ELECTRIC YARD TRACTOR PRODUCT DESCRIPTION

Report Date: July 15, 2014

INTRODUCTION

This report provides a comprehensive overview of the battery-electric drive system developed by Transportation Power, Inc. (TransPower) for installation into Class 8 yard tractors, also known as “yard hostlers,” “yard goats,” and “shunts.” This zero emissions technology is designed to meet or exceed diesel yard tractor performance standards while producing zero emissions and greatly reducing operating costs by eliminating fuel use and simplifying vehicle maintenance.

YARD TRACTOR VEHICLE MODELS

TransPower’s “ElecTruck™” drive system is inherently flexible and can be installed in a wide variety of vehicle models. TransPower currently offers a version of this battery-electric system customized for use in Kalmar Ottawa tractors manufactured by Cargotec. Five tractors of this model have been converted by TransPower to electric drive over the 2012-14 period in the course of designing, testing, improving, and ultimately perfecting this variant of the ElecTruck™ system. TransPower can therefore offer electric propulsion systems compatible with Kalmar Ottawa tractors immediately. Similar propulsion systems can be provided for other tractor models, but for any tractor models other than Kalmar Ottawa tractors, there would be additional work involved in attaining the same level of seamless vehicle integration that TransPower has already achieved with the Kalmar Ottawa tractor model. Figure 1 is a photo showing two newly manufactured Kalmar tractors received by TransPower in late 2013, prior to replacement of their diesel engines with electric drive systems. TransPower can install electric drive systems into new tractors like these or can convert existing tractors to electric drive.

Figure 1. Kalmar tractors shortly after receipt from Cargotec.

ELECTRIC YARD TRACTOR DESIGN VALIDATION

The variant of the ElecTruck™ system installed into Kalmar tractors was designed by TransPower specifically for yard truck applications. The current system design is the result of more than three years of analysis, test, and evaluation, which included:

- Testing of key electric drive components on a water-brake dynamometer for several months in mid-2012;
- Test driving of two early prototype Tractors by TransPower for six months (September 2012 to March 2013);
- Chassis dynamometer testing of one of the first two prototype tractors at the University of California, Riverside in March 2013; and
- Operational testing of both early prototype tractors under harsh conditions in San Antonio, Texas from April through July 2013.

The last phase of testing just described included approximately 1,000 miles of use of two electric tractors under real-world operating conditions by HEB, a large retailer, at HEB's major distribution center in San Antonio. Figure 2 shows one of these electric tractors pulling a heavy refrigerated trailer. The two prototype tractors demonstrated performance equal to or superior to diesel tractors in many respects, including faster acceleration, the capacity to pull loads of more than 80,000 lb., and top operating speeds of greater than 40 miles per hour. Equipped with extra-large battery subsystems weighing nearly 6,000 lb., these tractors were able to operate continuously for up to 13 hours on a single battery charge and equaled the HEB record for most containers moved by a tractor in a single shift (45).

Figure 2. Early prototype electric tractor pulling container at HEB facility in Texas.

The extensive testing of TransPower's first two prototype tractors identified the areas in which the electric drive system required improvement to enhance system reliability and robustness. Acting on the data collected during this extended test program, TransPower developed a second generation drive system design featuring several such improvements. These included development of a more rugged version of TransPower's unique "Automated Manual Transmission," which improves performance by using proprietary software to control a manual transmission. TransPower also made major improvements to the design of the yard tractor battery energy storage subsystem, including adaptation of a revolutionary new battery management system, and developed a new integrated approach to installing drive system controls that simplifies vehicle integration and servicing.

Figure 3 is a computer illustration of the updated electric yard tractor design resulting from the prototype testing and design validation process just described. This illustration prominently shows the large battery boxes mounted to each side of the tractor. Figure 4 is an illustration of the new "Power Control and Accessory Subsystem" (PCAS) utilized to pre-integrate most accessory and control components.

