X.4 Demonstration of Fuel Cell Auxiliary Power Units (APUs) to Power Transport Refrigeration Units (TRUs) in Refrigerated Trucks

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Subcontractors:
Nuvera Fuel Cells, Billerica, MA
Ballard Power Systems, Burnaby, BC, Canada

Project Start Date: June 1, 2012
Project End Date: December 31, 2017

Overall Objectives

- Demonstrate the viability of fuel cell-based transport refrigeration units (TRUs) for refrigerated Class 8 trailers.
- Assess the performance of the fuel cell-based TRUs by demonstrating these systems with 800–1,000 hours of commercial deliveries. During the demonstration, the system performance will be independently evaluated.
- Use the demonstration data and market assessment to develop a business case that will determine if lifecycle cost parity can be achieved with incumbent technologies.

Fiscal Year (FY) 2016 Objectives

- Manage the subcontract team led by Nuvera Fuel Cells as they develop a fuel cell-based TRU for refrigerated Class 8 trailers.
- Compete and place subcontract for second fuel cell-based auxiliary power unit (APU) for a commercial TRU.

Technical Barriers

This project addresses the following technical barriers from the Market Transformation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

(C) Inadequate private sector resources available for infrastructure development

(E) A lack of flexible, simple, and proven financing mechanisms

(F) Inadequate user experience for many hydrogen fuel cell applications

Technical Targets

This project directly addresses the Market Transformation subprogram targets described in Section 3.9.4 of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan by developing a pathway for the introduction of fuel cell technologies into the transport refrigeration unit market. The project involves the two primary United States TRU manufactures, ThermoKing and Carrier Transicold. They will be actively involved in overcoming the logistical and other nontechnical challenges associated with implementing this new technology, resulting in a smoother adoption into the marketplace. The deployments by large potential customers who already have used or are using fuel cell-based lift trucks will provide valuable data on the performance of the technology in real-world operations and can be used to benchmark the benefits of the technologies. The TRU manufacturers and demonstrators will provide input into the business case to create a clear picture of the value proposition of this new technology. Furthermore, this particular niche market will significantly increase hydrogen usage, reduce hydrogen cost, and further establish the hydrogen infrastructure at food distribution centers.

FY 2016 Accomplishments

- Developed a preliminary value proposition analysis to determine the tipping point between positive, marginal, and negative net present values. This value proposition will help determine the conditions when lifecycle cost parity can be achieved with incumbent technologies.
- Performed laboratory demonstrations integrating the fuel cell stack, prototypic balance of plant, power electronics, and TRU in preparation for the real-world demonstration that will benchmark the benefits of the technology.
- Competed and awarded subcontract to Ballard Power Systems for a second fuel cell-based TRU demonstration to allow a second pathway for the introduction of fuel cell technologies into the transport refrigeration unit market.

INTRODUCTION

A TRU is a high-powered air conditioning system used in cooling cold goods during on-road transport. It is generally powered by a separate diesel engine. Replacing this diesel engine with a fuel cell will address recent state and federal environmental mandates to reduce emissions, address noise restrictions found in many urban areas, reduce system maintenance, and improve the overall energy efficiency of the system. The initial market for this application would be food distributions centers where vehicles return to a central facility for refueling and where fuel cell lift trucks have already been established. This market will further expand the hydrogen usage at these sites and increase fuel cell market penetration.

The purpose of this project is to perform two demonstrations of fuel cell-based TRUs using two separate fuel cell teams as shown in Table 1. These demonstrations will provide user experience for over-the-road fuel cell applications that will mitigate commercial risk in developing this new technology.

