eTRU Refrigerated Warehouse Technology Demonstrations

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ABSTRACT

Diesel-engine-driven trailer refrigeration units (TRUs) have been the standard means for reliably keeping fresh and frozen foods cool in over-the-road transport. They are critical to maintaining a high level of quality and safety in our national 'cold chain'. However, the diesel engines that power TRUs emit noise and air pollutants while the unit is running on diesel power. With the rising fuel prices, the cost of running these units has increased.

An alterative to using a diesel engine full-time is to use an electric Trailer Refrigeration Unit (eTRU) that has electrically driven components and can be powered by either an on-board diesel generator or a shore-power grid connection. While this unit is connected to shore power, diesel usage is eliminated completely, reducing cost and the related diesel emissions. It also offers higher inherent reliability, requires less refrigerant charge, and has a much lower potential for leakage. However, eTRUs built to U.S. specifications face several market penetration barriers – primarily, higher initial costs and the lack of a significant shore-power infrastructure.

To overcome these barriers, a team of experts was assembled to demonstrate a U.S.-spec eTRU. The team, consisting of Shurepower, LLC, New York State Energy Research and Development Authority, U.S. Environmental Protection Agency SmartWay Transport Partnership, U.S. Department of Energy, Carrier Transicold, New West Technologies, LLC, Maines Paper & Food Service Inc., Willow Run Foods Incorporated, and New York State Electric and Gas, is demonstrating and collecting real-world data on the fuel and emissions impact of eTRUs in New York State.

Background

Project Description

In September of 2005, the New York State Energy Research and Development Authority (NYSERDA) awarded a cost-shared contract to Shurepower, LLC for the design, installation, and field demonstration of electrified loading docks and parking spaces for heavy-duty diesel trucks and refrigerated trailers. This project demonstrates electric Trailer Refrigeration Units (eTRUs) and will document their ability to reduce air pollution, noise, maintenance costs, and diesel fuel use. The new Carrier Transicold TRU featuring Deltek™ hybrid diesel electric technology, which can be directly powered by electricity, is being used to demonstrate this capability.

The demonstration project is located at the Maines Paper & Food Service, Inc. distribution facility in Conklin, NY and the Willow Run Foods Inc. facility in Kirkwood, NY. It is the first of its kind to supply grid electric power to over-the-road eTRUs while they are parked. Ten parking spaces have been electrified at Maines to serve as a staging area for the trailers, while eTRU power connections have been installed at two loading dock bays at Willow Run.

Ten demonstration trailers at Maines and nine demonstration trailers at Willow Run have been equipped with the Deltek™ eTRUs. A patent-pending under-trailer wiring system was installed in each to transmit electricity from the rear connection point at the loading bay side to the eTRU mounted on the front of the trailer.

Description of eTRU Technology

An electric trailer refrigeration unit is a trailer refrigeration unit that operates electrically, either via electric power supplied by land-based shore power or by electric power supplied by an on-board, diesel-powered electrical generator. Given the present volatile energy markets, along with the fact that electric power from the grid costs significantly less than the diesel fuel required to run a TRU, considerable operational cost savings can be obtained by operating these units on electric shore power.

It is important to make the distinction that an eTRU is not the same as a traditional mechanically-driven diesel TRU with standby electric plug-in capability. The electric standby ability lacks the capacity to "pull down" trailer temperatures when powered by shore power electricity. These units are capable of maintaining the existing trailer temperatures; however, the diesel engine would have to engage to provide the required power if a temperature pull down is required. The eTRU is capable of pulling down trailer temperatures operating on electric shore power alone, so the diesel generator set is not engaged during this process.

The eTRU design has fewer moving parts than a traditional mechanically-driven TRU, resulting in significant uptime and cost benefits from less frequent repairs than traditional mechanically-driven TRUs encounter (e.g. belt failures, etc.) as well as additional cost savings from reduced fuel use. An additional benefit of electric-connected eTRUs is their quiet operation and the lack of on-site emissions, allowing the refrigerated trucking industry to adapt to environmental constraints such as areas that restrict noise and air pollutants.

