ELECTRIC YARD TRACTOR DEMONSTRATION PROJECT

FINAL REPORT AND FINAL OPERATIONS REPORT
for
City of Los Angeles Harbor Department Agreement Number 13-3146
Electric Yard Tractor Demonstration ("EYTD") Project
Report Date: May 29, 2015
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This project (the "Project") leveraged TransPower's electric yard tractor experience to build the next generation of yard tractor, two of which were placed into port demonstrations and for operation by port terminal operators throughout and beyond the contract period of performance. The ultimate destination for the two tractors is Eagle Marine Terminals at the Port of Los Angeles. This zero emissions technology is designed to meet or exceed diesel yard tractor throughput while producing zero emissions at a higher rate of energy efficiency than the diesel counterparts.

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a. City contract number: 13-3146, Electric Yard Tractor Demonstration ("EYTD") Project

b. Reporting time period: September 20, 2014 through May 22, 2015

c. Brief, overall project description

This project (the "Project") leveraged TransPower's electric yard tractor experience to build the next generation of yard tractor, two of which have been placed into port demonstrations and that will be operated by with port terminal operators throughout and beyond the contract period of performance. The ultimate destination for the two tractors is Eagle Marine Terminals at the Port of Los Angeles. This zero emissions technology is designed to meet or exceed diesel yard tractor throughput while producing zero emissions at a higher rate of energy efficiency than the diesel counterparts.

d. Description of work completed during the reporting period, including a discussion of problems encountered and how those problems were resolved, along with other relevant activities

This *Final Report and Final Operations Report* covers the entire period of performance during the Project, from July 23, 2013 through May 22, 2015. Work during the project was divided into eight sequential tasks, and this report is organized in corresponding fashion, discussing each of these eight tasks in the sequence in which they were performed. The last task to be completed was *Task 8, Tractor In-Service Demonstration,* whose partial completion was documented in our most recent *Quarterly Progress Report* dated March 19, 2015, which also served as an *Interim Operations Report* covering the first few months of tractor operations under Task 8. This report reviews progress that was reported on March 19 and in prior Quarterly Progress Reports, and augments this information with updated data and results from operation of the two electric tractors from mid-March through May 22, 2015.

Task 2, Tractor Acquisition and Preparation

Task 2, Tractor Acquisition and Preparation, consisted of three main subtasks:

- Task 2.1, Tractor Acquisition
- Task 2.2, Electric Truck Design Update
- Task 2.3 Diesel Engine and Parts Removal

Following are brief summaries of the work accomplished under each of these project tasks.

Task 2.1, Tractor Acquisition – The Kalmar tractors converted to electric drive were ordered from Cargotec in August 2013. Cargotec confirmed receipt of TransPower's down payment for the tractors on December 11, 2013 and immediately shipped the tractors to TransPower via truck. The two tractors arrived at TransPower on the morning of December 16, 2013. Figure 1 is a photo showing the two tractors shortly after they were unloaded from Cargotec's delivery truck in the back lot of TransPower's facility in Poway, CA.

Figure 1. Kalmar tractors shortly after receipt from Cargotec.

The tractors were delivered to TransPower about two months later than originally expected, due primarily to Cargotec having a busy production schedule in late 2013. While awaiting completion of tractor manufacturing, TransPower made excellent

progress in other areas, such as completing a major revision to the overall drive system design (discussed below in the Task 2.2 description) and acquisition of numerous key drive system components. In fact, TransPower completed assembly of the motive drive units to be installed into both tractors, each consisting of a main drive motor and Eaton 6-speed transmission configured to use TransPower's proprietary Automated Manual Transmission (AMT) technology. This work and this subsystem are discussed in more detail below under *Task 5, Motive Drive Subsystem Integration.*

Figure 2. Motive drive units assembled and awaiting installation.

Following receipt of the two Kalmar tractors, the vehicles were driven for a day to collect data and to characterize their operation, and measurements were made to confirm the dimensions of the battery boxes and other key components that have been awaiting fabrication pending physical inspection of the tractors. The tractors were then moved into TransPower's facility for removal of their engines and transmissions (see Task 2.3 description below).

Task 2.2, Electric Truck Design Update – The objective of this subtask was to make required engineering modifications to the design of the "ElecTruck™" drive system developed by TransPower for off-road tractors, based on analysis of port requirements

and lessons learned from testing of two earlier prototype yard tractors that were built by TransPower using an earlier variant of the ElecTruck™ drive system in 2012. Project manager Frank Falcone visited Eagle Marine Terminals to collect data on the operation of their yard tractors first hand, and developed a detailed list of operating requirements that were used to guide the redesign effort between July and early December 2013. The redesign effort also benefited from lessons learned during testing of TransPower's first two prototype tractors in Texas between April and July 2013. While these tractors exhibited high performance and the ability to function for up to 13 hours on a single battery charge, they also encountered frequent maintenance issues, which were traced to three main causes:

Failures of the transmissions shifting mechanism – While the previous tractors validated the functionality of TransPower's automated manual transmission, one of the company's key innovations, the shift mechanism used on the previous tractors was designed originally for light-duty vehicles, and despite efforts by TransPower to strengthen the mechanism, it failed frequently when subjected to the harsher operating conditions of heavy-duty yard tractors. This problem was resolved by adapting the heavier duty Eaton transmissions and shift mechanisms which were pictured in Figure 2. This transmission hardware has performed flawlessly during more than three months of drive testing of an electric school bus built by TransPower using this configuration, providing increased confidence that it will perform well in the new yard tractors.

Battery subsystem failures – An unintentional discharge of the batteries in one of the previous two yard tractors resulted in extended down time for this vehicle and potentially damaged a number of battery cells (the 224 cells that were on this tractor are still being evaluated). This problem was traced to a combination of improper maintenance (failure to plug in the tractor when it was left idle for an extended period) and a failure of the battery management system (BMS) technology used in TransPower first two tractors. To make future incidents of this nature less likely with the new tractors, the new tractor design initially featured an upgraded BMS that was intended to use TransPower's own control software, customized for the tractor operations, and a new battery sensing board that was expected to yield more accurate and reliable measurements of battery temperature and voltage than battery boards TransPower has purchased from other manufacturers. As discussed later in this report, it was ultimately decided not to install the new battery sensing boards on the two tractors, as their development took longer than anticipated, but the BMS eventually installed on the two tractors did feature many improvements over the version used in TransPower's first two tractors.

Accessory subsystem failures – During testing of the previous two tractors, intermittent problems were observed with the variable frequency drives (VFDs) used to control the accessory motors. The new tractor design addresses this issue by utilizing a new inverter product from a German company, Lenze. The Lenze inverter has a more rugged design for automotive applications and offers better reliability than the Vacon VFDs used in the first prototype tractors, which were adapted from industrial applications. The overall accessory subsystem design was also simplified by using the Lenze inverters, as we will no longer need to house the inverters in a separate enclosure to protect them from dust and moisture.

In addition to the component upgrades described above, the tractor redesign effort resulted in major changes in how the components will be packaged and integrated into the tractors. A decision was made to reduce the battery cell count from 224 cells to 120 cells per tractor, which greatly reduces the number of power and data connections between cells, as well as reducing the overall weight of the tractor by approximately one ton. To partially offset the loss of energy storage capacity, it was decided to adopt 400 ampere-hour (Ah) cells in the new tractor design, versus the 300 Ah cells used in the previous two tractors. This results in a net reduction of energy storage capacity of approximately 28.5% as compared with the two preceding tractors, but evaluation of the Eagle Marine duty cycle suggested that this will still be ample energy storage to meet its operational requirements. As discussed later in this report, operating experience gained with the two tractors later in the project reconfirmed that battery storage capacity is sufficient. The new design also takes advantage of the high-power (70 kW) inverter-charger unit (ICU) installed onto each tractor, which can fully recharge the battery pack in less than two hours. Under the Eagle Marine duty cycle, the tractor will be able to stop to recharge is batteries every four hours for up to an hour each time. This will enable the tractors to operate for up to 16 hours per day with battery packs sized to provide approximately 150 kilowatt-hours (kWh) of total energy storage.

The new yard tractor design also departs from TransPower's previous practice of splitting battery cells into many small modules. Whereas the previous two tractors each housed their batteries in 14 separate modules, the new design utilizes only two larger modules on each vehicle. Figure 3 is a computer illustration of the new yard tractor design, showing the two large battery boxes – one mounted to each side of the tractor just behind the cab. Installing all the batteries into two compartments, both mounted to the outside of the frame rails, was an approach we adopted to make all the cells and BMS easily accessible for troubleshooting or replacement. One of the disadvantages of the pervious tractor design was that nearly 100 batteries were installed into modules under the tractor cab. Accessing these modules required not only the lifting of the cab, but electrical disconnection and removal of the ICU and a large central control module, which were mounted on top of the battery modules. This made it particularly difficult and time-consuming to access, inspect, or replace any battery or battery-related components installed in this area. The batteries in the new design are housed in heavy metal structures, which provide additional protection for the batteries in the event of side collisions. The compartment also features a lid which tilts up to provide access to the batteries and other contents of the module.

Figure 4 is an illustration of how the ICU and main accessory components were designed for integration in the new tractor design. The concept shown here is to pre-assemble as many components as possible into a single structure, which can then be installed into the tractor as quickly and easily as possible. With this design advance, there are only four major components installed into each tractor – the motive drive unit (shown previously in Figure 2), the two battery compartments, and the ICU/accessory assembly shown in Figure 4. This design approach was adopted with the goal of greatly reducing the amount of time spent installing components into the tractor vehicle, and to eventually help facilitate a commercial transition to shipping components to Cargotec for them to install into tractors on their own assembly lines.

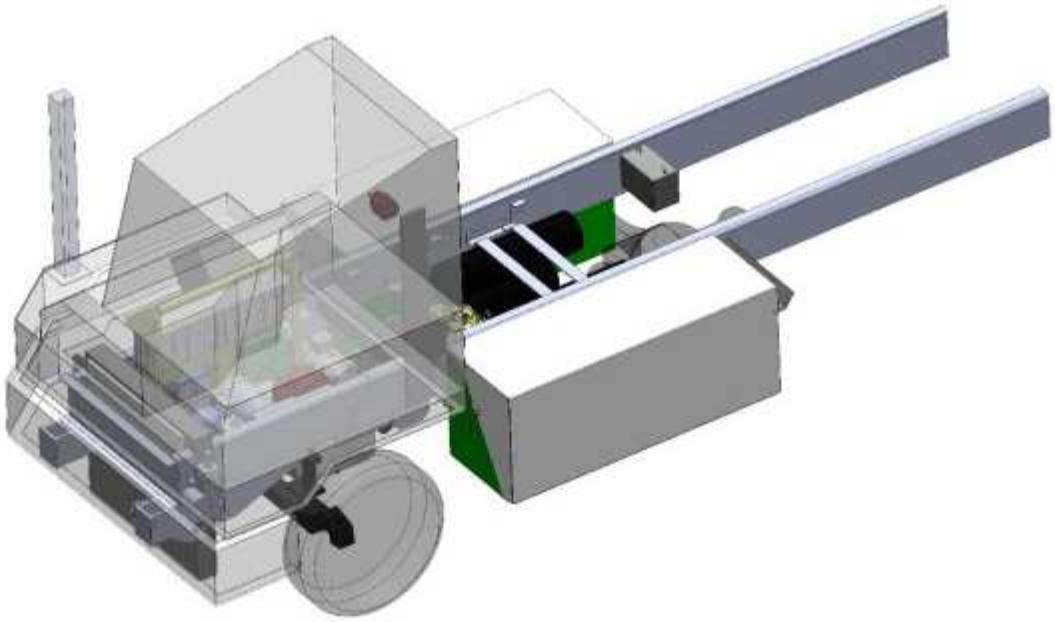


Figure 3. Computer illustration of the new electric yard tractor design.

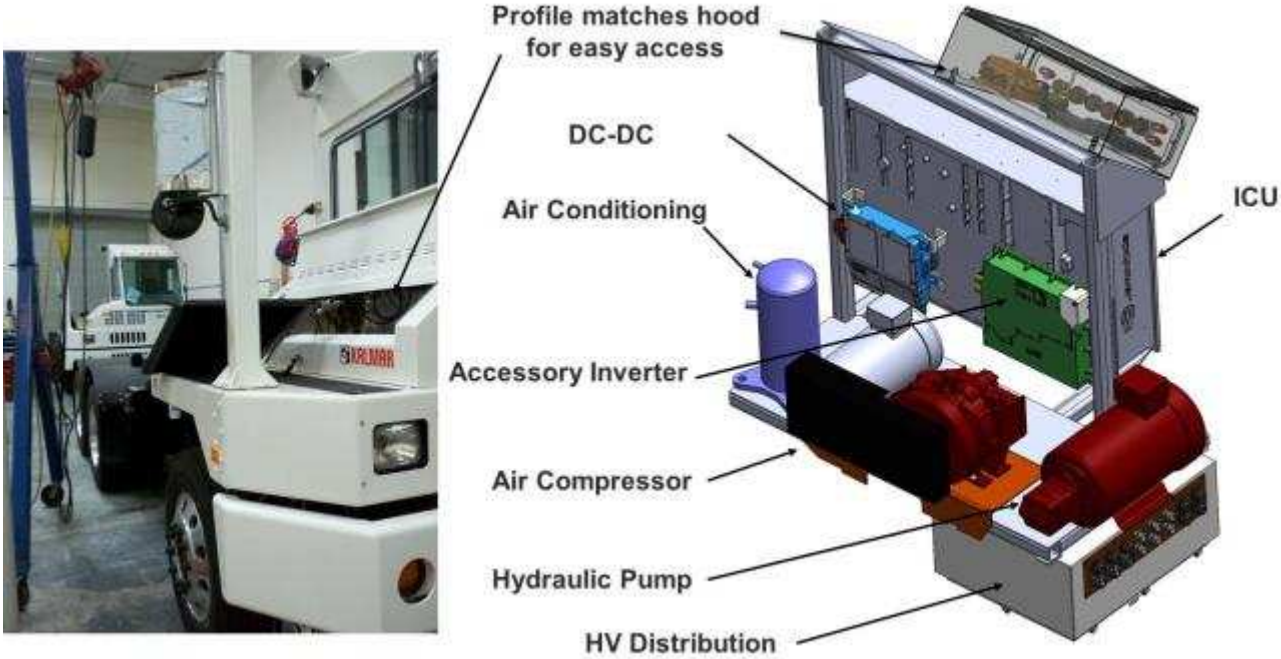


Figure 4. Drawing showing pre-assembly of ICU and accessory components.

Task 2.3, Diesel Engine and Parts Removal – As discussed above, the two yard tractors converted to electric drive on the EYTD project were delivered to TransPower on December 16, 2013. Removal of the engines and transmissions from these vehicles

was initiated on December 17, 2013 and completed on December 20, 2013, thereby completing Task 2.3. Figure 5 shows the engine being removed from one of the tractors. Completion of the Task 2 activities cleared the way for installation of electric drive components into the two tractors.

Figure 5. Engines during and after removal from tractors, with transmissions below.

Task 3, Energy Storage Subsystem Integration

Task 3, Energy Storage Subsystem Integration consisted of three main subtasks:

- Task 3.1, Fabricate Battery Modules and Support Hardware
- Task 3.2, Acquire and Install Cells and Battery Management System Parts
- Task 3.3, Complete Internal Battery Module Wiring

Following are brief summaries of the work accomplished under each of these tasks.

Task 3.1, Fabricate Battery Modules and Support Hardware – As discussed in our Task 2.2 description above, the tractor battery module configuration was significantly redesigned following an evaluation of lessons learned from an earlier yard tractor design implemented in two tractors test operated in Texas during the summer of 2013. In the Texas tractors, batteries were installed into 14 modules on each tractor. After building and operating these tractors for about a year, it was determined that reducing

the number of battery modules would reduce the amount of external wiring and assembly time. We also concluded that installing battery modules under the tractor cab, which is where six of the modules on each Texas tractor were stowed, created a serviceability issue because these modules are difficult to access – especially the modules in the lower of the two tiers as integrated into the Texas tractors.

To address these issues, we redesigned the battery modules for the POLA/Eagle Marine tractors to make them significantly larger, so fewer modules would be required. The selected design utilizes two modules mounted in vertical tiers on each side of the tractor, utilizing a single module lid on each side to cover both tiers. This revision significantly reduces parts count and simplifies battery cell integration, while also reducing the external wiring which proved to be costly to install and a challenge to maintain on the Texas tractors. Figure 6 is a photo of one of the battery compartments of the new design shortly after installation on the first tractor, POLA-1.