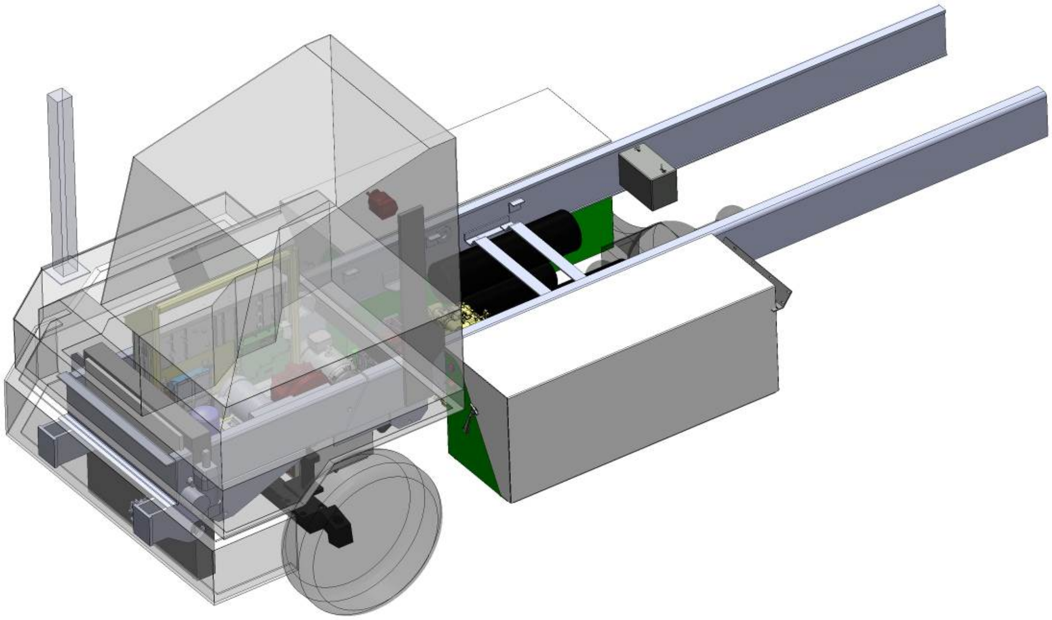

Figure 3. Computer illustration of the new electric yard tractor design.

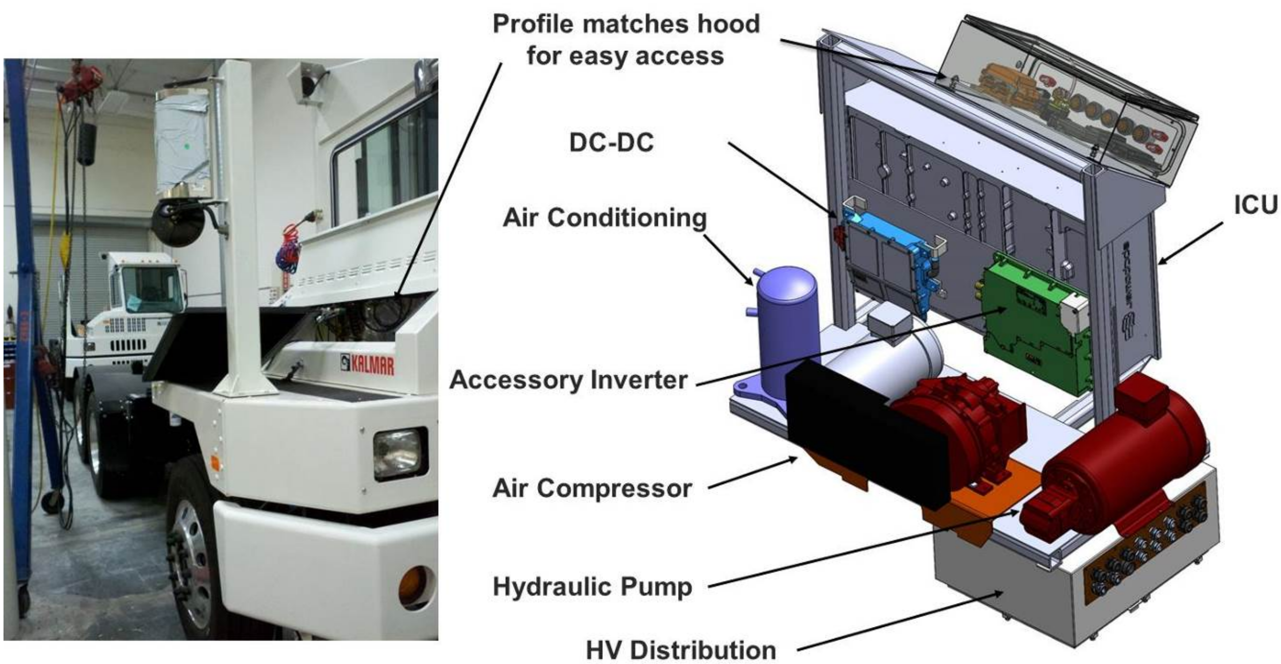

Figure 4. Illustration of Power Control and Accessory Subsystem and its location.