An eTRU consists primarily of electrically driven components, as opposed to the mechanically-driven components used in traditional TRUs. The eTRU includes a sealed compression system (like household refrigeration) that requires less maintenance than the mechanically-driven units in traditional TRUs, and severely reduces the likelihood of refrigerant leakage (vis-à-vis an open drive system with a mechanical shaft seal). Using electric components allows the eTRUs to be entirely powered by a plug-in electrical connection while they are parked or being loaded. The diesel generator set provides electric power when traveling over-the-road.

Carrier Transicold's Deltek™ eTRU technology. The Deltek™ technology utilizes three major components to deliver refrigeration and heating: a direct-injection diesel engine, a high-performance electric generator, and an electrically-driven hermetically-sealed compressor. The high-performance generator driven by the diesel motor powers the electrical system and components; this eliminates most of the mechanical components used by conventional TRUs. Carrier also developed the innovative Deltek™ product architecture using advanced permanent magnets, which are capable of producing a high magnetic field with very low mass. The unit's all-electric performance allows for connection to an electric 460VAC power source, eliminating the need to run the diesel motor (Carrier Corporation 2006a, 2006b).

Utility Motivation

The United States consumes over twenty million barrels of petroleum each day, with two-thirds of that total being consumed for transportation. The eTRU technology represents a cost-effective way to replace petroleum use with domestically-produced electricity to improve the nation's energy security. Additionally, eTRU technology creates a significant new market for power generation which is of great interest to electric utilities.

Technology and Market Study

A technical and market study was performed in 2005 to evaluate the potential for eTRUs in the United States as well as their environmental and economic impact. This study was co-funded by NYSERDA and Shurepower, and focused on deploying this technology in New York State. It investigated the emission reduction potential for eTRUs, considered optimal eTRU operational specifications, and discussed the business cases for both current diesel TRUs with electric standby and eTRUs. Potential partners were contacted to discuss participation in a future eTRU technology demonstration (Perrot & Tait 2005).

Study results. The study revealed several conclusions that impact the economic viability and environmental impact of eTRUs. The major findings from the report are:

- Future TRU systems will have to be cost-competitive on a lifecycle basis relative to conventional TRU systems if they are to effectively compete in the marketplace. These new units will have to be more efficient and more environmentally friendly to comply with future environmental regulations and constraints. Furthermore, there is a strong possibility that these conventional systems will have an electric option to comply with new anti-idling restrictions in key urban markets.
- eTRUs appear to be a promising technology for U.S. fleets due to increasingly higher diesel fuel prices and stricter emissions regulations. This conclusion is based on the operational cost analysis, localized emission and noise elimination benefits of diesel-driven TRUs and eTRUs, the successful operation of these units in Europe, and the interest demonstrated by the refrigerated transport industry in the United States.
- Warehouses and trailer parking areas can be easily retrofitted to incorporate the electrical service required to operate eTRUs. Adequate electric service exists at many of these facilities due to the electrical requirements of their current refrigeration equipment. The engineering and installation of the electrical distribution and wiring may be provided to the facility at a reduced cost by a local power utility or government subsidy.
- Regulations may require the adoption of these units in environmentally sensitive areas. The U.S. EPA and CARB have proposed stringent emission regulations, and local regions have discussed restricting the operation of diesel-powered TRUs. Depending on future TRU regulations, these units may also have the advantage of being able to operate in restricted areas, further increasing their value.
- The cost of diesel fuel and the decreased associated maintenance requirements of eTRUs offer operator savings and rapid payback of the incremental purchase price difference. As diesel prices average over $2.50 per gallon, the payback on an eTRU can be obtained in less than 8 months for an incremental capital cost increase of 10% compared to a TRU

and in less than 23 months for an incremental capital cost increase of 30%. This rapid payback provides a significant economic incentive for fleets to purchase these units. Additional savings will come from productivity gains from increased uptime.