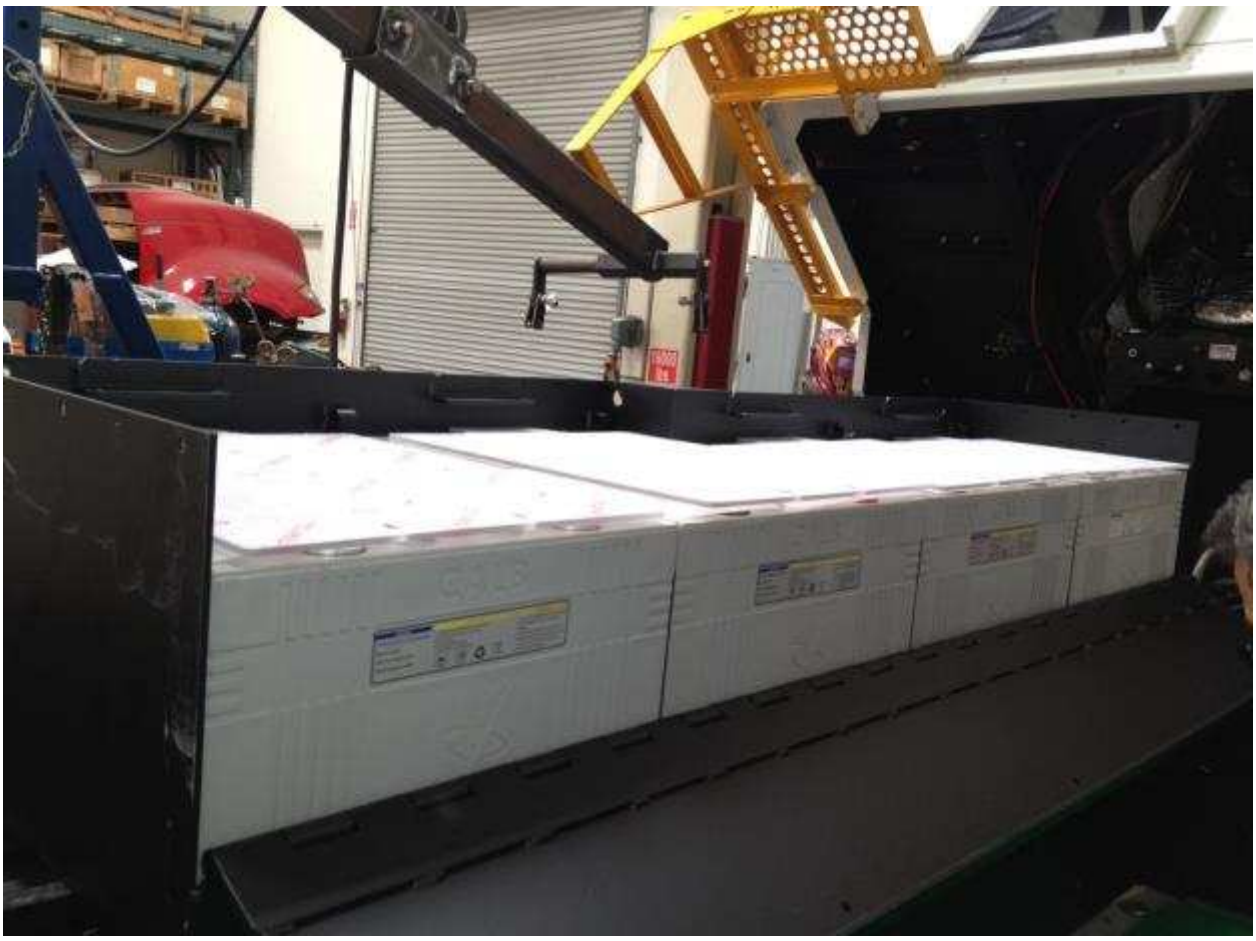


Figure 6. Upper battery compartment containing 28 cells.

The upper module shown in Figure 6 contains 28 CALB 400 Ah cells, the front four of which can be seen in the foreground. The enclosure is mounted on top of a lower compartment, shown in Figure 7. The lower compartment contains 32 CALB cells, hence the two compartments on each side house a grand total of 120 cells, which supply 154 kilowatt-hours of total energy capacity.

Figure 7. Photo of cells in upper compartment of new battery enclosure design.

Installing all the batteries into two compartments, both mounted to the outside of the frame rails, will make all the cells and battery management system (BMS) hardware easily accessible for troubleshooting or replacement. As indicated in both preceding photos, the upper and lower battery enclosures each feature a hinged panel which swings down to partially expose the batteries in the front of the enclosure, making it easier to inspect and service the batteries. The enclosures also have a number of subtle but important design features to facilitate the installation and connection of the cells, and the mounting of the BMS hardware used to monitor and balance all the cells. Figures 6 and 7 also show that the batteries in the new design are housed in heavy metal structures, which provide additional protection for the batteries in the event of side collisions.

Task 3.2, Acquire and Install Cells and Battery Management System Parts – The cells, BMS sensors, and related parts for the POLA tractor energy storage subsystems were received during the first two months of 2014, and the enclosures for the POLA tractors during March 2014. The process of installing the cells and BMS parts into the enclosures for the two POLA tractors went very quickly, enabling this subtask to be completed within a period of only about two weeks, by mid-March. This experience confirmed our expectation that the new ESS design would be much easier to integrate

than the design used in previous tractors. Figure 8 is a photo of the cells and BMS parts installed into modules on one of the POLA tractors, prior to final installation of the BMS. At this stage of assembly, the BMS sensors, provided by Flux Power, were temporarily mounted to plastic covers shielding the cells, as shown in Figure 8.

Figure 8. Battery enclosures on first POLA tractor, showing BMS sensors.

These BMS sensors and cable assemblies are the same type used on the Texas tractors. The temporary installation shown above was kept in place during the summer of 2014 as TransPower tested a new BMS product, discussed in more detail below. However, the new BMS wasn't fully developed and validated in time for use on the POLA tractors, so a decision was made late in the summer to stick with the Flux BMS sensors, which were our original choice for these tractors. Improvements in Flux Power's BMS firmware and our own BMS control software gave us confidence that there would not be any repeats of the most serious of the BMS-related problems observed on the Texas tractors (discussed in the Task 2.2 description above).

Task 3.3, Complete Internal Battery Module Wiring – Task 3 also confirmed our ability to simplify the wiring inside the battery modules. This wiring consists of bus bars used to connect the cells and low voltage wiring to connect the cells to the BMS sensors. in August 2014, the decision was made to use the commercially-available

BMS product provided by Flux Power in POLA-1. The enclosures for this tractor were rewired as shown in Figure 9 and installed into each tractor.

Figure 9. Battery enclosures installed on POLA-1, equipped with Flux BMS hardware.

At the time, it was also decided to test new BMS hardware in POLA-2. This new "Cell-Saver™" BMS is a product that had been undergoing development and testing by TransPower and our power electronics partner EPC Power since mid-2013. Final installation of the new BMS into the POLA-2 battery modules was completed in late August 2014. Figure 10 is a photo showing the ESS fully installed on POLA-2 with the new Cell-Saver™ BMS. The green boxes visible on top of the grey battery cells are the BMS sensor/balancing boards designed and developed by EPC, the key hardware elements of the new BMS. Up until September 2014, it was our intent to deliver POLA-2 for operational testing with this BMS. However, testing of the new BMS on POLA-2 and a similar tractor built for IKEA revealed several problems that we felt could not be completely resolved until well into the tractor demonstration period. To avoid the possibility of having to significantly reduce operating experience to deal with issues related to the new BMS, we elected to replace the new BMS boards on POLA-2 with the same Flux BMS boards installed on POLA-1.

Since deployment of the two POLA tractors, the issues experienced with the Cell-Saver™ BMS have been resolved, and this new BMS product is operating reliably on an electric drayage truck that was completed by TransPower in August 2014. Based on successes in perfecting the Cell-Saver™ BMS boards in late 2014 and early 2015, a decision was recently made to install this system into several additional prototype electric drayage trucks, including "EDD-5" through "EDD-7" under TransPower's current *Electric Drayage Demonstration* project and one of two trucks being developed to operate on Siemen's "eHighway" overhead catenary power system.

If experience with the Cell-Saver™ BMS continues to be favorable, it will most likely be used in future electric yard tractors. Cell-Saver™ balances cells more rapidly than the Flux BMS or other off-the-shelf solutions, using an active "charge shuffling" technique. The result of slow balancing is that batteries tend to develop greater differences in capacity over time, which can reduce operating range and require the tractors to periodically be plugged into the grid for extended periods (up to several days)

for full rebalancing. Fortunately, the POLA tractors are charged frequently and haven't exhibited this problem during the operational phase of the current project (see Task 7 and 8 descriptions below). Hence the Flux BMS boards are working adequately to support the main project objective of demonstrating the essential feasibility of using electric yard tractors for port terminal operations and related activities.

Figure 10. Battery enclosures temporarily installed on POLA-2, featuring new BMS.

Task 4, Power Conversion and Control System Integration

Task 4, Power Conversion and Control (PCCS) Subsystem Integration consisted of three main subtasks:

- Task 4.1, Assemble Inverter-Charger Units
- Task 4.2, Assemble Central Control Modules
- Task 4.3, Fabricate Mounting Hardware and High-Voltage Wiring Harnesses

Following are brief summaries of the work accomplished under each of these project tasks.

Task 4.1, Assemble Inverter-Charger Units – Inverter-Charger Units (ICUs) were assembled for both POLA tractors. The ICU is the most prominent element of the PCCS subsystem, which is now referred to as the Power Conversion and Accessory Subsystem (PCAS). The ICU was developed in partnership with emerging power electronics pioneer EPC Power Corp., originally for electric Class 8 trucks in 2011-12 and then adapted with minimal modifications to yard tractors. The ICU performs two vital functions in all of TransPower's vehicle applications: while the vehicle is moving, it converts DC power from the battery subsystem into AC power for the main drive motor, and while the vehicle is plugged in for recharging, it converts AC power from the grid into DC power to recharge the battery pack. Each ICU supplies up to 150 kW to the vehicle traction motor. The POLA tractors each use a single JJE/Fisker motor and are equipped with a PCAS employing one ICU, as compared with large on-road trucks that sometimes require two JJE/Fisker motors and which utilize two ICUs. When one of the POLA tractors is stopped and plugged in to recharge the batteries, its ICU is used as a battery charger. A single ICU can recharge a vehicle's battery pack at power levels of up to 70 kW. In the POLA yard tractor configuration, the batteries can be fully charged by a single ICU in less than two hours. The ICU is also designed to perform a potentially valuable third function that will help generate even greater market acceptance – vehicle-to-grid (V2G) functionality. When TransPower vehicles are plugged into the electric power grid, the ICUs will be capable of providing ancillary services such as frequency regulation to help stabilize the grid. However, this is not a goal of the POLA tractor project.

In addition to combining the functions of a motor inverter and battery charger, the ICU is unique in its use of advanced technologies to reduce the system's size, weight, and cost, while providing high efficiency, reliability, and power quality. Specific design features include use of high-voltage insulated gate bipolar transistors (IGBTs), liquid-cooled heat sinks, and high switching frequencies. Figure 11 is a photo of the interior of one of the ICUs. The entire device is about the size of a suitcase and weighs about 300 pounds.

Figure 11. Interior of ICU.

Both ICUs were built by EPC for this project as part of a production run of about two dozen ICUs built by EPC for various TransPower vehicle projects. The ICUs are currently operating reliably in both POLA tractors, as well as on about ten other TransPower vehicles, so there is high confidence that these devices will continue to perform well in the POLA tractors. The high charging power level of the ICU will be particularly valuable in the tractor operating environment at Eagle Marine Terminals, where the tractors are expected to be used for three four-hour shifts each day, with about an hour between shifts. Using the ICU for "opportunity charging" of the tractor batteries during these one-hour layovers will enable the tractors to complete all three shifts with about one-third fewer batteries than would otherwise be necessary.

Task 4.2, Assemble Central Control Modules – In most of TransPower's early prototype vehicles, a Central Control Module (CCM) was employed to house main high voltage electrical connections and the accessory inverters used to supply power for electrically-driven accessories such as power steering and air conditioning. The two early prototype yard tractors built by TransPower in 2012-13 were among the first generation of vehicles to use this type of CCM, one of which is shown in Figure 12. The accessory inverters are the two similar devices visible toward the right side of the CCM. This was the CCM design we originally planned to use in the POLA tractors. However, vehicles using the accessory inverters shown in Figure 12 experienced numerous failures of the accessory subsystems due to recurring problems with these inverters, which were originally developed and sold by Vacon for industrial applications and adapted by TransPower to vehicle applications. In late 2013, TransPower elected to discontinue use of the Vacon inverters, and instead for our current generation of vehicle drive systems we now use an inverter manufactured by a German company, Lenze, which was designed for automotive applications. Experience to date confirms that this inverter is more reliable than the Vacon inverters. The Lenze inverters are also packaged in sealed enclosures, so they do not require the protection of the sealed box used in our previous generation CCMs.

Figure 12. CCM concept originally planned for use in the POLA tractors.

Redesign of the CCM to omit the accessory inverters has freed up space within the CCM, which remains about the same size as the earlier version, enabling more control components to be installed into the enclosure while also making it less cluttered. This increases the accessibility of the components for installation and servicing. Figure 13 is a photo of the interior of the new CCM as installed into one of the PCAS assemblies built for the POLA tractors. Some of the components visible in the photo are microprocessors for vehicle control (at the far left of the photo), a DC-to-DC converter (black box in the upper right corner), and a set of fuses (to the left of the DC-to-DC converter).

Figure 13. Interior of new CCM as integrated into the POLA tractor PCAS assemblies.

Task 4.3, Fabricate Mounting Hardware and High-Voltage Wiring Harnesses – The PCAS assembly utilizes a new integrated structure to

physically mount most of the PCAS (formerly PCCS) components. The PCAS is a new system integration concept to accommodate the major components used for vehicle control and electrically-driven accessories, including the Inverter-Charger Units (ICUs) discussed above. In our first few prototype vehicles, we mounted the ICUs, power controllers, and accessory components directly to vehicles, spread around in various locations and connected with cables. This required us 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 installed. In the integrated PCAS concept, these components are pre-integrated into a specially designed structure and the many wiring and cooling connections between these components are completed before installation into the tractor. The entire PCAS assembly is then hoisted into the engine compartment as a single unit and connected to the tractor and remainder of the drive system with minimal additional integration hardware and wiring. The approach of pre-integrating all of the PCAS components into a single structure not only reduces TransPower's assembly time, but is expected to accelerate market acceptance of the ElecTruck™ system by forming the basis of drive system "kits" that are easy for established original equipment manufacturers (OEMs) to install into vehicles on their own assembly lines.

Major components integrated into the PCAS assemblies are:

- Inverter-Charger Unit (ICU)
- Central Control Module (CCM)
- High Voltage Distribution Module
- Accessory inverters
- DC-to-DC converters
- Air compressors
- Electric motors to run hydraulic and air systems
- Heater
- Cooling pump

Figure 14 is a photo of the two completed PCAS assemblies for the POLA tractors during final preparations for installation into the tractors. The most prominent element of the PCAS assembly is the ICU, the large metallic colored box mounted near the top of each assembly. Since the high-voltage junction box is mounted to the bottom of the PCAS assembly with its access door facing down, the entire assembly is built on an elevated stand as shown, enabling technicians to more conveniently access the high-voltage wiring harness from underneath. After the PCAS assembly is installed into the tractor, these cables are routed to the

Figure 14. Completed PCAS assemblies prior to installation into the POLA tractors.

main drive motor and other high-voltage components. Figure 15 is a photo showing how the PCAS assembly appears following installation into the tractor. Visible directly in front of the ICU are electrically-driven accessory components, discussed in more detail below.

Figure 15. PCAS assembly installed into tractor.

Task 5, Motive Drive Subsystem Integration

Task 5, Motive Drive Subsystem Integration consisted of two main subtasks:

- Task 5.1, Acquire Motor, Transmission, and Driveline
- Task 5.2, Integrate Transmissions

Following are brief summaries of the work accomplished under each of these tasks.

Task 5.1, Acquire Motor, Transmission, and Driveline – The Motor, Transmission, and Driveline components for both tractors were acquired during the fourth quarter of 2013. The configuration was designed to utilize as much of the existing Cargotec tractor driveline as possible, which helped reduce installation costs. Figure 2 on page 3 showed the completed assemblies of the motive drive units prior to installation into both tractors, each consisting of a main drive motor and Eaton 6-speed transmission configured to use TransPower's proprietary Automated Manual Transmission (AMT) technology. The main elements of the motive drive subsystems are clearly evident in this photo. The main electric drive motors are the silver disks visible toward the bottom

of the photo. These motors are manufactured by JJE, a Chinese company which is one of the world's leading motor manufacturers. These particular motors are an interesting choice for the POLA tractors because they were originally designed for the Fisker Karma, a hybrid-electric passenger car, in a joint development effort involving JJE and Quantum Technologies, Worldwide. In fact, the two motors pictured in this photo were acquired from Quantum, a firm based in Irvine, CA. Since this purchase, TransPower has established a direct business relationship with JJE which now enables TransPower to acquire these and other motor models from JJE more cost-effectively than by going through Quantum.