These and other elements of TransPower's new electric yard tractor drive system are described in more detail in the following sections, which discuss TransPower's vehicle conversion process and the unique features of the extraordinary ElecTruck™ yard tractor propulsion system.

TRACTOR PREPARATION

Figure 5. Engine being removed from a Kalmar tractor.

The first step in integrating the ElecTruck™ system into a yard tractor is to prepare the base tractor vehicle for installation of the drive system. This principally involves removal of the engines and transmissions from each vehicle to be converted. Figure 5 shows the engine being removed from one of the tractors converted to use the latest variant of this ElecTruck™ system. The ElecTruck™ system is fully integrated with the Kalmar tractor, both structurally and electronically, so tractor preparation also includes decoding all of the vehicle's control software and identifying the routing and functions of all electrical wiring. Standard dashboard control and displays are utilized to the greatest extent possible to simplify user adaptation to the ElecTruck™ system.

MOTIVE DRIVE SUBSYSTEM

Following vehicle preparation, the first major task is typically to assemble and install the motive drive subsystem used for vehicle propulsion, which consists of a main drive motor and Eaton 6-speed manual transmission configured to use TransPower's proprietary Automated Manual Transmission (AMT) technology. Two completed motive drive subsystems prior to tractor installation are pictured in Figure 6, which clearly shows the main elements of the motive drive subsystem. The main electric drive motor used to propel the rear axle is the metallic-colored disk at the bottom of each assembly. The motors are manufactured by JJE, a Chinese company which is one of the world's leading motor manufacturers. These particular motors are an interesting choice because they were originally designed for the Fisker Karma, a hybrid-electric passenger car, in a joint development effort involving JJE and Quantum Technologies, Worldwide. The JJE motor provides unusually high power and torque for such a compact design, and has undergone extensive product testing and validation as part of the large investments made by Fisker in its drive system technology.

Figure 6. Motive drive subsystem assemblies prior to tractor installation.

Also visible in Figure 6 are the six-speed Eaton transmissions used in the ElecTruck™ motive drive subsystems. On top of each transmission are perpendicular silver cylinders which are the main components of the Eaton "X-Y shifter" mechanism which enables computer-controlled actuation of the transmission. This is a new innovation Eaton has developed over the past decade to improve the efficiency of their transmissions when used with conventional diesel engines. TransPower's adaptation of this technology to electric vehicles 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.

Figure 7 is a photo of a motive drive subsystem after installation into a Kalmar tractor. One of the key innovations of the AMT system is TransPower's use of the JJE-Fisker drive motor to rapidly synchronize the transmission, which results in extraordinarily smooth shifting and eliminates the jerkiness associated with most heavy-duty vehicle shifting mechanisms. This makes tractors using the AMT extremely pleasant to drive a well as providing high performance across the tractor's entire speed range. The AMT also improves operating efficiency as compared with conventional automatic transmissions because it eliminates the need for a torque converter, which typically spins all the time and constantly drains energy. System robustness is assured by use of Eaton's rugged transmission and X-Y shifting mechanism. TransPower's AMT software has been developed and perfected in stages since

Figure 7. Motive drive subsystem installed.

early 2012, and 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.

ENERGY STORAGE SUBSYSTEM

As illustrated previously in Figure 3, the current ElecTruck™ yard tractor design utilizes large battery modules mounted on each side of the tractor. Earlier TransPower designs utilized smaller battery modules, but extensive TransPower testing and real-world operating experience demonstrated that it is easier to install and maintain a smaller number of larger battery enclosures, which require less wiring between modules and provide more internal space for interior battery wiring, battery management hardware, and associated components. The yard tractor configuration uses two vertical tiers of battery enclosures on each side of the vehicle, utilizing a single module lid on each side to cover both tiers. Figure 8 shows the lower tier of 32 batteries installed in a tractor prior to installation of the battery management system (BMS) and electrical connections. The batteries shown are 400 ampere-hour (Ah) lithium iron phosphate ($LiFePO_4$) cells manufactured by China Aviation Lithium Batteries (CALB), one of the world's largest battery manufacturers. Through extensive testing in yard tractors and other heavy-duty vehicles, TransPower has found the $LiFePO_4$ cells to be extremely safe and durable, as have other users of such cells around the world.

Figure 8. Lower tier tractor battery module housing 32 $LiFePO_4$ cells.

