hours over three months, averaging about 45 hours driven per month. Figure 50 on the next page, details the daily miles for the Terminalift drayage truck.

Figure 49: Drayage Truck and Reach Stacker at Terminalift

Photo Credit: TransPower

Figure 50: Miles Driven by Terminalift Drayage Truck

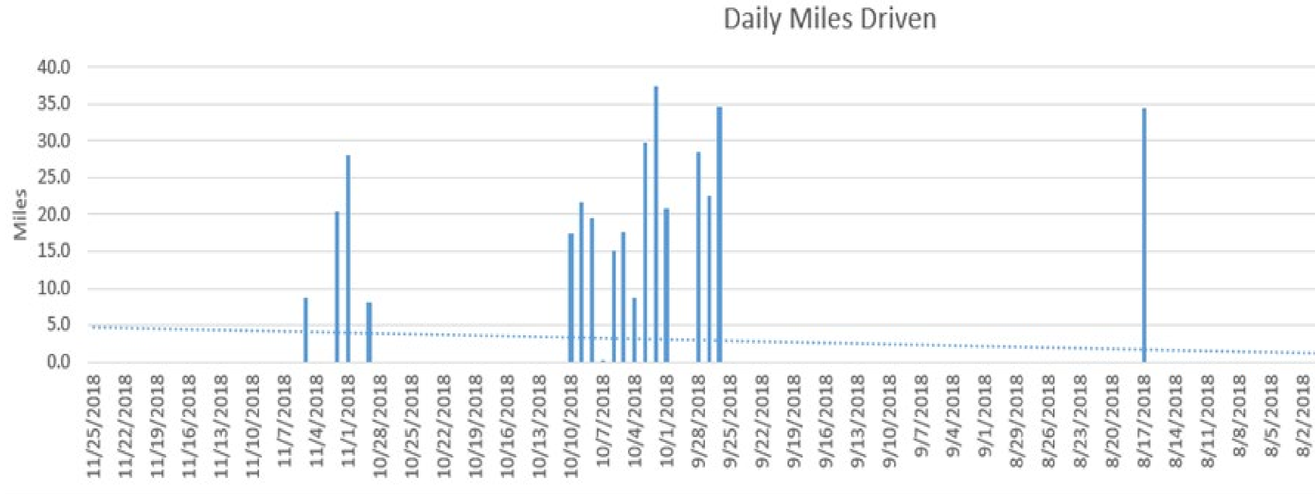


Photo Credit: TransPower

The duty cycles from Terminalift's drayage truck produce the following statistics:

- Average distance per day: 21.0 miles.
- Maximum distance per day: 37.5 miles.
- Average energy consumption: 1.5 kWh /mile.
- Average moves per day: 1.
- Average speed: 11.0 miles per hour.
- Percent time driving versus idling: 17 percent.
- Total battery-electric vehicle miles: 254.0.

Comparable statistics are not available for the reach stacker because efforts to achieve sustained operation of the reach stacker with the YHKAM batteries were still in process when the grant period ended.

Operations Summary

Despite some challenges, the TABEPV project field demonstration produced significant accomplishments. As of the end of the project, the two Dole yard tractors continued to accrue mileage and hours at an excellent rate can be seen in Table 2 on the next page. The success of this deployment supported TransPower's continuing efforts to drive battery-electric yard tractor adoption and commercialization. Partly as a result of TABEPV successes, Kalmar adopted the TransPower drive system as its battery-electric vehicle powertrain and qualified the system for California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project. Late in the TABEPV project, Kalmar purchased two drive system kits from TransPower for its Production part approval process and then placed an order for 10 more kits. Activities with Kalmar are described in more detail in the following chapter. In addition, the two ProStar drayage trucks built during TABEPV were immediately followed by the commercial sale of two similar trucks to Pasha Stevedoring at the Port of Los Angeles, which led to TransPower being selected to provide battery-electric drive systems for Peterbilt trucks. By the end of the TABEPV grant, approximately 40 Peterbilt trucks were contracted for conversion to battery-electric drive by TransPower.