TABLE 1. Fuel Cell-Based Transport Refrigeration Unit Demonstration Teams

Project Role	Nuvera Team	Ballard Team
Fuel Cell Supplier, System Integrator	Nuvera	Ballard
Transport Refrigeration Unit Supplier	ThermoKing	Carrier Transicold
Demonstration Partner	H-E-B	Walmart

APPROACH

Each of the two demonstrations will be performed by a team consisting of a fuel cell system supplier and integrator, TRU system supplier, and demonstration site. Each demonstration will be 800 to 1,000 hours in duration and will consist of actual deliveries of cold goods. During the demonstration, data will be collected from the hydrogen refueling station, fuel cell system, TRU, and the delivery truck to allow an independent techno-economic analysis and a system evaluation relative to available DOE targets. These results will be used to develop a business case and commercialization plan that can be implemented at the conclusion of the demonstration.

In preparation for these demonstrations, a preliminary business case will be developed and safety and regulatory issues addressed. The system development will include appropriately sizing the fuel cell stack to be comparable with the incumbent technology. The system must be designed and tested to ensure road-worthiness. These demonstration may also require the installation of the on-site hydrogen infrastructure for refueling.

RESULTS

The Nuvera and Ballard team's progress with the fuel cell-based TRU demonstration projects are described below.

ThermoKing Business Case Development. A critical piece of the development of a fuel cell-based TRU is the value proposition analysis. Although the Nuvera/ThermoKing commercial system has not been developed, a preliminary evaluation was performed to determine the impact of hydrogen and diesel costs on the net present values of the system as shown in Table 2. The study included an estimate for the incremental cost increase for a fuel cell TRU with assumptions regarding the operational duration, maintenance, and tax credit benefits from using a fuel cell. The results of the analysis indicate that if the $4.00/kg DOE target for hydrogen price can be achieved, a positive net present value is possible with modest diesel price increase over current values.

TABLE 2. Nuvera/ThermoKing Example Value Proposition Analysis

With Investment Tax Credit				
Hydrogen	TRU Incremental Cost	Diesel $4.00	Diesel $6.00	Diesel $8.00
Hydrogen $2.50	$21,000	$ 21,888	$ 57,399	$ 92,980
Hydrogen $4.00	$21,000	$ 9,297	$ 44,878	$ 80,459
Hydrogen $6.00	$21,000	$ (21,990)	$ 13,592	$ 49,173
Hydrogen $8.00	$21,000	$ (53,276)	$ (17,695)	$ 17,887
Hydrogen $10.00	$21,000	$ (84,563)	$ (48,981)	$ (13,400)
Hydrogen $12.00	$21,000	$ (115,849)	$ (80,268)	$ (44,686)

Assumptions: (1) 20 kW fuel cell with twice the efficiency improvement over diesel, (2) 12-year trade cycle, (3) 2,000 operating hours per year, (4) Diesel internal combustion engine maintenance cost delta $3,400, (5) federal tax credit of 30% of fuel cell system cost, up to $3,000/kW.

In addition to the value proposition analysis, the business case performed a "voice of the customer" activity where interviews were made with fuel service distribution and grocery companies representing the functions of warehousing, fleet operations and maintenance, engineering, and senior management. As expected, the biggest driver was found to be the return on investment. Use of a fuel cell-based TRU must make economic sense. However, companies meeting their sustainability goals was also important to those interviewed. A part of this sustainability is driven to ensure recently mandated regulatory requirements are met. Additional customer needs included the need to reduce noise pollution, reduce fuel cost uncertainty, and ensure food product integrity. A key customer need is that of reducing the risk of new technologies. While companies are willing to be technology leaders by employing new technologies such as fuel cells, a proven "track record" of the technology is very important before it is implemented. The demonstrations being performed for this project will provide the beginnings of this much-needed "track record."

Nuvera Fuel Cell System Development. In addition to the development of a business case, the Nuvera team has designed the packaging of the fuel cell system. It will be undermounted on a Class 8 trailer using the frame of an existing ThermoKing SGSM 3000 diesel genset. The original components will be removed and replaced with the fuel cell stack, balance of plant, and power electronics as shown in Figure 1. The ThermoKing TRU selected for the demonstration is the Precedent C-600. This particular TRU is a plug-in hybrid system that allows the use of either the diesel generated power or 480 VAC three-phase shore power during operations. As a result, the demonstration of this system requires that the fuel cell direct current (DC) power be converted to alternating current (AC) power to supply the TRU.

