ELECTRIC YARD TRACTOR DEMONSTRATION PROJECT

FINAL REPORT

for

San Joaquin Valley Air Pollution Control District (SJVAPCD)
Technology Advancement Program Agreement Number C-21516-A
Electric Yard Tractor Demonstration ("EYTD") Project
Report Date: July 21, 2015

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This project (the "Project") leveraged TransPower's electric yard tractor experience to build the next generation of yard tractor, one of which was placed into an operation demonstration by IKEA at its main California Distribution Center in Lebec, CA. 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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ACKNOWLEDGMENT

Transportation Power, Inc. ("TransPower") wishes to acknowledge the support of the San Joaquin Valley Air Pollution Control District (SJVAPCD) which, via its Technology Advancement Program (TAP) provided $500,000 in funding to support the Electric Yard Tractor Demonstration Project. TransPower wishes to also acknowledge financial support of the U.S. Environmental Protection Agency, which contributed a significant portion of the TAP funds. Finally, TransPower acknowledges the support of IKEA, which provided valuable guidance to TransPower during the design and manufacturing of the prototype tractor and whose commitment to the success of this project helped enable this tractor to meet and exceed all operational expectations.

a. ***City contract number:*** C-21516-A, Electric Yard Tractor Demonstration ("EYTD") Project

b. ***Reporting time period:*** August 3, 2013 through August 31, 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, the first prototype of which was placed into operational service with IKEA at its Tejon Pass Distribution Center in Lebec, California in September 2014. 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* covers the entire period of performance during the Project, from August 3, 2013 through August 31, 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.*

Task 1, Administration

Task 1, Administration, covered project technical and financial management and reporting of project results. Financial results are discussed at the end of this report.

Task 2, Tractor Acquisition and Preparation

In December 2013, TransPower completed *Task 2, Vehicle Acquisition and Preparation.* This task consisted of three main subtasks:

- 2.1 Acquisition of Kalmar Ottawa single-rear-axle diesel tractor from Cargotec
- 2.2 ElecTruck™ design update from previous two-axle demonstration
- 2.3 Diesel engine & parts removal and sale of un-needed equipment

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

Task 2.1, Tractor Acquisition – The Kalmar tractor converted to electric drive was ordered from Cargotec in August 2013, with the expectation it would be delivered to TransPower in October 2013. However, manufacturing of the tractor took significantly longer than expected, and TransPower was not notified that the tractor was manufactured and ready to ship until Friday, December 6, 2013. The tractor arrived at TransPower on the morning of December 23, 2013.

While awaiting completion of tractor manufacturing, TransPower made excellent progress in other areas, such as completing a major revision to the overall "ElecTruck™" drive system design (discussed below in the Task 2.2 description) and acquisition of numerous key drive system components (discussed below under subsequent main task descriptions).

Following receipt of the Kalmar tractor, the vehicle was driven for a day to collect data and to characterize its 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 tractor was then moved into TransPower's facility for removal of its engine and transmission (see Task 2.3 description below).

Task 2.2, ElecTruck™ 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 IKEA distribution center 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 IKEA's Tejon Distribution Center 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 May 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 are discussed in more detail under the Task 5 description below.

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 damaged a number of the 224 battery cells that were on this tractor. While most of these cells were eventually salvaged and used in other vehicle demonstrations, this was a costly failure which severely curtailed the duration of the demonstration of one of the two tractors in Texas during the summer of 2013. 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 the two Texas tractors. To make future incidents of this nature less likely with the new tractors, the new tractor design features an upgraded BMS that will use TransPower's own control software, customized for the tractor operations.

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 has been shown to offer better reliability than the Vacon VFDs used in the first prototype tractors, which were adapted from industrial applications. The overall accessory subsystem design was simplified by using the Lenze inverters, as we no longer need to house the accessory 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 some 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 resulted in a net reduction of energy storage capacity of approximately 28.5% as compared with the two Texas tractors, but evaluation of the IKEA duty cycle indicated that this would be ample energy storage to meet its operational requirements. The new design 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.

Figure 1 is a computer illustration of the updated EYTD design resulting from the improvements just described. This illustration prominently shows the large battery boxes mounted to each side of the tractor, discussed in more detail below.

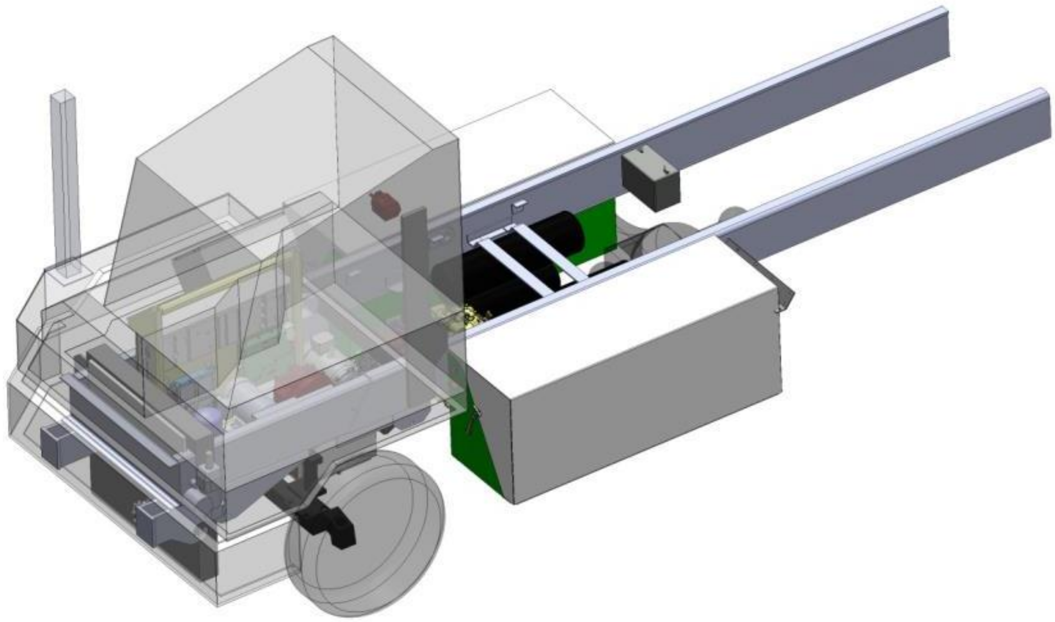

Figure 1. Computer illustration of the new electric yard tractor design.

Figure 2 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.

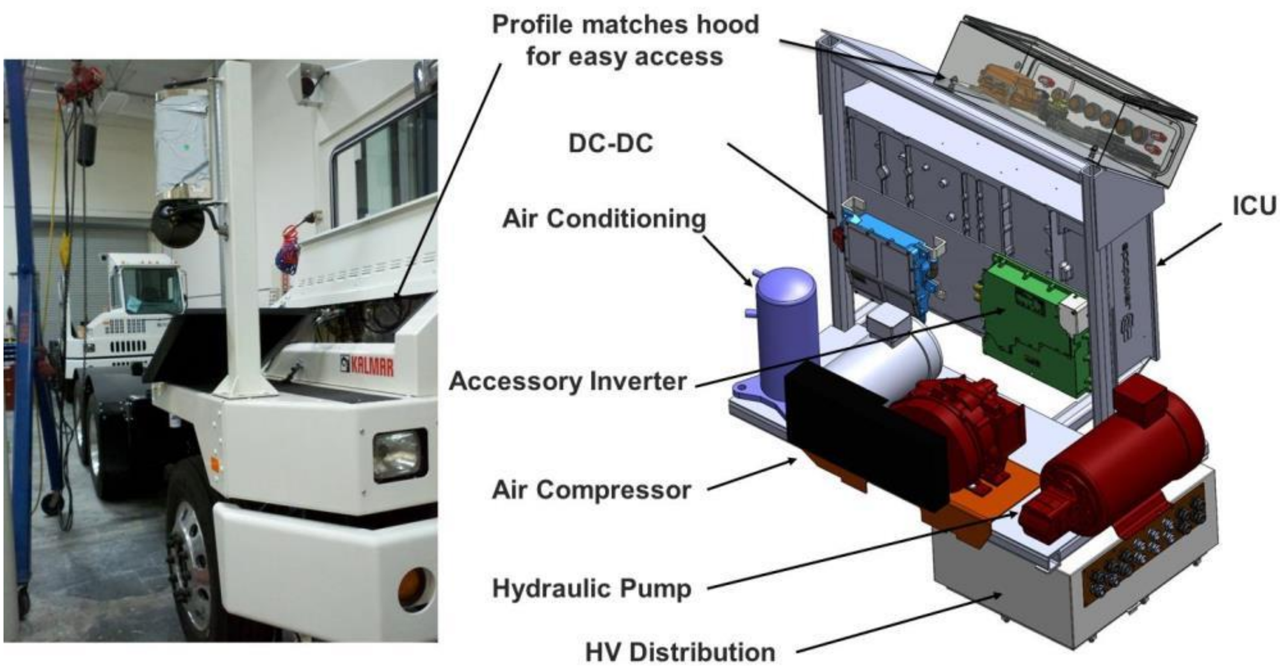

Figure 2. Drawing showing pre-assembly of ICU and accessory components.

With this design advance, there are only four major components installed into each tractor – the motive drive unit (discussed below under Task 5), the two battery compartments, and the ICU/accessory assembly shown in Figure 2. This approach greatly reduces the amount of time spent installing components into the tractor vehicle, and is expected to eventually help facilitate a commercial transition to shipping components to Cargotec for them to install into tractors on their own assembly lines.

Task 2.3, Diesel Engine and Parts Removal – As discussed above, the yard tractor to be converted to electric drive on the EYTD project was delivered to TransPower on December 23, 2013. Removal of the engine and transmission from this vehicle was completed on January 3, 2014, thereby completing Task 2.3. Figure 3 is a photo of the engine being removed from the tractor and Figure 4 is a photo of the tractor following removal of the engine and transmission.

Completion of the Task 2 activities just described cleared the way for subsequent tasks which entailed installation of electric drive components into the tractor, a process that proceeded rapidly and efficiently, given the additional time that was invested in improving the drive system design and installation concept.

Figure 3. Engine being removed from the tractor.

Figure 4. IKEA tractor after removal of engine and transmission.

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 IKEA tractor 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.

Task 3.2, Acquire and Install Cells and Battery Management System Parts – The cells, BMS sensors, and related parts for the IKEA tractor energy storage subsystem were received during the first two months of 2014, and the enclosures for the IKEA tractor were populated with these items in early February 2014. This enabled the complete integration of the IKEA tractor ESS by the end of February 2014, including the mounting of the ESS modules onto the IKEA tractor. This experience confirmed our expectation that the new ESS design would be much easier to integrate than the design used in previous tractors. Figure 5 is a photo of one of the battery compartments of the new design shortly after installation on the IKEA tractor.