Table 2: Yard Tractor and Drayage Truck Usage Summary

	Dole-1 Yard Tractor	Dole-2 Yard Tractor	BAE Systems Drayage Truck	Terminalift Drayage Truck	Totals
Total Miles	5,750	4,300	1,500	250	11,800 miles
Total Hours of Operation	670	570	820	140	2,200 hours
Total kWh	40,000	16,550	5,700	950	63,200 kWh
Diesel Gallons Equivalent	2,668	2,288	286	46	5,288 diesel gallon equivalents
Total Nitrous Oxide Reduction	75	65	10	1	151 kg
Total Particulate Matter Reduction	3	2	1	1	7 kg
Total Hydrocarbons Reduction	4	3	1	1	9 kg
Total Carbon Dioxide Reduction	27,250	23,350	2,900	450	53,950 kg

Photo Credit: TransPower

CHAPTER 5: Commercialization and Outreach

TransPower's leadership in the battery-electric heavy-duty Class 8 truck and yard tractor technologies has not only led to advancement of clean transportation but also towards a commercialization path for both manufacturing stakeholders and fleet early adopters. These collaborations have led to commercial agreements with major original equipment manufacturers including Kalmar, Dina, and Peterbilt Motors. Kalmar has branded the T2E battery-electric yard tractor model and currently has dealerships nationwide offering this zero-emissions product; Dina s another major manufacturer of yard tractors and has partnered with TransPower to deliver 38 battery-electric yard tractors to SSA Marine at the Port of Long Beach with potential future commercial potential; and Peterbilt Motors is one of America's most respected and high volume original equipment manufacturer of Class 8 trucks.

The relationships that TransPower has built in the traditional diesel supply chain underscore the successes that have been achieved in the TABEPV project. TransPower's most mature collaborations have been with Kalmar, thanks in large part to the CEC-funded TABEPV and Heavy-Duty Electric Yard Tractor projects. As TransPower built the first TABEPV project battery-electric yard tractor and garnered operating information, this data was disseminated to Kalmar and Kalmar dealers. In early 2016, TransPower shipped one of its earlier second-generation electric tractors to Ottawa, Kansas for testing by Kalmar at a local Walmart distributor. It was an excellent learning opportunity for TransPower to have a tractor testing at this facility. The TransPower tractor was driven approximately 100 miles over three test days, averaging over 30 miles a day. The battery-electric yard tractor did about 24 pulls per hour which is on par with a diesel T2.

Drivers preferred the TransPower tractor's torque, ease of operation, and heater and air conditioning capabilities. There were, however, some concerns expressed by Walmart drivers regarding the difficulty of climbing into the tractor cab without the benefit of steps, which were not available in earlier TransPower tractor designs due to the large battery packs. As discussed in Chapter 2, though, this issue was resolved with the new battery pack designs used in the TABEPV third-generation yard tractors.

To help speed up TransPower's drive system manufacturing throughput and move closer to Kalmar's Ottawa-based integration, Kalmar manufacturing experts made a series of production planning visits to TransPower starting in August 2017. A month later, Kalmar manufacturing personnel visited TransPower to help integrate components into the second TABEPV tractor, which served as a training exercise in preparation for assembly of future tractors at Kalmar's Ottawa manufacturing facilities.

In September 2017, following the replacement of energy storage subsystem mounts on the first TABEPV tractor, the tractor was shipped to Kalmar's Ottawa facility in Kansas, where Kalmar employees were trained on the new equipment and the tractor was tested on the facility's new yard tractor test track.

In conjunction with the transportation of the tractor to Kansas, Harry Meyer, TransPower's vice president of manufacturing, visited Kalmar for a week of meetings to discuss the electric yard tractor bill of materials and manufacturing processes. These meetings were part of Kalmar and TransPower preparations for installing the TransPower drive systems into Kalmar tractors at the Ottawa facility, a critical transition on the path to full-scale commercialization. Figure 51 is a photo of the Grimmway tractor on Kalmar's Ottawa test track.

Figure 51: Tractor on Kalmar Ottawa Test Track

Photo Credit: TransPower

To further advance preparations for large-scale manufacturing, TransPower held meetings with Kalmar's sales, marketing, and service staff to discuss the market and commercialization plans. After the T2E tractor was tested in Kansas, it was transported to Atlanta for the North American Commercial Vehicle show, where it was the centerpiece of Kalmar's exhibit, and can be seen in Figure 52. While participating in the show, Kalmar and TransPower representatives received a customer inquiry for purchasing battery electric T2Es.