- Improvements to the eTRU electric plug location are needed and may be accomplished through the development of industry standards designed to reduce market barriers. Trailers should be equipped with hardware to allow connections to be made from the shore power to the eTRU. This will eliminate the requirement of connecting the eTRU, located at the front of the trailer, directly to the electricity supply, located at the rear of the trailer. This can become a very difficult endeavor for temporary electric cabling.

Based on these conclusions, it was decided that an eTRU demonstration should be pursued to confirm the assessment results and to validate the cost assumptions for the installation of the electrical connections and operation of the eTRUs. A field demonstration would provide information on the actual value of eTRUs, their impact on profit margins, and the actual payback period for a trucking company purchasing eTRUs. Emission reduction calculations will indicate the localized and net environmental impacts of this technology. Following the promising results of the technology and market study, the second phase of this project, which includes the design and demonstration of a facility capable of powering eTRUs, was pursued.

Demonstration of Technology

Requirements for the Demonstration

Several supporting components must be incorporated into the demonstration to fully evaluate the real-world applicability of the technology. Four essential elements must be completed to ensure the demonstration is complete and will provide representative results.

1. <u>eTRU selection</u>: Pre-commercial or commercial eTRUs must be used to evaluate the trailer equipped with refrigeration units under typical operating conditions found in the refrigerated transport industry. These trailers should be used on standard routes which are similar to those typically used by other refrigerated trailers. This type of operation will permit the evaluation of real-world benefits.
2. <u>Trailer Wiring System</u>: The trailers must be equipped with a wiring system that allows the eTRU to be connected at the rear of the trailer. This is necessary because the trailers are typically backed up to unloading docks and into their parking spaces, as is the case at Maines and Willow Run. The wiring system limits the extension cable length required to connect the eTRU to the electric shore power pedestal in the dock or parking space.
3. <u>Refrigerated Warehouse Operations</u>: A refrigerated warehouse facility with the necessary electrical power and the staff capable of maintaining the eTRUs is needed. Adequate electric power distribution is required to supply the eTRUs with the required 23 amp, 460VAC, 3-phase power. The electrical connections must be designed to permit the secure and safe transfer of power from the pedestals to the eTRU connection as well as providing protection from physical damage from accidental impact or drive-off. The warehouse facility will incorporate the eTRU equipped trailers into their daily operations, treating the units as part of the fleet. However, as would be done at any facility using

these units, the facility manager should attempt to maximize the amount of time these units are connected to shore-power electric power.

4. Electrical Facility Deployment: A data collection system must be installed to record the electric power usage of each eTRU and will be configured for basic data collection capabilities to ensure the units are operating properly.

eTRU Selection

The eTRU selected for this demonstration project is the Carrier Transicold Vector 1800MT. This multi-temperature trailer refrigeration unit was selected as it is the only eTRU currently available in the U.S. This unit is typical of the eTRU technology and is anticipated to offer increased system reliability, performance, and an estimated thirty percent reduction in maintenance costs. A photograph of the unit can be seen in Figure 1.

Figure 1. Carrier Vector 1800MT eTRU

Source: Carrier Corporation

Trailer Wiring System

The eTRU is installed on the front of the trailer facing the tractor, and the integrated electrical connector is at the bottom of the unit. A means of connecting the eTRU to the shore power connection was needed. It was decided to hardwire a cable into the eTRU and route the cable along the underside of the trailer. The original eTRU electrical connector was removed and remounted at the rear of the trailer. This is shown in Figure 2. A second separate extension cable will be used to make the connection between the rear of the trailer and the shore power receptacle. This design provides for an acceptable voltage drop and highest protection from damage from unintended drive-offs while still connected.

