Demonstration of Next Generation Technology for Ultra-Low Emissions Truck Refrigeration in the San Joaquin Valley

District Contract Number: C-32565

FINAL REPORT
June 7, 2019

Project Team:
eNow, Inc.
Johnson Refrigerated Truck Bodies
Challenge Dairy Products, Inc.

1. Executive Summary

Refrigeration for food products delivery in urban settings is facing major challenges: Diesel fuel is costly, emissions and noise are highly undesirable, food product safety regulations are becoming more stringent, and diesel driven transport refrigeration units (TRUs) have very high maintenance expense. Consequently, fleet owners and operators are seeking improvements in fuel use, environmental performance, and productivity without compromising food product safety.

The demonstration project described in this report was successful in developing and testing a hybrid all-electric refrigeration system for medium duty commercial vehicles that employed multiple energy sources to achieve significant benefits for end users and the environment, including:

- Significant emissions reductions (>90%) compared to a conventional diesel engine powered TRU
- Significant operation and maintenance (O&M) cost reductions (>80%) compared to a conventional diesel engine powered TRU

- Potential for twelve hour route durations
- Minimum truck engine operation for delivery routes
- Improved refrigeration quality (e.g., +/- 5°F temperature control during route conditions)
- Maintain refrigeration temperatures during long duration delivery stops or if the delivery truck is out-of-service

These benefits were demonstrated on one Class 7 truck on actual urban delivery routes by fleet partner Challenge Dairy during extended operations through the San Joaquin Valley.

The project team consisted of eNow, Inc. (eNow), Johnson Refrigerated Truck Bodies (Johnson), and Challenge Dairy Products Inc. (Challenge Dairy), who are industry leaders in the fields of Solar PV, Power Electronics, Truck Refrigeration, and Refrigerated Truck operations. Challenge Dairy was the “host” of the hybrid all-electric refrigeration system and provided the “wheels on the ground” in the appropriate environment to conduct the tests by Johnson and eNow.

Overall, the demonstration was very successful in developing and testing a completely new approach to refrigerated truck TRU design that was shown to reduce CO_2 by 93% and criteria pollutant emissions (i.e., CO, NO_x, PM) by almost 100%. The estimated O&M cost reduction is estimated to be 81% and the estimated overall lifecycle cost reduction is estimated to be 77% based on the results of the demonstration testing. This large decrease in lifecycle cost is due primarily to a projected longer life and lower O&M costs for the all-electric system compared to the high cost of operating, maintaining, and replacing a small diesel engine powered TRU. By far the largest annual cost savings comes from eliminating the use of diesel fuel for refrigeration system, which saves almost $17,000 annually in extended (12-hour) duration deliveries. In addition to lower O&M costs, vehicle up-time was dramatically improved with the hybrid all-electric TRU compared to the conventional diesel TRU system. The truck with the hybrid all-electric TRU achieved an up-time of 90% compared with the truck with the diesel TRU, which achieved an up-time of only 66%.

Demonstration testing over the course of the 56-week over-the-road demonstration period showed that solar contributed 676 kWh (83%) of the hybrid all-electric TRU power, and the battery contributed 143 kWh (17%). Solar contributed another 548 kWh while the vehicle was parked, which helped reduce the amount of shore power required to charge the batteries while parked at the Challenge Dairy distribution center. In addition, for half of the weeks studied (i.e., 28 out of 56), the solar PV charging system contributed a net charge to the battery in addition to powering the hybrid all-electric TRU while on route. The battery voltage results, which are indicators of battery health and state of charge, show that the average battery voltage was well above 48VDC for the duration of demonstration period, and the battery average and minimum voltages would have been much lower if solar PV were not supplying a bulk of the energy to the hybrid all-electric TRU. In fact, it is estimated that a much larger (and heavier) battery would have been required.

Johnson and eNow plan to continue to work together on the commercialization of the hybrid all-electric refrigeration system for medium- and heavy-duty refrigerated truck applications. Based on the results of this demonstration and additional performance testing, Johnson truck bodies is planning to release a new hybrid all-electric (i.e., solar plus battery) refrigeration system using both cold plate and an active evaporator in the first quarter of 2021. The ongoing development, testing, and commercialization of the technology are evidence of the great promise for the technology.

The project team wishes to acknowledge the San Joaquin Valley Air Pollution Control District (District) team for their financial, administrative, technical, and project management support of this project. This project could not have been conducted without their significant assistance.

2. Background

Refrigeration for food products delivery in urban settings is facing major challenges: Diesel fuel is costly, emissions and noise are highly undesirable, food product safety regulations are becoming more stringent, and diesel driven transport refrigeration units (TRUs) have very high maintenance expense. Major TRU manufacturers recently bypassed new emissions regulations by switching to smaller diesel engines (<25 hp) that are currently not regulated. These diesel engine powered TRUs typically produce NO_X emissions that are almost 13 times greater and PM2.5 emissions that are over 80 times greater per gallon than today's heavy duty vehicle engines,[1] which use advanced after treatment systems like selective catalytic reduction (SCR) to meet strict emissions regulations. Although more efficient than the larger TRU diesel engines used in the past, these smaller TRU diesel engines don't do much to reduce the emissions of NO_X, particular matter, or ROG/VOCs. In addition, noise pollution continues to be a problem related to the diesel engine powered TRUs running when the delivery truck is stopped making a delivery, especially in urban settings. Consequently, fleet owners and operators are seeking improvements in fuel use, environmental performance, and productivity without compromising food product safety.

3. Technology Description

Hybrid All-Electric TRU

The hybrid all-electric refrigeration system that was developed and tested for medium temperature refrigeration applications (dairy and produce) in this demonstration project employed two forms of energy storage: eutectic medium (i.e., "cold plates"), and a high quality absorbent glass matt (AGM) lead acid auxiliary battery system. The all-electric refrigeration system operated at 48VDC and was originally conceived to accept energy from multiple electrical sources including utility power (i.e., shore power), solar-based power, and - as a back-up option - power from the vehicle electrical system when the vehicle is operating. However, it was determined that power from the vehicle electrical system was not necessary, so the refrigeration system was designed to operate free of on-board emissions using utility and solar-based power only. In the final design, the cold plates and auxiliary batteries were initially charged from utility power that was delivered to the vehicle when it was plugged in at its "home base" overnight.

[1] Based on 0.207 lb (94.15 grams) NOx and 0.0296 lb (13.44 grams) PM2.5 per gallon for a conventional TRU and 0.016 lb NOx and 0.00036 lb PM2.5 per gallon for a 2014 MY Class 7 Truck traveling 25 mph on average. See Emission and Fuel Use Reduction section for sources and other details.

When the truck was operated on a delivery route, or parked at its "home base" during the day, the auxiliary batteries were charged by roof mounted solar photovoltaic (PV) panels.

Cold plate-based refrigeration is highly energy efficient; however, weight (which impacts vehicle fuel economy and emissions) and frost accumulation (which impacts refrigeration efficiency and therefore route durations as well as utility energy use and emissions) have been traditional issues with systems that rely upon cold plates only. Johnson's hybrid all-electric refrigeration system significantly reduces weight and avoids frost accumulation through the intelligent control of an electrically operated evaporator system that traps and eliminates moisture from the air within the refrigerated compartment. Weight reduction is achieved via the high capacity auxiliary battery system and through the use of sub-eutectic temperatures with the cold plate elements of the design.

In addition, solar energy, captured from specially designed PV panels on the vehicle's roof, provide a completely silent and emissions free source of energy to recharge the TRU's auxiliary battery system. eNow Inc. designs and sells lightweight and durable PV systems for the medium and heavy duty truck market. eNow's flexible and highly durable PV panels were mounted on top of the refrigerated truck's roof to capture sunlight and convert it to direct current (DC) electricity. eNow's solar charge controller maximized the power output of the PV panels and efficiently charged the auxiliary battery system. The use of solar not only reduces overall fuel use and emissions, but it also has the potential to extend refrigeration runtime, which can enable 12-hour route durations even during hot summer days.

Data Collection Equipment

Automatic data collection was accomplished through two tools: Onset computer RX3000 with HOBO Link (HOBO RX3000), and Emerson iPro DAC performance monitoring system (iPro). Both tools had cellular communications so data and alerts could be transmitted in real time or near real time.