On top of each transmission are perpendicular silver cylinders which are the main components of the Eaton "X-Y shifter" mechanism which enables computer-controlled actuation of the transmission. This is a new innovation Eaton has developed over the past decade to improve the efficiency of their transmissions when used with conventional diesel engines. TransPower's adaptation of this technology to electric tractors required TransPower to develop proprietary software that commands the transmission to shift gears based on the speed of the JJE motor and other electric vehicle operating conditions, which are constantly monitored by TransPower's "EVControl™" control system.

As discussed previously, earlier prototype electric tractors built by TransPower experienced frequent failures in their shifting mechanism. After months of tractor testing in simulated and actual service, it was determined that these problems were caused by use of an X-Y shifter mechanism developed by another company for racing car applications. This system has since been improved by TransPower by adapting it to the more modern and rugged Eaton transmission and X-Y shifting mechanism. However, testing of TransPower's AMT technology with the early version of the shifting mechanism in 2012-13 helped TransPower to perfect the AMT software, which was first demonstrated with the more rugged Eaton transmission and X-Y shifter in a prototype electric school bus which was completed by TransPower in August 2013.

Task 5.2, Integrate Transmissions – The objective of this subtask was to modify two transmissions by incorporating AMT hardware and software, including bench testing and calibration. In early January 2014, TransPower began the process of integrating the motive drive systems with the two POLA tractors. This activity was originally intended to be completed during *Task 7, Tractor Integration and Checkout,* but was accelerated because the motive drive subsystems were assembled earlier in the project than originally expected. This subtask was simplified by the availability of a new Eaton transmission already equipped with an "X-Y shifter" mechanism compatible with TransPower's AMT software. The subtask was further simplified by the fact that identical transmission hardware was installed into an electric school bus built by TransPower, using the exact same motor-transmission configuration, during the summer of 2013, and performed flawlessly during several months of drive testing through the end of January 2014. This made bench testing and calibration of the transmission unnecessary, as all the data that would have been gained from bench testing was provided by operating the school bus.

Figure 16 is a photo of the motive drive subsystem after installation into POLA-1. One of the key innovations of the AMT system is TransPower's use of the JJE-Fisker

drive motor to rapidly synchronize the transmission, which results in extraordinarily smooth shifting and eliminates the jerkiness associated with most heavy-duty vehicle shifting mechanisms. This makes tractors using the AMT extremely pleasant to drive a well as providing high performance across the tractor's entire speed range.

Figure 16. Motive drive subsystem fully integrated into POLA-1.

The AMT also improves operating efficiency as compared with conventional automatic transmissions because it eliminates the need for a torque converter, which typically spins all the time and constantly drains energy. System robustness is assured by use of Eaton's rugged transmission and X-Y shifting mechanism. TransPower's AMT software was developed and perfected in stages since early 2012, and has shown the ability to operate predictably and reliably in a variety of heavy-duty vehicle applications including on-road Class 8 trucks and electric school buses as well as yard tractors.

Task 6, Electrically-Driven Accessory Subsystem Integration

Task 6, Electric Accessory Integration consisted of two main subtasks:

- Task 6.1, Acquire Accessory Parts
- Task 6.2, Assemble Accessories

Following are brief summaries of the work accomplished under each of these tasks.

Task 6.1, Acquire Accessory Parts – All parts for the electrically-driven accessories for both POLA tractors were first acquired. The function of the electrically-driven accessories in the yard tractors is to provide electrical power to operate the following critical vehicle devices:

- Power steering
- Pneumatic braking
- Heating, ventilation, and air conditioning
- 5th wheel lift (Figure 17)

Most electric vehicles require electric accessories to operate the first three of the devices listed above, which in conventional engine-driven vehicles are typically powered by belt-driven alternators connected to the engine. Obviously, electric vehicles don't have engines so these types of "power take-off' (PTO) devices cannot be used. In TransPower's ElecTruck™ electric drive system, various electronic and mechanical devices are integrated to enable energy from the main battery subsystem to be used to power these vehicle functions. The yard tractors present an additional challenge in their use of a 5th wheel lift (Figure 17), a mechanical device near the back of the tractor that is lifted to engage the tractor with trailers as quickly as possible. Significant accessory parts integrated into the PCAS assemblies are:

Figure 17. 5th wheel lift on one of the POLA tractors.

- Accessory inverters
- DC-to-DC converters
- Air compressors
- Electric motors to run hydraulic and air systems
- Heater
- Cooling pumps

Significant accessory parts that are not installed into the PCAS assemblies, but are installed into the tractors in other locations, are:

- Transducers
- Coolant sensors
- Various hydraulic fittings
- Hydraulic bypass valve
- 5th wheel pressure sensor

Task 6.2 Assemble Accessories – As discussed previously, some elements of the TransPower accessory subsystem are integrated into the Power Control and Accessory Subsystem (PCAS), which combines much of the control hardware and high-voltage wiring of the TransPower system with the main electrically-driven accessory components. Pre-assembly of the PCAS units greatly simplifies the final stage of vehicle integration, as wiring or other issues can be resolved before components are installed throughout the vehicle, on a portable structure that can be easily moved and maneuvered to provide convenient access to its various components.

Figure 18. View of the PCAS assembly showing the accessory motors in the foreground.

Figure 18 shows a partially built PCAS assembly before installation into one of the POLA tractors, with several of the main electrically-driven accessory components visible in the foreground. The blue motor to the right is the motor used to drive the hydraulic pump which pumps power steering fluid to the steering and 5th wheel lift systems. Directly to the left of the steering pump motor is the air compressor assembly, which consists of an electric motor that drives a belt-driven oil-less scroll compressor. The air system is quiet and efficient, charging the air system only when air pressure needs to be restored.

Power for these motors is supplied by a small accessory inverter which converts DC power from the battery subsystem to AC power as required by the accessory motors. As discussed under Task 3.2, the Lenze accessory inverter selected for this project is one of the newest ElecTruck™ components to be utilized on the POLA tractors. Some effort was required to get the Lenze inverters to interface properly with the rest of the drive system, but once these compatibility issues were resolved, the Lenze inverters proved to be more reliable than the Vacon industrial inverters they replaced. A related key accessory component integrated into the PCAS assembly is the DC-to-DC converter which steps down the battery voltage to the 12-volt level required by several tractor systems (Figure 19).

Figure 19. Close-up view of the DC-to-DC converter installed into PCAS assembly.

Completing the accessory subsystem required installation of components into the POLA tractors utilized to route fluid and air to the various components that use them. The pump used for power steering fluid is actually a two-stage pump that also pumps the hydraulic fluid used to lift and lower the 5th wheel lift. The air system used for braking also locks and unlocks the 5th wheel lift. Figure 20 is a photo showing some of the hydraulic plumbing installed into one of the POLA tractors. In addition to these items, there are other tractor components we don't classify as "accessory" components but that are connected to or powered by the accessories. These include items that are part of the tractors as originally equipped by Cargotec, such as the lights, horn, and cabin lift mechanism, all of which are powered by the DC-to-DC converter installed on our PCAS assembly. These also include a few items we install such as radiator fans and the transmission control box, also powered by the 12-volt power supply.

Figure 20. Hydraulic plumbing in one of the POLA tractors.

Task 7, Tractor Integration and Checkout

Task 7, Tractor Integration and Checkout consisted of two main subtasks:

- Task 7.1, Perform Drive System Integration
- Task 7.2, Perform Drive Testing

Following are brief summaries of the work accomplished under each of these tasks.

Task 7.1, Perform Drive System Integration – Drive system integration was performed in a series of phases over the period extending from December 2013 through August 2014. Early drive system integration activities, performed during the first 2-3 months of this period, focused on fabricating mounting hardware and installing these items into the two tractors. The next phase of work was focused on installing the four major ElecTruck™ subsystems into the tractors:

- Motive Drive Subsystem (MDS)
- Power Control and Accessory Subsystem (PCAS)
- Energy Storage Subsystem (ESS)
- Vehicle Integration Subsystem (VIS)

Strictly speaking, some elements of the VIS are mounting hardware items of the type installed into the tractors at the beginning of the integration period, but most are wiring harnesses, coolant plumbing, and ancillary components that were installed after the other three major subsystems. The MDS was the first of these subsystems to be

installed; as documented in our Task 5 discussion, these subsystems were installed into both tractors by the end of January 2014.

The PCAS assemblies for both tractors were installed during the second quarter of 2014. This installation required preliminary installation prior to final installation to perform a final fit check and to validate all interfaces. Connection of the various PCAS electrical and fluid lines to the remainder of the tractors proceeded throughout the summer. Figure 21 shows the PCAS installation installed in one of the two tractors in early August, following completion of all connections and during final testing of these connections. The open cabinet visible in the foreground is the Central Control Module (CCM) which houses much of the tractor's central control circuitry. The blue cylindrical object to the left of the CCM is one of the electrically-driven accessory motors. The PCAS assembly also houses the inverter-charger unit (ICU), which is mounted directly behind the CCM in this photo. As discussed in the Task 4.1 discussion, the ICU performs the dual functions of controlling the tractor's drive motor and recharging the tractor's battery packs. The relatively rapid installation of the PCAS assemblies confirmed our expectation that pre-integrating the controls and accessory components into a PCAS-like structure would greatly accelerate the process of installing these items into the tractors.

Figure 21. PCAS assembly installed into one of the POLA tractors.

The battery enclosures comprising the major part of the ESS in both tractors were assembled by the end of March 2014, but as documented in our Task 3 discussion, finalization of the ESS did not occur until late summer 2014, following testing of two different battery management system (BMS) products. Ultimately, an improved version of the commercially-available Flux Power BMS was selected for the two POLA tractors, using TransPower software for BMS control. This solution was selected over the new "Cell-Saver™" BMS system developed by TransPower and our power electronics partner EPC Power, which has since been perfected, but was deemed too risky to use on the POLA tractors when the ESS had to be finalized in August 2014. Finalization of the ESS design enabled both tractors to be physically completed by the end of August 2014, enabling drive testing to begin.

Task 7.2 Perform Drive Testing – Drive testing of POLA-1 was initiated in late August 2014. Initial testing was focused on this tractor because we were invited to display an electric tractor at the PortTech Expo on September 17, 2014. A decision was made to test POLA-1 as thoroughly as possible by this date, with the goal of having it sufficiently vetted that it could be delivered to Eagle Marine Terminals immediately after the Expo, which was located in San Pedro in close proximity to the Port of Los Angeles. POLA-1 was first tested without hauling any loads and was then tested pulling a trailer loaded with concrete blocks to a total weight of about 45,000 lb. Figure 22 shows POLA-1 pulling this trailer around TransPower's Poway facility during one of these test runs. Approximately 50 miles of problem-free test operations were accumulated by mid-September, providing the confidence to display POLA-1 at the PortTech Expo and to subsequently deliver it for use near the ports.

Figure 22. POLA-1 being test driven at TransPower's Poway facility.

However, the electrical work needed to install charging plugs at Eagle Marine Terminals had not been performed by the time the Expo concluded, so as an interim step we delivered the tractor to SA Recycling, a truck operator near the Port of Los Angeles which recently had charging infrastructure installed to support one of our

electric drayage trucks. As discussed in more detail below in our Task 8 discussion, the delay in installing charging infrastructure at Eagle Marine turned out to be much longer than expected, resulting in a decision to alternate POLA-1 between SA Recycling and Total Transportation Services, Inc. (TTSI), another drayage operator near Long Beach, for an extended period. Following the initial deployment of POLA-1 at SA Recycling, POLA-2 was fully commissioned and test driven by TransPower through much of the fourth quarter of 2014.

Every possible effort was expended to expedite the installation of charging infrastructure at Eagle Marine. TransPower chief scientist James Burns visited Eagle Marine prior to the PortTech Expo, met with Eagle Marine personnel and their electrician, and offered suggestions to reduce the cost of the electrical work from the original amount quoted, which was about $32,000, to approximately $19,370. This is a reduction of about 40%. TransPower also expressed a willingness to contribute to the cost of the electrical work, but similar issues have arisen at locations where TransPower electric drayage trucks are to be deployed, and covering the cost of all electrical work at all of these locations was determined to be impossible for TransPower to absorb. Ultimately, an agreement was reached for the Ports to assist in funding the installation of charging infrastructure at Eagle Marine Terminals, but the process of formalizing this funding commitment and completing the work at Eagle Marine as not completed as of the date of this report. The following section describes how the in-service demonstration requirements of the project were met under these circumstances.

Task 8, Tractor In-Service Demonstration

Both tractors were drive tested extensively at TransPower's facilities in Poway following commissioning of the vehicles under Task 7. Drive testing of POLA-1 began in earnest in early September 2014 and POLA-2 initiated drive testing in early October 2014. As discussed previously, testing in Poway including hauling a trailer loaded with about 45,000 lb. of concrete blocks to validate the tractors' towing capabilities.

After being unveiled at the PortTech Expo on September 17, 2014, the first tractor, "POLA-1," was initially placed into service at SA Recycling, a drayage firm that supports the Port of Los Angeles. However, at that time, SA Recycling had only marginal yard tractor usage requirements. Subsequently (following the conclusion of the July-September reporting period), the tractor was placed into service with a drayage firm, Total Transportation Services, Inc. ("TTSI") which has a larger demand for yard tractor services to accumulate hours and miles. As discussed in more detail below, POLA-1 was returned to SA Recycling in March 2015 with the expectation that it would be used more frequently, but after several weeks of inactivity the tractor was returned to TTSI, where it is expected to remain until longer term deployment with Eagle Marine Terminals.

The second tractor, "POLA-2," was initially delivered to Dole Fresh Foods in mid-December 2014 and began regular operations at Dole in January 2015. As also discussed in more detail below, POLA-2 has been actively used by Dole and has accumulated a valuable data base of mileage and heavy trailer "pulls." POLA-2 is expected to remain at Dole until the move of both tractors to Eagle Marine.

Also, around the time testing of the two POLA tractors began in August and September 2014, a third tractor identical in design to the two POLA tractors was entered into service at IKEA's main California distribution center near Bakersfield. The POLA tractor project benefited directly from much of the R&D and "trial and error" performed during manufacturing and testing of the IKEA tractor throughout the first nine months of 2014. The IKEA tractor was the first tractor to ever incorporate numerous design innovations which were then replicated on the POLA tractors. As discussed in preceding sections, these design improvements included a new energy storage subsystem (ESS) design featuring larger battery enclosures, a new motive drive subsystem (MDS) design MDS featuring six-speed manual transmissions supplied by Eaton, and a power control and accessory subsystem (PCAS) featuring new methods of installing vehicle control and accessory components including the Inverter-Charger Unit (ICU) used for motor control and battery charging.

As also discussed in preceding sections of this report, completion of the tractors was delayed for several weeks due to changes in the planned approach for battery management. For several months during the project, a goal was pursued to upgrade the sensing-balancing boards used in TransPower's battery management system (BMS) to take advantage of a newly designed board TransPower has been developing with partner company EPC Power, with funding from a parallel R&D project. The new boards are designed to provide increased balancing capability through active "charge shuffling," which could conserve energy by moving charge from higher to lower cells (redistribution) as opposed to consuming the energy in high cells as heat so low cells catch up. However, as discussed previously, a decision was made late in the summer of 2014 to utilize off-the-shelf BMS boards supplied by Flux Power on the two tractors.

Operation of the two POLA tractors to date has shown that this was a wise choice. The Flux BMS has performed reliably and has kept battery cells in balance more than adequately to meet the operating needs of these tractors. The Flux BMS is also performing well on the IKEA tractor, which is being used more intensively than either of the POLA tractors. More generally, all of the major design innovations incorporated into the two POLA tractors seem to be achieving or exceeding their desired results.

Overview of POLA-1 Operations – POLA-1 was used by SA Recycling for about a month, then used at TTSI's yard starting in late October, 2014. During the first ten weeks of 2015, POLA-1 was operated for approximately 235 hours and moved more than 1,000 containers containing various goods shipped by TTSI. On March 12, 2015, POLA-1 was moved back to SA Recycling for use at Pier T at the Port of Long Beach (Figure 23), where the tractor was expected to experience greater use than it had been experiencing with TTSI. On March 18, 2015, shortly after POLA-1's arrival at SA Recycling, the tractor was successfully demonstrated to visiting members of the ARB and Port staff. However, SA Recycling was unable to expand from its traditional recycling operations to more conventional container movements in April 2015 as expected, so POLA-1 was rarely used after its return to SA Recycling. In early May, POLA-1 was returned to TTSI where it resumed operations at a rate of about 7-14 miles per day until the end of the contract.

Figure 23. POLA-1 in operation at Pier T at the Port of Long Beach.

Over the course of approximately nine months of testing and in-service use, POLA-1 accumulated more than 500 miles of operation. This is a substantially lower mileage figure than achieved by POLA-2 over a shorter period – as discussed below – but is not necessarily indicative of tractor utilization, as many yard tractors are used for very short distances, average less than 3 miles per hour (MPH), and spend large percentages of their time idling. Furthermore, the aggressive start/stop profile of a tractor in a small yard can incur more wear and tear much of the same manner that a conventional automobile that drives within a city does versus one that is driven farther but mostly on the highway. TTSI's use of POLA-1 certainly fits within this profile.