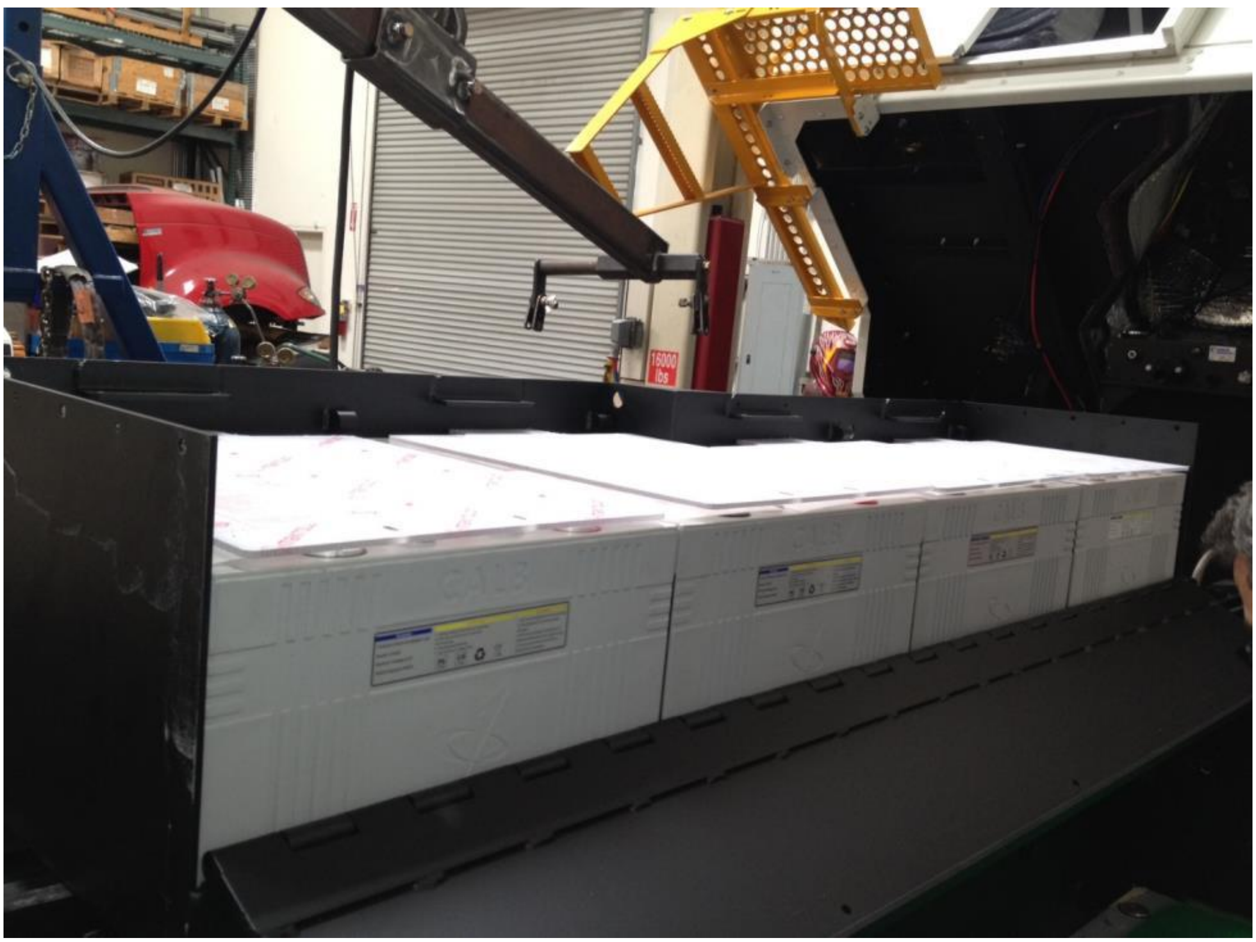

Figure 5. Upper battery compartment containing 28 cells.

The upper module shown in Figure 5 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 6. 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 6. 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, makes 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 5 and 6 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.

Installation of the battery management system (BMS) was performed much later in the project, due to delays in testing and evaluation of the new "Cell-Saver™" BMS TransPower originally intended to install into the IKEA tractor. The Cell-Saver™ BMS was designed to offer several advantages over the Flux Power BMS used on the previous Texas yard tractors and other commercially-available battery management products. Unique features of the Cell-Saver™ BMS and their benefits include:

- Greater processing capability, enabling more accurate measurements of cell voltage. This helps improve balancing of cells, which can extend vehicle operating range and battery life.
- High-current continuous, active charge shuffling, enabling energy from more fully-charged cells to be transferred continuously to lesser-charged cells. Most competing BMS products achieve balancing through passive charge dissipation, which drains energy from higher-charged cells but which simply reject this energy in the form of heat, rather than transferring the charge to lower cells. The active approach of the Cell-Saver™ BMS eliminates this energy waste and improves the efficiency of the system.
- Bolt-on feature, enabling BMS sensor boards to be bolted directly to the bus bars connecting cell terminals. Other competing BMS products require the routing of wires from cell terminals to the BMS boards. Eliminating this wiring reduces assembly time and maintenance issues relating to the possibility of wires becoming damaged or disconnected.
- Higher voltage tolerances, enabling the BMS to be utilized with higher voltage architectures than competing BMS products.

The Cell-Saver™ BMS is also designed with a level of sophistication that allows us to add additional features over time if this becomes desirable.

Figure 7 is a photo showing both Flux BMS boards and Cell-Saver™ BMS boards connected to batteries in one of the IKEA tractor modules. This photo clearly shows the bolt-on feature of the Cell-Saver™ BMS boards and the simplicity of their wiring scheme. This trial installation of both BMS boards was performed in March 2014 while testing of prototype Cell-Saver™ boards by the board manufacturer EPC and by TransPower continued. By April 2014, sufficient confidence was gained to order the 60 Cell-Saver™ BMS boards required for use on the IKEA tractor. During July 2014, these boards were installed into the IKEA tractor, completing the last major phase of tractor integration and enabling drive testing to begin. As discussed in more detail later in this report, this testing revealed a few significant flaws in the design of the Cell-Saver™ BMS boards that were not caught during bench testing during the first half of 2014. As a result, a decision was made to remove the Cell-Saver™ BMS boards from the IKEA tractor and replace them with Flux Power BMS boards. Concurrent work to improve the Flux Power BMS had enabled TransPower to use the Flux Power BMS reliably by the summer of 2014, enabling this switch to be made. The Flux Power BMS boards on the IKEA tractor were ultimately replaced with Cell-Saver™ BMS boards, but not until a year later, after the Cell-Saver™ design flaws were completely fixed.

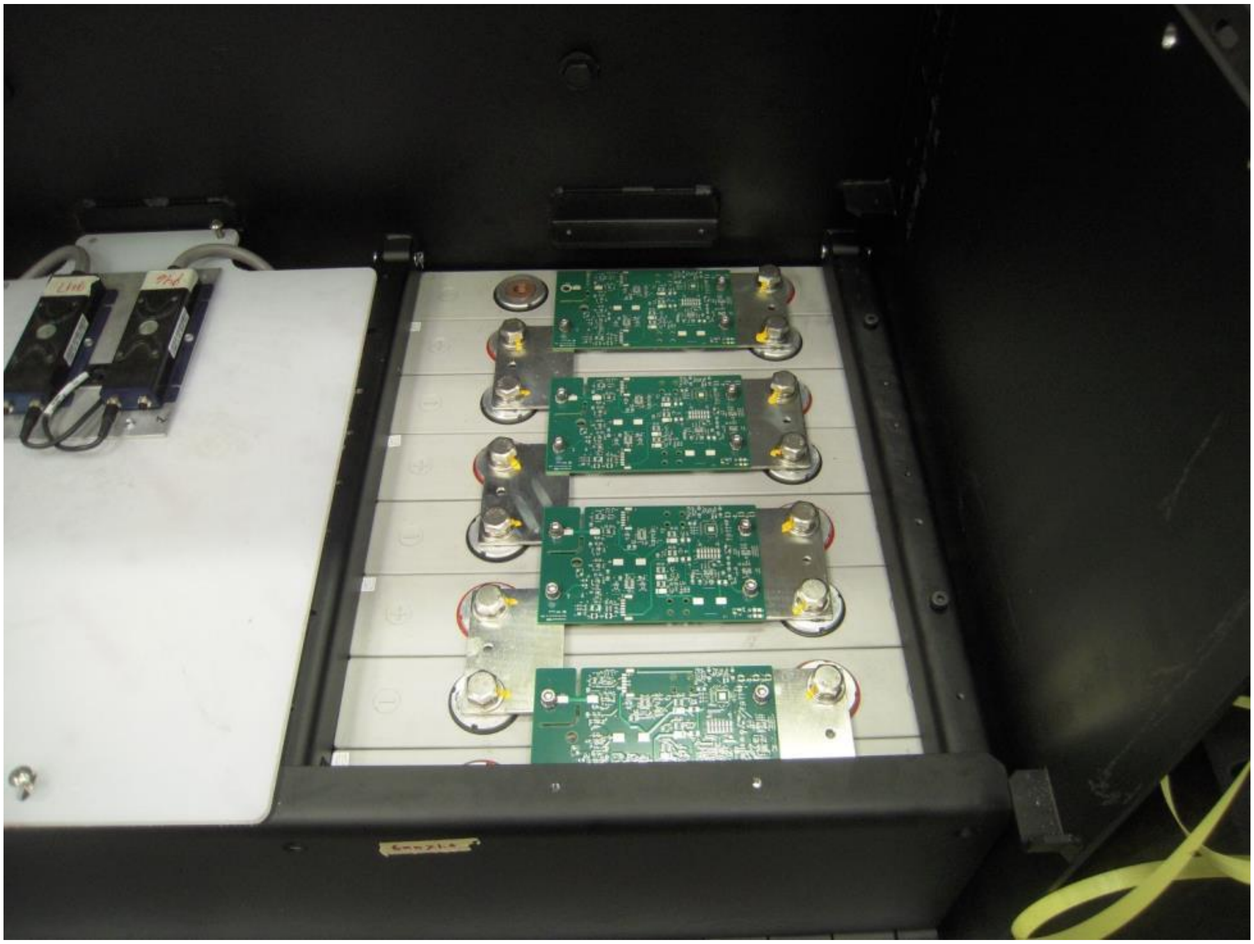

Figure 7. Prototype boards for new BMS being tested.

Task 3.3, Complete Internal Battery Module Wiring – Task 3 confirmed our ability to simplify the wiring inside the battery modules, using the new Cell-Saver™ BMS. Figure 8 is a photo showing two of the IKEA battery modules fully wired with the Cell-Saver™ BMS boards in late July 2014. However, as discussed above, in August 2014, the decision was made to use the commercially-available BMS product provided by Flux Power in the IKEA tractor. The enclosures for this tractor were then rewired to accommodate the Flux BMS and re-installed into the tractor. Upon retesting of the tractor to confirm the functionality of the Flux BMS, commissioning of the tractor was declared completed and the tractor was delivered to IKEA.

Since deployment of the IKEA tractor, the issues experienced with the Cell-Saver™ BMS have been resolved, and this new BMS product is operating reliably on other electric trucks completed by TransPower since August 2014. Based on successes in perfecting the Cell-Saver™ BMS boards in late 2014 and early 2015, a decision was made in July 2015 to replace the Flux BMS boards in the IKEA tractor with the Cell-Saver™ BMS boards before the end of the demonstration phase of this project. This replacement will be completed in August 2015 and the tractor will remain in service with IKEA permanently with the new Cell-Saver™ BMS boards that were originally intended to be used on this project.

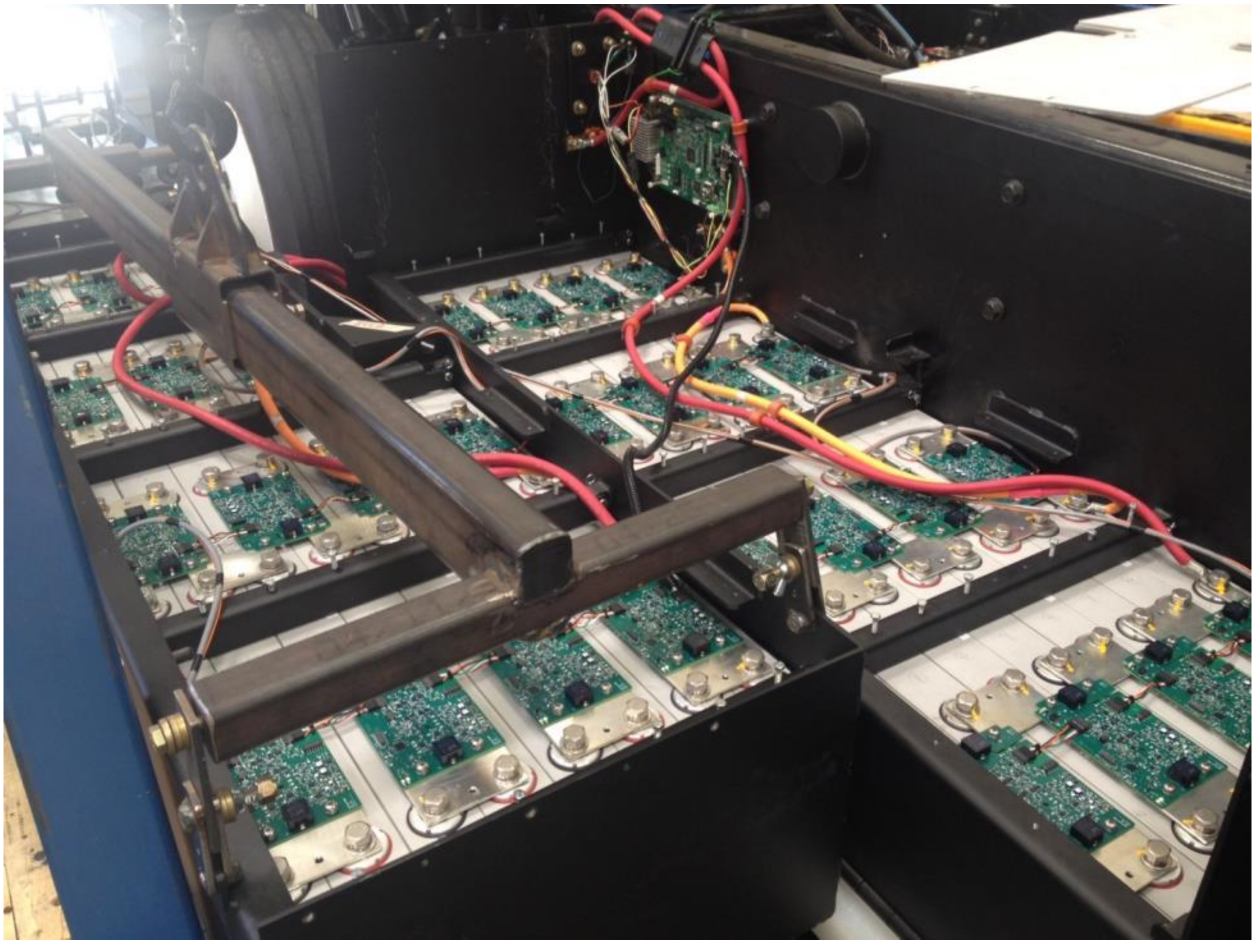

Figure 8. IKEA tractor battery enclosures fully wired with new BMS.