The HOBO RX3000 enables multiple sensors to collect data and send information to the Cloud every half hour. A software tool called HOBO Link is used to display data and generate data downloads for further processing. Data is sampled every 10 seconds and averaged into 5-minute log records. Data points collected with the HOBO RX3000 included:

- Battery voltage of each of the 4 batteries
- Battery charger electrical current to each battery
- Shore power energy input
- Solar panel current
- Compressor current
- Condenser fan current
- Evaporator fan current
- Ambient temperature
- Temperature of the interior of the box
- Solar radiation (intensity)

Data was downloaded each week and entered into a spreadsheet where the data was analyzed and recapped into weekly averages. Key data was reviewed to determine the health of the electrical system and batteries. The HOBO system also had alerts set to notify various parties via email or text messages of problems like low battery voltage.

The iPro is an all-encompassing heating, ventilation, and air conditioning (HVAC) control and data collection system. It collects data on cooling and heating functionality of the refrigeration system. Data points collected with the iPro included:

- Discharge Pressure
- Suction Pressure
- Manifold Temperature
- Discharge Air Temperature
- Box Temperature
- Suction temperature
- Ambient Temperature
- Battery Voltage
- Defrost start and end times
- Time and duration of door openings
- Warning and system faults

The iPro data was collected and managed by both Emerson Electric technicians and Johnson Truck Body technicians. The box temperatures presented in the Results section are based on the iPro reporting as this temperature measurement was the most accurate.

4. Detailed System Design

The following section describes the hybrid all-electric refrigeration system design, which was also published in the proceedings of the *17th International Refrigeration and Air Conditioning Conference* at Purdue.[2]

The all-electric refrigeration system utilizes a fully electric condensing unit featuring a high efficiency variable speed scroll compressor with economized vapor injection and 48VDC input variable speed drive. Inside the refrigerated body is a dual evaporator system consisting of eutectic plates and direct expansion evaporator. Powering the system is a 48VDC battery pack which is charged by utility power at night and via solar panels during the day. The entire system is controlled with a single system controller which is programmed to optimize both efficiency and reliability.

A typical eutectic plate system, sometimes called “cold plate systems”, is shown in Figure 1. This design uses stored energy in the form of frozen fluid to cool the refrigerated box. The eutectic plates contain a brine solution which is designed to freeze at an appropriate temperature

[2] Vehr, Shawn (Emerson Electric), “A Low Emission, Electrified Solution for Refrigerated Trucking”, 17th International Refrigeration and Air Conditioning Conference, July 9-12, 2018

corresponding to the goods it is carrying. The plates act as an evaporator in the refrigeration cycle with an electric condensing unit mounted elsewhere on the truck. Typical operation is to power the condensing unit only overnight to freeze plates. During the delivery route the box is cooled by using the stored energy in the plates. This method of refrigeration has the notable benefit of eliminating the diesel engine and associated fuel and maintenance costs. The main drawback of this method is the inability of the refrigeration system to run while on route. This reduces the achievable route duration and temperature control.

The hybrid eutectic or hybrid all-electric system demonstrated in this project is shown in Figure 2. The term hybrid refers to the nature of how the box is cooled by utilizing both a direct expansion evaporator and eutectic plate storage. The truck refrigeration system is fully electric and contains a 48VDC condensing unit, eutectic plate evaporator (containing 4 plates), and direct expansion evaporator. Power to run the system is supplied by an on board 48VDC battery pack. 48VDC power was selected to stay below the 60-volt level at which point additional safety precautions must be used. 48VDC power is also an emerging technology in the automotive market, so 48VDC parts and equipment are coming down in price with the much higher automotive volumes. Batteries are charged via utility power and on-board charging system at night while the truck is docked and via roof mounted solar panels during the day. The solar panels measure 139.3 ft^2 (12.9 m^2) and have the capability of producing 12.9 Watts/ ft^2 (139 Watts/m^2).

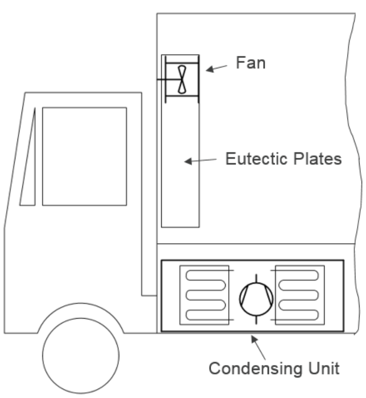

Figure 1: Eutectic Plate System Diagram

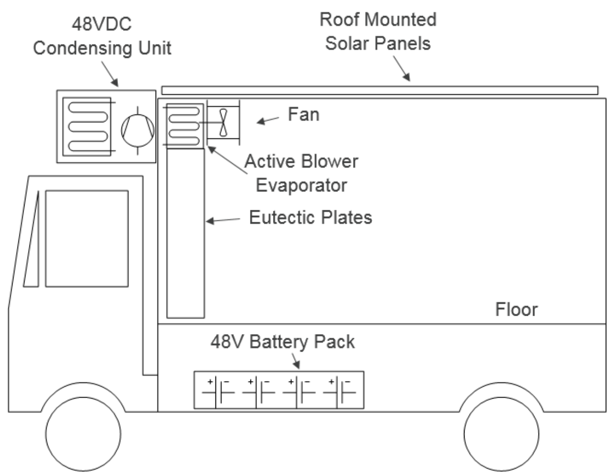

Figure 2: Hybrid All-Electric System Diagram

A more detailed hybrid all-electric system design is shown in Figure 3. The 48VDC condensing unit contains a 48-volt variable speed drive powering a variable speed scroll compressor, micro-channel type condenser and economized vapor injection (EVI) circuit. The EVI circuit allows further capacity and efficiency improvements, particularly at high ambient operating conditions. Solenoid valves are placed in the system to allow adjustment of evaporator operation. This gives the ability to cool the box via eutectic only, direct expansion evaporator only, or both combined. Of note is the 48VDC condensing unit design which can run at a low 48-volt level but at the same time produce the required refrigeration capacity to maintain a 20 ft (6.1 m) long refrigerated truck at 36°F (2.2°C) under all ambient requirements. Two new components were developed specifically for this application, the 48VDC variable speed drive and variable speed compressor.

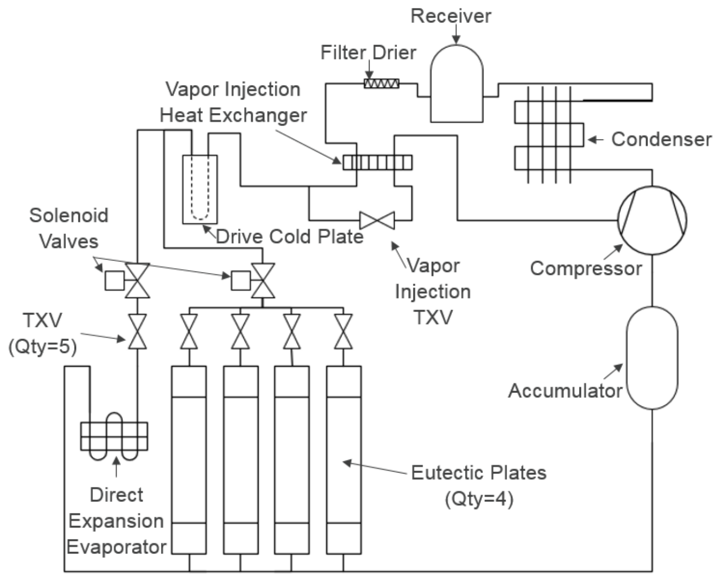

Figure 3: Hybrid All-Electric Refrigeration System Design

5. Objectives

The project objectives were to demonstrate a unique combination of technologies including a vehicle integrated solar power approach that reduces CO_2 emissions by 86%, NO_X emissions by 98%, PM2.5 emissions by 97%, and operation and maintenance (O&M) costs by about 90% as compared with conventional diesel engine powered TRU approaches. These benefits were to be demonstrated on one Class 7 truck on actual urban delivery routes by fleet partner Challenge Dairy during extended operations through the San Joaquin Valley. The hot San Joaquin Valley provides significant weather contrasts, with intense summer heat, to properly conduct the necessary tests under real-world conditions.