Overview of POLA-2 Operations – POLA-2 first spent a couple months testing at TransPower, then in December, 2014 it moved to Dole for testing and operations at its terminal at the Port of San Diego. After a few weeks of initial testing and driver orientation in December and early January, the tractor was entered into regular service moving containers. During its approximately seven months of testing and operation, POLA-2 accumulated approximately 1,200 total miles. Mileage during operations with Dole was typically between 200 and 300 miles per month. Figure is a photo of POLA-2 in operation at Dole's Port of San Diego terminal in early January 2015. POLA-2 has moved more than 6,200 containers during its operation at Dole, a mix of containers loaded with Dole fruit products and unloaded containers returned to ships for transport back to Dole farms.

Figure 24. POLA-2 in operation at Dole's terminal at the Port of San Diego in January.

General observations regarding the two tractors:

- POLA-1 uses between 5 and 6 kilowatt-hours (kWh) per mile while POLA-2, operated more efficiently at Dole, typically uses between 3 and 4 kWh/mile.
- POLA-1 is rarely driven for more than 3 hours during any 8-12 hour shift, while POLA-2 moving time is up to 5 hours per day, while running 8-16 hours of single and double shift operation.
- Both tractors easily complete their daily shifts with a single battery charge and are capable of being fully charged between shifts, even at charge rates far lower than the maximum 70 kW charge rate enabled by the ICU.
- Overall reliability has been exceptional, especially for early-stage prototypes such as these. Drive system components that have failed include battery sensors, inverter voltage sensors, and 12-volt batteries – all common failure modes for early-stage vehicles. There have also been some software-related issues requiring resolution. These problems were often sensed remotely before in-service failure and were all remedied within 1-3 business days, rarely causing any actual downtime for the operators.
- Both POLA-1 and POLA-2's dedicated fleet operators enjoy the quieter and smoother operation of the electric tractors, and especially appreciate being able to keep the doors and windows open without the risk of diesel emissions entering the cab. Dole longshoreman also commented that the tractor has more power than a diesel tractor, and its air conditioning works extremely well.

Tractor Infrastructure and Operating Locations – The tractors have been operated primarily at TTSI and Dole because of delays experienced in installing electrical infrastructure at Eagle Marine Terminals, where the tractors were originally expected to be deployed for the demonstration phase of this project. TransPower has been working with Eagle Marine to finalize a site-specific infrastructure plan at their APL Terminal demonstration site. The Port of Los Angeles ultimately agreed to cover the cost of installing the necessary electrical service at Eagle Marine, but the process of formalizing this support was not completed within the period of performance of this contract. TransPower has agreed to assist with installation of the charging infrastructure after the contract ends, if necessary, which will include the following tasks:

- Wiring additions/upgrades to the physical location/building that will host the tractors;
- Integration of the electrical hardware assembly that transfers power to the tractors. This hardware includes ground fault detection, a 200A high speed circuit breaker, and the 208VAC, 200A 3-phase vehicle connector. This assembly is referred to collectively as an Electric Vehicle Supply Equipment (EVSE) assembly. This assembly matches the power available at the truck's deployment location with the power format required by the truck, it provides the cabling and connector to transfer power to the truck, and it manages safety aspects of power flow to the truck;
- Final mechanical and electrical installation of the charging infrastructure hardware assembly at the demonstration site, with functional verification.

Figure illustrates the location chosen by Eagle Marine for parking/charging of the tractors. The effort will be in two phases: the first phase will complete the installation of a fully functional temporary charging capability and provide this temporary charging in less than two weeks. The temporary hardware is already available and ready to ship to the installation site. The second phase will upgrade the EVSE functionality of the existing temporary installation to include TransPower's latest EVSE product. Lead times of 4-5 weeks associated with the newest EVSE components require this two-step installation. TransPower will procure, assemble and deliver a charging infrastructure hardware package for installation by Eagle Marine's approved electrician, contract and oversee that installation at the Eagle Marine/APL facility, and verify that system's operation.

Deliverables will include electrical infrastructure additions to the Eagle Marine operations building at APL; fabrication by TransPower of two EVSE devices; purchase and integration of transformer(s), cables, connectors, and safety switches; siting and wiring of the assembled equipment package; and electrical connection of that package to the building wiring. TransPower has agreed to support continued operation of the two POLA tractors at Eagle Marine beyond the period of performance of this contract, at its own expense, until the end of 2015. Continued use of the tractors at Eagle Marine after this date will require some means of financially supporting continued vehicle support by TransPower.

Figure 25. Tractor charging locations selected at Eagle Marine Terminals.

In the meantime, operation of the two POLA tractors at TTSI and Dole has enabled the project to meet all of its fundamental goals, which are to show that the two tractors are capable of operating in a real-world port environment with adequate reliability and performance. Another key goal was to collect data on tractor operations and cost-effectiveness so the cost of ownership of electric tractors can be compared with that of standard diesel tractors.

To enable capture of energy use and other data from POLA-1 and POLA-2 during actual operations, data logging capability was installed into both tractors in early January 2015. These data can be used to extrapolate parameters such as energy consumed as well as compare each tractor's performance against one another. Note that throughout this section, zero values (when the truck was not in use) have been omitted to permit accurate trend line estimation.

POLA-1 operated in a 2.75-acre yard that is (400’ X 300’), as depicted in Figure. At Dole’s San Diego Port facility, POLA-2 operates in much larger 91-acre area that is 2,200’ X 1800’ at its widest point (Figure).

Figure 26. TTSI Inc. trailer yard in Rancho Dominguez.

Figure 27. Dole facility at the Port of San Diego.

Task 9, Complete Tractor In-Service Demonstration and Final Report

The varying features of the operating sites and operator duty cycles have had a pronounced impact on how the tractors are driven, as can be seen in Figure. As these graphs demonstrate, POLA-1 maintained an average speed of 2.9 MPH while in operation at TTSI, whereas POLA-2 averaged about 6.8 MPH. These averages were calculated by averaging non-zero speed values reflecting the different operating topologies. The reduced average speeds combined with varying average drive vs. idle durations (discussed later) impact metrics such as rate of container movement which is useful to assess how much work the vehicle is accomplishing for given customer for a given amount of time, distance, or energy consumption.

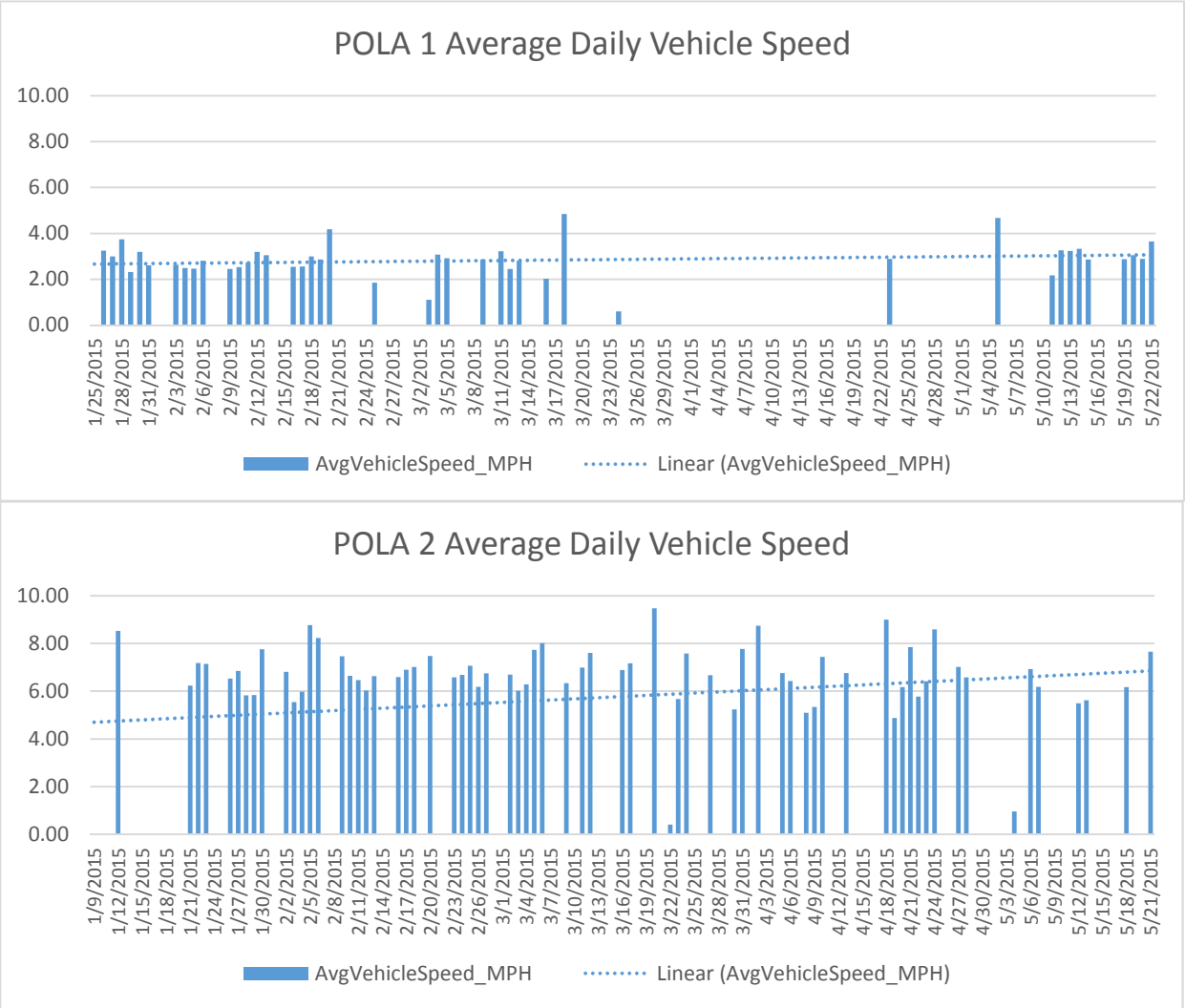
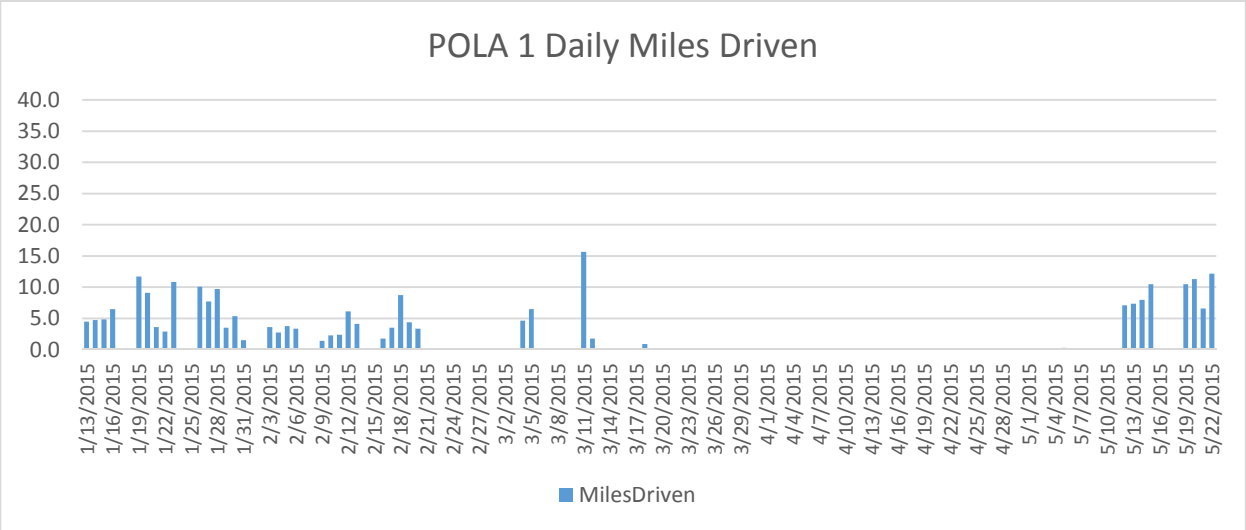


Figure 28. Tractor average vehicle speeds with a 14 day rolling average trend line.

Figur depicts daily miles driven for both tractors. As can be readily observed, POLA-1 saw much lower daily mileage than POLA-2, averaging 6.3 miles/day versus 15.8 miles/day for POLA-1. (Daily averages exclude days when tractors were not used).

POLA-1 peaked at 14.6 miles on March 11th while POLA-2 peaked at 36.5 miles on February 18th. POLA-1's reduced distance aligns somewhat well with the reduced average speeds previously discussed. As an additional comparative data point, the third tractor discussed above averaged about 9.2 MPH and 41.1 miles/day in use at IKEA's main California distribution center near Bakersfield. It has accumulated as many as 85 miles of use in a single day, operating for as many as three shifts. These disparities show there are significant differences in the levels of utilization for yard tractors in different settings, based on both average speed and intensity of use (number of hours of use per day).



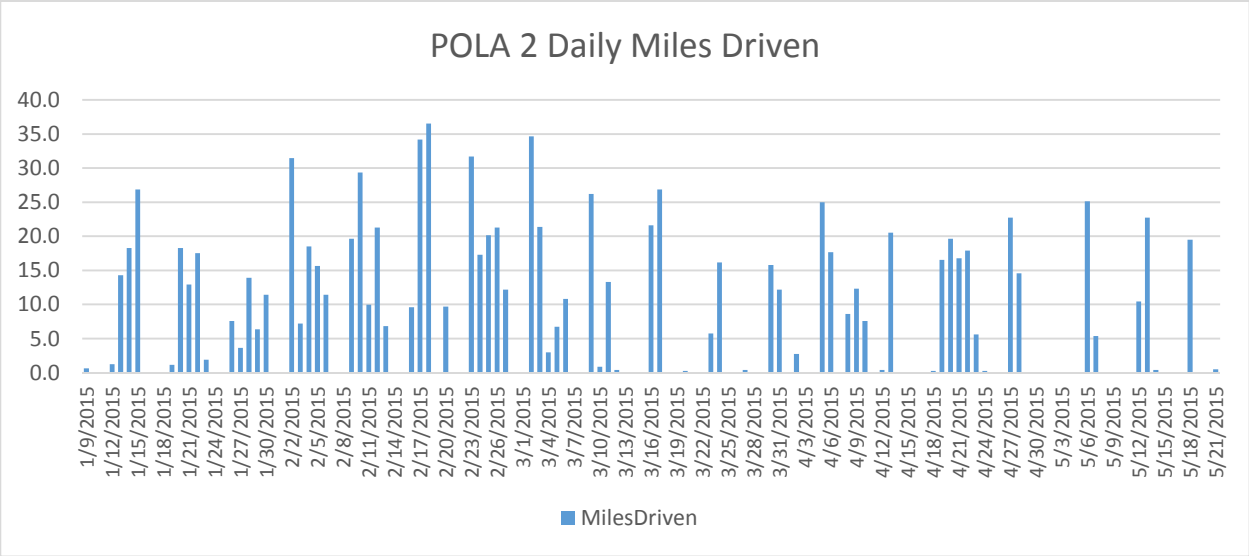
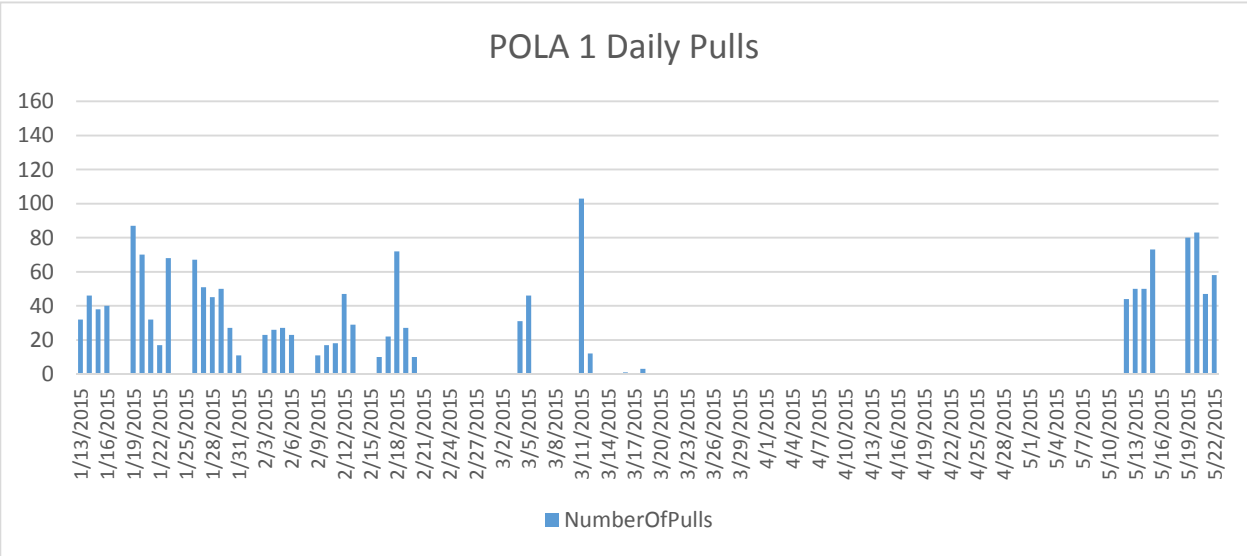


Figure 29. Daily miles driven.