Figure 52: Kalmar Tractor at the North American Commercial Vehicle show

Photo Credit: TransPower

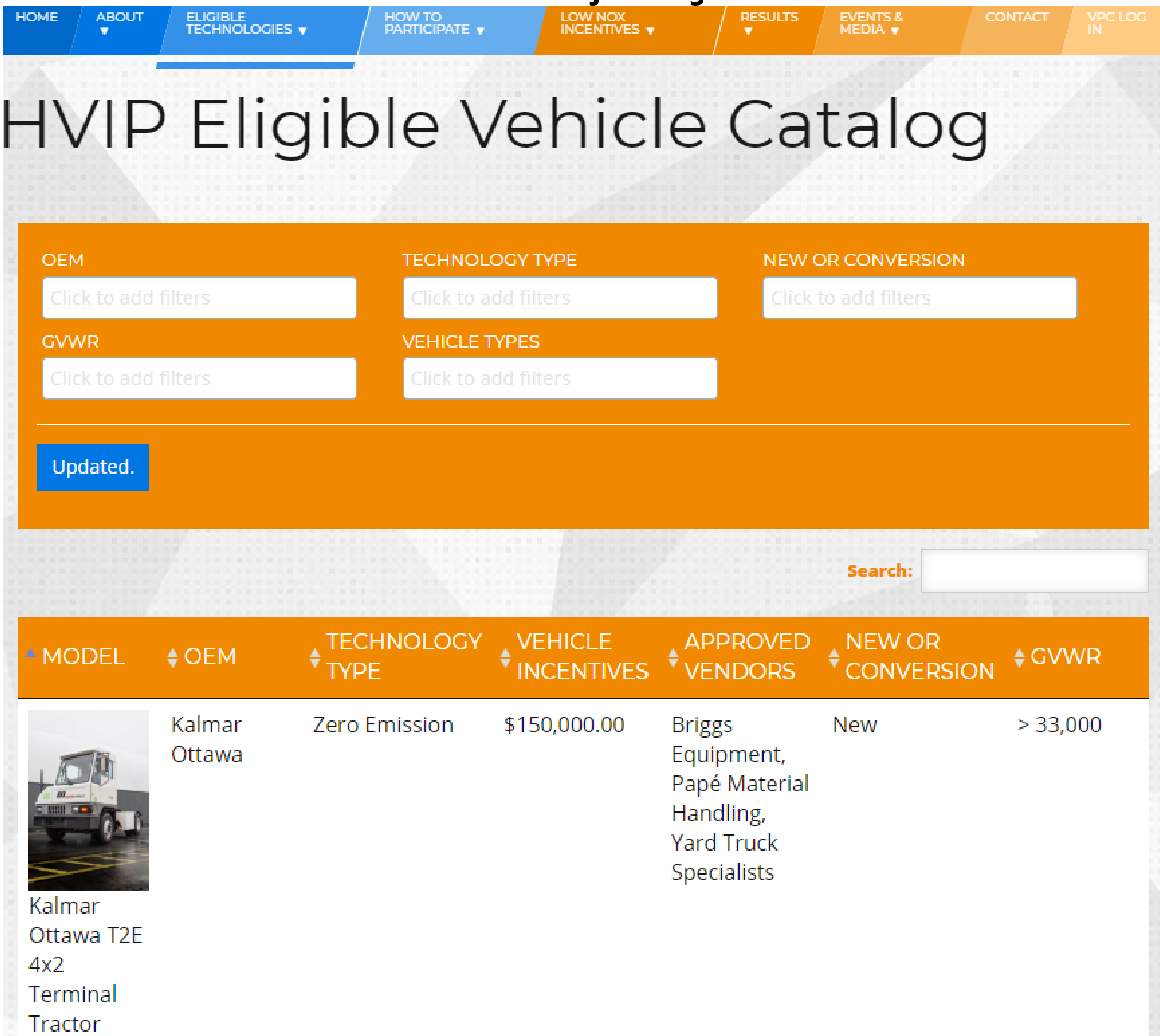
In March 2018, TransPower completed delivery of two complete drive system kits to Kalmar. These kits use Nissan battery modules and are nearly identical to the drive system configuration developed for the IKEA tractor. In April 2018, these kits were installed into two additional tractors being funded by Kalmar and TransPower as cost sharing under the Commercialization and Outreach task. In late-April and early-May of 2018, Kalmar showcased these tractors at its annual dealer meeting. At the same time, TransPower assisted Kalmar dealers in identifying potential clean vehicle funds across different states by holding webinars for grant funding and later assisted dealerships with different grant applications. While that was happening, Kalmar developed a multi-page marketing brochure of the battery electric T2E yard tractor, which touts the tractor's environmental, health, and reliability and productivity benefits, and can be seen in Figure 53. These activities significantly advanced the commercialization objectives of this project.