Specific objectives of the demonstration program included:

- Quantify emissions and fuel use reductions compared to a conventional TRU equipped with a small diesel engine
- Confirm refrigeration system maintenance cost reductions compared to a conventional TRU equipped with a small diesel engine
- Confirm extension of the typical delivery day from eight hours to twelve hours compared to a conventional cold plate refrigeration system

6. Project Team

The project team consisted of eNow, Inc. (eNow), Johnson Refrigerated Truck Bodies (Johnson), and Challenge Dairy Products Inc. (Challenge Dairy), who are industry leaders in the fields of Solar PV, Power Electronics, Truck Refrigeration, and Refrigerated Truck operations. eNow was responsible for the solar PV system development and testing, as well as overall project management. Johnson was responsible for the all-electric refrigeration system and truck body development and testing, and subcontracted with Emerson Electric (Emerson) who developed the all-electric 48VDC refrigeration system. Challenge Dairy was the “host” of the hybrid all-electric refrigeration system and provided the “wheels on the ground” in the appropriate environment to conduct the tests by Johnson and eNow. Individuals from each team member organization meet weekly to discuss the progress and performance to date as well as any issues. Action plans were developed as necessary.

eNow Inc.: eNow is an innovative, clean technology company that develops and sells solar power systems designed specifically for the transportation sector. eNow is currently selling 50-400 W solar PV charging systems that charge truck auxiliary batteries. These products are used to reduce or eliminate jump starts after extended periods without use and/or when parasitic electric loads are high (e.g., lift gate power) or continuous (e.g., monitoring systems). eNow has also designed larger systems (i.e., 500 to 7,000 W) to address no-idle auxiliary loads (e.g., sleeper truck HVAC “hotel loads” and large RV type trailers). eNow’s solar-powered systems received “CARB Approval” from the California EPA in May 2013, and were named one of HDT's 2014 Top 20 Products in February 2014. eNow is MVT (Mesilla Valley Transport) Solutions Certified^{TM}. The eNow team is made up of executives, engineers, and scientists, averaging over 25 years of experience. Prior to eNow’s formation, eNow’s team members were involved with the development of solar applications for NASA’s space program; the development and management of leading solar and battery power electronics; the management of large solar installations; the specification and sourcing of solar panels; and the management of companies at all levels.

Johnson Refrigerated Truck Bodies: Johnson is the largest dedicated refrigerated truck manufacturer in the US and is an industry leader in the development of all-electric refrigeration technology and high efficiency, long life refrigerated truck bodies. Johnson has more than fifty years of experience with the manufacture of light weight, fiberglass, refrigerated truck bodies. This experience includes integration of both diesel powered and cold plate refrigeration systems. Johnson has also commercialized electric refrigeration units that derive power directly from truck driveline (PTO) generators. Johnson is focused on increasing customer value and reducing overall life-cycle costs, and has a great interest in partnerships with key suppliers that offer product innovation thru supplier collaboration.

Challenge Dairy Products, Inc.: Challenge Dairy is a cooperative association responsible for the marketing and distribution of dairy products produced from 400 large family-owned dairies. Challenge Dairy has a tradition for natural, quality dairy products since 1911, and has built a reputation for quality throughout the Western States. Challenge Dairy’s Foodservice Division operates nearly 80 trucks in California from eight foodservice branches. The fleet is largely comprised of 20-foot Bobtail refrigerated trucks, which operate in various temperature zones from the southern California coastal communities of Los Angeles and San Diego to the summer heat of the San Joaquin Valley. Challenge Dairy’s refrigerated truck fleet is equipped with both conventional (i.e., diesel engine based) TRUs, and Johnson Cold Plate with Blower refrigeration units.

7. Scope of Work

eNow worked with Johnson and Challenge Dairy (Host) to develop and demonstrate a hybrid all-electric refrigeration system for mobile source reductions in the San Joaquin Valley. eNow and Johnson completed the design, fabrication, integration, testing, and real-world use of the PV and battery-electric truck refrigeration system on a class-7 truck refrigeration unit. The equipment was placed into service at Challenge Dairy in Fresno, California. eNow, Johnson, and Challenge Dairy performed the following tasks:

1. Task 1—Develop Requirements and Identify Key Objectives (eNow, Johnson)
    - 1.1. Identify subcontractor for Task 2.4 and submit respective sub-agreements to District for consent per section 15 of the agreement.
    - 1.2. Identify duty-cycle and refrigeration requirements of TRU
    - 1.3. Identify vehicle specs and delivery route for optimal PV design
    - 1.4. Identify goals such as emissions reductions, fuel savings, and ROI objectives

2. Task 2—Solar System and Refrigeration Technology Development and Testing (eNow, Johnson)
    - 2.1. Collect data on baseline vehicle (at least 1 month duration) at Challenge Dairy. Data includes, but not limited to the following:
        - 2.1.1. Operating hours, idle time, miles traveled, vehicle speed, fuel consumed, GPS data, ambient temperature, solar insolation
    - 2.2. Develop on-roof solar PV subsystem
    - 2.3. Procure and test PV equipment based on load prediction models
    - 2.4. Validate and test all new or modified equipment (subcontractor)
    - 2.5. Integrate PV system with refrigeration unit

3. Task 3—Integrate And Test New Truck Body On A Class-7 Truck Chassis (eNow, Johnson)
    - 3.1. Assemble and install PV-upgraded refrigeration system on truck
    - 3.2. Assemble and install performance monitoring equipment on truck
    - 3.3. Test vehicle in Johnson Engineering Facility's "hot room" @ 100°F

4. Task 4—Develop A Demonstration Plan (Johnson)
    - 4.1. Select suitable data acquisition systems for demonstration
    - 4.2. Train operators and other team members at Challenge Dairy location

5. Task 5—Demonstrate And Test Vehicle – Phase 1 (eNow, Johnson, Challenge Dairy)
    - 5.1. Demonstrate new TRU at Challenge Dairy
    - 5.2. Collect data on demonstration vehicle (6 months duration). Data includes, but not limited to the following:
        - 5.2.1. Operating hours, idle time, miles traveled, vehicle speed, fuel consumed, GPS data, ambient temperature, PV performance, grid power, battery state of charge
        - 5.3. Develop and conduct user experience survey for all Challenge Dairy vehicle operators, maintenance personnel and managers involved
        - 5.3.1. Each at beginning, half-point, and end of demonstration period
    - 5.4. Develop interim report based on information collected in subtasks 5.2 and 5.3.

6. Task 6—Demonstrate And Test Vehicle – Final Phase (eNow, Johnson, Challenge Dairy)

6.1. Demonstrate TRU at Challenge Dairy with modification from Task 5
6.2. Collect data on demonstration vehicle (8 months duration). Data includes, but not limited to the following:
   6.2.1. Operating hours, idle time, miles traveled, vehicle speed, fuel consumed, GPS data, ambient temperature, PV performance, grid power, battery state of charge
6.3. Develop and conduct user experience survey for all Challenge Dairy vehicle operators, maintenance personnel and managers involved
   6.3.1. Each at beginning, half-point, and end of demonstration period
6.4. Develop final report based on information collected in subtasks 6.2 and 6.3.

7. Task 7—Final Draft Report And Commercialization Plan (eNow, Johnson, Challenge Dairy)
   7.1. Finish comprehensive final report to include the following:
      7.1.1. Final design and features, summary of objectives met, and detailed cost assessment of demonstration compared to conventional TRU
      7.1.2. Commercialization plan based on outreach to key stakeholders
      7.1.3. Recommendations for future deployment of demonstrated system in California and the Valley

8. Deliverables

Task Name	Deliverable Description	Completion Date
Task 1—Develop Requirements and Identify Key Objectives	Documented specifications and requirements for design and development; documented objectives for demonstration and testing, sub-agreements for District consent	July 1, 2016
Task 2—Solar System and Refrigeration Technology Development and Testing	Documented results from solar and refrigeration system testing	Aug 31, 2016
Task 3—Integrate And Test New Truck Body On A Class-7 Truck Chassis	Complete demonstration vehicle ready for delivery to Challenge Dairy Products for demonstration	Feb 1, 2017
Task 4—Develop A Demonstration Plan	Completed vehicle training for demonstration	Mar 1, 2017
Task 5—Demonstrate And Test Vehicle – Phase 1	Interim demonstration report and recommendations for final phase of Demonstrate and Test Vehicle	Sep 1, 2017
Task 6—Demonstrate And Test Vehicle – Final Phase	Final demonstration report and recommendations for Final Report and Commercialization Plan	Apr 30, 2018
Task 7—Final Draft Report And Commercialization Plan	Final report summarizing demonstration results, objectives met, and next steps.	Oct 31, 2018

9. Challenges

As is expected for any first of a kind development and testing, the project encountered a number of challenges, most of which were addressed during the demonstration testing period. A summary of the challenges and corrective actions during the over-the-road demonstration period are presented below.