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 – TransPower's updated drive system design includes a new mechanism for housing the inverter-charger unit (ICU), one of the key components of the Power Control and Conversion System, which has since been renamed the Power Control and Accessory Subsystem (PCAS). The ICU is the most prominent element of the PCAS. It 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 IKEA tractor uses a single JJE/Fisker motor and is 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 the IKEA tractor 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 IKEA 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 IKEA 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 9 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 9. Interior of ICU.

The ICU was 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. After about eight months of regular operation at IKEA, a clamp in one of the cooling lines within the ICU came loose, resulting in a leak of cooling fluid that disabled the ICU and the tractor for about a week, until TransPower could replace the ICU. Apart from this one mishap, the ICU has performed reliably and with high efficiency in the IKEA tractor, as well as on about ten other TransPower vehicles, so there is high confidence that this device will continue to perform well in the IKEA tractor. The high charging power level of the ICU is particularly valuable in the tractor operating environment at IKEA, where the tractor is charged several times for brief periods each day, enabling the tractor to be used for up to three shifts per day. Using the ICU for "opportunity charging" of the tractor batteries during these brief stops enables the tractor to complete all three shifts with about 40% fewer batteries than would otherwise be necessary. As discussed later in this report, by the summer of 2015 the IKEA tractor was being used for up to 100 miles of operation per day.

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 10. 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 10 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 1. CCM concept originally planned for use in the IKEA tractor.

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 11 is a photo of the interior of the new CCM as installed into the type of PCAS assembly used in the IKEA tractor. 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).

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

Figure 11. Interior of new CCM as integrated into the IKEA tractor PCAS assembly.

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 12 is a photo of the completed PCAS assembly for the IKEA tractor prior to tractor installation. The most prominent element of the PCAS assembly is the ICU, the large metallic colored box mounted near the top of each assembly. The PCAS also includes high-voltage wiring harnesses and a high-voltage junction box mounted to the bottom of the PCAS assembly with its access door facing down, so 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 main drive motor and other high-voltage components.

Figure 12. PCAS assembly prior to installation into the IKEA tractor.

The PCAS was installed into the IKEA tractor early in the second quarter of 2014 to allow time to test all interfaces and begin the task of wiring the PCAS to the various components throughout the vehicle that rely on power routed through the PCAS. As discussed in the next task description, the PCAS also includes several of the major components of the electrically-driven accessories used on the IKEA tractor. Figure 13 is a photo of the PCAS assembly following its installation into the IKEA tractor. The assembly is mounted underneath the tractor cab in the space normally occupied by the tractor's diesel engine. The ICU is also prominently visible in this photo. In the foreground, the blue component is the electric motor used to run the tow-stage hydraulic pump that supports power steering and the 5th wheel lift, discussed in more detail in the following section. To the left of the hydraulic pump motor is the air compressor assembly which supplies air for the tractor braking system and for an interlock system that prevents the 5th wheel lift from operating while the tractor is in motion.

Figure 13. PCAS assembly installed in IKEA 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 the tractor 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. The key components of the motive drive subsystem are a main electric drive motor and an Eaton 6-speed transmission configured to use TransPower's proprietary Automated Manual Transmission (AMT) technology. The motor is 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 IKEA tractor because it was originally designed for the Fisker Karma, a hybrid-electric passenger car, in a joint development effort involving JJE and Quantum Technologies, Worldwide. The motor for the IKEA tractor was purchased from Quantum, but 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. In fact, late in the IKEA demonstration project, TransPower negotiated a partnership agreement with JJE granting TransPower the rights to market its motor products throughout North America.

The Eaton transmissions feature an "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, Mastershift, for racing car applications. Switching to the more modern and rugged Eaton transmission and X-Y shifting mechanism represents a major improvement in the TransPower motive drive subsystem, as evidenced by the fact that the IKEA tractor completed its one-year demonstration without any of the problems experienced with the Mastershift mechanism on the two Texas tractors in 2013.

Task 5.2, Integrate Transmissions – The objective of this subtask was to modify the transmission by incorporating automated manual transmission (AMT) hardware and software, including bench testing and calibration. 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.

These favorable circumstances enabled us to install the motive drive subsystem into the IKEA tractor extremely rapidly, resulting in preliminary installation of the subsystem during February 2014. Figure 14 is a photo of the motive drive subsystem after installation into the tractor.

Figure 14. Fully integrated motive drive subsystem.

The AMT 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 the IKEA tractor 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 15)

Figure 15. 5th wheel lift on a Kalmar tractor.

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 15), 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:

- 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 16. View of the PCAS assembly showing the accessory motors in the foreground.

Figure 16 shows a partially built PCAS assembly before tractor installation, 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 the Lenze accessory inverter discussed previously, which converts DC power from the battery subsystem to AC power as required by the accessory motors. 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 17).

Figure 17. Close-up view of the DC-to-DC converter installed into PCAS assembly.

Completing the accessory subsystem required installation of components into the IKEA tractor 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 18 is a photo showing some of the hydraulic plumbing installed into the IKEA tractor. 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 18. Hydraulic plumbing in the IKEA tractor.

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 tractor. 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, this subsystem was installed into the IKEA tractor by the end of February 2014.

The PCAS assembly for the IKEA tractor was 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 tractor was completed by the end of June 2014. The relatively rapid installation of the PCAS assembly confirmed our expectation that pre-integrating the controls and accessory components into a PCAS-like structure would accelerate the process of installing these items into the tractor.

The battery enclosures comprising the major part of the ESS 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 IKEA tractor, 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 IKEA tractors when the ESS had to be finalized in August 2014. Finalization of the ESS design enabled the tractors to be delivered in September 2014, enabling the demonstration phase of the project to begin.

Task 7.2 Perform Drive Testing – Drive testing of the IKEA tractor was initiated in July 2014. Figure 19 shows the IKEA tractor during one of its first test runs at TransPower’s Poway facilities on July 18, 2014.

Figure 19. IKEA tractor being test driven at TransPower’s Poway facility.

Initial testing demonstrated solid functionality of the basic drive system, but revealed problems with the new sensor-balancing boards used with the Cell-Saver™ BMS, which was tested for the first time in the IKEA tractor. Various software issues resulted in delays of a few weeks in early August. Subsequently, it was determined that the boards were able to achieve "charge shuffling" – the balancing function – when transferring energy to cells within the same module, but that failures often occurred when energy was transferred over longer cable runs from one module to another. This problem was traced to a particular board component that needed to be replaced. Based on these and a few other anomalies that were observed during the first several weeks of tractor testing, it was determined that it would be too risky to deliver the tractor to Lebec, hundreds of miles away from TransPower's facitliy, with the new BMS. The chosen solution to this problem was to replace the Cell-Saver™ BMS boards on the IKEA tractor with Flux Power BMS boards, which TransPower had been able to use with increasing reliability since completing an electric school bus using the Flux BMS in August 2013.

Testing of the IKEA tractor with the Flux BMS resumed in late August 2014. Several miles of testing was performed hauling a trailer loaded with 45,000 lb. of cement blocks (Figure 20). This testing showed the tractor to have impressive power.

Figure 20. IKEA tractor being testing with a heavy load at TransPower facility.

Successful drive testing of the IKEA tractor at TransPower demonstrated readiness to proceed to the final tests prior to delivering the tractor to IKEA – a series of tests on the chassis dynamometer at the University of California, Riverside (UCR). Figure 21 is a photo of the tractor during the dynamometer testing in early September, during which the tractor was tested for a day and a half under various duty cycles.

Figure 21. IKEA tractor during dynamometer testing at UC Riverside.

Testing on the UCR dynamometer confirmed that this tractor has performance characteristics and capabilities never before demonstrated on an electric or hybrid-electric tractor of this class. Table 1 summarizes the results of UCR calculations of greenhouse gas (GHG) emissions from the IKEA tractor, based on measured electricity consumption and estimates of the GHG produced in the generation of electric power. The IKEA tractor results are on the last row with the vehicle name “Elec 2014.”

Table 1. IKEA tractor greenhouse gas reductions, as measured by UCR.

	Estimated GHG_{est} - Medium 26k YT cycle					Estimated GHG_{est} -Heavy 72k YT cycle				
Vehicle	Calififornia			National		Calififornia			National	
name	g/100mi	% chng.	gCO_2/ton-mi	g/100mi	% chng.	g/100mi	% chng.	gCO_2/ton-mi	g/100mi	% chng.
Conv.	240	-	437	240	-	277	-	97.1	277	-
Hybrid_1	240	0%	437	240	0%	261	-6%	91.5	261	-6%
Hybrid_2	198	-18%	360	198	-18%	242	-12%	85.0	242	-12%
Elec_2012	118	-51%	215	163	-32%	170	-39%	59.7	235	-15%
Elec_2014	104	-57%	188	143	-41%	168	-39%	59.0	232	-16%

The data in Table 1 show that the IKEA tractor produced 57% fewer GHG emissions than a conventional diesel tractor when operating in a typical yard tractor duty cycle with a total weight of 26,000 lb., assuming electric power produced by a mix of sources typical in California. Using electric power generated with a more typical national mix of sources (e.g., more coal and less natural gas), the reduction was still 41%. At a heavier 72,000 lb., these reductions were calculated to be 39% using a California mix of electrical power and 16% using a national mix. The GHG reductions shown by the IKEA tractor were slightly greater than those demonstrated by the previous generation TransPower electric tractor during tests in 2013 (as shown on the row labeled "Elec 2012") and 2-3 times greater than the GHG reductions achieved with a competing hybrid-electric tractor tested in 2011.

The basis for these GHG reductions was the improved energy efficiency of the drive system in the IKEA tractor, compared with previous tractors tested. Figure 22 summarizes the energy use measurements taken during the UCR testing. The two bars on the left indicate that over the range of duty cycles tested, the IKEA tractor averaged 1.71 kilowatt-hours (kWh) of energy consumption per mile at a 26,000 lb. load and 2.78 kWh/mile at a 72,000 lb. load. As discussed in the following section, these measurements were subsequently corroborated during the year-long testing of the tractor at IKEA's California distribution center.