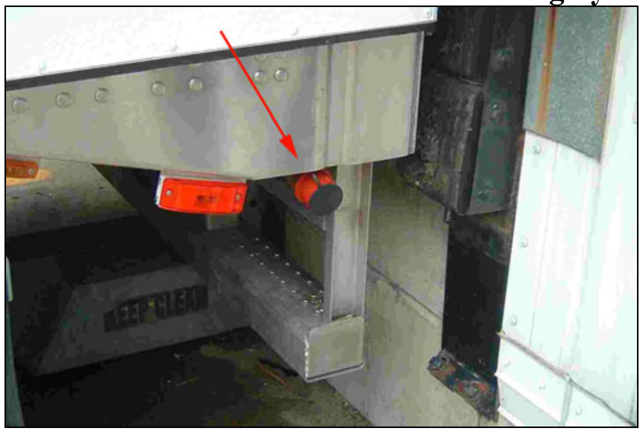
Figure 2. Connection of Trailer Wiring System to eTRU

Source: New West Technologies, LLC

A cable with a current carrying capacity of 35 amps (approximately 50% higher than the maximum load) was selected. Special attention was paid to the insulation material selection to ensure the cable could withstand the harsh conditions experienced underneath a trailer, taking into account the severe winters in New York State and the exposure to extreme cold, salt, and other deicing chemicals. The cable was routed through the existing conduit underneath the trailer that is currently used for wiring and brake lines.

The electrical connector was relocated from the eTRU to the rear of the trailer in front of the rear bumper, just behind the tandem axle assembly and just below the plane of the trailer load floor. This is shown in Figure 3. The connector is positioned between the mud flaps and the rear bumper and gives the connector and cable the best possible protection from road debris and road spray while still being convenient to connect to the power receptacle. The connector is mounted angled slightly down and to the rear to help reduce damage to the trailer wiring, connector, and eTRU in the event of an unintended drive-off.

Figure 3. Rear Driver Side View of Trailer Wiring System Outlet



Source: New West Technologies, LLC

Refrigerated Warehouse Operations

It is critical to identify the best possible partners for a successful demonstration project to ensure that full support is given throughout the project, since project activities can disrupt normal warehouse operations. The warehouse facility must have certain characteristics to make it a good demonstration partner, such as a training program for maintenance and operations staff, as well as the required infrastructure to support this type of project.

To identify partners for this project, four criteria were determined to down-select a facility. First, the fleet must be located in New York State within the New York State Electric and Gas (NYSEG) service area, since New York State money is co-funding the demonstration and NYSEG is contributing cost share. Second, the fleet must be a refrigerated fleet operating at least 20 trailers to successfully demonstrate the eTRUs. For a successful demonstration, 10 trailers must be available for a control fleet in addition to the 10 demonstration trailers. Third, the fleet must be willing to acquire and operate the pre-commercial Carrier Transicold Deltek™ eTRUs in their operational fleet for the demonstration. As such, the fleet must be committed to demonstrating new and innovative high-technology solutions and integrating these into their operations. Finally, the warehouse facility must have the electrical infrastructure to support 30 amp, 460VAC, 3-phase service to each pedestal. After all criteria were applied, Maines Paper & Food Service Inc., headquartered in Conklin, NY, was selected as the best possible candidate for the warehouse demonstration partner. Maines is one of the leading food service distributors in the nation and has nine distribution centers supporting restaurants, healthcare and educational facilities, and other food service customers in thirty-five contiguous states throughout the Northeast, Mid-Atlantic, Gulf States and the Midwest.

Electrical Facility Deployment

Shurepower, in conjunction with New West Technologies and local contractors, designed and installed the electrical eTRU facilities. Each of the ten eTRUs requires a maximum of 23 amps, so the design incorporates 30 amp connections to ensure adequate current capacity and the wire is sized to ensure that fluctuations in power quality and voltage drop due to the long wiring run from the main power feed did not affect eTRU operation.

An installation plan was developed for the required 300 amp, 460VAC 3-phase service. The design incorporated infrastructure components from a prior 110VAC electrical installation that was used for truck tractor block heaters. The previously-installed electrical conduit and I-Beam electrical outlet mountings were utilized for the eTRU electrical supply. The electrical supply was installed by a general contractor using established engineering practices to ensure that all codes and standards were satisfied. The run of 900 feet, much longer than typical installations supplying this level of power, was engineered to supply the maximum operational power required during 100% system utilization. To accomplish this, a single 500 MCM 600 Volt, 4 conductor copper wire was run 400 feet from an existing distribution panel inside the warehouse equipped with a 300 amp, 480VAC, 3-phase breaker to a junction box at the end of the warehouse. At the junction box, the line was divided into two separate 350-foot runs of 500 MCM wire feeds through the existing 2-inch conduit. These two wire runs each separately carry 150 amp of 460VAC, 3-phase power to a newly-installed weatherproof distribution panel with ML breakers located adjacent to the electrified staging area. A photograph of the newly installed distribution panel can be seen in Figure 4.