June 2017

- Truck body had issues maintaining temperature in high ambient temperature conditions. Specifically, the truck body took a long time to recover in 115°F ambient temperature on plate hold over alone when condensing unit shut down on suction pressure. Corrective

Action: Changed cut in pressure from 45 psi to 40 psi. Note that the issue was later found to be due to frost.

- All-electric refrigeration system showed evidence of undercharge (low subcooling). Poor subcooling caused reduced capacity and overheated the drive as it is cooled by subcooled liquid refrigerant. Corrective Action: Leak check system and added refrigerant.
- Charging issues with batteries, including batteries occasionally being undercharged when connected to shore power. Corrective Action: Battery charger capabilities were reviewed to ensure they were sufficient to accommodate required charge demand. It was later discovered that this issue resulted because the battery charging wires were undersized.

July 2017

- Emerson refrigeration controller malfunctions when system is unplugged at unexpected times. Corrective Action: Controller software update by Emerson to eliminate issue.
- Slowly rising discharge air temperatures over time, suspected frost accumulation. Body temp at 75°F on Saturday 7/8/18. It was determined that operator error resulted in the refrigeration system not being turned on. Corrective Action: Informed operator of error and continued to monitor the issue.
- Relay K-11, which shuts solar charging off when plugged into shore power, failed. Corrective Action: New relay shipped next day air and installed by Central Valley Trailer Repair (CVTR)[3].
- Report from Challenge that the truck body did not go into defrost mode. In the event we have a "Battery Out Of Range" alarm, the defrost cycle is negated; however the refrigeration system can be forced into defrost mode in the maintenance screen if needed. Corrective Action: Checked defrost time duration and manifold temperatures and verified operation of defrost pump. Everything checked out. Determined the truck body likely needs more time to defrost because the unit runs during the day and comes back with cold plates. Increased defrost time and continued to monitor the issue.
- Relay K11 appeared to fail again. Corrective Action: eNow reviewed the solar HOBO link data which showed the solar charging was not active while the battery was plugged into shore power for 2 weeks, but the relay appeared to be working. The battery chargers were changed from 2-stage to 3-stage charging. Voltage over the weekend looked the same as before the switch.

August 2017

- Two more instances of poor subcooling similar to what was seen in the past. The issue appeared to be occurring when doors open and close. Corrective Action: Added more refrigerant to the system.

September 2017

- No new issues

October 2017

[3] CVTR is a Great Dane Trailer authorized service center in Fresno.

- Unable to connect to Emerson's cellular monitoring system (iPro online) to get data, but refrigeration system continued to operate properly. Modem service was shut down due to potential malware. Corrective Action: New modem shipped to CVTR and installed, and old modem was returned to Emerson.
- Continued charging issues with batteries. Corrective Action: Sent replacement batteries to CVTR and shipped old batteries back to Lifeline for testing and possible reconditioning. Also recommended increasing battery charger cable sizing from chargers to batteries, along with re-routing to shorten lengths. Unfortunately, these modifications could not be performed at CVTR and would have required bringing the truck to Johnson's facility in Wisconsin. It was determined that this was not feasible until May 2018 given the amount of time the truck would be out of service.

November 2017

- Imbalance of battery #3. Corrective Action: CVTR checked cabling at batteries and chargers, and found a ground wire loose on the battery charger. Lifeline evaluated the batteries that were previously removed and determined they were undercharged and damaged.

December 2017

- Over voltage alarm occurred on Emerson controller when voltage reached 60VDC. This occurred on a cold day during the route. Corrective Action: eNow checked maximum solar charging setting to avoid over voltage trip.
- Current battery equalizers had low amperage. Corrective Action: Held discussions with supplier and prototype ideas.

January 2018

- Current battery equalizers had low amperage. Corrective Action: eNow engineers traveled to Fresno to check out equalizer and determined the equalizers were undersized.

February 2018

- No new issues

March 2018

- Continued charging issues with batteries. Corrective Action: Shipped batteries to supplier to evaluate and recondition. However, batteries were damaged when shipped back to supplier, so new batteries had to be reordered. New batteries were shipped to CVTR to be installed when battery charger wiring update is performed.

April 2018

- Continued charging issues with batteries. Corrective Action: A group discussion was held to discuss the best way to rewire the battery chargers on field truck, and components were ordered for field rewiring of battery chargers.
- iPro controller error. Corrective Action: Emerson remotely synchronized clock on iPro controller.

May 2018

- Higher than normal discharge air temperature. Corrective Action: CVTR inspected unit and found no issues.

June 2018

- Continued charging issues with batteries. Corrective Action: Johnson completed the battery system rewire at Central Valley Trailer Repair and continued to monitor system for performance. The charging issues appear to have been corrected with this action.

10. Project Results

Emissions and Fuel Use Reduction

Shore Power Emissions Factors

Utility electrical power is used to recharge the refrigerated truck's cold plates and batteries of the hybrid all-electric system as well as to provide refrigeration when either the hybrid all-electric or diesel TRU vehicle is out-of-service. In the Fresno area, this power is sourced by PG&E and contains a significant percentage of generated power from hydro as well as from wind sources. Natural Gas is the only non-renewable fuel source owned by PG&E, and it is only 17% of their total resource mix. However, PG&E also purchases energy from unknown sources from other firms, and this category is 13% of their total resource mix. Therefore, for purposes of the subject analysis; we used average California emission factors, except for CO_2, in which case we have a specific value from PG&E published in their Carbon Footprint Calculator Assumptions document: 0.524 pounds CO_2 per kWh.[4]

A 2012 California Building Energy Efficiency publication was used to determine criteria emission factors for in-state generation displacements for air quality impact considerations. These emissions factors were applied to the shore power used (kWh) during the demonstration period: 0.0327 grams CO per kWh, 0.020 grams NO_x per kWh, 0.010 grams PM per kWh, and 0.0032 grams SO_2 per kWh of shore power used.[5] It is noted that PG&E has almost totally eliminated sulfur dioxide (SO_2) from their utility plants since the 2012 publication.

Diesel TRU Emissions Factors

Diesel fuel is used to power the diesel TRU's small diesel engine, which in turn is used to provide cooling power and recharge the refrigerated truck's cold plates. In the Fresno area, a California Air Resources Board (CARB) diesel fuel is used, which has an ultra-low sulfur content. Note that the control vehicle's diesel TRU contains an older diesel engine that is not equipped with a diesel particulate filter (DPF). Consequently, particulate matter (PM) emissions are much higher than newer diesel-powered refrigeration units that are equipped with DPFs.