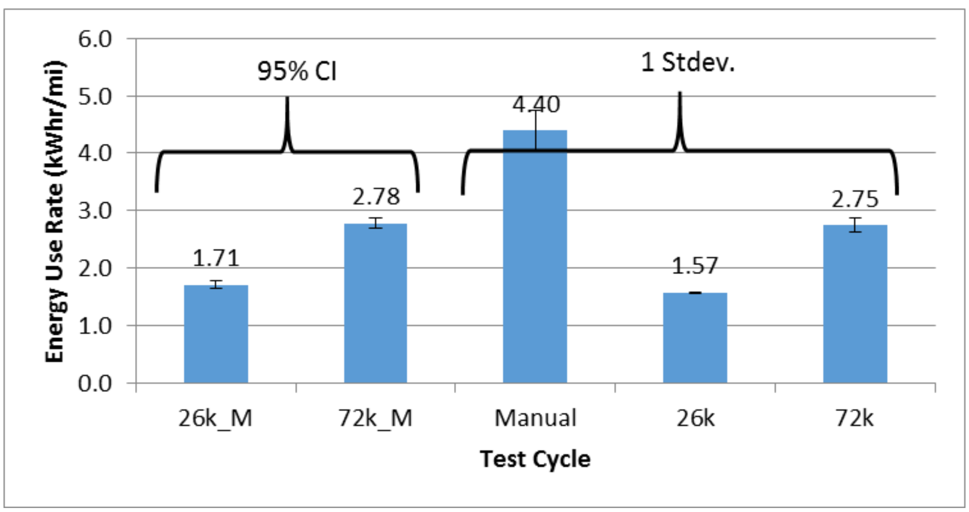

Figure 22. Summary of energy use computations resulting from UCR testing.

The energy efficiency of the IKEA tractor has significant economic as well as environmental implications. At prevailing electricity and diesel fuel costs, an electric tractor using TransPower's system has about one-quarter to one-third the energy cost per mile of a conventional diesel tractor, representing the potential for about $10,000 per year in energy savings. This conclusion is discussed in more detail in the following section of this report. In April 2015, UCR completed its independent report of its testing of the IKEA tractor. Following are the principal conclusions of the report, reprinted verbatim from the *Conclusions* section of the report ("YT" stands for "Yard Tractor"):

"The following are the highlighted conclusions that can be made for the all-electric YT tested at UC Riverside:

- *The vehicle performed well on the transient medium and heavy YT test cycles, suggesting its performance is well matched to a conventional vehicle.*
- *The all-electric YT performed the sustained load tests from 20% to near 100% load for several minutes without any failures or issues.*
- *The vehicle CAN and Hioki precisions power meters were in good agreement and were within 3% for the heavy cycles and 5% for the medium YT cycles. This suggests the energy measurement system from the YT is relatively accurate and reasonable for in-use characterization to within 5%.*
- *The close agreement between the vehicle reported SOC and Hioki energy measurements suggests the vehicle SOC is accurately accounting for the vehicles energy usage.*
- *The peak power of the YT was slightly over 150 kW, which slightly exceeds that of the specification.*
- *The power losses between the electric YT batteries to the wheels averaged 25.0%±1.5% and were fairly consistent from high to low load and at high and medium speeds. The power loss was significantly higher (40%) at high speed and 20% load.*
- *The drive energy losses was higher for the transient tests compared to the steady state speed tests and averaged 38% for the medium YT cycle and 27% for the heavy YT cycle.*
- *The regen energy difference between the chassis and vehicle was 69% for the medium YT cycle and 66% for the heavy YT cycle. This suggests 31% - 34% of the kinetic energy was recovered during vehicle braking, respectively.*
- *The non-modified cycle represents the real world YT operation and, thus, the non-modified YT cycle results are used in the analysis of maximum range, but for comparisons purposes the modified YT cycle energy rate is used.*
- *The YT energy consumption was 1.71 kWhr/mi of energy for the medium loaded YT modified cycle and 2.78 kWhr/mi for heavy loaded YT modified cycle. The non-modified cycle showed slightly lower energy consumption and averaged 1.57±0.01 kWhr/mi for the light load and 2.75±0.13 kWhr/mi for heavy loaded cycle.*
- *The energy rate (kWHr/mi) for both cycles did not change with SOC from 95% to 20% SOC. This suggests vehicle performance from full to near empty is the same.*
- *The specified total capacity agrees with what was measured in this report and is 154kWhr.*
- *The YT range is estimated for the non-modified cycles and is 78.1 miles for the medium YT cycle and 44.2 miles for the heavy YT cycle based on a usable capacity of 123 kWhr (~20% SOC).*
- *The all-electric YT energy cost was estimated to be $29.10/100 miles, as compared to $103/100miles for the conventional YT and $85.10/100 miles for the hybrid on the medium YT cycle. This is a cost savings of 72% and 66% over the*

conventional and hybrid YTs, respectively. The all-electric YT showed a slightly lower benefit when tested on the heavy YT cycle.

- *The all-electric YT showed a fuel economy (FE) that ranged from 22 MPG_{de} for the medium YT cycle and 13.5 MPG_{de} for the heavy YT cycle.*
- *The all-electric FE of 22 MPG_{de} was a 452% improvement over the conventional YT and a 354% improvement over the Hybrid_2 YT for the medium loaded YT cycle. For the heavy YT cycle, the all-electric improvement was 291% and 242% over the conventional YT and Hybrid_2 YT, respectively.*
- *No tail pipe emissions from the all-electric vehicle were emitted during the testing."*

– End of excerpt from UCR report –

Task 8, Tractor In-Service Demonstration

The tractor arrived at IKEA on September 5, 2014. Figure 23 is a photo of the tractor immediately after its arrival at IKEA, with IKEA associate Arlene Finlayson happily perched atop one of the tractor's battery enclosures.

Figure 23. Tractor just after arrival at IKEA.

Overview of IKEA Operations – IKEA promptly installed charging infrastructure enabling the tractor to quickly enter service when it arrived. The charging location is a warehouse where trailers are shuffled between 250 docks, an additional warehouse, and sometimes to an offsite staging area. The tractor parks up to an unused dock where the charging outlet has been installed (Figure 24).

Figure 24. IKEA Tractor parking and charging infrastructure.

TransPower commissioned IKEA's charging hardware, performed driver/safety training and performed some service on September 8, 2014. September 9, 2014 was the tractor's first full day of service. For the first week of operations, TransPower employees continued assisting IKEA personnel in learning how to operate and charge the tractor.

The tractor performed well from the start, hauling IKEA's heavy trailers without difficulty. Figure 25 is the tractor performing a test run during its first week of operations at IKEA, and Figure 26 is another photo of the tractor in operation at this site.

IKEA has been very supportive of the project and has made exceptional efforts to use the tractor to its abilities. As a result, a large and comprehensive data base has been and continues to be created enabled a breadth of data analysis. As of the date of this report, the tractor has been operating continuously at the IKEA distribution center for nearly 11 months, and has accumulated more than 10,000 miles of operational use. Tractor use has increased to approximately 1,350 miles per month, representing a rate of more than 16,000 miles per year. High reliability and efficiency have validated the promising results achieved during the UCR dynamometer tests.

Figure 25. Tractor during first week of test operations at IKEA.

Figure 26. Another photo of IKEA tractor in operation at the Tejon facility.

Tractor Infrastructure and Operating Location – The tractor has been operated solely at IKEA's Tejon Facility located in Lebec, CA. This IKEA facility has a 1.8 MW solar array which powers much of the main building and enables the electric tractor to obtain approximately 90% of its recharge power from renewable energy. This makes the tractor a near zero emissions vehicle from a wells to wheels standpoint and provides an excellent example of sustainable mobility. Since the building continues to over-produce, the truck's charging node still enjoys a zero increase in the electric bill which means the costs to fuel the truck are also nearly zero. Figure 27 is an aerial photo of the site, with Interstate 5 visible to the right of the property.

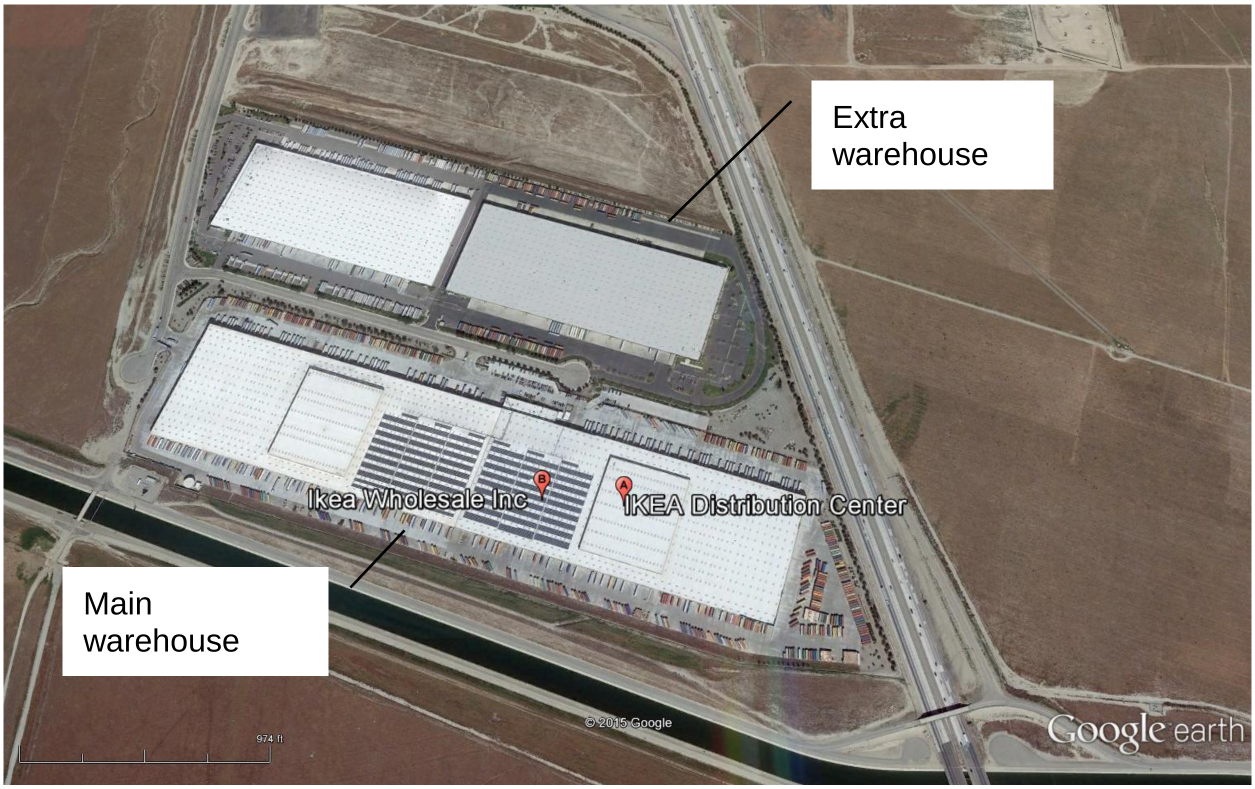

Figure 27. IKEA Tejon facility.

Figures 28 and 29 are aerial photos providing additional details. Figure 28 shows the parking areas for the electric tractors in comparison to the diesel tractor parking area, and Figure 29 shows Dock 251, a steeply inclined dock where full trailers are often staged. The 20% grade at this dock is actually too steep for the electric tractor, as there is insufficient room for the tractor to gain momentum and the tractor has insufficient torque to back up onto the elevated "pad" and thus up to the building. This issue was not identified at the initial site visit, but is the only site-related limitation identified to date. Future tractors will be designed with higher inverter torque and lower axle gearing, enabling them to easily maneuver trailers up these grades. In addition, TransPower is in discussions with IKEA regarding the possibility of replacing the 7.17:1 rear axle on the existing tractor with one that accommodates a 9.14:1 rear axle ratio, which would enable this dock to be used. The remainder of the facility is easily accessible.