The upper tier of batteries used in TransPower electric tractors, shown in Figure 9, houses 28 cells, providing a total of 60 cells on each side and 120 cells in the entire subsystem. This provides a total of approximately 150 kilowatt-hours (kWh) of total energy storage, of which 70-90% is usable, depending on user needs. The typical approach to battery management is to use no

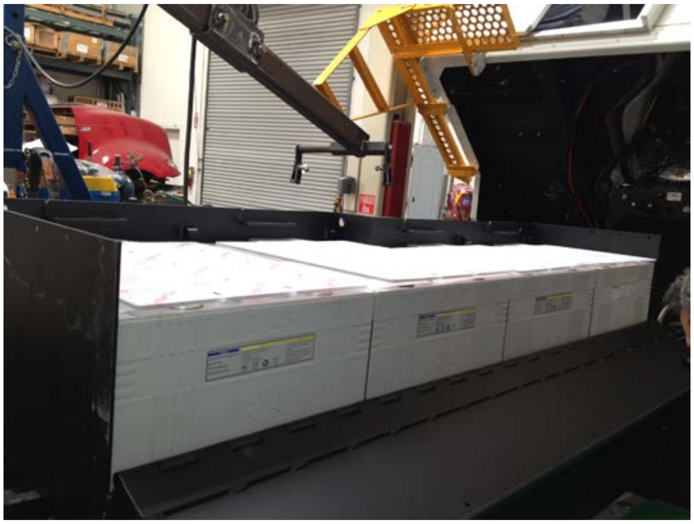

Figure 9. Upper tier of tractor batteries containing 28 cells.

more than 80% of the total energy, or about 120 kWh, which is expected to allow 2,000 to 3,000 discharge cycles. Limiting use to 70% of total available energy can increase battery life to as many as 5,000 cycles. These estimates are all based on battery manufacturer test data and will require several years of vehicle operation to be independently confirmed. However, the data suggest that even if these limits are not achieved, batteries in a typical tractor experiencing one full discharge cycle per day can be expected to last 10 years or more if properly maintained and balanced.

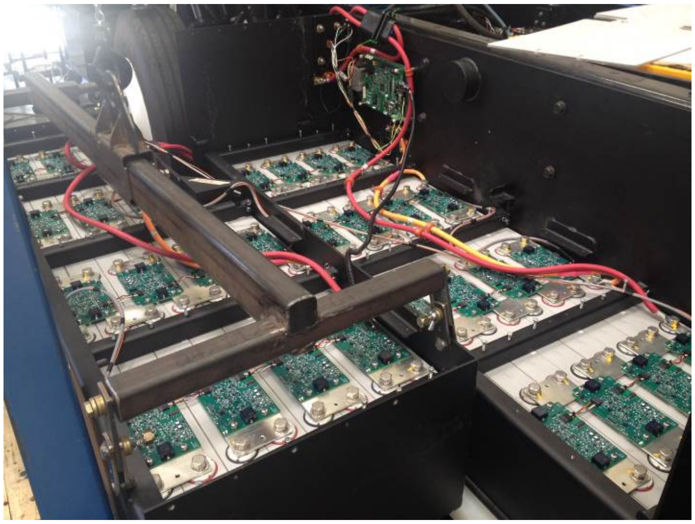

Figure 10. Tractor battery enclosures with BMS installed.

Providing proper battery maintenance is the job of TransPower's Cell-Saver™ battery management system, a brand new product developed in collaboration with power electronics pioneer EPC Power Corp. Cell-Saver™ utilizes sophisticated sensor/balancing boards which are connected to every other cell, and which constantly measure the temperature and voltage of each individual cell. These values are monitored and recorded by the ElecTruck™ control system, which responds to temperature or voltage values outside of safe limits by alerting the tractor operator or, when necessary, disabling the drive system or specific drive system features to prevent damage to the battery subsystem or vehicle. Figure 10 shows the upper and lower tiers of battery enclosures on an electric tractor following installation of the BMS sensor/balancing boards and associated cabling. The Cell-Saver™ central controller can be seen mounted to the inner side of the enclosure to the right.

To varying degrees, the monitoring features offered by Cell-Saver™ are common among commercially available BMS products, but the Cell-Saver™ BMS also offers several unique features, including:

Greater processing capability, enabling more accurate measurements of cell voltage. This improves 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. The active approach of Cell-Saver™ eliminates this energy waste and improves the efficiency of the system. Cell-Saver™ also performs balancing with 6 amps of current, a significantly faster rate than competing BMS products, which balances cells quickly and reduces time required to fully charge and equalize the pack.