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[4] https://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf

[5] Loyer, J. and Alvarado A., "Criteria Air Emissions And Water Use Factors For Gas And Electricity Efficiency Savings for the 2013 California Building Energy Efficiency Standards", March 19, 2012

A 2010 National Renewable Energy Laboratory (NREL) publication was used to determine the emissions factors for the diesel TRU. The NREL publication presents emissions factors for the type of diesel-powered Thermoking TRU used by the control vehicle (with and without a DPF) when operating on CARB diesel fuel. These emissions factors were applied to the diesel fuel used (gallons) during the demonstration period: 30.2 pounds CO_2 per gallon (17,975 g/gal), 47.2 grams CO per gallon, 94.15 grams NO_x per gallon, 13.44 grams PM per gallon, and 0.0 grams SO2 per gallon of diesel fuel used.[6]

Comparison of Results

The hybrid all-electric refrigeration system with integrated solar, was projected to reduce CO_2 emissions by 86%, NO_X emissions by 98%, and PM2.5 emissions by 97% as compared with conventional TRU approaches. The actual emissions reductions were evaluated based on testing results from a Class 7 refrigerated truck during a 56-week over-the-road demonstration period (June 2017-June 2018) in normal delivery operations through the San Joaquin Valley as part of Tasks 5 and 6 of the proposed work. Table 1 shows the total hours operated during the demonstration period for both the Diesel TRU (control) truck and the Hybrid All-Electric TRU truck. Total fuel used, shore power used, and emissions are normalized based on the total hours operated for each truck. The calculated emissions reductions based on the actual diesel fuel and shore power used during the demonstration period were 93% CO_2, 100% CO, 100% NO_x, 100% PM, and 13% SO_2 emissions. These tremendous emissions savings are a result of replacing the cooling energy that is conventionally supplied by a small diesel engine (on a conventional TRU), with a combination of utility power and solar power, which have much lower and zero emissions, respectively.

In addition, the measured fuel use reduction during the demonstration period was 100%, due to the decision to exclude charging the auxiliary batteries from power provided by the vehicle's electrical system (PTO) when the vehicle is operating. Shore power use was also reduced by 13% for the hybrid all-electric TRU due to battery and cold plate charging provide by the roof-mounted solar PV.

[6] R.A. Barnitt (NREL), et al, "Emissions of Transport Refrigeration Units with CARB Diesel, GTL Diesel, and Emissions Control Devices", 2009 SAE Powertrain, Fuels, and Lubricants Meeting, NREL/CP-540-46598, May-2010

Table 1: TRU Fuel Use and Emissions Performance Comparison (per hour of operation)

TRU Performance During Demo Period	Units	Diesel TRU	All-Electric TRU	Difference
Total Hours Operated	hours	959	1,260	31%
Diesel Fuel Used	gallons/hour	1.54	-	-100%
Shore Power Used	kWh/hour	7.65	6.63	-13%
CO2	lbs/hour	50.5	3.48	-93%
CO	grams/hour	72.8	0.22	-100%
NOx	grams/hour	145	0.15	-100%
PM	grams/hour	20.7	0.07	-100%
SO2	grams/hour	0.024	0.021	-13%

Lifecycle Cost Reduction

Table 2 presents and performance and cost assumptions used for the hybrid all-electric refrigeration system and conventional diesel TRU based on results of the demonstration and input from the team's (i.e., Johnson) operational experience as well as EIA data for Diesel Fuel[7]and Utility Power[8] prices in California. The Capital Cost assumption for the refrigeration technology is based on detailed cost assessment by Johnson, which shows a selling price of $3,000 less than a conventional diesel TRU is possible for a fully-deployed system. eNow's 1,800 W solar system would retail for around $7,000 today, but when fully deployed, we project the price will drop to below $5,000 based on discussion with our suppliers, which would result in a combined hybrid all-electric refrigeration system price that is equivalent to today's conventional diesel TRUs (i.e., $19,000 for Carrier and ThermoKing). Additionally, Johnson believes the Technology Life and Maintenance Costs for the hybrid all-electric refrigeration system will be substantially improved due to the elimination of a conventional TRU's small diesel engine, resulting in lower annual capital and O&M costs.

Table 2: Lifecycle Cost Performance and Cost Assumptions

Performance and Cost Assumptions	Next Gen Refrig	Conventional TRU	Units	Source
Diesel Fuel Used	-	1.54	gal/hr	Demonstrated performance
Shore Power Used	6.63	7.65	kWh/hr	Demonstrated performance
Daily Hours of Operation	12	12	hour/day	Modeled performance based on demonstration results
Annual Days of Operation	300	300	days/yr	Input assumption
Capital Cost	$ 19,000	$ 19,000		Johnson experience and costs projections
Technology Life	12	5.56	years	Johnson operational experience (20,000 hours TRU engine life)
Interest Rate	2%	2%		District Assumption
CRF	0.095	0.192		Calculation
Diesel Fuel Price	NA	3.067	$/gal	EIA Diesel Fuel Price for CA 2017 annual
Utility Power Price	0.1576	0.1576	$/kWh	EIA Commercial Electricity Price for CA 2017 annual
Maintenance Costs	0.104	0.200	$/hour	Johnson operational experience (1000-2000 hour service intervals)

7 http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_sca_m.htm
8 http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a

The hybrid all-electric refrigeration system with integrated solar, was projected to reduce O&M costs by 90% and lifecycle costs (total cost of ownership) by 79% compared with conventional TRU approaches. The actual costs were evaluated based testing results from a Class 7 refrigerated truck during a 56-week over-the-road demonstration period (June 2017-June 2018) in normal delivery operations through the San Joaquin Valley as part of Task 5 and 6 of the proposed work. The estimated O&M and lifecycle cost reductions are estimated to be 81% and 77%, respectively due primarily to a projected longer life and lower O&M costs of the all-electric system compared to the high cost of operating, maintaining, and replacing a small diesel engine powered TRU. By far the largest annual cost savings comes from eliminating the use of diesel fuel for refrigeration, which saves almost $17,000 annually in extended (12-hour) duration deliveries. Diesel fuel is replaced with "free" solar power and less than $4,400/year in electricity (utility) costs.

Table 3: TRU Lifecycle Cost Results Comparison

Annual Cost Calculations - 12 hour days, $/year	**Diesel TRU**	**All-Electric TRU**	**Incremental Cost**	**% Reduction**
Capital	$ 3,648	$ 1,797	$ (1,851)	*51%*
Diesel Fuel	$ 16,972		$ (16,972)	*100%*
Utility Power	$ 4,343	$ 3,763	$ (580)	*13%*
Maintenance	$ 720	$ 375	$ (345)	*48%*
O&M Total	*$ 22,035*	*$ 4,138*	$ (17,897)	*81%*
Total	**$ 25,682**	**$ 5,935**	**$ (19,748)**	***77%***

Maintenance costs are also expected to be reduced by eliminating the engine, belts and seals required in a traditional system in favor of a totally hermetic system which is free from refrigerants leaks associated with shaft seals. In addition to lower O&M costs, vehicle up-time was shown to dramatically improved with the hybrid all-electric TRU compared to the conventional diesel TRU system. The truck with the hybrid all-electric TRU achieved an up-time of 90% compared with the truck with the diesel TRU, which achieved an up-time of only 66%. Uptime benefits are difficult to quantify, but can be a substantial benefit to refrigerated truck operators due to simplified logistics, reduced spoilage/returned product costs, and increased driver and customer satisfaction.

Solar Performance and Delivery Route Extension

While the demonstration testing did not evaluate solar route extension directly, which would have required a second control vehicle with a hybrid all-electric TRU and no solar charging capability, testing did show that the bulk of the energy provided to the hybrid all-electric TRU while traveling on-route was delivered by the solar PV charging system, rather than by the battery energy storage system. Over the course of the 56-week over-the-road demonstration period, solar contributed 676 kWh (83%) of the hybrid all-electric TRU power, and the battery contributed 143 kWh (17%). Solar contributed another 548 kWh while the vehicle was parked, which helped reduce the amount of shore power required to charge the batteries while parked at the Challenge Dairy distribution center. In addition, for half of the weeks studied (i.e., 28 out of 56), the solar PV charging system contributed a net charge to the battery in addition to powering the hybrid all-electric TRU while on route. See Figure 4 for solar and battery charging results while the hybrid all-electric TRU was on route during the 56-week demonstration period (June 2017-June 2018). Note that negative battery energy delivered indicates weeks when the solar PV charging system contributed a net charge to the battery.