Figure 4. Distribution Panel Receiving 300 amp, 460 VAC, 3-Phase Electrical Feed

Source: New West Technologies, LLC

The power receptacles for the eTRUs are mounted on an I-beam located on the centerline between two adjacent parking stalls; thus each pedestal provides power for the two adjacent stalls. Again, existing conduit was utilized to provide two feeds of 30 amp, 460VAC, 3-phase power to five I-Beams. The previous installation of 110VAC electrical connections is shown in Figure 5 and the 460VAC system is shown is Figure 6.

Figure 5. I-Beam Equipped with 110VAC Electric Power Shown Prior to eTRU Connection Installation

Source: New West Technologies, LLC

Figure 6. I-Beam Equipped with 460VAC Electric Power Shown with New Wiring and Power Receptacles Installed

Source: New West Technologies, LLC

Power Outlet Connections

Since electrical and safety standards for eTRU power outlets do not exist, several aspects of the connection hardware were deemed to be critical for the design of the units used in this application. The primary design emphasis was safety, followed by durability, weather resistance, and the anticipated compatibility with future eTRU systems and electrical connections. An interlocked outlet was selected to ensure that the circuit is de-energized prior to the cable being disconnected from the outlet. The cable has detachable connections at both the pedestal and the trailer. The outlet was also designed to break away in the event of an unintended drive-off. This will trip the circuits and terminate power to prevent exposure to a live outlet. Circuit breaker protection is provided in the electrical distribution panel cabinet. Power outlet connections must be UL listed to ensure safety of the system. The National Electrical Manufacturers Association (NEMA) has established a range of standards for electrical equipment enclosures. A NEMA 4X level enclosure protection classification is suited for outdoor use and provides a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed water; and the formation of ice on the enclosure (NEMA 2005). NEMA 4X was established as the minimum design protection level for the connection enclosure because snow and ice are prevalent in the Conklin, NY area.

Heavy-duty stainless steel construction was used for the individual connection enclosures. This will enable the power outlets to withstand environmental impacts as well as protect the units in case of trailer impact or drive-off. The connector design was chose to be compatible with a number of major manufacturers.

Cable and plug requirements to connect the trailer outlets to the pedestal outlets were standardized at 25 feet to enable any trailer to use any cable for connection. Because the outlet enclosure is located between two parking stalls, one trailer will need a longer wire run to connect to the power since the outlets installed on the trailer are all in the same location. The longest cable run between the trailer and pedestal is 18 feet. A 25-foot extension cable was used to allow for enough wire slack to allow the majority of the cable to lay on the ground rather than possibly being suspended between the trailer and pedestal to limit the stress on the connectors. An evaluation of the wire type for the extension cable was performed and a cable type was selected that would permit flexibility and protection from environmental conditions (e.g. temperature, oil, water). The female plug receptacle was selected to match the eTRU connector used by Carrier.

Facility Training and Safety Signage

Management staff, maintenance staff and yard truck drivers from Maines who would use the eTRU electrical connections were trained to safely operate the system's hardware, including the proper procedure for making the physical connection between the trailer and the shore power pedestal. Precaution and safety were emphasized to ensure that everyone understood the potential for bodily harm due to the voltage and power present in the system. This training minimizes the potential for physical damage to the hardware due to improper connections and unintended drive-offs. A reference sticker with instructions for connecting and disconnecting the electrical wiring was placed on each pedestal; the instructions require that the pedestal be connected last and be disconnected first to allow the outlet's interlock feature to prevent damage to the connectors and receptacles caused by arcing. A warning sticker was also placed on each trailer next to the mounted connection as an added precaution to ensure that the trailer side connection was handled only when the pedestal side connection was disconnected.