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.

POWER CONTROL AND ACCESSORY SUBSYSTEM

The Power Control and Accessory Subsystem (PCAS) is an integrated assembly containing most of the major components used for power control and distribution in the ElecTruck™ system. The PCAS also houses most of the major components of the ElecTruck™ electrically-driven accessory subsystem. Figure 11 is a photo of the two completed PCAS assemblies prior to tractor installation. The most prominent element of the PCAS assembly is the Inverter-Charger Unit (ICU), the large metallic colored box mounted near the top of each assembly. Like TransPower's Cell-Saver™ BMS, the ICU was developed in partnership with EPC Power Corp. The ICU is an equally revolutionary electric vehicle product which performs two vital functions in the ElecTruck™ system: while the tractor is moving, it converts DC power from the battery subsystem into AC power for the main drive motor, and while the Tractor 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 and can recharge a tractor battery pack at power levels of up to 70 kW. When used in conjunction with the Cell-Saver™ BMS, the ICU can fully recharge and balance the tractor battery pack in less than four hours.

Figure 11. Completed PCAS assemblies prior to tractor installation.

Specific design features include use of high-voltage insulated gate bipolar transistors (IGBTs), liquid-cooled heat sinks, and high switching frequencies. Figure 12 is a photo of the interior of one an ICU. The high charging power level of the ICU will be particularly valuable in situations where tractors are heavily used for more than one shift per day. For example, using the ICU for "opportunity charging" of the tractor batteries during one-hour layovers can enables a tractor to complete three 4-hour shifts each day.

Figure 12. Interior of ICU.

The PCAS also includes high-voltage wiring harnesses and a High-Voltage Distribution Module (HVDM) which routes power from the ICU to the main drive motor and the battery enclosures. Another prominent element of the PCAS is the Central Control Module (CCM). The CCM houses many of the specialized electronic components use to control the ElecTruck™ system, including vehicle control microprocessors, a DC-to-DC converter, and fuses. Figure 13 is a photo of the interior of a CCM showing many of these components. The ElecTruck™ system uses modern models-based controls which enables TransPower to rapidly adjust control parameters to reflect lessons learned during vehicle operation or to accommodate new components as technologies advance and newer products become available. The inherent flexibility of the ElecTruck™ control system and TransPower's commitment to continuously updating the ElecTruck™ design help assure customers that it's tractor drive systems will never be out of date. The ElecTruck™ system is also equipped with a sophisticated UniCAN data acquisition system which monitors and records data from all components, providing diagnostic data critical to proper vehicle maintenance and troubleshooting of problems as they occur.

Figure 13. Interior of CCM as integrated into each PCAS assembly.

ELECTRICALLY-DRIVEN ACCESSORY SUBSYSTEM

The function of the electrically-driven accessory subsystem in the ElecTruck™ system is to provide electrical power to operate the following critical vehicle devices:

- Power steering
- Pneumatic braking
- Heating, ventilation, and air conditioning
- 5th wheel lift

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 the 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. Yard tractors present an additional challenge in their use of a 5th wheel lift, a mechanical device near the back of the tractor that is lifted to engage the tractor with trailers as quickly as possible.

As mentioned previously, some elements of the TransPower accessory subsystem have been integrated into the Power Control and Accessory Subsystem (PCAS). Figure 14 is a PCAS photo highlighting several of the main electrically-driven accessory components. 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.

Figure 14. PCAS photo highlighting several accessory components.

Power for these motors is supplied by a small accessory inverter which converts DC power from the battery subsystem to AC power as required by the accessory motors. The accessory inverter used in the latest version of the ElecTruck™ system is a new inverter manufactured by a German company, Lenze, which was designed specifically for heavy-duty automotive applications. The Lenze inverters are compatible with standard automotive control protocols and are packaged in sealed enclosures for environmental protection. A related accessory component integrated into the PCAS assembly is a DC-to-DC converter which steps down the battery voltage to the 12-volt level required by several tractor systems, such as the lights, horn, and cabin lift mechanism.

The ElecTruck™ accessory subsystem also includes components integrated directly into the tractor as well as those pre-integrated into the PCAS assembly. Components installed directly into the tractors include the plumbing utilized to route fluid and air to the various components that use them. As discussed previously, the power steering system and the 5th wheel lift are both powered hydraulically, using a two-stage electrically-driven pump mounted to the PCAS assembly. The air system used for braking also locks and unlocks the 5th wheel lift. TransPower utilized its previous experience testing prototype yard tractors to evaluate the speed with which the 5th wheel lift must be raised and lowered to meet tractor operator expectations, and the motors, pumps, and various accessory devices required for operation of the 5th wheel lift have been sized accordingly.