Figure 53: Marketing Materials from Kalmar T2E Product Brochure

Photo Credit: Kalmar Global

A major milestone that was achieved after the successful shows and demonstrations of these tractors by the California Air Resources Board making the Kalmar T2E eligible for California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project. The vehicle approval for Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project required joint engineering and marketing efforts from both TransPower and Kalmar. TransPower also supported three Kalmar dealerships to secure vendor status approval to process the vouchers for Kalmar's fleet customers, which can be seen in Figure 54. Additionally, the T2E tractor was listed as an eligible vehicle for the state of New York's Truck Voucher Incentive Program.

Figure 54: Kalmar T2E Listed as Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project-Eligible



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Kalmar Ottawa T2E 4x2 Terminal Tractor	Kalmar Ottawa	Zero Emission	$150,000.00	Briggs Equipment, Papé Material Handling, Yard Truck Specialists	New	> 33,000

Photo Credit: California Air Resources Board

The demonstration yard tractors have positively engaged and influenced fleet operators. The uptime and consistent use of the yard tractors helped forge relationships with end users. Fleet investment in battery-electric vehicle infrastructure and familiarity with heavy-duty electric performance has advanced the early adoption of these technologies.

What was learned from Kalmar and the TABEPV project can be applied broadly to understand industry needs, build reliable products, and ensure long-term success. TransPower has taken a similar approach to commercialization with Dina, a yard tractor and heavy-duty equipment manufacturers. Currently, TransPower is in the beginning stages of co-engineering the Dina chassis with the ElecTruck system and other fleet-based technological advancements. While this project receives Air Resources Board funding, the potential to create a viable commercial product similar to the Kalmar approach is great.

The TABEPV drayage truck demonstrations also garnered the attention and support of Peterbilt Motors. TransPower collaborated with Peterbilt on a battery-electric Class 8 truck, which is an electric version of Peterbilt's Model 579. Since then, Peterbilt created a co-branded line of this truck named as the Model 579 Electric Vehicle. In addition to this milestone, TransPower has integrated electric drive systems into Peterbilt refuse trucks (Model 520 Electric Vehicle) and medium-duty trucks (Model 220 Electric Vehicle). Figure 55 shows the unveiling of the Model 220 Electric Vehicle. Based on TransPower's extensive experience and accumulation of real-world demonstration miles, Peterbilt has continued to collaborate extensively with TransPower. TransPower foresees a similar path with Peterbilt by commercializing these initial products, achieving sales at nationwide scale, and creating a zero-emissions turning point in heavy-duty applications. TransPower has also been approached by several major original equipment manufacturers for potential future commercial relationships, which signifies the success of the CEC multi-grant investments into TransPower.

Figure 55: Media Article Featuring Peterbilt Model 220 Electric Vehicle

CCJ COMMERCIAL CARRIER JOURNAL | NEWS | EQUIPMENT | BUSINESS | TECH | PRODUCTS | BLOGS

Peterbilt adds the 220EV medium-duty electric model to its EV model range

Jeff Crissey | @JeffCrisseyCCJ | *January 8, 2019*

At the Consumer Electronics Show in Las Vegas, Peterbilt Motors Company continued the rollout of its electric vehicle lineup with the Peterbilt 220EV, a zero-emission, battery-powered version of its Model 220 medium-duty cabover aimed at city delivery and urban applications.

The medium-duty 220EV is Peterbilt's third electric vehicle model and is aimed at inner-city and local pickup & delivery applications.

Photo Credit: Commercial Carrier Journal

Future Plans

TransPower has worked with Kalmar dealership networks such as Cal-Lift and Papé Material Handling to get strategic service providers in order to drive commercialization. TransPower also works directly with Dina and Peterbilt engineers to integrate the advanced electric drive systems into original equipment manufacturer chasses. Meanwhile, Kalmar and TransPower continue to work on manufacturing processes at Kalmar's Ottawa facility.

The particular success of the T2E has garnered national attention across other freight facilities and major fleet operators. As of the end of this project, Kalmar and TransPower have been in discussions with at least 20 different fleet operators that have expressed interest in electrification. The list of fleet operators can be seen in Table below.

Table 3: Potential Fleet Purchases of the Battery-Electric Kalmar T2E

Fleet operator	Location	Number of Units
Albertsons	Nationwide	To be determined
Beltway	Maryland	To be determined
Blue Diamond	Sacramento, California	1
Dole	Port of San Diego, California	2
Estes	Nationwide	To be determined
Everport Terminals	Port of Los Angeles, California	2
FedEx	Nationwide	To be determined
Grimmway Farms	Bakersfield, California	1
Harris Ranch	Central Valley, California	1
HEB	Texas	To be determined
IKEA	El Tejon, California	2
NFI	Port of Los Angeles, California	To be determined
Penske	Nationwide	To be determined
Raley's	Sacramento, California	1
Starbucks	Nevada	2
Total Terminals International	Port of Long Beach, California	To be determined