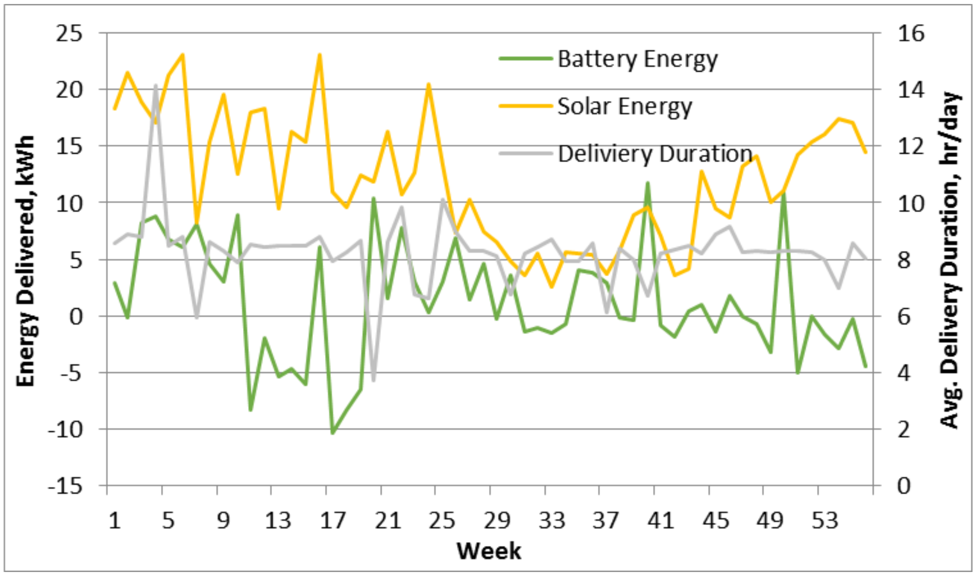

Figure 4: Hybrid All-Electric TRU Energy Delivered While Truck is On Route

The battery voltage results, which are indicators of battery health and state of charge, show that the average battery voltage was well above 48VDC for the duration of demonstration period, and the minimum voltage only fell below 40VDC twice (i.e., 36.1V in week 20 and 38,9 week 29). These two low voltage events are probably a result of disconnecting the batteries during an inspection or maintenance event. The battery average and minimum voltages would have been much lower if solar PV were not supplying a bulk of the energy to the hybrid all-electric TRU. In fact, it is assumed that a much larger (and heavier) battery would have been required. See Figure 5 for battery average and minimum voltage results while the hybrid all-electric TRU was on route during the 56-week demonstration period (June 2017-June 2018).

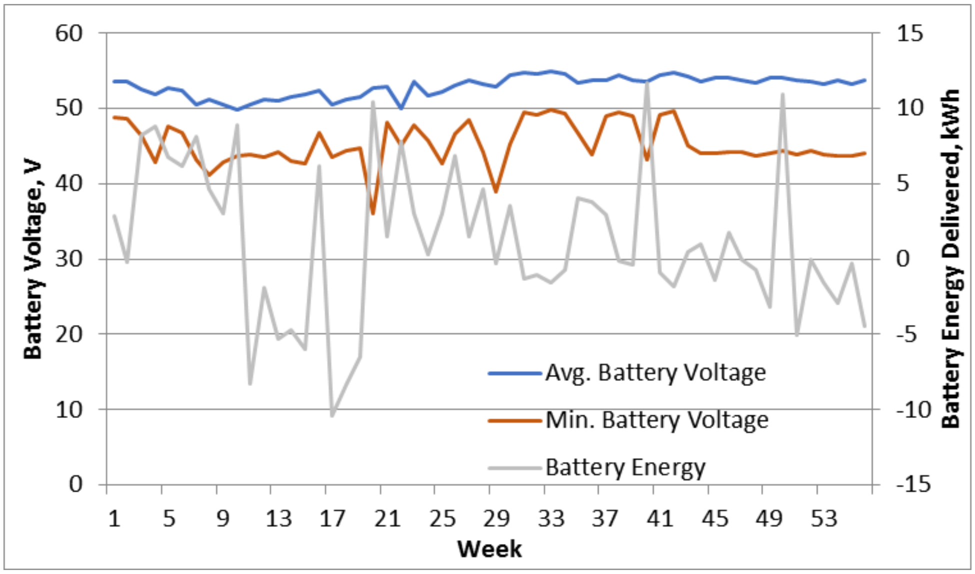

Figure 5: Hybrid All-Electric TRU Battery Voltage While Truck is On Route

A simulation was also conducted which showed an expected total power consumption of 13.5 kWh over the course of a high ambient 10-hour delivery route. Since power is derived from a 48VDC battery pack, the estimated Amp-hr requirement was found by dividing the Watt*hr consumption by 48VDC. While this analysis does not consider the fluctuations in voltage as batteries are charged and depleted, it can be used as a first pass estimate to size the battery pack. Using this analysis, with an assumed 255 Amp*hr battery pack shows the batteries depleted to roughly 156 Amp*hr or 61% at the end of the 10-hour route. This result suggests the battery pack is sized adequately to maintain box temperature. Running this same extreme ambient analysis with zero solar energy input (rainy day) suggests the batteries may be fully depleted, and therefore a larger battery pack would be required. In this scenario, the presence of the eutectic plates allows the system to continue to provide capacity and maintain box temperature until the end of the route at which time the truck is plugged into utility power and batteries can be re-charged.[2]

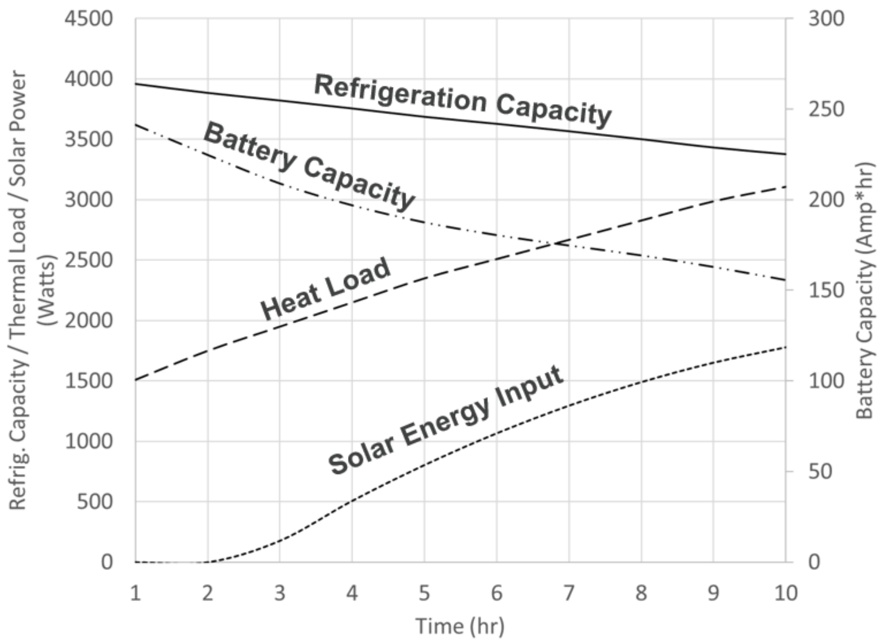

Figure 6: Hybrid All-Electric TRU Simulated Battery Life Bin Analysis Results[2]

Given the demonstrated and simulated performance of the solar PV charging system, it is anticipated that a typical delivery day could be extended well beyond the 7.24 hours the hybrid all-electric TRU averaged over the course of the demonstration period.

Refrigeration Quality Improvement

As can be seen in Figures 7 and 8, both the “control truck” with the conventional Diesel TRU and the truck with the hybrid all-electric TRU deviated from +/-5°F temperature control demonstration target during the hottest summer months (i.e., weeks 6-16 which spanned the middle of June through the end of August 2017). However, both truck’s temperature control was within acceptable limits for dairy delivery.