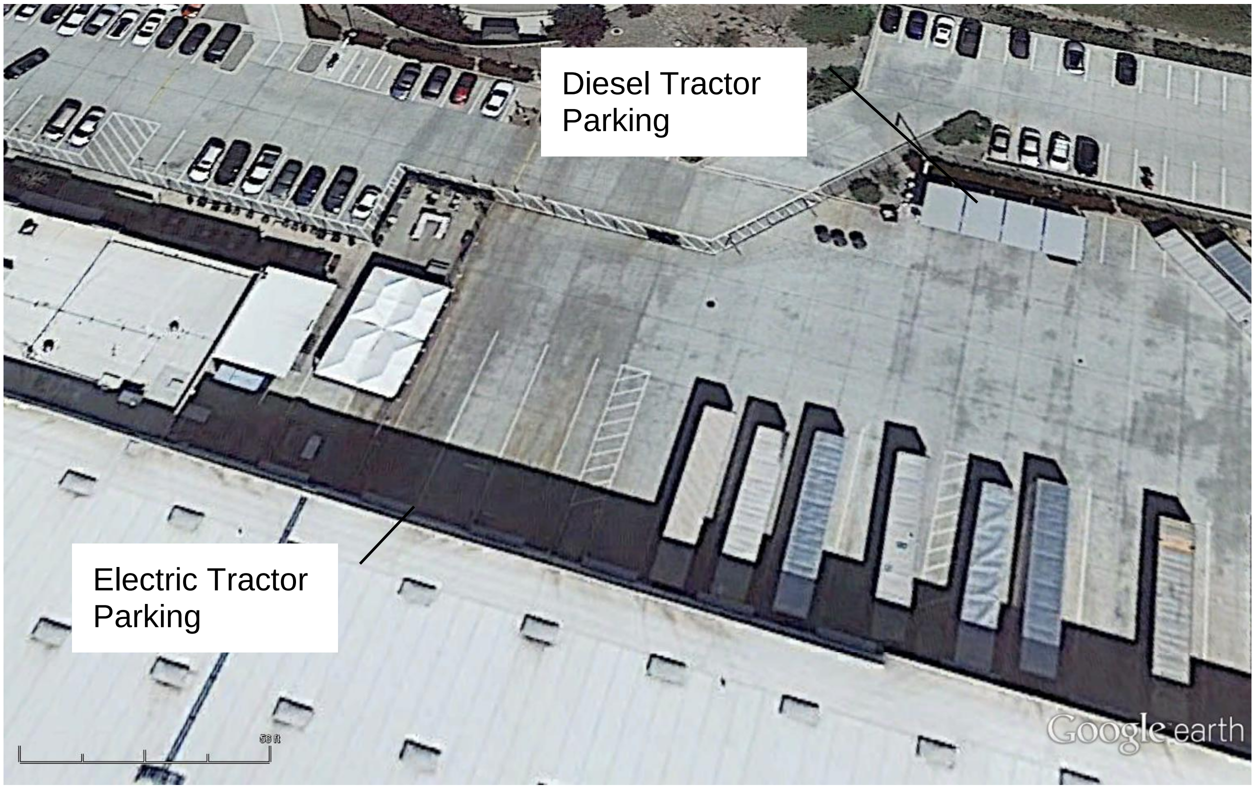

Figure 28. Tractor parking.

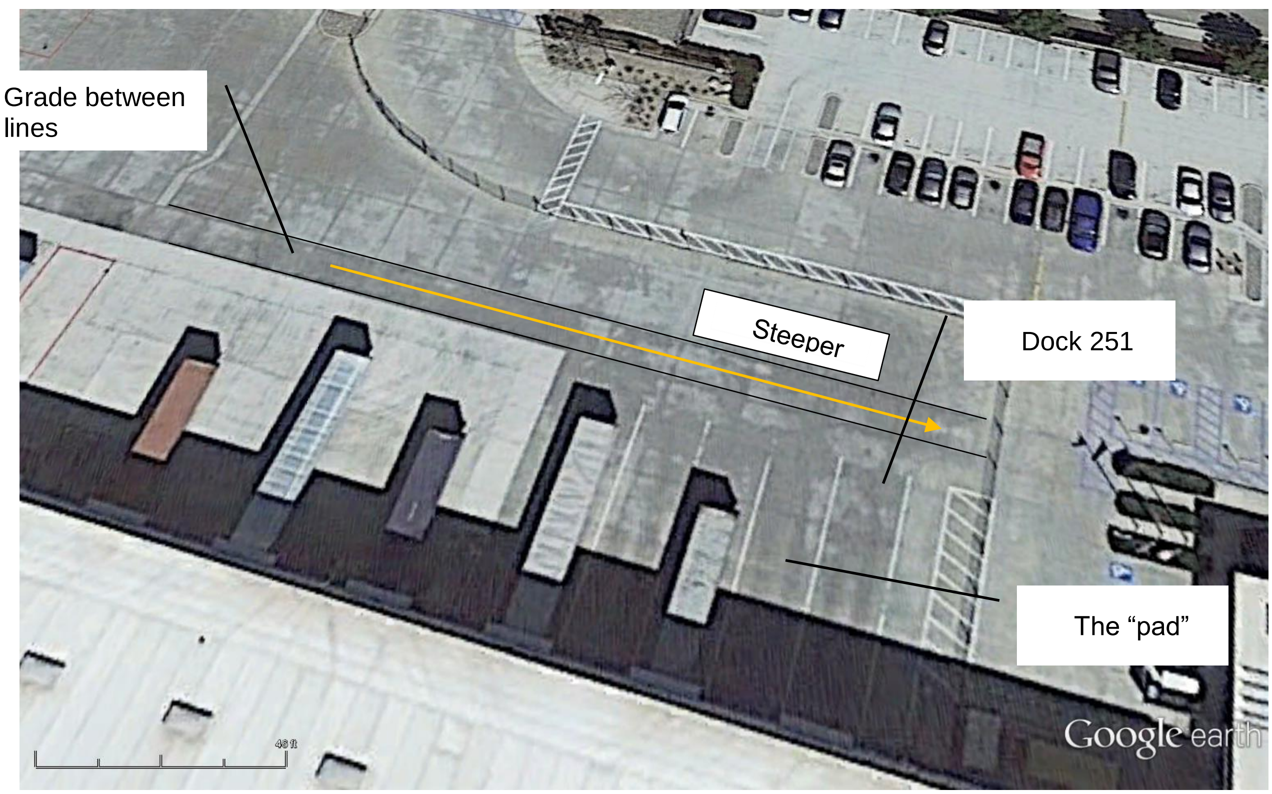

Figure 29. Dock 251.

IKEA operates three shifts per day 7 days per week. 1st shift typically moves a larger number of empty trailers and does so around the portion of the building closer to the freeway. By the time second shift starts, many trailers are loaded and thus are being staged for pick up. 3rd shift often receives full and empty trailers and stages them at docks for transfer to the warehouse. Although a tractor can stage anywhere at any time, the different shifts to tend to operate in different areas, as depicted in Figure 30, as cargo is unloaded, sorted within the building, packed, and shipped.

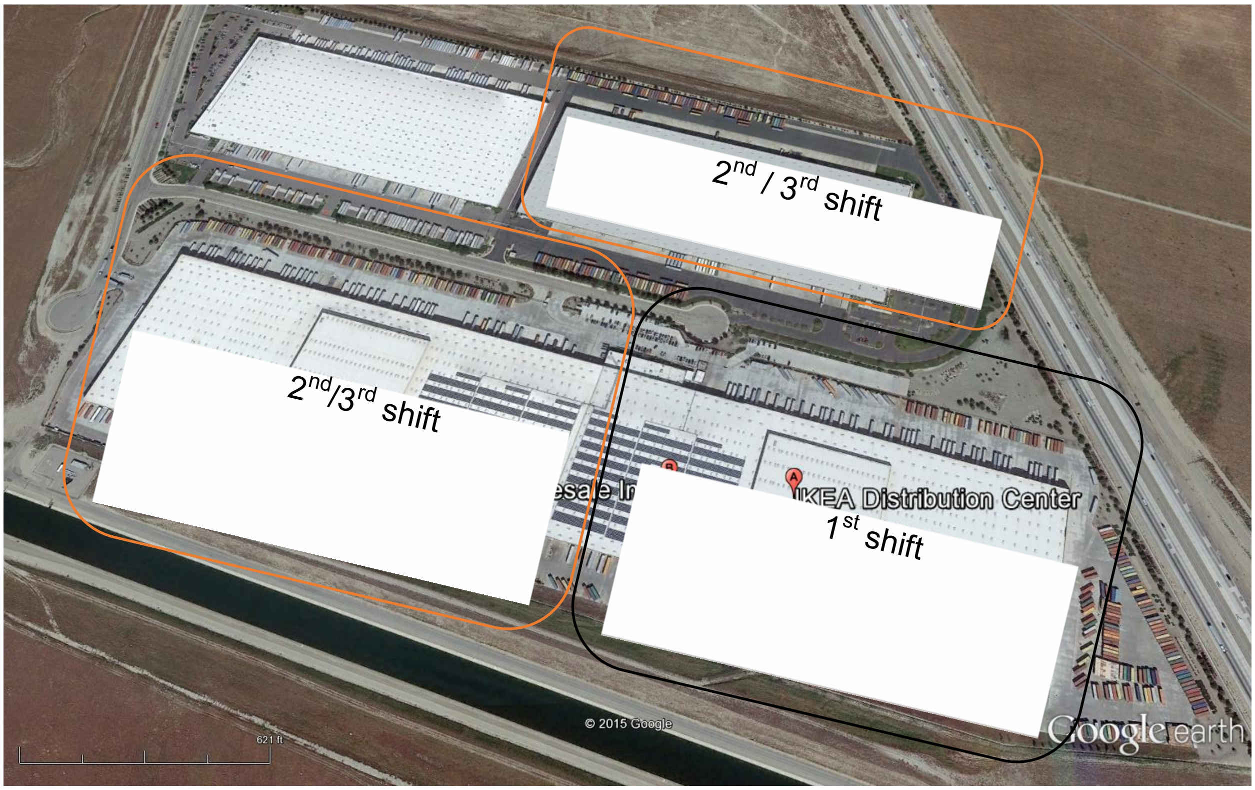

Figure 30. IKEA operational areas.

General Observations Regarding the Tractor – Between September 2014 and January 2015 the tractor was put into 1st shift service. This allowed the IKEA and TransPower to test the tractor under increasing loads as the months went by addressing any issues in stages. In January/February the vehicle began 2 shifts per day in a staggered pattern where the 1st shift driver operated one shift Sunday through Thursday while the other 2nd shift Tuesday through Saturday. The tractor continued that pattern until April 18, 2015, when a 3-shift day was completed. Thereafter 3 -shift days were added until the tractor reached its present status where it will operate for 3 shifts four to five days a week, with the remainder being 1-2 shift-days. The tractor is not presently used on Saturdays. Table 1 is a schedule showing typical operating and charging intervals. Areas shaded in green indicate charging opportunities. Charging during breaks is key to the tractor's ability to complete three shifts in a single day.

Table 1. Tractor operating schedule.

IKEA Tractor Schedule												
0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
3rd Shift						1st Shift			Lunch	1st shift		
12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00
1st shift		Inter-shift Break		2nd Shift				Lunch	2nd Shift			

As mentioned previously, the IKEA tractor has accumulated more than 10,000 miles of operation over an operational demonstration period of just under 11 months to date. This is more mileage than has been accumulated by any truck or tractor deployed by TransPower to date. Over the course of the demonstration, the tractor has averaged 9.5 miles per hour (mph) and has been operating for an average of about 11 hours per day. However, with the increased use the tractor has been experiencing since April 2015, average speed is now over 13 mph and daily use has been averaging 20 hours. The 3 shifts per day includes trips off the main property to an adjacent warehouse, at which point it is able to completely assume the duties of a diesel tractor. As a result, average daily distances which started at 20-30 miles per day rose to 60-80 and now can exceed 100 miles per day. The ability to perform this heavy usage can be attributed to the tractor's efficient use of energy and ability to recharge quickly from the 70 kW on board charger.

A few important specific observations regarding the electric tractor's performance are summarized as follows:

- The tractor uses roughly 2.05 kWh/mi at the wall which is outstanding for this type of vehicle. Interestingly, the consumption has dropped since January in this tractor as well as others presumably due to warmer temperatures reducing battery resistance and thus increasing overall efficiency.
- The tractor is typically charged during lunch breaks and breaks between shifts. This amount of charging is just enough to support 3 shifts per day though with little margin.
- Reliability has been very good. The tractor is on track to complete more than 12,000 miles by the time it completes its first year of operation, which is on par with IKEA's diesel tractors. This is especially impressive given that the electric tractor spent most of its first year operating for only 2 shifts per day.
- The tractor has operated though all 4 seasons in temperatures below freezing as well as in the 100+ degree range, also enduring heavy rains as well as lengthy dry spells.
- Drivers report they like the tractor's quiet operation, lack of diesel fumes, and excellent air-conditioning.