Photo Credit: TransPower

CHAPTER 6: Conclusion

The TABEPV project was funded by the CEC to demonstrate the feasibility of utilizing advanced batteries in electric drive systems for various types of heavy-duty port vehicles, including Class 8 drayage trucks, yard tractors, and cargo-handling equipment such as reach stackers. During the course of the project, two drayage trucks, two-yard tractors, and a reach stacker were converted to battery-electric operation and deployed with terminal operators at the Port of San Diego. As of the end of the project, the two yard tractors and one drayage truck remained in regular use at this port, and the second drayage truck was fully functional but returned to TransPower because the terminal operator to which it was assigned exited the trucking business. The reach stacker never entered operation due to the failure of its selected battery technology to work reliably.

TransPower accepted the risk of trying the new battery product because it offered a 60 percent higher energy density than competing batteries using the same lithium iron phosphate chemistry and because prior tests of the battery product in TransPower's laboratories were successful. Unfortunately, use of the new battery product in vehicles during the TABEPV project revealed severe defects, such as leakage of electrolyte and the tendency to rupture under physical stress. These deficiencies were discovered early enough in the TABEPV project to switch to more reliable lithium iron phosphate battery technologies for the two drayage trucks and yard tractors, but not in time to change the battery selection for the reach stacker. Despite the reach stacker setback, the TABEPV project resulted in important successes. The two yard tractors accumulated more than 10,000 miles of battery electric operation with Dole Fresh Fruits, displacing nearly 5,000 gallons of diesel fuel and reducing carbon emissions by nearly 50,600 kg over the course of the TABEPV project, even after accounting for carbon emitted during generation of the electricity used to charge the tractors' batteries. The two TABEPV tractors and both TABEPV trucks operated with a high degree of reliability and gained the confidence of the participating fleet operators. Of even greater significance, the success of the TABEPV project motivated Kalmar to commit to electrification of its yard tractors on a commercial scale. Within a few weeks of the conclusion of the TABEPV project, Kalmar purchased 27 TransPower electric drive systems on a commercial basis, for installation into tractors to be manufactured by Kalmar during the second half of 2019. Kalmar also requested that TransPower increase its yard tractor battery electric drive system production rate to 150 kits per year by the beginning of 2020, anticipating huge commercial demand for this product. In addition, the yard tractors and drayage trucks using the designs developed during TABEPV were ordered by terminal operators at other California ports, including Pasha Stevedoring at the Port of Los Angeles and at the Long Beach Container Terminal at the Port of Long Beach.

Due to the achievements of the TABEPV project, TransPower executed a five-year supply agreement with Kalmar on May 1, 2017 in conjunction with the rollout of the first battery electric T2E tractor at the Advanced Clean Transportation Expo.

GLOSSARY

BATTERY ELECTRIC VEHICLE (BEV)—Also known as an "All-electric" vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are:

- Forecasting future statewide energy needs
- Licensing power plants sufficient to meet those needs
- Promoting energy conservation and efficiency measures
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
- Planning for and directing state response to energy emergencies

ELECTRIC VEHICLES (EV)—A broad category that includes all vehicles that are fully powered by electricity or an electric motor.

KILOGRAM (kg)—The base unit of mass in the International System of Units that is equal to the mass of a prototype agreed upon by international convention and that is nearly equal to the mass of 1,000 cubic centimeters of water at the temperature of its maximum density.

KILOWATT (kW)—One thousand watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon, a typical home—with central air conditioning and other equipment in use—might have a demand of 4 kW each hour.

KILOWATT-HOUR (kWh)—The most commonly used unit of measure telling the amount of electricity consumed over time, means one kilowatt of electricity supplied for one hour. In 1989, a typical California household consumed 534 kWh in an average month.

TRANSPOWER ADVANCED BATTERY-ELECTRIC PORT VEHICLES (TABEPV)—TransPower and Meritor have announced the completion of two multi-year projects for the development, testing and evaluation of advanced, zero-emission electric yard tractors and Class 8 trucks. Meritor is an investor in TransPower. The two recently completed projects were initiated simultaneously in mid-2015 following the competitive award of $6 million to TransPower for the purposes of improving and demonstrating its electric vehicle technologies that use permanent magnet motors, large battery packs and advanced controls to power heavy vehicles.[16]

[16] TransPower's Advanced Battery-Electric Port Vehicles Project https://www.truckinginfo.com/329175/meritor-and-transpower-complete-electric-vehicle-demonstration-projects