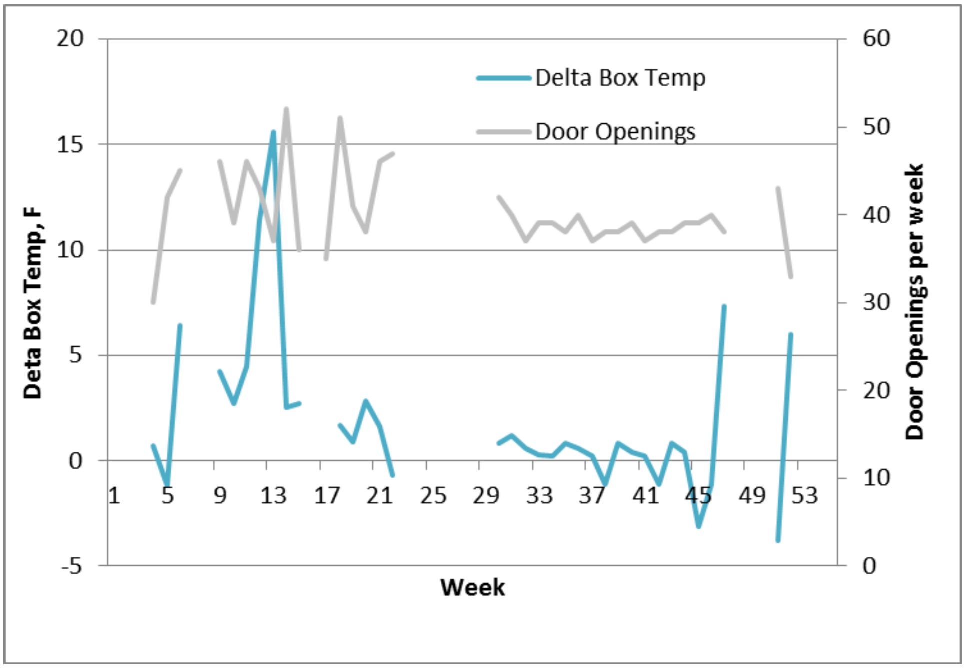

Figure 7: Diesel TRU Truck Temperature Control and Door Openings

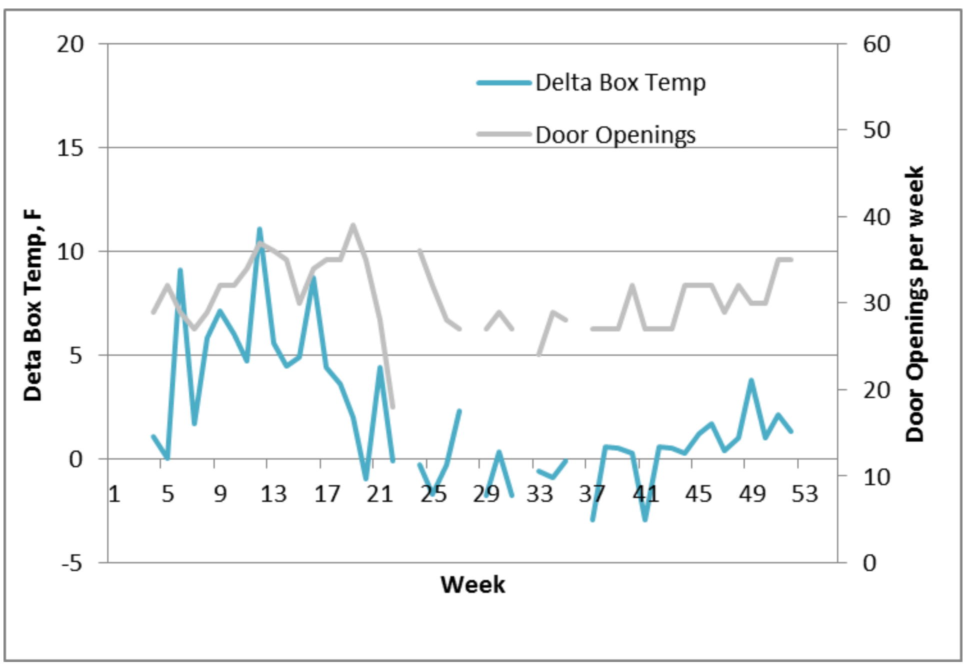

Figure 8: Hybrid All-Electric TRU Truck Temperature Control and Door Openings

Table 4 compares the average weekly refrigeration performance of both trucks. Note that the daily shift durations were very similar for each truck, and both maintained a similar temperature control from the start to the end of the shift (i.e., Delta Temp); although the "start", "ending", and "average" box temperatures for the truck with the hybrid all-electric TRU were generally lower by 1-2°F. The number of door openings for the control truck was higher than the truck with the hybrid all-electric TRU, averaging 40.1 per week for the control truck and 30.5 per week for the truck with the hybrid all-electric TRU, but both trucks exceeded the 30 openings per week target established for the demonstration. More significantly, the average door opening hours were very similar for each truck.

Table 4: Refrigerated Truck Average Weekly Performance Comparison

Average Daily Truck Performance	Units	Diesel TRU	All-Electric TRU	Difference
Shift Duration	hours/day	7.43	7.24	-3%
Door Openings	number/day	40.1	30.5	-24%
	hours/day	4.95	4.47	-10%
Box Temperature (F)	Start	37.5	36.5	-3%
	Ending	39.4	38.4	-2%
	Average	38.8	36.9	-5%
	Delta Temp	1.86	1.97	5%

User Experience

Successes: Challenge Dairy is very interested in the significant diesel and maintenance cost savings of the hybrid all-electric refrigeration system with solar truck body, and the emissions reduction capability is also of interest. Other benefits were the significant reduction in noise by the all-electric refrigeration system compared to a traditional diesel engine powered TRU, and the positive feedback from their customers related to their efforts in reducing harmful emissions.

Challenges: There were unexpected delays in installing the diesel meter and having it function properly the first few months of the project. In addition, the all-electric refrigeration system only used one type of battery for most of the testing, not the 2-3 different battery technologies that were planned. Lastly, in mid May 2018, the all-electric refrigeration system started experiencing a low battery alarm very early in the morning after the batteries had been plugged in all weekend, and the alarm was reported nearly each day starting May 14. Challenge Dairy was unsure what affect this had on the performance of the refrigeration system, so the driver made additional efforts to be very sure the truck door was closed at every opportunity. The log of May 29 shows the box at 41 degrees at 7 a.m. and up to 48 degrees at 11:48 a.m. These issues need to be resolved before the all-electric refrigeration system can be used in regular operations at Challenge Dairy.

Conclusion: Challenge Dairy will consider converting their fleet to the all-electric refrigeration system with solar truck body, but they need to understand more about what caused the battery issues (i.e., was it a solar charging issue, or battery charging issue that created the problems?). Other concerns include the ability to quickly correct issues when they arise, and the cost of the solar truck body compared to an all-electric refrigeration system without solar.

Metrics for Success

The hybrid all-electric refrigeration system was sufficiently successful to warrant continued operation of the demonstrated emissions control equipment based on the criteria established in the original Statement of Work.

Metric	Target	Demonstrated
Functional and cost-effective	Yes, but may require further technology development to improve emissions	Yes, although battery charging issues must be resolved
Emissions (e.g., NOX, PM2.5, CO2) and diesel fuel use reduction compared to a conventional TRU equipped with a small diesel engine	>25% reduction	90-100% reduction
Operating and maintenance cost reduction compared to a conventional TRU equipped with a small diesel engine	>$4,000	$17,900
System target pricing for complete electric refrigeration system competitive with a conventional TRU equipped with a small diesel engine	<125%	100% (estimated)
Life target[9]	>8 years	12 years (estimated)
Extends the typical delivery day compared to a conventional cold plate refrigeration system	Yes	Yes (estimated and simulated)
Vehicle operating (maximum engine running) time[10]	<3 hours per shift	0 hours per shift
Operating shift hours	12 hr/day 300 days/yr	>7.24 hr/day* >200 day/yr*
Refrigerated compartment door openings (service factor = 1.5, reference ambient air temperature = 100 Deg. F)	40-60 min/shift	>60 min/shift
Weighs less than a conventional TRU equipped with a small diesel engine[11]	<1,075 lb	TBD
Superior performance compared to a conventional TRU equipped with a small diesel engine	Yes	Yes, better up-time, lower average box temperature
Quiet operation compared to a conventional TRU equipped with a small diesel engine	Yes	Yes
Temperature control during route conditions	<+/- 5°F	+/- 2°F (average)
Ability to maintain refrigeration temperatures during long duration delivery stops or if the delivery truck is out-of-service compared to a conventional cold plate refrigeration system	Yes	Yes

* Note: the demonstrated operating shift hours was limited by the Challenge Dairy's regular delivery schedule.

11. Budget and Schedule

The planned budget for the demonstration project was $1,235,357 in total project costs, of which $439,882 was approved for District funding. The final project budget request from the District was $294,882, which is $145,00 less than budgeted due to some reduced scope related to solar PV panel testing, and reduced labor due to data collection automation and project management efficiencies. Table 5 provides the breakout of District funding for Tasks 2-7 of the project. Note that Task 1 was ineligible for District funding due to research and development nature of the work.