INTEGRATED ELECTRIC DRIVE SYSTEM

The major ElecTruck™ subsystems just described are available individually or in various combinations to tractor manufacturers, as well as being installed by TransPower into tractors as a turn-key vehicle conversion service. TransPower manufactures and supplies all of the mounting hardware, wirning harnesses, and other integration hardware required for installation of the ElecTruck™ subsystems into yard tractors. Figure 15 is a photo of a Kalmar yard tractor following integration of the ElecTruck™ system, with the cab lifted to enable viewing of the major components.

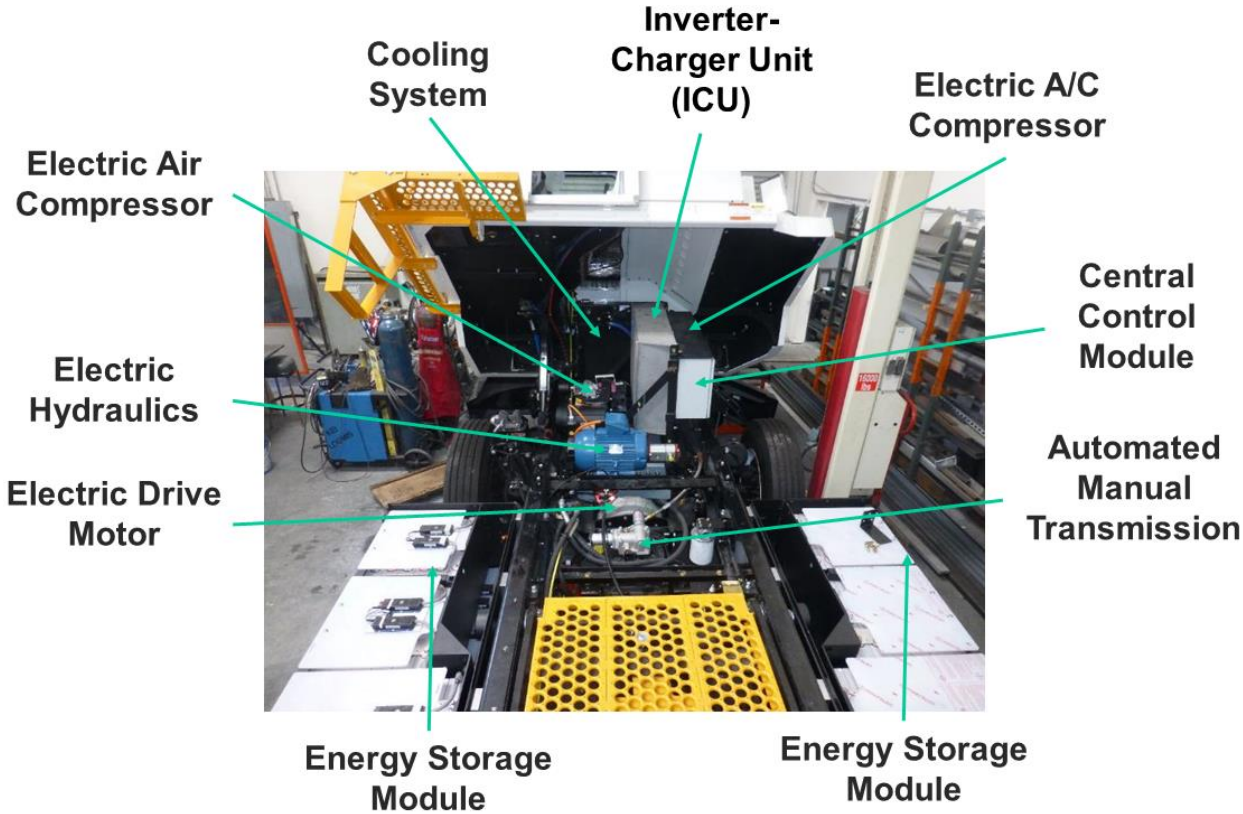

Figure 15. Kalmar tractor with ElecTruck™ system fully installed.

Similar drive systems using the same basic components are available for conversion of nearly every type of heavy-duty vehicle to electric drive, including on-road Class 7 and 8 trucks, and various type of rail vehicles. Hybrid range extension subsystems using various fuels including natural gas and hydrogen are also available.

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