Detailed Analysis of Tractor Operating Data – Features of the operating site and duty cycle have had a pronounced impact on how the tractor is driven, as can be seen in Figure 31. The average speed is calculated by averaging non-zero speed values. The tractor has maintained a relatively constant average speed of 9.6 MPH over the duration of the project with some more recent days seeing averages over 12 MPH. The 20-period rolling average trend line suggests that more recent average speeds closer to 10 MPH. It is suspected that the transfer between warehouses can raise the average speeds due to more time in transport vs. maneuvering into a dock. For comparison, similar electric tractors maintained average speeds of 2.9 mph while in operation at a Long Beach drayage firm operating in a small yard, and about 6.8 mph while operating at a larger port terminal at the Port of San Diego. The 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.

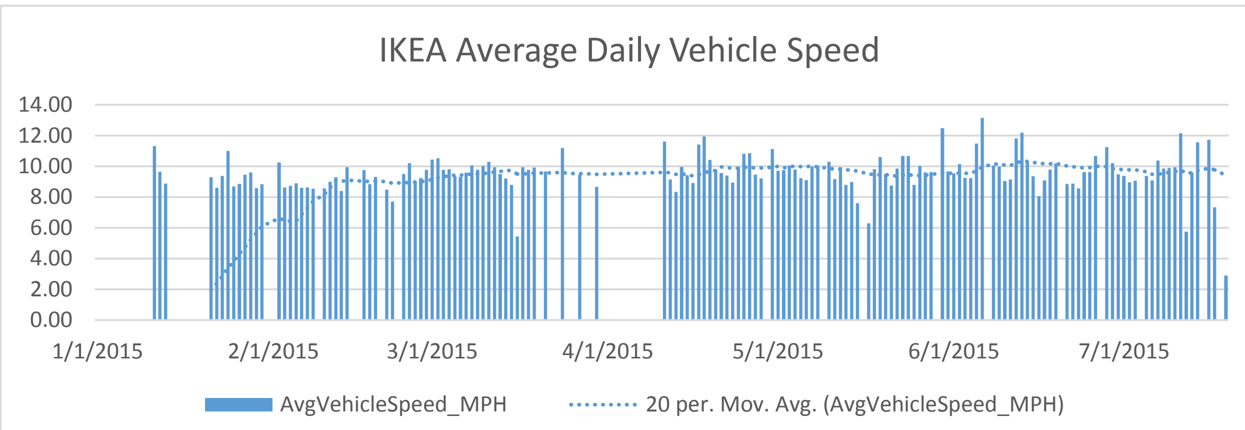

Figure 31. Tractor average vehicle speeds.

Figure 32 depicts daily miles driven per day. As the 20-period rolling average shows, distance per day has been steadily increasing, peaking on June 26, 2015 at 101 miles in a day. This graph helps to illustrate the present use model where 3-shift days are repeated three to five days in a row, followed by a break. IKEA is commencing the busy season leading up to “Black Friday” and it is expected that distances will continue to remain high or increase. For comparison, the two other electric tractors deployed by TransPower shortly after the IKEA tractor was deployd have been averaging about 16-17 miles per day (excluding days when tractors are not used). 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).

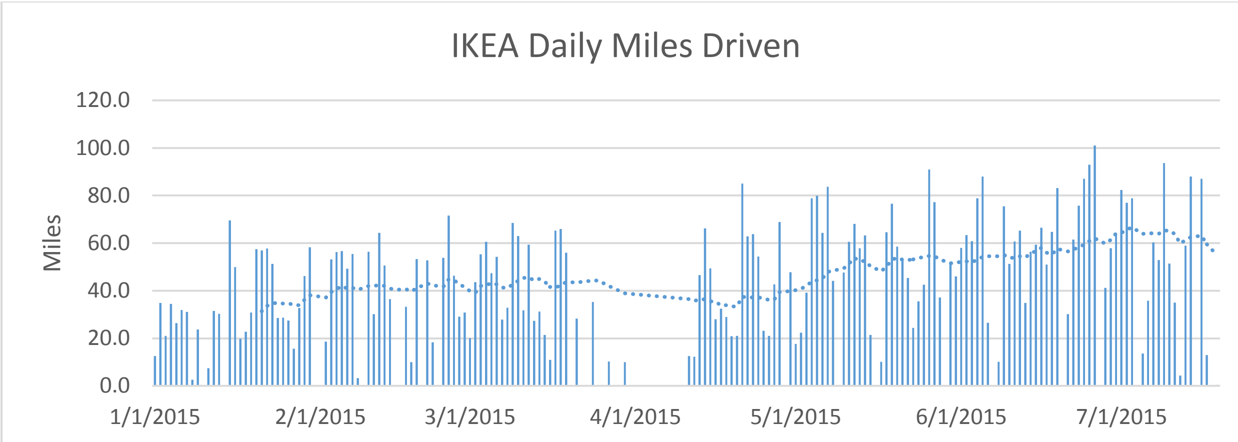

Figure 32. Daily miles driven by the IKEA tractor.

IKEA sees a widely varying amount of container movement, as illustrated in *Figure*). Much of the variation is related to whether the tractor was operated for 1, 2, or 3 shifts on a given day. Other factors can include the part of the building where the tractor was most used and the number of trips taken to the adjacent warehouse. Between January and April 2015, the tractor spent much of its time in one area where moves were shorter, resulting in fewer average miles per day. In many cases trailers were simply shunted from one dock to another a few docks away. As the tractor transitioned to 2 and 3 shifts per day hauling more loaded trailers to staging areas, the number of trailers pulled may decline, despite significant increases in daily mileage – clearly suggesting longer distances between trailer "pulls" (a "pull" is defined as transporting a load for 30 seconds or more and then setting it down for at least 30 seconds). The other two tractors deployed by TransPower in late 2014 and early 2015 have averaged about 45-60 container pulls per day, although one of these tractors (the one operating in the small drayage firm yard) has occasional spikes to 140 pulls per day.

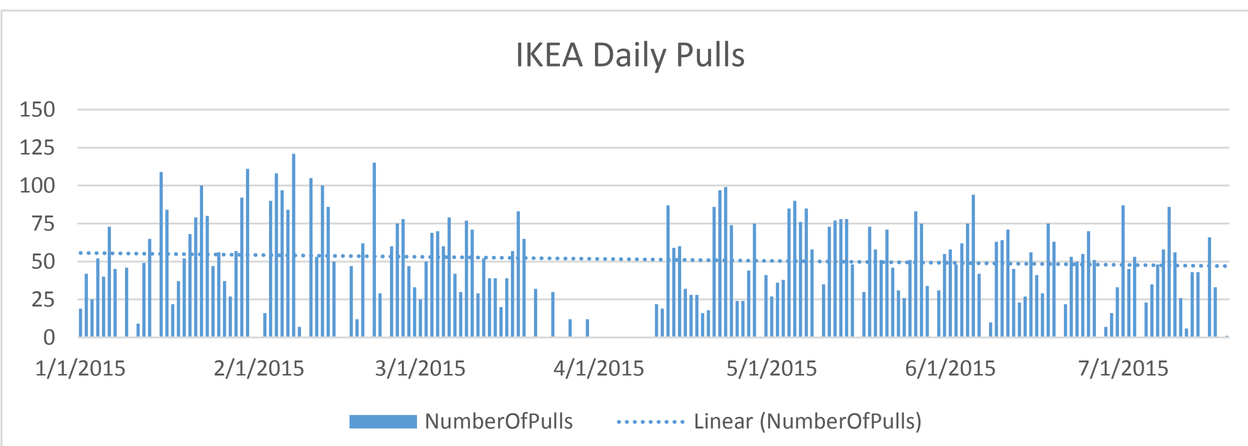

Figure 33. Number of tractor pulls per day.

Another key factor affecting tractor performance is cargo mass, which, like daily miles driven, can vary considerably in IKEA operation. 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 reporting the load on the tractor's rear axles. The axle load is multiplied by a factor to get an inferred trailer load. It should be noted that at actual trailer weight is not known, just estimated. The daily value is an average of load while moving and includes weight values from no trailer to the maximum that day.

Figure 34 plots average daily weight load for the IKEA tractor. As indicated, the 20-period rolling average suggests that the average load has increased over time. This is consistent with the expanded usage where the tractor is moving more loaded trailers to staging areas, versus shunting a higher amount of empty trailers from dock to dock. Initially, the tractor averaged roughly 20,000 lb. per day which is less than 33% of a loaded 65,000 lb. trailer, suggesting a significant portion of the loads were closer to the 8-10,000 lb. empty trailer weight. Today the tractor is averaging over 30,000 lb., or closer to half the weight of a fully loaded trailer. This aligns with the understanding that the tractor runs the lighter shift at the aforementioned lighter loads and then the heavier load shifts in the evening hours. For comparison, TransPower's two other electric tractors presently have average daily loads of 20-25,000 lb. and more than 58,000 lb., respectively.

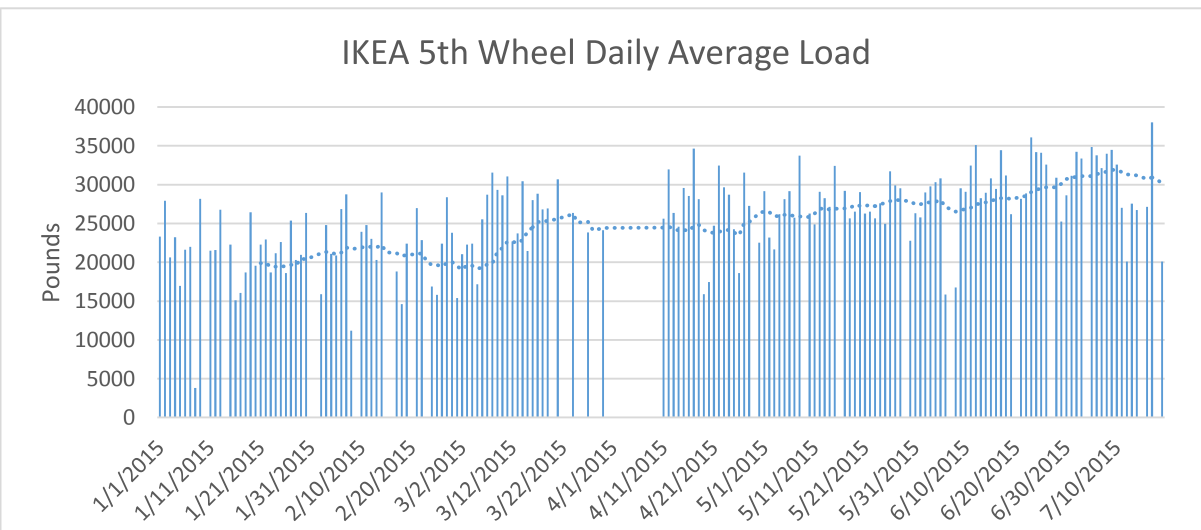

Figure 34. Fifth wheel estimated trailer load.

Operation of the IKEA tractor enabled the compilation of various statistics that are helpful for predicting operating costs, including pulls per kWh and pulls per mile (Figure 35). Depending on how the operator tracks productivity, projections can be made as to how many pulls can be accomplished, how much distance is traveled, and how energy would be consumed. The IKEA tractor has averaged 1.2 pulls per mile since January but that value has been declining. This observation also aligns with the understanding that the tractor is carrying each load larger distances. In February, the tractor was averaging over 1.5 pulls per mile but today that value is closer to 0.75 pulls per mile, suggesting that each carry today is 2 times longer than it was at other points. March 16, May 17, and July 17, 2015 represent days in which there were spikes in pulls per mile and kWh consumed. On those, days distances were short (10-20 miles), average speeds were 6.3- 7.6 MPH (below the 9.6 MPH overall average), DC consumption was 2.4-2.9 kWh/mi (above the overall average 2.05 kWh/mi), average trailer weight was over 29,000 lb., and the pull count was high. These factors suggest that the tractor was operating in a confined low speed area where increased throughput and energy consumption per mile are to be expected.