Not surprisingly, POLA-1 and POLA-2 see different levels of container movement. When in use at TTSI, POLA-1 averaged about 41 container "pulls" per day – a "pull" being defined as transporting a load for 30 seconds or more and then setting it down for

at least 30 seconds (*Figure*). POLA-2 averaged 45 pulls per day and saw utility peak in February. It is notable that although average speeds and distances vary by 60 and 67% respectively, container throughput only varies by 30% and is likely attributable to the short distances between trailers at TTSI's small yard where the tractor can get from trailer to trailer more quickly.



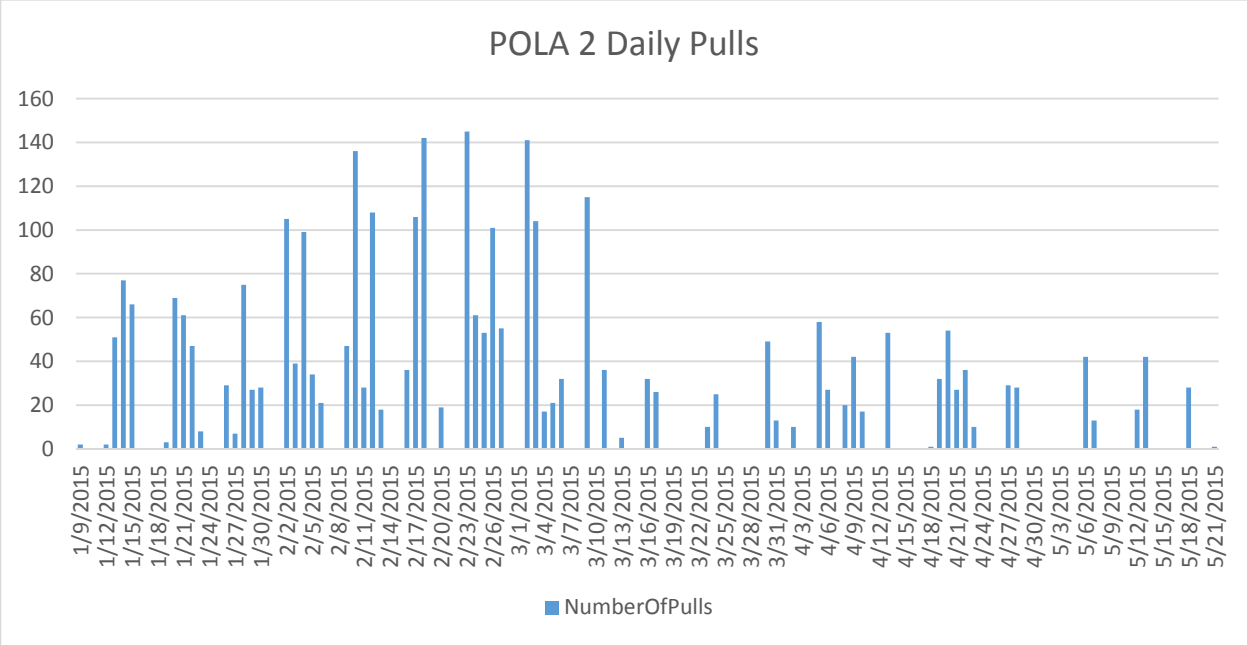


Figure 30. Number of tractor pulls per day.

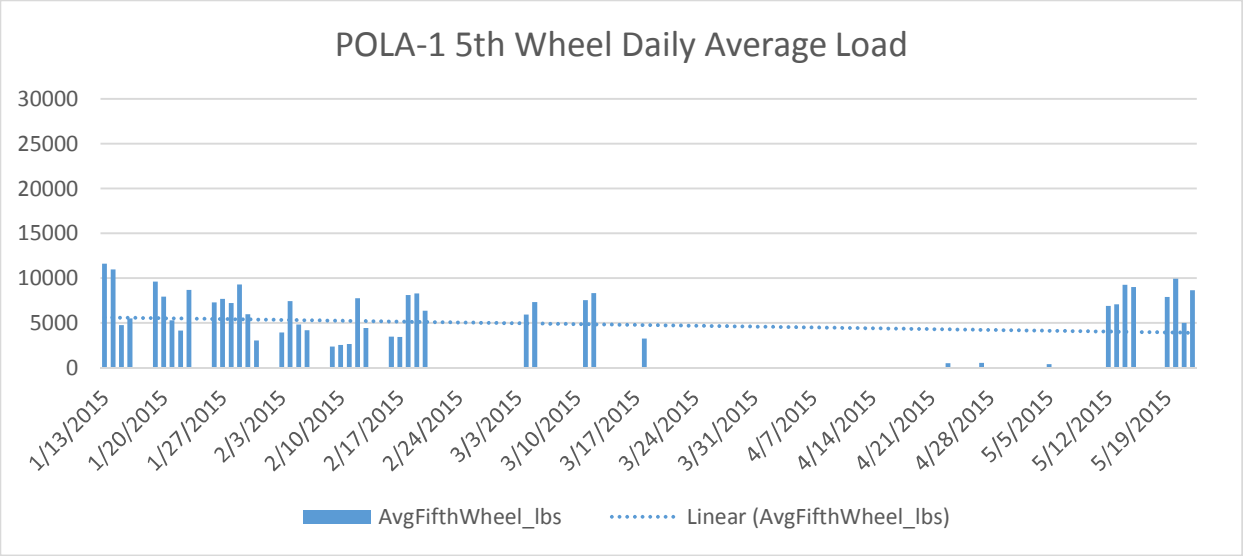
Another key factor affecting tractor performance is cargo mass, which was found to differ significantly between the TTSI and Dole operating environments. On each tractor, cargo weights are estimated using a pressure sensor within the fifth wheel hydraulic lift lines. This sensor is useful for increasing regenerative braking as load increases and, if

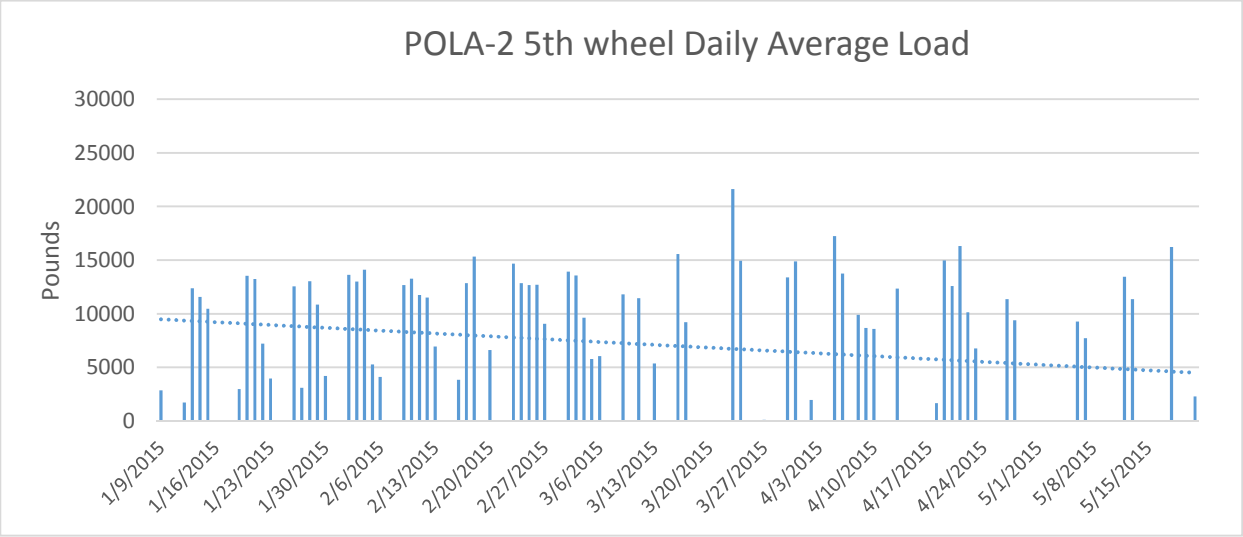
properly calibrated, also reporting the load on the tractor's rear axles. TransPower has acquired a few calibration points, and while more points would improve accuracy, is confident the estimated rear axle load is within a few thousand pounds.Loads carried by any tractor can vary from zero (if unloaded) to more than 50,000 lb., so the best way to compare tractors operating in different settings is to contrast their average daily loads. Figure shows the average daily fifth wheel loads for POLA-1 and POLA-2, with similar data for the third tractor at IKEA included for reference. Fifth wheel loads represent the load the trailer places directly on the fifth wheel plate. The daily averages include periods of no trailer, empty trailers, and trailers with varying loads.

As evident from this figure, POLA-1 carried consistently lower minimum, average, and maximum daily loads than the other two tractors. This could be due to a number of factors, including the likelihood that a wider variety of goods are handled by TTSI than by Dole or IKEA, whose loads always tend to be heavy (furniture and water-laden fruit). The average daily container load pulled by POLA-1 at TTSI was approximately 17,237 lb., with a maximum daily average of 31,700 lb. on January 13th, while POLA-2 maintained a daily average of 28,087 lb. at Dole, with a maximum daily average of 58,976 lb. on March 23rd. The heavier loads carried at Dole have helped validate the higher capacity of the "port spec" yard tractor selected for this project, which is rated for total vehicle loads of up to 130,000 lb.

Compared to the IKEA tractor, POLA-2 has a lower minimum payload but higher average and maximum payloads. POLA-2's lower minimum payload is due to the fact that it operates unloaded more frequently than the IKEA tractor. POLA-2's higher average and maximum loads suggest that when it does carry loads, they are frequently heavier than IKEA's furniture loads, which are very constant. In fact, one of the most obvious conclusions that can be drawn from these data is that the IKEA tractor has by far less fluctuation in load-carrying than either of the POLA tractors. IKEA reports that most of its loads reach the maximum allowable mass before the trailer has reach maximum volumetric capacity.

While POLA-2 has experienced the highest average and maximum average loads, it is interesting to note that even on its most demanding days, its battery state of charge (SOC) declined slowly. The top graph in Figure illustrates this by showing the SOC of the POLA-2 battery pack over a two-hour period during which the tractor experienced its highest maximum average load. As indicated, SOC had a relatively modest drop, from 99% to 87% over this period, suggesting that under this drive cycle, even though the loads are heavy, the tractor is capable of operating for more than 12 hours. The maximum loads measured by the tractor's 5th wheel sensor during this interval were roughly 48,000 lb., representing what the tractor felt with the difference resting on the trailer's rear axles. Given that food products are typically evenly distributed and the 48,000 lb. does not account for the trailer axles, it is likely more than 50,000 lb. was resting on the trailer wheels (payload plus axles, suspension, etc.), which – when added to the 18,000 lb. tractor – would bring total combined weight to about 120,000 lb. The lower graph in Figure shows POLA-2 motor temperature, fifth wheel load, and vehicle speed over the same two-hour period. As indicated, motor temperature held very steady during this intensive use period, suggesting minimal risk of motor overheating.





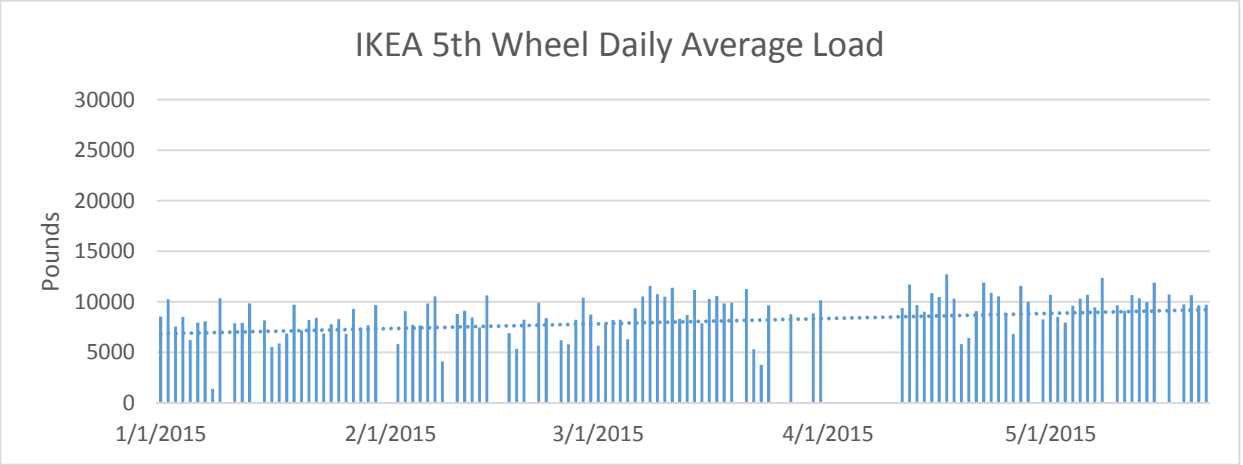
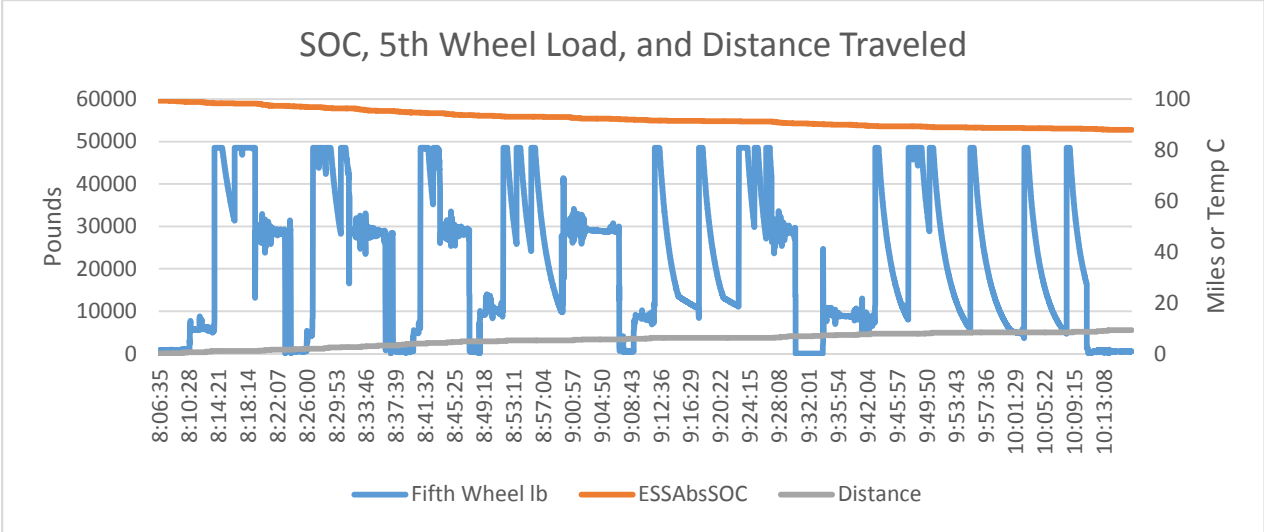


Figure 31. Fifth wheel estimated load.