Data Collection

A proprietary wireless data collection system was installed to collect electricity usage data including instantaneous electrical loads and other electricity usage data for each eTRU connection. This system uses a high-speed Internet connection to permit real-time access to on-site data.

In addition, data are being collected from the eTRUs directly via the Carrier Transicold DataLink™, which provides a complete temperature and operating history. The DataLink™

system uses sensors to record critical trip temperature data, including supply- and return-air temperature, bulb temperature, network events, and alarms. The DataLink™ data collection system on the demonstration fleet is equipped with the optional door-opening and fuel-level sensors. All data are time stamped to be able to properly match up with the facility-based system data (Carrier Corporation 2003).

Results to Date

An analysis was performed using preliminary data to calculate the fuel savings an eTRU (Carrier Transicold Vector 1800MT) operating on standby electric power provides compared to a conventional TRU (Carrier Transicold Genesis) operating on diesel fuel. Typically, TRUs (both conventional or eTRU) cycle the temperature control system (engine, compressor, fans) off and on to maintain the trailer temperature. The fuel consumption rate for TRUs varies between manufacturer, operation, ambient conditions, and type (single or multi-temperature). Single temperature models inherently use less fuel than multi-temperature models. Due to limited test data, an average fuel consumption rate of 0.75 gal/hour (to maintain 0°F) was determined, using manufacturer data for both types of conventional TRUs. Although this is a rough estimate, it permits a baseline fuel consumption rate to be established and fuel use and cost savings to be calculated. This fuel consumption rate will be refined when specific fuel consumption data become available. Electric usage data from four months of eTRU field test data (September to December 2006) shows that the average power demand is 7.7kW.

To calculate the operational savings, a diesel fuel price of $2.725/gallon (AAA 2007) was used resulting in an average hourly diesel fuel cost of $2.044/hr. Using an electricity cost of $0.1298/kW-hr (USDOE 2007), the average hourly cost for operation on electric standby power is $0.999/hr; resulting in $1.045/hr of cost savings (51.1% less than diesel use). The projected incremental price difference between a conventional TRU and an eTRU is estimated at $2,500. Using these parameters, the incremental cost of the eTRU could be paid off in just under 2,400 hours of electric plug-in use based on fuel displacement savings alone. The 2,400 hours of electrical connection time can be achieved in one year of use resulting in a 12 month payback of the incremental cost. However, it should be noted that this payback calculation does not include the cost for the facility electrical upgrade and electrical connection pedestal installation. As a side note, New York has the second highest electricity rates in the country; thus the hourly savings and payback will improve in areas where electricity rates are lower.

The fuel consumption rates of the two types of TRUs was also compared. Using the limited fuel usage data that are available, the eTRUs have demonstrated fuel consumption rates 2.5% lower than the conventional TRUs when both units are operating on diesel fuel power. This increased fuel efficiency further shortens the payback time when the fuel efficiency savings are combined with the diesel fuel displacement savings. In addition, Carrier has estimated that the maintenance costs for the Deltek™ Vector hybrid diesel electric eTRU technology are 20-30% less than a conventional TRU. However, detailed information on typical maintenance costs was not available, so these costs were not included in this payback analysis. Any additional savings from maintenance cost reductions will shorten the payback period even further.

Conclusions

This project has successfully completed the elements required to demonstrate the eTRU in real-world conditions. All components needed to operate these units have been designed, produced, and completed. The eTRUs and the high-voltage under-trailer wiring systems are installed on the trailers, the electrical facility construction has been completed and is operational, the data collection systems have been installed and are operational, and the warehouse facility has integrated eTRU units into their fleet.

Data collection is now underway to document the operational characteristics and benefits of the eTRUs compared to conventional TRU operations. Preliminary data indicate that these hybrid-electric TRUs are more fuel efficient and have the capability to efficiently use electric power permitting a rapid payback on investment. A comprehensive analysis will continue for one year, at which time a final report will be issued.

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