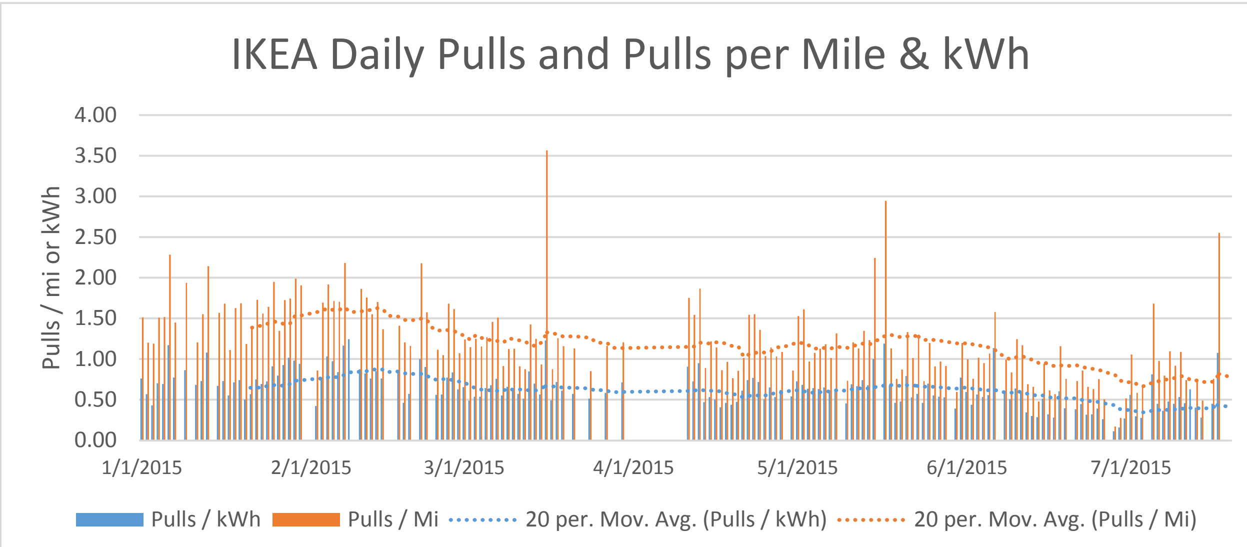

Figure 35. Pulls per DC kWh and mile.

The IKEA tractor has enjoyed a relatively stable rate of energy consumption from a kWh/mi standpoint. Figure 36 depicts the total DC energy consumed per day as well as the rate of that day's consumption in kWh/mi. Prior to April, the DC consumption averaged around 2.2 kWh/mi. Also, days of highest consumption often had the lowest total consumption, which aligns with observations from TransPower's other electric tractors. This observation holds true into May, but in June the correlation sees exceptions. On July 3, 2015 the tractor averaged 2.42 kWh/mi while consuming 190 kWh of total energy over 79 miles. However, on June 26, 2015 the tractor average 1.93 kWh/mi while consuming a record 194 kWh of energy over 101 miles. Each day had an average load of roughly 30,000 lb. Despite the somewhat shorter operating duration, on June 26 the tractor had a higher average speed of 10.7 mph vs. the July 3 average speed of 9.1 mph, suggesting that the tractor spent more time in open spaces. This seems to align with the observation that operating in small, cramped areas increases tractor energy consumption. The overall trend has been favorable, with DC energy consumption dropping slighlty over time to less than 2 kWh/mi.

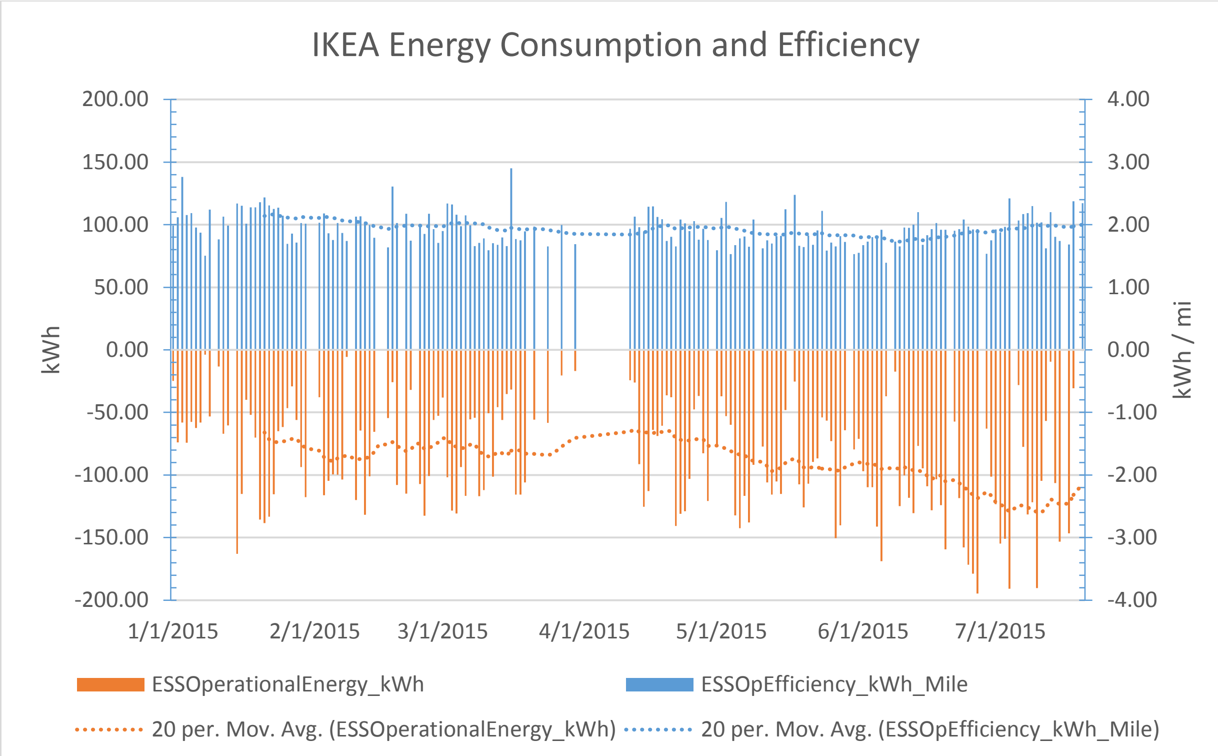

Figure 36. Operational energy consumed and rate of consumption per mile.

As the tractor ramped up from 1 to 3 shifts per day, the prevailing question lingered as to whether or not the Flux BMS could balance the batteries fast enough to support this level operation. At, for example, 2 shifts per day, the vehice has a 5 hour break overnight, when the batteries can be “topped off” and balanced. Typically, batteries under the IKEA operating conditions need on average of 3.3 hours per day to balance. Flux BMS balancing only occurs near the top of charge and thus if the vehicle is frequently charged but for short durations the risk is that it will accumulate very little balancing time since the truck is pulled off of the plug just as the batteries reach full charge states. Figure 37 compares minimum and maximum daily states of charge (SOC). There are number of instances in June and July where the tractor did not reach 100% SOC during a given day, despite regular use. Analysis reveals that the BMS is indeed not able to keep up with the duty cycle. After a few days of 3-shift operation, the lower cells do not reach the threshold required to reset the SOC counter to 100%, which occurs at voltages in the lower 3.4 region at low charge currents. In one case the lowest cell was only 3.38V, which is too low at low charge currents to be considered full. Presently the breaks in 3-shift operation are allowing the BMS to catch up. However, as discussed previously, in August 2015 the tractor BMS will be upgraded to the newer “Cell-Saver™” BMS, which utilizes more sophisticated balancing algorithms at balancing currents significantly higher than the Flux system. This is expected to maintain pack balance even under aggressive opportunity charging environments.

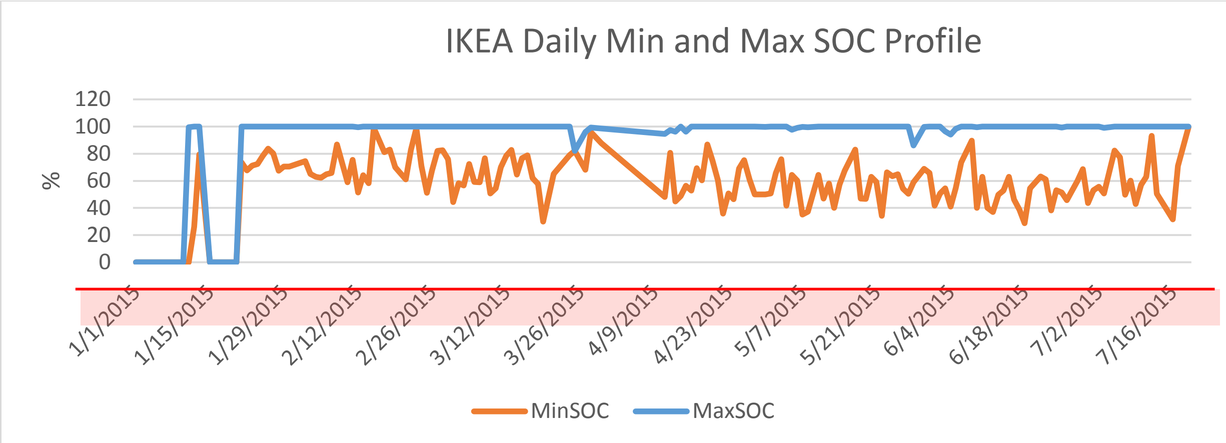

Figure 37. Minimum and maximum daily SOC profiles.

Another utility metric is the amount of time the vehicle spends idling vs. driving, "idling" defined as the tractor being on but not moving, and "driving" defined as the tractor being in motion. Total operation time is the sum of the two for a given day. Figure 38 shows hours of idling vs. driving each day during the first seven months of operation of the IKEA tractor in 2015.

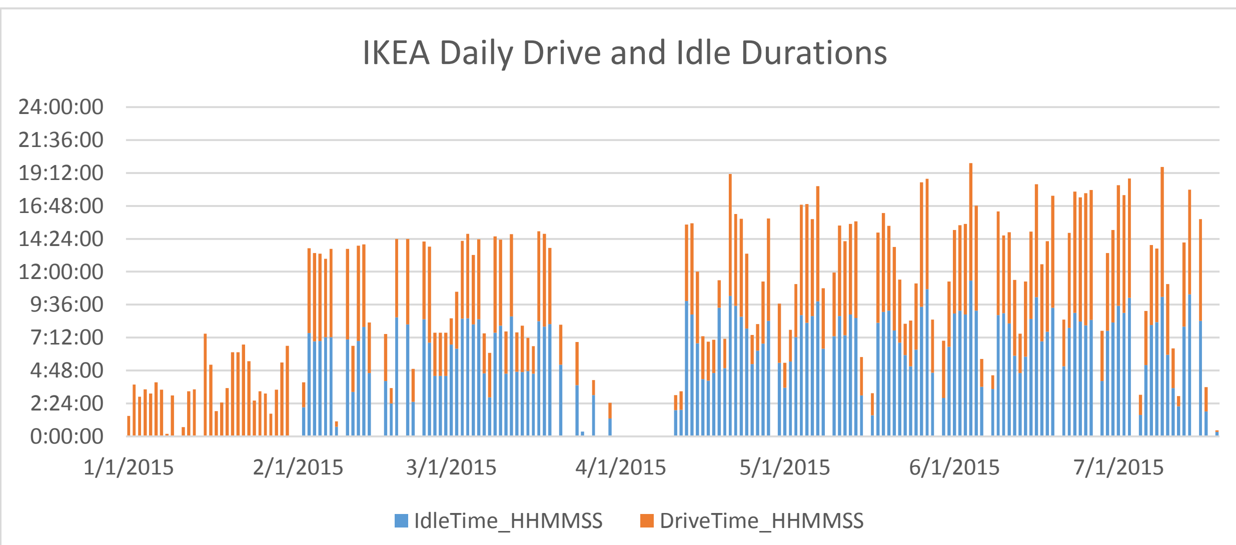

Figure 38. Driving versus idle time.

Even with accessories such as heating and airconditioning on, the tractor consumes very little energy during idling, on the order of 1 kW. While this is a low value compared to powertrain energy consumption, other demonstrations have shown the excessive idling can aggregate small amount of energy over a large reduction in aggregate mileage which can distort metrics such as kWh/mi while drastically reducing overall consumption. Fortunatly, the IKEA tractor is well utilized. The ratio of drive time to idle time is 0.76 where a value one 1 would mean equal drive and idle times per day. Interestingly, on days such as June 26 and July 3, 2015, the ratio was 0.86 and 1.11, respectively. Not then surprising is the fact that days with high mileage have high drive to idle ratios due longer periods of carrying a trailer. As the tractor continues to operate over three shifts, it expected that the average ratio will continue to increase. Drive time on average occupies 53% of a day's total operation time wheras idle time occupies 59%. For comparison, TransPower's other two electric tractors have had drive/idle ratios of .42 and .56 respectively, although one of these tractors has seen a recent increase to 1.07, along with reduced rates of energy consumption, due to the tractor doing much more work more efficiently.