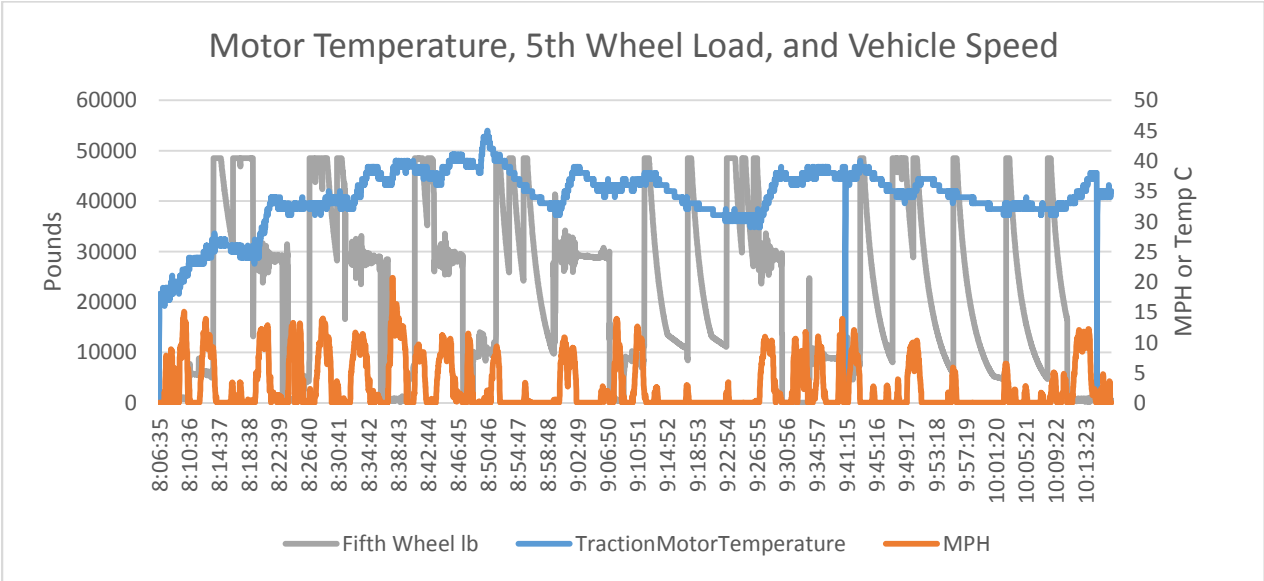
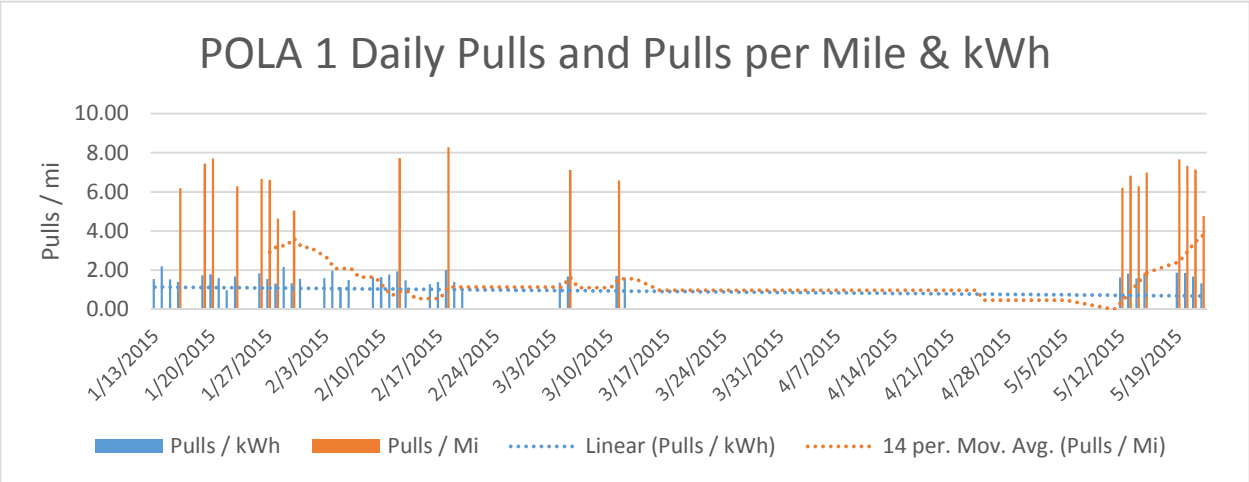


Figure 32. POLA-2 heavy load day

Operation of the POLA tractors enabled the compilation of various statistics that are helpful for predicting operating costs, including pulls per kWh and pulls per mile (**Error! Reference source not found.**). Depending on how the operator tracks their productivity, projections can be made as to how many pulls can be accomplished, how much distance is traveled, and how energy would be consumed. POLA-1 generally averaged between 6 and 8 pulls per mile, while POLA-2 typically averaged between 2 and 4 pulls per mile. For reference, the IKEA tractor averaged between 1 and 2 pulls per mile. POLA-2 carried fewer than half as many containers per mile as POLA-1 because it traveled more than twice as far for each container pull, due to longer distances between container pick-ups and drop-offs. The longer distances traveled by

POLA-2 also help explain its higher energy use per pull relative to POLA-1, although this is also partly due to the fact that POLA-2 hauls heavier containers with Dole than POLA-1 hauls at TTSI. In addition to the fact that Dole's fruit is comparatively heavy, Dole's containers weigh more because they contain refrigeration units.



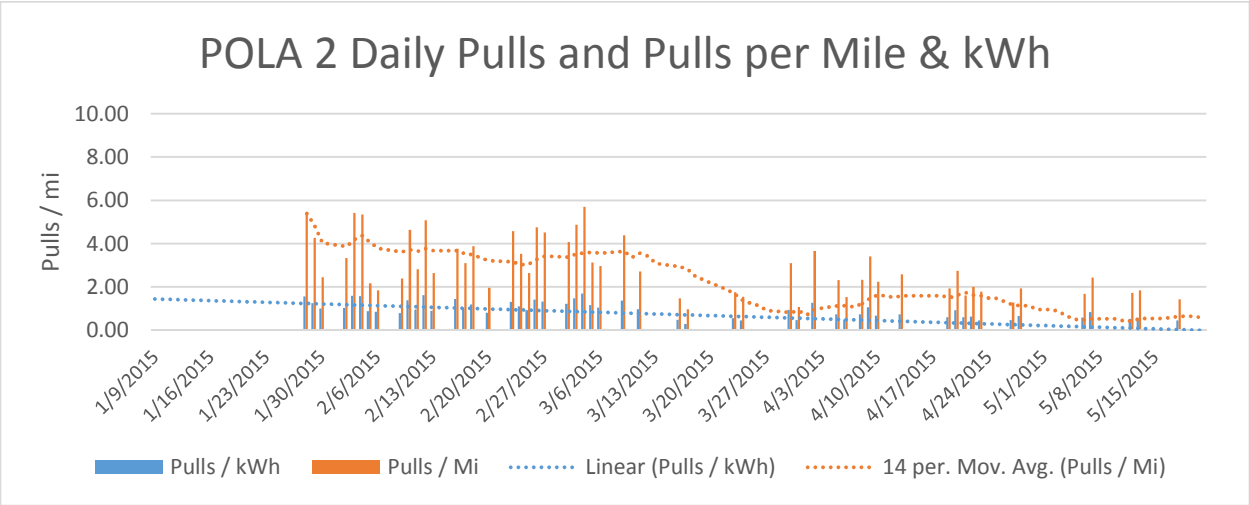
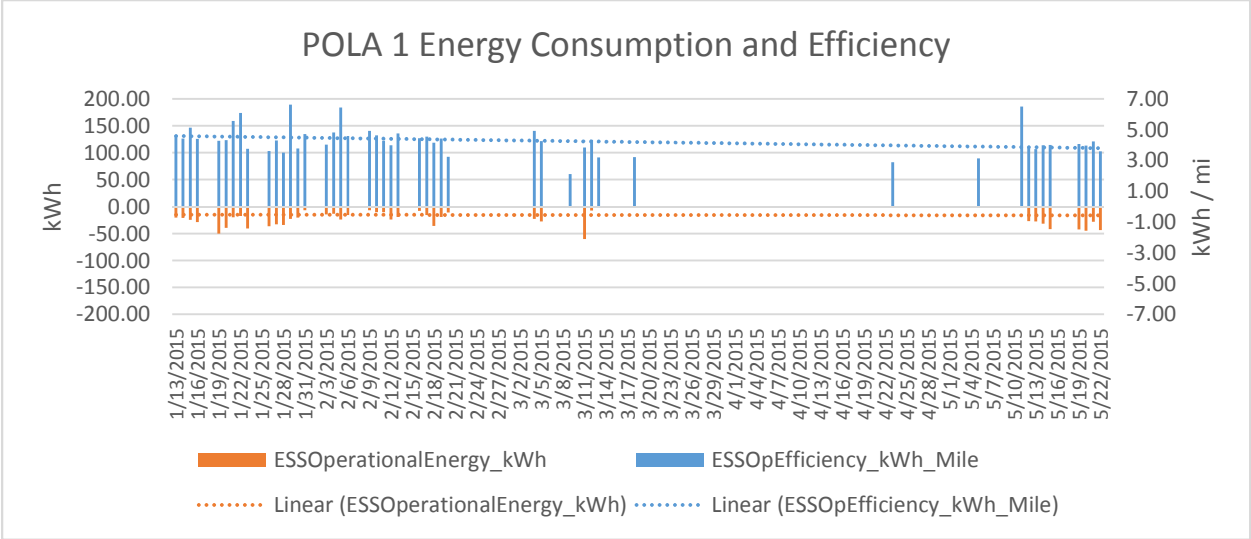


Figure 33. POLA 1 and 2 pulls per DC kWh and mile.

It is interesting to note that, while POLA-2 used more energy per pull to haul its heavier containers longer distances, it also used less energy per mile (3.46 kWh/mile) than POLA-1 (5.28 kWh/mile). This suggests that the tractors operate more efficiently when carrying fewer containers longer distances, even if the containers are heavier. Figure shows total daily energy usage for the two tractors along with average energy efficiency. Daily energy use is measured along the left axes and indicated by the orange bars, showing that POLA-1 uses up to about 50 kWh per day but typically uses 30 kWh or less, while POLA-2 frequently uses more than 50 kWh/day and regularly consumes between 75 and 100 kWh/day.



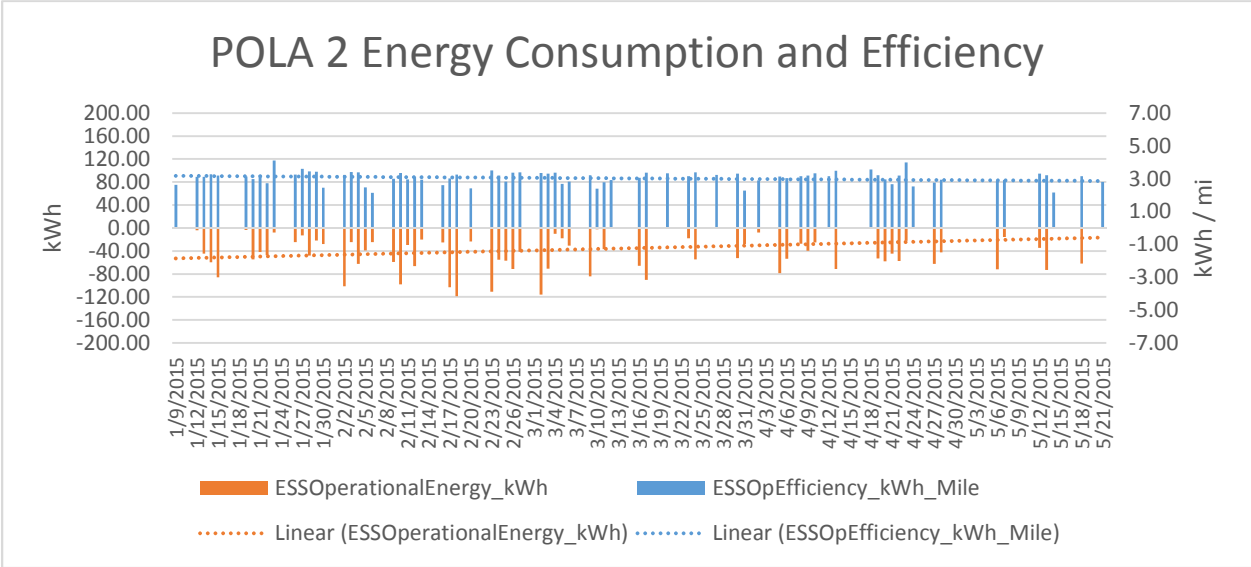
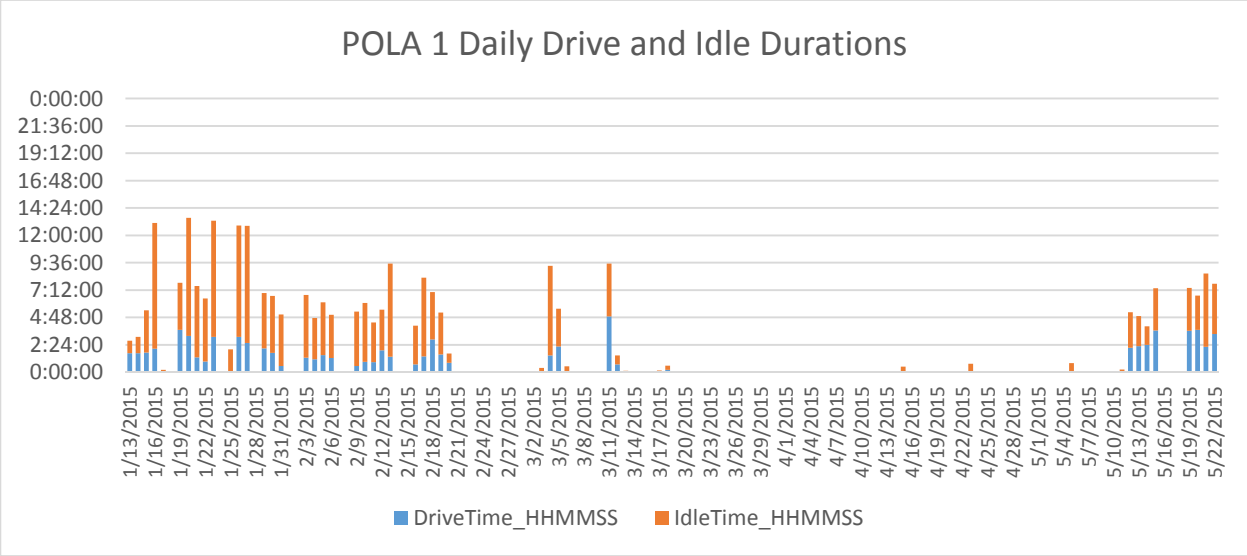


Figure 34. POLA-1 and POLA-2 energy use profiles.

On average, POLA-1 consumed a relatively low 25.6 kWh of DC energy per day, despite a higher rate of consumption. Days of most elevated kWh/mi are often days with lower total energy consumption. Factors at TTSI that contribute to low energy use and low efficiency include long idling intervals, short travel distances, and low average speeds – which can reduce regenerative braking opportunities. By contrast, POLA-2 operated with a lower rate of energy consumption while consuming a significantly higher daily average of 34.2 kWh of DC energy.

This suggests that tractors operating in small yards with relatively low levels of activity may appear less efficient because they use more energy per mile, but also use very little overall energy and may therefore offer substantial benefits over diesel tractors that spend large amounts of time idling and wasting fuel. This conclusion seems to be confirmed by UC Riverside dynamometer testing of a third electric yard tractor using an identical drive system to those installed into the POLA tractors, the results of which are

summarized in the "Summary of Findings" section near the end of this report. The impact of driving versus idle time can impact overall efficiency is graphically displayed in **Error! Reference source not found.**. Drive time is simply the time the vehicle is in motion. Idle time is time the vehicle is keyed on but not moving. Average overall time in operation is average of the sum of drive and idle times for each given day with zero values ignored.



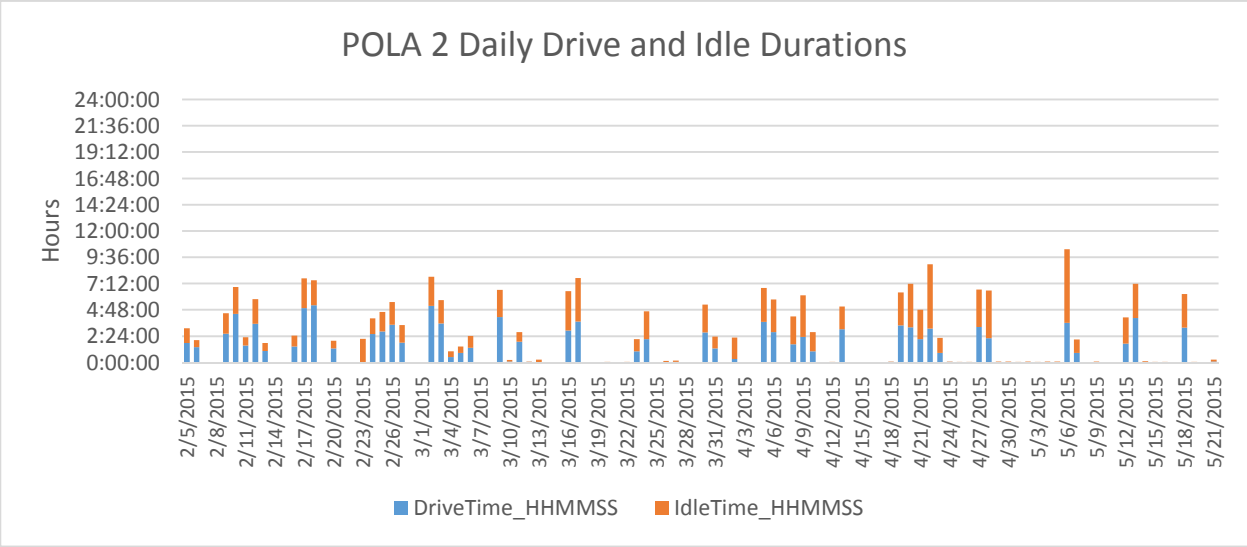


Figure 35. POLA-1 and POLA-2 driving versus idle time.