[9] Diesel TRUs are specified for 20,000 hours (~4.5-6.4 years)
[10] Enables vehicle level fuel savings and idle reductions
[11] Diesel TRU with ½ filled fuel tank approximately 1075 lbs.

Table 5: District Funding by Project Task

District Funded Project Task	Budgeted District Cost	Actual District Cost
Task 2—Solar System and Refrigeration Technology Development and Testing	$38,204	$34,072
Task 3— Integrate and Test New Truck Body	$206,454	$151,612
Task 4— Develop a Demonstration Plan	$59,995	$11,436
Task 5— Demonstration and Testing – Phase 1	$37,160	$27,858
Task 6 – Demonstration and Testing - Final	$37,160	$24,300
Task 7—Final Draft Report and Commercialization Plan	$20,920	$16,117
10% Retention	$39,989	$29,488
Total	**$439,882**	**$294,882**

In addition to District funding the project Team provided addition cost-share funding. The total cost of Tasks 2-7 of the project was $569,810. Table 6 provides the breakout of total project costs for Tasks 2-7 of the project. Project costs for each team member are presented in the Appendix.

Table 6: Total Costs by Project Task

Task	Labor		Equipment		Other		Total	
	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost
2	$ 28,149	$ 57,684	$ 9,708	$ 18,715	$ -	$ 901	$ 37,857	$ 77,300
3	$ 96,408	$ 207,100	$ 72,050	$ 104,624	$ -	$ -	$ 168,458	$ 311,723
4	$ 12,706	$ 22,202	$ -	$ -	$ -	$ 4,419	$ 12,706	$ 26,621
5	$ 30,953	$ 50,606	$ -	$ -	$ -	$ 3,433	$ 30,953	$ 54,039
6	$ 27,000	$ 65,032	$ -	$ -	$ -	$ -	$ 27,000	$ 65,032
7	$ 17,908	$ 35,094	$ -	$ -	$ -	$ -	$ 17,908	$ 35,094
TOTAL	**$ 213,124**	**$ 437,718**	**$ 81,758**	**$ 123,339**	**$ -**	**$ 8,753**	**$ 294,882**	**$ 569,810**

The planned project period was to span 22 months, which included a 6-month implementation period and 16-month over-the-road demonstration period. Assuming a January 1, 2015 start date, the project was to be completed by October 31, 2016. The actual project period spanned 35 months, which included a number of months of contract negotiations with all team members, a 13 month (56 week) over-the-road demonstration period, and 11 months to complete the final analysis and reporting. The project start date was July 1, 2016, and the final completion date was June 7, 2019 upon submission of this final report.

12. Next Steps

Future Deployments of Demonstration Truck

Johnson Truck Bodies has replaced the all-electric refrigeration system AGM batteries with new AGM batteries and will continue to work with eNow and Emerson to monitor the demonstration truck performance for at least another year. It is the team's intention to update the demonstration truck with the latest upgrades that come available. For example the team will install Nickel Zinc battery technology, which will provide more energy storage capacity for the same weight and space as the existing AGM batteries.

Commercialization Plan

Johnson and eNow plan to continue to work together on the commercialization of the hybrid all-electric refrigeration system for medium- and heavy-duty refrigerated truck applications. Based on the results of this demonstration and additional performance testing, Johnson truck bodies is planning to release a new hybrid all-electric (i.e., solar plus battery) refrigeration system using both cold plate and an active evaporator in the first quarter of 2021. Based on the successful testing and monitoring of the hybrid all-electric refrigeration demonstration unit, one of the next generation designs will forego the cold plate technology and incorporate only on-board condenser/evaporator technology using primarily solar and battery energy for over-the-road power. Johnson is also developing a low temperature option for frozen foods.

Johnson and eNow have been actively marketing their next generation all electric system to the industry. The team presented their all electric active evaporator demonstration vehicle (using only an active evaporator) at the TMC (Technology and Maintenance Council) Show in March of 2018 to showcase the operational aspects of all electric refrigeration systems. In addition, the all-electric active evaporator operational unit was presented at the IFDA (International Foodservice Distributors Association) Show in October 2018. From these two show presentations, the team has identified up to 12 potential customers for field trials in 2019. The team is presently processing two units for customers' field use and evaluation. The intention is to have fully developed and commercialized products for both all electric cold plate/evaporator systems and all electric evaporator only systems available for general sale for Model Year 2020.

13. Conclusions

Overall, the demonstration was very successful in developing and testing a completely new approach to refrigerated truck TRU design that was shown to reduce CO_2 by 93%, criteria pollutant emissions (i.e., CO, NO_x, PM) by almost 100%, and operating costs by more than 80% compared to a conventional diesel-powered TRU. The ongoing development, testing, and commercialization of the technology is evidence of the great promise for the technology. There were also a number of challenges, which is expected for any fist of a kind production model testing. Most issues were resolved over the course of the demonstration, but these issues did result in some end-use customer dissatisfaction. One lessoned learned from this demonstration is to include a dedicated demonstration partner who is experienced in over-the-road monitoring and testing, since these skills are not intrinsic to most technology companies like Johnson, Emerson, or eNow.

One persistent issue, the battery charging issue, was not resolved until the end of the demonstration. This charging issue was determined to be due to improper charging cable specification. Corrective actions were identified early on in the demonstration, but were not able to be carried out due to the requirement of an extended out of service period, which was not acceptable to the host company (and reasonably so). Fortunately, the team believes this issue has been resolved and is very optimistic that future results from the demonstration truck will be even better than those during the demonstration period.

14. Appendix

Table 7: eNow Costs by Project Task

Task	Labor		Equipment		Other		Total	
	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost
2	$ 8,949	$ 17,361	$ 9,708	$ 18,715	$ -	$ 901	$ 18,657	$ 36,977
3	$ 8,208	$ 15,924	$ 3,050	$ 5,888	$ -		$ 11,258	$ 21,811
4	$ 5,506	$ 10,682	$ -		$ -	$ 4,419	$ 5,506	$ 15,101
5	$ 4,953	$ 9,609	$ -		$ -	$ 3,433	$ 4,953	$ 13,042
6	$ 5,800	$ 11,252	$ -		$ -		$ 5,800	$ 11,252
7	$ 11,808	$ 22,907	$ -		$ -		$ 11,808	$ 22,907
TOTAL	**$ 45,224**	**$ 87,734**	**$ 12,758**	**$ 24,603**	**$ -**	**$ 8,753**	**$ 57,982**	**$ 121,090**

Table 8: Johnson Costs by Project Task

Task	Labor		Equipment		Other		Total	
	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost
2	$ 19,200	$ 40,323	$ -		$ -		$ 19,200	$ 40,323
3	$ 88,200	$ 191,176	$ 69,000	$ 98,736	$ -		$ 157,200	$ 289,912
4	$ 7,200	$ 11,520	$ -		$ -		$ 7,200	$ 11,520
5	$ 6,000	$ 9,520	$ -		$ -		$ 6,000	$ 9,520
6	$ 6,000	$ 6,400	$ -		$ -		$ 6,000	$ 6,400
7	$ 4,500	$ 7,200	$ -		$ -		$ 4,500	$ 7,200
TOTAL	**$ 131,100**	**$ 266,139**	**$ 69,000**	**$ 98,736**	**$ -**	**$ -**	**$ 200,100**	**$ 364,875**

Table 9: Challenge Dairy Costs by Project Task

Task	Labor		Equipment		Other		Total	
	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost	SJV Funding	Total Cost
2	$ -		$ -		$ -		$ -	$ -
3	$ -		$ -		$ -		$ -	$ -
4	$ -	$ -	$ -		$ -		$ -	$ -
5	$ 20,000	$ 31,477	$ -		$ -		$ 20,000	$ 31,477
6	$ 15,200	$ 47,381	$ -		$ -		$ 15,200	$ 47,381
7	$ 1,600	$ 4,987	$ -		$ -		$ 1,600	$ 4,987
TOTAL	**$ 36,800**	**$ 83,845**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 36,800**	**$ 83,845**