Table 2 is a compilation of monthly and total demonstration phase operating data. It is interesting to extrapolate what 12 months could look like if these rates of usage were to average out. Presently the tractor is on track to achieve 12,000-13,000 miles over its first year of operation, which is typical for a diesel tractor. However, if the tractor operated as it did in the month of June all year, the tractor would exceed 20,000 miles per year. This suggests the possibility that the tractor is capable for shunting more trailers than a typical diesel tractor.

Table 2. Project Summary

IKEA Data Summary									
	Previous	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**Project to Date**
Km per Month	3880	1216	1591	1629	1264	2363	2692	1464	**16099**
Miles per Month	2411	756	988	1012	786	1468	1673	910	**10004**
Total Charge Energy (ESS)		2156	1938	1828	1523	2730	3178	1859	**15211**
Total Charge Energy (Wall)		0	0	2031	1627	2879	3403	1988	**11928**
Total Pulls		1523	1475	1082	933	1599	1303	766	**8681.0**
Total Hours in Operation		103	224	235	206	348	377	201	**1694**
Average kWh/hr				8.63	7.90	8.27	9.03	9.90	**8.75**
Pulls / mi		2.02	1.49	1.07	1.19	1.09	0.78	0.84	**1.21**
Average kWh/mi (ESS)		2.85	1.96	1.81	1.94	1.86	1.90	2.04	**1.91**
Average kWh/pull (ESS)		1.42	1.31	1.69	1.63	1.71	2.44	2.43	**1.98**
Average kWh/mi (Wall)		0.00	0.00	2.01	2.07	1.96	2.03	2.19	**2.05**
Average kWh/pull (Wall)		0.00	0.00	1.88	1.74	1.80	2.61	2.60	**2.13**
Odometer End Value (km)		5096	6687	8316	9580	11943	14635	16099	**16099**
Odometer End Value (mi)		3167	4155	5167	5953	7421	9094	10004	**10004**

Tractor Reliability and Service Record – The IKEA tractor uses TransPower's second generation electric drive system for yard tractors and was essentially a complete redesign when compared to the first generation system first tested in 2012. As a result, the tractor was essentially a first-of-a-kind vehicle, representing an advanced prototype stage of development and refinement. Regardless, the tractor suffered very few failures, proving itself as an excellent foundation for larger deployments. With the exception of an ICU replacement, failures were typically addressed within one day, and occurred most frequently during the first few months 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.

IKEA In-Service Issues and Remedies

- **11/05/2014: Erroneous charge cable connected signal.** Replaced relay and modified logic (for all vehicles)
- **11/17/2014: Erroneous battery cell readings reported by BMS unit.** BMS connector was not seated correctly and thus problem addressed by properly seating the connector.
- **12/17/2014: General service call.** Software updates, repaired heater wiring issue, inspected accessory inverter wiring, installed a drain lid, inspected heater wiring seals.
- **01/08/2015: Erroneous battery cell reading reported by BMS unit.** Adjacent units swapped and recalibrated to ID issue. Issue did not return, root cause unknown. Powertrain software updated.
- **03/27/2015: Truck will not start, fault light.** ICU voltage sensing board failed. During repair a leak was found, ICU dried, repaired, and test driven. ICU software updated.
- **04/03/2015: Truck suffering from intermittent shutdowns:** Inspection revealed the ICU coolant leak caused significant corrosion causing CAN communication failure. Issue addressed on next work order.
- **04/10/2015: ICU replacement and cooling loop upgrade:** The ICU was removed and replaced with a new unit containing upgraded hose clamps to better address leakage. The cooling loop was rerouted to reduce overall pressure while improving cooling to key components such as the motor.
- **04/16/2015: Erroneous battery cell reading reported by BMS unit:** Cell 60 reported as below the allowable threshold, however, independent measurement shows cell is within limits. BMS inspected, truck restarted, problem no longer present, root cause unknown.
- **04/28/2015: Cooling fans not operating:** Data review showed abnormally high temperatures during charging. Inspection revealed the cooling fan fuse had blown. Fuse replaced.
- **04/30/2015: Truck would not start:** Software bug discovered that erroneously set a fault. Software updated, problem addressed.

Table 3 sums and averages the project totals for key operating metrics.

Table 3. Project totals and summary.

IKEA Data Summary	
	Project to Date
Miles per Month	10004
Total Charge Energy (ESS)	15211
Total Charge Energy (Wall)	11928
Total Pulls	8681.0
Total Hours in Operation	1694
Average kWh/hr	8.75
Pulls / mi	1.21
Average kWh/mi (ESS)	1.91
Average kWh/pull (ESS)	1.98
Average kWh/mi (Wall)	2.05
Average kWh/pull (Wall)	2.13
Odometer End Value (mi)	10004

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 a Kalmar Ottawa diesel tractor to battery-electric propulsion, using a new and improved version of TransPower's ElecTruck™ drive system. The tractor was 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 IKEA tractor – 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 IKEA tractor 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. The IKEA tractor is the first battery-electric yard tractor of the 100,000 lb. weight class known to have operated reliably in a real-world environment on a sustained basis. From the first day the IKEA tractor was deployed in September 2014, it 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 IKEA tractor accumulated a total of more than 12,500 miles of real-world operation during the one-year demonstration phase of this project, producing a wealth of valuable data.

Testing of four other tractors over the past year 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 the 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 39 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 UCR. 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 a year of operation of the IKEA tractor at IKEA's distribution center, TransPower and IKEA personnel estimate that the TransPower electric tractor will cost about $5,000 to $6,000 less per year to maintain than a typical IKEA diesel tractor. Other than replacement of the IKEA tractor ICU due to a simple design flaw that was easily fixed, no significant maintenance or repairs were required for the IKEA tractor or the two Port of Los Angeles tractors during the full year that these tractors were tested and operated between August 2014 and August 2015.

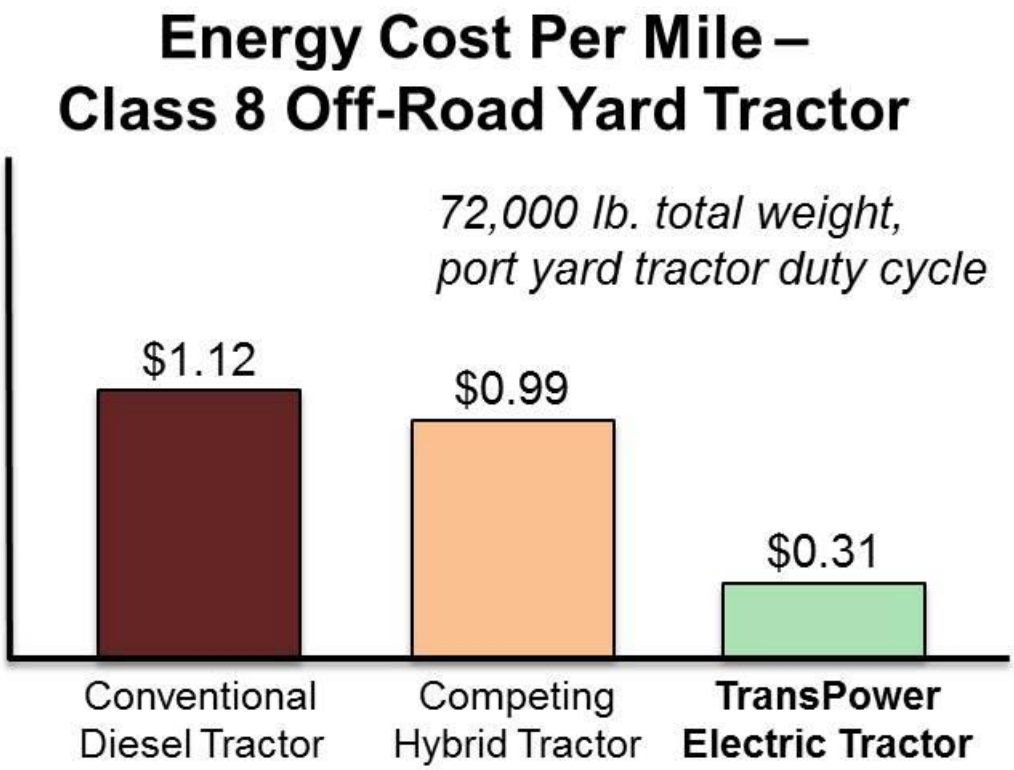

Figure 39. Cost per mile of using TransPower electric tractor versus conventional diesel and competing hybrid-electric designs. (Source: UC Riverside/College of Engineering-Center for Environmental Research and Technology [CE-CERT] dynamometer lab).

The IKEA tractor and both Port of LA tractors were demonstrated extensively in real-world operating conditions – testing sufficient to validate the UCR dynamometer testing results and TransPower's analytical predictions – which were the main goals of the project. 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 IKEA tractor has demonstrated unambiguously that electric propulsion is a practical alternative for heavy-duty Class 8 yard 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 (see following section).

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 an additional tractor at IKEA's California distribution center, along with expanded tractor operations at ports, warehouses, other 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 two additional tractors and entering them into service at the Port of San Diego and near the Port of Long Beach.
- 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 IKEA tractor. One has been operating

temporarily at the Port of San Diego and the other has been deployed with 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 port terminal operators APM, Evergreen, and Pasha, along with Walmart, FedEx, Kroger, BNSF Railway, Bolthouse Farms, Foster Farms, and Purolator.

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.

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.

The other three fleet operator partners who will begin operating electric tractors to be 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 the Port of Los Angeles and several fleet operators regarding the possibility of teaming up to pursue funding from the Greenhouse Gas Reduction Fund, which recently released a solicitation for funding for projects involving electric yard tractors. 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.

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 40 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), but each of the two tractors subsequently built for the Port of Los Angeles (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.

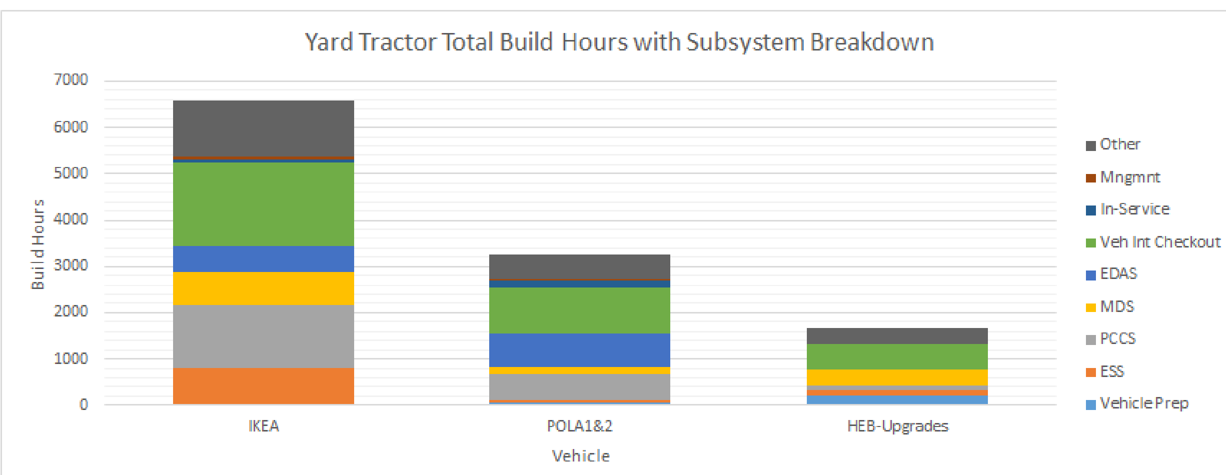

Figure 40. Trend in tractor assembly hours over the course of the EYTD Project.

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 July 31, 2015 total $TBD. This included $500,000 in SJVAPC funds and $TBD in cost sharing. Sources of cost share included:

- TransPower and Cargotec cost sharing directly in support of the EYTD project: $TBD.
- IKEA cost sharing related to operation of the tractor: $TBD.
- **TOTAL: $TBD**