The average overall POLA-1 daily operating duration was roughly 6 hours and 46 minutes, which aligns well with TTSI's 8 hour shift, where there would be a lunch break plus two shorter breaks. POLA-1 had a drive/idle ratio of .47or 47%, meaning it was driven 47% of the time it was in service and idled the remaining 53% of the time. Furthermore, POLA-1 was in operation for only 32% of the day. This is because in smaller yards like TTSI's, speeds are very low, moves are very short, and much time is

spent jockeying for position and hooking and un-hooking containers. Essentially, the faster the vehicle reaches a trailer either due to higher speed/acceleration and/or short distances between them, the greater the idle time is likely to be even though the vehicle can realize increased total throughput.

POLA-2 averaged 2 hours and 32 minutes a day driving vs. 4 hours and 31 minutes spent idling. The average overall operating duration was roughly 5 hours and 59 minutes, which seems a bit short of 8 hour shift even when taking into account breaks. POLA-2 had a drive/idle ration of for a ratio of .56 or 56%, indicating it was driven 56% of the time while it was in operation and idled for the remaining 44% of its operating time. It was operated for 42% of each day. Dole's larger yard allows for higher speeds and more time spend driving from the ship to the container yard and less time jockeying for position. Looking more closely at Figure, one can see that there are days when POLA-2 was operated for well over 8 hours. Presumably this is when ships were arriving and being unloaded. Conversely, the tractor was operated for far less than 8 hours on many other days. TransPower's understanding is that this reflects the port's practice of shutting the truck off when it is not in use, whereas TTSI appears to leave the vehicle on even when not in use. Prolonged idling while consuming very little energy, aggregates zero distance and has the potential to skew the kWh/mi figures. However, even when left idling, the electric tractor is not emitting any emissions, while a diesel tractor is actively polluting.

Tables 1 and 2 provide a compilation of monthly and total demonstration phase operating data for the two tractors. San Diego Gas & Electric Company (SDG&E) assisted in the data collection process for POLA-2 by instrumenting the Dole facility with AC power measurement hardware. These measurements identified an AC energy measurement error within the ICU. Once this issue was corrected in April 2015, we observed a 10-12% reduction in the AC energy consumption reported by the vehicle, as compared with DC energy consumption. As can be observed in Table, calculated AC energy consumption is much closer to DC consumption measured by the vehicle starting in April, reflecting an estimated 92% charging efficiency. The third tractor in operation at IKEA has been charging at a calculated efficiency of 93%, supporting this data point. POLA-1 data suggest higher AC energy use relative to DC energy, but these data are skewed through March by the ICU measurement error described above.

A factor affecting the overall energy efficiency of both tractors is the fact that the vehicles remained energized whenever plugged in, during which certain tractor accessories continued to run. At lower charge rates and during extended periods of non-use (e.g., weekends), the charger spends more time supporting hotel loads such as cooling pumps, controllers, and fans. While the amount of energy consumed during these periods was relatively small, its relative impact was greater in the case of a tractor such as POLA-1 whose total energy use is comparatively small. One potential future improvement that would address this inefficiency is incorporating an "auto-hibernate" feature into the tractors that would shut down the vehicles completely once their energy storage subsystems are completely balanced and other safety criteria are met.

Tables 1 and 2 corroborate earlier data indicating that POLA-2 has driven farther and pulled more containers than POLA-1, and that POLA-2 has used more energy than POLA-1 while using it more efficiently.

Table 1. POLA-1 project summary.

POLA 1 Project Summary							
	Previous Miles	January	February	March	April	May	Project to Date
Km per Month	518	79.4	96.4	47.6	0.2	148.6	890.2
Miles per Month	322	49.3	59.9	29.6	0.1	92.3	553.3
Total Charge Energy (ESS)		393.7	278.0	157.5	15.2	293.2	1137.6
Total Charge Energy (Wall)		433.8	306.4	173.6	16.8	323.1	1253.6
Days in Operation		15.0	14.0	4.0	0.0	9.0	42
Total Pulls		681	362	195	0	584	1822.0
Pulls / mi		13.8	6.0	6.6	0.0	6.3	8.19
Average kWh/mi (ESS)		7.98	4.64	5.32	0.00	3.17	5.28
Average kWh/pull (ESS)		0.58	0.77	0.81	0.00	0.50	0.66
Average kWh/mi (Wall)		8.79	5.11	5.87	0.00	3.50	5.82
Average kWh/pull (Wall)		0.64	0.85	0.89	0.00	0.55	0.73
Odometer End Value (km)		405	501	549	549	698	698
Odometer End Value (mi)		251.7	311.6	341.1	341.3	433.6	434

*Vehicle did not receive auto-hibernation feature (present on POLA-2) during charging until April and thus used more AC energy that it would have. Also, error was found in AC current reported by inverter, was reporting 10% high.

** Value lower than DC energy due to small samples over a lower month, actual value is higher and reflected in Year End Projections

***Values extrapolated from March ratio of ESS to wall energy.

Table 2. POLA-2 project summary.

POLA 2 Project Summary							
	Previous Miles	January	February	March	April	May	Project to Date
Km per Month	151.8	249.8	586.0	348.0	348.0	160.0	1843.6
Miles per Month	94.3	155.2	364.1	216.2	216.2	99.4	1145.6
Total Charge Energy (ESS)		608.1	1180.4	723.8	696.1	357.1	3565.5
Total Charge Energy (Wall)		668.4	1297.5	795.6	765.1	392.6	3919.2
Days in Operation		15	19	13	14	6	73
Total Pulls		621	1353	626	444	170	3214.0
Pulls / mi		4.0	3.7	2.9	2.1	1.7	2.87
Average kWh/mi (ESS)		3.92	3.24	3.35	3.22	3.59	3.46
Average kWh/pull (ESS)		0.98	0.87	1.16	1.57	2.10	1.34
Average kWh/mi (Wall)		4.31	3.56	3.68	3.54	3.95	3.81
Average kWh/pull (Wall)		1.08	0.96	1.27	1.72	2.31	1.47
Odometer End Value (km)		402	988	1336	1684	1844	1844
Odometer End Value (mi)		249.5	613.7	829.9	1046.1	1145.6	1146

*In April, an error was found and corrected in AC current reported by inverter, was reporting 10% high.

** Value lower than DC energy due to small samples over a lower month, actual value is higher and reflected in 12-month projections.

***Values extrapolated from March ratio of ESS to wall energy.

A key finding from the SDG&E instrumentation is that POLA-2's on-board charger operates with a 98-99% Power Factor rating, a best in class number for a charger of this magnitude.

Tractor Reliability and Service Record – Both POLA tractors use TransPower's second generation electric drive system for yard tractors and were essentially complete redesigns when compared to the first generation system first tested in 2012. As a result, these tractors were essentially first-of-a-kind vehicles, representing an advanced prototype stage of development and refinement. Regardless, the tractors suffered very few failures, proving themselves as excellent foundations for larger deployments. Failures were typically addressed within one day, and occurred most frequently during the first month of service – as would be expected for a demonstration of such a vastly redesigned and improved tractor. Below is a list of types of failures experienced during the demonstration phase of the project.

POLA-1 In-Service Issues and Remedies

- **Broken air fitting** – Prototype Assembly issue, resolved in production
- **BMS required re-calibration** – inherent issue with off the shelf Flux BMS system, Transpower Cell Saver system has report 0 calibration issues in EDD test vehicle.
- **Routine software updates** – Every 3 months vehicle software is improved to increase reliability, improve diagnostics and increase efficiency
- **Coolant fitting inside inverter charger unit -** Prototype Assembly issue, resolved in production
- **Inverter charger HV Sense Board –** updated high voltage sense board addresses voltage and temperature sensing issues with a resistor network. All ICU's in the fleet have been addressed or are in process for board revision replacement.
- **BMS local battery sense harness -** Prototype Assembly issue, resolved in production. Cell Saver design reduces harness and thus such harness based failures by 70%.
- **Grounding of pedal sensor –** Vehicle's operator cab grounding where pedal sensor was inadequate. Updated grounding methodology which fixed sensing issue. Issue was resolved on all 5 of TransPower's Kalmar based yard tractors.

POLA-2 In-Service Issues and Remedies

- **Routine software updates -** Every 3 months vehicle software is improved to increase reliability, improve diagnostics and increase efficiency
- **BMS local battery sense harness -** Prototype Assembly issue, resolved in production. Cell Saver design reduces harness and thus such harness based failures by 70%.
- **12V Jump Start –** Longshoreman have a habit of leaving the 12V battery connected safety lights always on. Training and Signage has helped reduce

this issue.

- **Coolant fitting inside inverter charger unit -** Prototype Assembly issue, resolved in production
- **Accessory inverter drive calibration –** Lenze Accessory Drive inverter was re-calibrated to address nuisance overcurrent faults due to higher hydraulic loads, and different operator habits at Dole than typical to IKEA and TTSI. This calibration update has helped reduce accessory drive glitches in all Transpower Yard Tractors and Drayage Trucks.
- **Inverter charger HV Sense board -** updated high voltage sense board addresses voltage and temperature sensing issues with a resistor network. All ICU's in the fleet have been addressed or are in process for board revision replacement.

Table 3 sums and averages the project totals. It is interesting to extrapolate what 12 months could look like if these rates of usage were to average out. Total miles, charge energies, and pulls were done averaging monthly data then multiplying by 12 months.

Table 3. Project totals and summary.

Project Totals and Averages		IKEA
Miles per Month	1699	4604
Total Charge Energy (ESS)	4703	9502
Total Charge Energy (Wall)	5173	9992
Days in Operation	115	1551
Total Pulls	5036	6244
Pulls / mi	5.53	1.38
Average kWh/mi (ESS)	4.37	2.10
Average kWh/pull (ESS)	1.00	1.54
Average kWh/mi (Wall)	4.81	2.21
Average kWh/pull (Wall)	1.10	1.62
Odometer End Value (mi)	1579	11290

SUMMARY OF PROJECT FINDINGS

The Electric Yard Tractor Demonstration (EYTD) project, with significant contributions and cost sharing from several parallel efforts, resulted in the conversion of two Kalmar Ottawa diesel tractors to battery-electric propulsion, using a new and improved version of TransPower's ElecTruck™ drive system. The tractors were manufactured largely as planned during the early stages of the project, drawing on lessons learned from TransPower manufacturing and testing of two earlier prototype electric tractors in 2011-13. Key features of the new drive system installed into the POLA tractors – including

larger battery enclosures, a more robust transmission, and an integrated power and accessories assembly – were identified as urgent needs during the design phase at the start of the project and the two tractors were built as designed and envisioned.

The performance of the two POLA tractors validated the importance and the benefits of these and other design innovations, demonstrating the ability of the TransPower-built electric tractors to operate reliably for long periods in real-world operating conditions. These are the first battery-electric yard tractors of the 100,000-lb. weight class known to have operated reliably in real-world environments on a sustained basis. The demonstration phase of the project was truncated by a few months and had to be shifted from the initial planned demonstration site at Eagle Marine Terminals, for various reasons described earlier in this report. However, once the tractors were deployed, they performed reliably and gained a far greater amount of actual operating experience than any electric or hybrid-electric tractor of this class deployed previously. Electrically-driven tractors deployed on previous demonstration projects have typically failed to provide the power, towing capacity, operating range, or reliability demanded by fleet operators. Driver input and review of energy and other use models helped TransPower improve and refine operational parameters. The two tractors accumulated a total of more than 1,600 miles of operation, most of this in real-world use, producing a wealth of valuable data.

Testing of a third tractor with IKEA, using the same design of the POLA tractors, provides further evidence that the TransPower tractor design offers significant environmental and economic benefits over competing tractor designs, including hybrid-electric as well as conventional diesel tractor systems. These results are given further weight by a report recently released by UC Riverside (UCR), which documents extensive testing of the IKEA tractor on UCR's chassis dynamometer in September 2014. During this testing, UCR measured the energy efficiency of the electric tractor and compared it with the efficiency of similar Kalmar Ottawa tractors tested with diesel and diesel-hybrid drive systems. UCR then estimated the potential energy cost savings of electric tractors using TransPower's drive system, taking into account prevailing prices for diesel fuel and electricity. This tractor was subsequently placed into service at IKEA's California distribution center in Lebec, providing additional comparative data to help frame the results of this contract. Figure 36 summarizes the results of this testing and analysis, showing the estimated cost per mile of using a TransPower electric tractor in comparison with the cost of using a conventional diesel tractor or a hybrid-electric tractor. The hybrid tractor costs are based on testing of a competing hybrid tractor a few years ago.

As indicated, TransPower's electric tractor has an estimated energy cost of 31 cents per mile, compared with $1.12 per mile for an equivalent diesel yard tractor and 99 cents per mile for the latest hybrid yard tractor tested by CE-CERT. This shows that the TransPower electric tractor has less than one-third the energy cost of either of these two options. The high reliability of the TransPower tractors also suggests that additional maintenance savings may accrue to future users. After eight consecutive months of operation of the third tractor at IKEA's distribution center, TransPower and IKEA personnel estimated that the TransPower electric tractor would cost about $5,000 to $6,000 less per year to maintain than a typical IKEA diesel tractor. No significant

maintenance or repairs were required for the two POLA tractors during the 8-9 months that both of these tractors were tested and operated during this project.

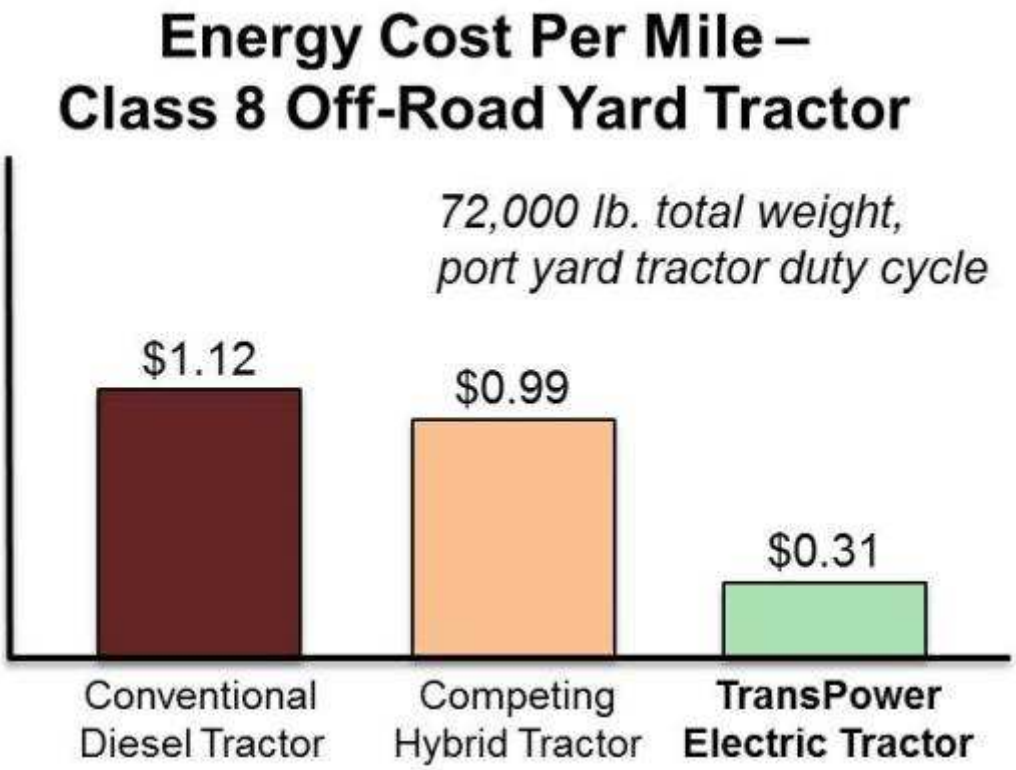


Figure 36. Cost per mile of using TransPower electric tractor versus conventional diesel and competing hybrid-electric designs. (Source: UC Riverside/CE-CERT dynamometer lab).

While the in-service demonstration project under this contract was not executed at the intended site, Eagle Marine Terminals, both POLA tractors were demonstrated extensively in port-like operating conditions – testing sufficient to validate the UCR dynamometer testing results and TransPower's analytical predictions – which were the main goals of the project. Dating back to early September 2014, when POLA-1 began test operations this first tractor accumulated a total of 9 months of testing and in-service use through the end of the project. POLA-2, which began drive testing about a month later, accumulated a total of about 8 months of various operations. Therefore, the two tractors accumulated a combined total of 17 months of testing and in-service use to validate their functionality and support data collection during the contract term. This exceeds the 12 months of total testing required by the ARB for completion of Task 8 and submission the *Final Operations Report*. Eliminating the time spent in TransPower testing and the 6 weeks of idle time POLA-1 spent at SA Recycling in March and April 2015, the tractors still have spent at least 12 months in real world service – 7 months by

POLA-1 (1 month at SA Recycling, followed by 6 months of total operations by TTSI) and 5-1/2 months by POLA-2 (with Dole).

The diversion of the two tractors from the planned demonstration at Eagle Marine Terminals to the Dole, TTSI, and SA Recycling sites yielded an unplanned benefit in that this enabled the collection of data under a variety of operating conditions. As discussed throughout the latter sections of this report, significant differences in how the tractors were operated among the various sites resulted in significant differences in measured energy efficiency and other key parameters. This suggests that the benefits of electric yard tractors could vary significantly, depending on each application and how the tractors are used in each application.

Other key lessons learned from the demonstration phase of the project include:

- Charging infrastructure is a key concern. While the battery charger itself is on the tractor, the electrical work and supporting infrastructure to support charging remain significant in most cases. Site preparations to accommodate electric tractor operations can be extensive and require advance planning and budgeting.
- Due to the variations in how tractors are used, widespread adoption of the technology may require that various options be offered. For example, users who have less intensive operations or who can charge the batteries more frequently can potentially use tractors with smaller battery packs, which can reduce tractor weight and cost.
- Accessory loads, while small, can represent a significant percentage of total energy consumption for tractors that are out of use for extended periods. Development of a “hibernation” mode to reduce energy consumption during periods of non-use could be a worthwhile design improvement for certain applications.
- Overall energy consumption is reduced significantly by the various drive system innovations introduced during this project, including the automated manual transmission and efficient electrically-driven accessories. Improved management of battery charging appears to offer the potential for additional gains.
- Not all tractors require high-power fast charging. Providing a flexible range of charging options could enable such users to save money on charging infrastructure and to potentially avoid higher electricity costs associated with utility demand charges.
- Drivers are generally very happy with the electric tractor option once they are properly trained and get used to the differences from standard diesel tractors. Proper training and follow-up service are key to enhancing the user experience and gaining product acceptance.

In summary, the two POLA tractors have demonstrated unambiguously that electric propulsion is a practical alternative for heavy-duty Class 8 terminal tractors. As evidence of the success the EYTD project had in demonstrating the benefits of electric

tractors using TransPower's technology, five different fleet operators teamed up with TransPower to acquire funding to deploy seven additional electric tractors, at sites from San Diego to Sacramento, in 2016.

PLAN FOR COMMERCIALIZATION

The first step in TransPower's plan for commercialization of the technologies demonstrated during the EYTD Project is to continue to operate these tractors while simultaneously expanding the demonstration fleet to include additional tractors at the Ports of Los Angeles and Long Beach, along with expanded tractor operations at warehouses, distribution centers, and other locations where yard tractors are commonly used. Focusing on the State of California, TransPower's goal is to place at least 100 electric yard tractors into demonstration fleets over the next five years. This will enable the accumulation of millions of miles and hundreds of thousands of hours of operation over this period, providing sufficient experience and data to perfect the electric drive system and build the interest of tractor OEMs such as Cargotec, along with tractor operators worldwide.

TransPower made significant progress toward achieving this first step during the course of the EYTD project, by:

- Completing a third tractor and entering it into service at IKEA's main California distribution center, as discussed earlier in this report. As of the date of this report, the IKEA tractor has accumulated nearly 7,000 miles of operation, and is operating for as many as three shifts per day.
- Completing an upgrade of the two earlier prototype tractors that were tested in Texas in 2013. These two tractors now use the same drive system installed into the POLA tractors. One has been operating temporarily at the Port of San Diego and the other has been showcased to various tractor operators in Southern California, pending long-term deployment with a tractor fleet operator in the Greater Los Angeles area (tentatively selected to be Osterkamp).
- Securing commitments from five fleet operators to use additional electric yard tractors – IKEA, Harris Ranch, Devine Intermodal, Grimmway Farms, and Dole – and successfully competing for funding from the California Energy Commission (CEC) to demonstrate a total of seven new electric yard tractors at their facilities. These tractors will be operating throughout California – two in Sacramento, three in the San Joaquin Valley, and two in San Diego.
- Attracting tentative interest from several additional tractor fleet operators, who are in various stages of discussion with TransPower regarding acquisition of additional tractors for demonstration purposes. This growing list of fleet operators includes Walmart, FedEx, Kroger, BNSF Railway, Bolthouse Farms, Foster Farms, Purolator, and Pasha.

The prominence of the fleet operators showing interest in electric tractors using TransPower's technology suggests that TransPower's commercialization prospects are very encouraging. Following establishment of an expanded demonstration fleet, along with continuous improvement of its drive system to reflect lessons learned during the demonstrations, the second step in TransPower's plan is to commercially market the yard tractor drive system directly to tractor original equipment manufacturers (OEMs) and tractor fleet operators.

From TransPower's inception in 2010, we have collaborated closely with established vehicle OEMs such as Cargotec, which provide excellent paths to market through their manufacturing and dealership infrastructures. We have also developed a stable supply chain with reliable partners such as EPC, Eaton, JJE (our primary motor supplier), and multiple battery suppliers. These relationships provide a strong foundation for our tractor commercialization plan, and give us confidence that we can scale up manufacturing of our EV components and the vehicles that use them, as we generate increased user demand for heavy-duty EVs in our target markets.

The new electric yard tractor projects funded by the CEC will help us stimulate this market demand by facilitating new relationships with three important new path-to-market partners engaged in major agricultural operations in California – Harris Ranch, Grimmway Farms, and Devine Intermodal – and will build on an important existing relationships with IKEA and Dole. All are ideal channel partners for deployment of battery-powered yard tractors, as summarized in Table 4. IKEA seeks to build on the success of its current electric tractor – the first prototype using TransPower's improved ElecTruck™ design – which is nearly a "well-to-wheels" zero emission vehicle by virtue of the fact that 90% of its energy comes from IKEA's on-site solar photovoltaic system. Having a key customer with the global presence of IKEA cast a vote of confidence in the ElecTruck™ system by placing a second tractor into service will send a strong message throughout the global retail community. In fact, IKEA is presently considering adopting electric yard tractors at three other distribution centers in North America – in Tacoma, Washington; Savannah, Georgia, and Perrysville, Maryland. IKEA's head of North American Sustainability has also offered to help TransPower reach out to other globally-recognized retailers who use yard tractors.

The other three fleet operator partners who will begin operating electric tractors built by TransPower in 2016 will help TransPower demonstrate and perfect variants of our tractor system that can operate in challenging agricultural environments, where the tractors will be exposed to soil, water, chemicals, and uneven terrain. Success in these environments could lead to widespread agricultural use of electric tractors such as TransPower's, which would have significant air quality benefits in disadvantaged communities such as those targeted by the ARB. The two tractors at Devine Intermodal will share field support resources TransPower will deploy in early 2016 to support two electric school buses to be operated in Napa, creating regional project synergies.

TransPower is in discussions with several fleet operators regarding the possibility of teaming up to pursue funding from the Greenhouse Gas Reduction Fund, which is expected to consider funding for projects involving electric yard tractors during the second half of 2015. In the longer term, TransPower intends to work closely with the ARB and other agencies to leverage various other forms of financial incentives, such as

Proposition 1B buy-down incentives, to help fleet operators deal with the higher up-front cost of electric yard tractors. At the same time, TransPower will work to steadily reduce the cost of its drive system, constantly seeking lower cost components and manufacturing methods. Another grant received by TransPower from the California Energy Commission during the course of the EYTD Project will fund several new manufacturing initiatives aimed at achieving exactly these goals.

Table 4. Tractor partners, interests, and significance to path-to-market development.

Partner	Interests in New CEC Projects	Path-to-Market Significance
IKEA	IKEA's tractor will build on the enormous success of its first prototype electric tractor and support IKEA's goal of electrifying all its California tractors.	IKEA is one of the world's largest and most prominent retail firms, with the potential to drive sales and showcase the capabilities of electric yard tractors on a global basis.
Harris Ranch	Harris Ranch has a long-standing interest in sustainability projects that can improve air quality in the San Joaquin Valley, and a desire to improve the economics of its transportation operations.	Harris Ranch is California's largest beef producer and the largest ranch in on the West Coast, representing a major customer that could drive sales of electric tractors for agricultural purposes.
Grimmway Farms	Grimmway Farms is committed to sustainability, as evidenced by its 2011 *PG&E Clean and Green* award for energy efficiency and environmentally progressive business practices.	Grimmway Farms is a high visibility agricultural concern with several locations around California that are potential sites for adoption of electric tractors. Its HDEYT site is in the distressed San Joaquin Valley.
Devine Intermodal	The new CEC project supports Devine Intermodal's goal of deploying smart technologies and demonstrating environmental concern.	Devine Intermodal is strategically located in the State Capitol and will operate tractors at two major facilities, the Blue Diamond almond plant and Farmer's Rice Cooperative.
Dole Food Company	Operation of the two new electric tractors supports Dole sustainability goals including port-focused initiatives that have reduced container yard fuel use by 33% since 2007.	Founded in 1851, Dole is the world's largest producer and marketer of fresh fruits and vegetables, and can thus become a large, extremely high-visibility customer for electric tractors.

Our strategy for directly addressing the high cost of electric yard tractors is to continue achieving dramatic reductions in the labor effort required to convert tractors using the ElecTruck™ system, while initiating steps to drive down the costs of major ElecTruck™ system components. We can currently assemble a complete "kit" – all of the subsystems required for the conversion of large Class 8 yard tractors – in very low volumes, for a total cost of about $240,000 per vehicle. When the cost of the tractor itself and installation of the kit is factored in, the total cost of the tractor is about $350,000. These figures must be reduced to achieve significant market capture. Table 5 provides approximate cost figures to summarize the cost reductions we believe are possible. As indicated, we believe that a reduction of about 25% from today's costs is possible by 2017, and that another reduction of approximately one-third is possible by 2020 with further manufacturing improvements and increases in manufacturing scale. This would bring the 2020 cost down to $120,000 – half the current cost.

Table 5. Current yard tractor kit assemnly costs and projected cost reductions.

Cost Element	Current Cost	2017 Target Cost	2020 Target Cost
Energy storage subsystem structures	$10,000	$5,000	$2,000
Battery management system (BMS)	15,000	7,500	1,500
Inverter-charger unit (ICU)	30,000	20,000	15,000
Motive drive subsystem	20,000	17,000	12,000
PCAS – other components/assembly	75,000	55,000	40,000
Batteries	55,000	50,000	35,000
Other component/subsystem costs	35,000	25,000	14,500
TOTAL	**$240,000**	**$180,000**	**$120,000**

We believe that most of these cost reductions can be achieved through intelligent redesign and manufacturing of a few key components. For example, each ICU presently costs $30,000. We believe the cost of this ICU in large production quantities can be driven down to $15,000, resulting in a $15,000 net cost reduction by 2020. We also hope to reduce the cost of the ElecTruck™ battery management system from $15,000 to $7,500 per tractor by 2017, and by 2020 we believe this cost can be reduced to $1,500. Combined with reductions in the costs of battery structures and the batteries themselves, we believe the total cost of the battery subsystem can be reduced from $80,000 today by more than 50% by 2020 - to $38,500.

In addition to driving down our component costs, another key cost-competitiveness goal is to transition our current three-stage production line, which is geared toward turn-key conversion of vehicles, to a modified three-stage production line where many integrated drive system kits can be validated and shipped to OEMs for installation on their assembly lines, rather than always installed into vehicles by us. We will continue performing complete vehicle conversions indefinitely, but truly large-scale penetration of the heavy-duty EV market with our ElecTruck™ components will require that OEMs begin installing these components into their vehicles. Packaging our EV components into kits to facilitate this process will drive down manufacturing costs to the lowest possible levels and enable OEMs to provide warranties and support for heavy-duty EVs via their existing distribution networks. At the 2020 target cost of $120,000, we could sell kits profitably to OEMs at a price that could enable OEMs to sell fully-equipped high-end electric Class 8 tractors for about $250,000. This would reduce the incremental cost of an electric yard tractor to less than $150,000 and increase the likelihood of widespread market acceptance of our technology.

The EYTD project made a major contribution toward enabling TransPower to improve the cost-effectiveness of electric tractor manufacturing. Figure 37 shows the steep reductions TransPower has been able to achieve in the number of hours required to manufacture prototype electric yard tractors over the course of the EYTD project. As indicated, the tractor deployed at IKEA in September 2014 took more than 6,500 hours to manufacture (left bar), while each of the two POLA tractors subsequently built under

this project (center bar) took approximately half as many hours. More recently, the upgrades of the two tractors previously operated in Texas was achieved with fewer than 2,000 hour per tractor (right bar) – less than one-third of the effort required to build the IKEA tractor only one year earlier. This cost-effectiveness is due in part to TransPower's success in adapting similar components to multiple vehicle models. This trend is very encouraging and suggests that in commercial scale, electric yard tractors will be built very cost-effectively.

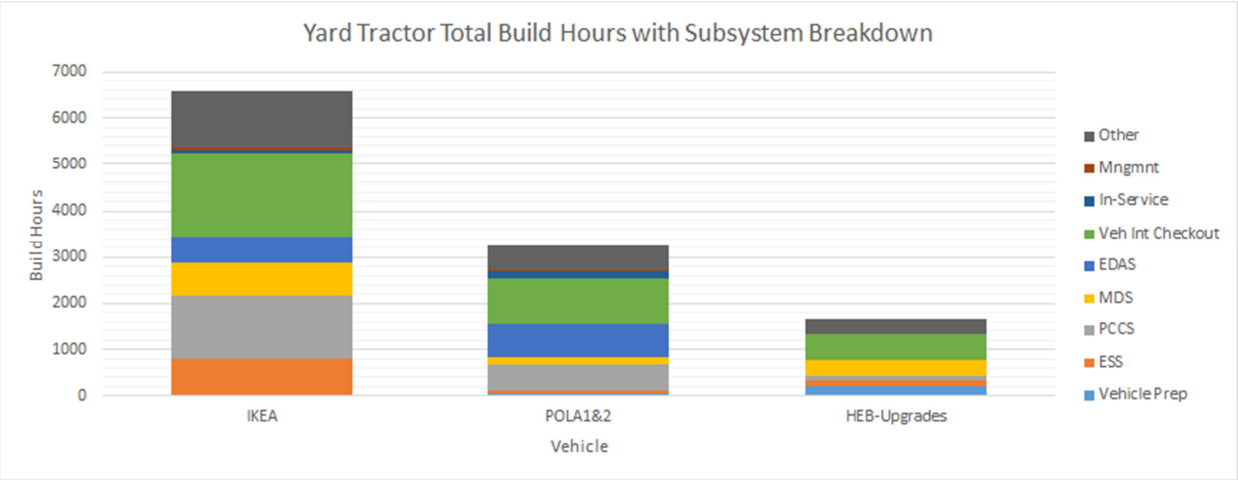


Figure 37. Trend in tractor assembly hours over the course of the EYTD Project.

In summary, we view yard tractors as one of the most promising markets for our ElecTruck™ electric drive products. Diesel-powered yard tractors are among the dirtiest and least fuel-efficient classes of commercial vehicles. Their duty cycles have greatly fluctuating power requirements, under which diesel engines operate inefficiently. Fuel use for a single tractor can be as high as 10,000 gallons/year. Applying battery-electric propulsion to yard tractors is a natural market opportunity because using batteries to meet peak power requirements is more efficient than ramping engines up and down. Yard tractor use is concentrated at many locations under pressure to reduce emissions, such as ports, rail yards, and distribution centers – operations that tend also to be in disadvantaged communities in greatest need of clean vehicle technologies and high-tech jobs.

FINANCIAL PERFORMANCE

TransPower's total project expenses through May 27, 2015 total $2,194,536. This included $1,000,000 in ARB funds and $1,148,466 in cost sharing. Sources of cost share included:

- TransPower and Cargotec cost sharing directly in support of the Port EYTD project: $376,939.

- TransPower cost sharing related to parallel IKEA tractor development: $340,079.
- TransPower cost sharing related to development of common components used on other vehicles developed in parallel with POLA tractors: $205,574.
- TTSI and Dole cost sharing related to operation of POLA-1 and POLA-2: $165,874.
- Port of Los Angeles staff time spent managing project: $60,000.
- **TOTAL: $1,148,466**

The estimates of cost sharing related to the IKEA tractor and other parallel projects were calculated as percentages of the TransPower labor expenses related to common aspects of these projects. Since the IKEA tractor drive system is virtually identical to the POLA tractor drive systems, we counted 50% of the total labor cost of the IKEA project as cost share, assuming the other 50% was related to tasks specific to building and supporting the IKEA tractor and involved no learning applicable to the POLA tractors. However, as the materials purchased during the IKEA project were used solely for the IKEA tractor, none of these expenses were claimed as cost sharing on the POLA EYTD project. The remainder of the POLA-EYTD cost share related to other projects was calculated by estimating the labor effort expended on these projects in developing the common energy storage, automated manual transmission, and PCAS technologies used in the POLA tractors. Again, only labor expended on developing these specific subsystems was included in the calculation. The $205,574 estimate of this cost share represents only about 5-10% of the total investment in these parallel projects during the course of the POLA-EYTD project. The total cost share slightly exceeds the $1,145,934 cost share target established at the beginning of the project. In addition, TransPower has agreed to continue supporting operation of these tractors at the Ports once they are entered into service at Eagle Marine Terminals, at least through the end of 2015.