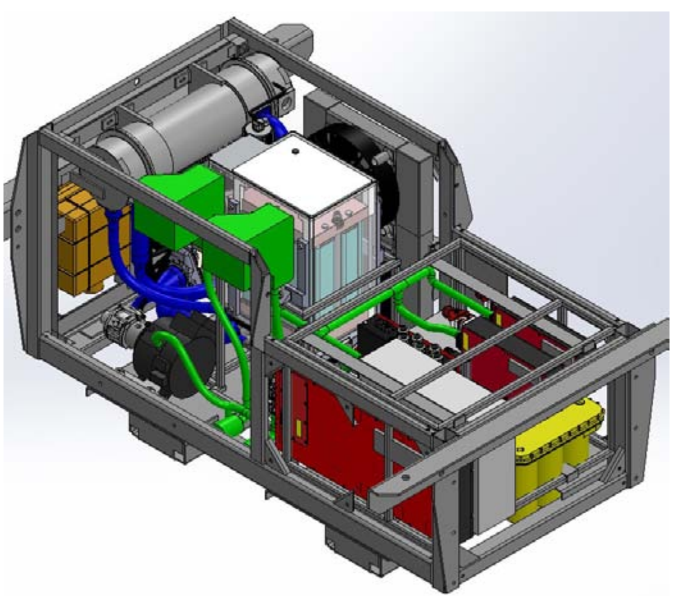

FIGURE 1. Preliminary design of the Nuvera team fuel cell system for the TRU APU

The four subsystems in the fuel cell-based TRU system being developed by Nuvera are the prototypic balance of plant, fuel cell stack, power electronics, and the TRU itself. The goal of the laboratory acceptance test before the demonstration was to test all of subsystems together as an integrated system. Although this full integration was not completed before Nuvera went into an 18-month project pause, they did test several subsystems together as shown with the circles in Figure 2.

The first demonstration was performed with the fuel cell and prototypic balance of plant. The balance of plant components used in this demonstration were assembled to fit within the trailer under-mounted generator frame. The testing was performed for three hours and successfully demonstrated a maximum of 28 kWe DC power in both a modulated and sentry cycle mode. One of these two operational modes will be down-selected before the commercial demonstration. Modulated mode varies the power as required by the TRU while the sentry cycle is a simple on/off configuration.

The second demonstration evaluated the fuel cell with the power electronics subsystem. Non-prototypical balance of plant components were used. In this 2.5 h test, the system successfully demonstrated 21 kWe of three-phase 480 VAC power. Power generated was dissipated with an induction motor and brake load. The final demonstration coupled the fuel cell stack and power electronics with a SLXe-300 TRU. Once again non-prototypical balance of plant components were used in this demonstration. This European TRU operates at 9 kWe maximum and a single power level as compared to the Precedent that operates at 17 kWe and two power levels. The test lasted for four hours and demonstrated that the fuel cell system can be successfully integrated with a TRU (see Figure 3).

Selection of the Ballard Team. During FY 2016 a second team was selected to develop and demonstrate a fuel cell-based TRU. The process of development of a request for proposal, performance of an open competition, technical and cost evaluation of the proposals, and negotiation with the selected offeror were performed. The results of this process yielded the Ballard team as the second demonstration team.

CONCLUSIONS AND FUTURE DIRECTIONS

The development and demonstration of a fuel cell auxiliary power system for Class 8 refrigerated trailers is a first step in expanding fuel cell use to TRUs. This demonstration will increase fuel cell market penetration and further break down technical and nontechnical barriers to hydrogen and fuel cell use.

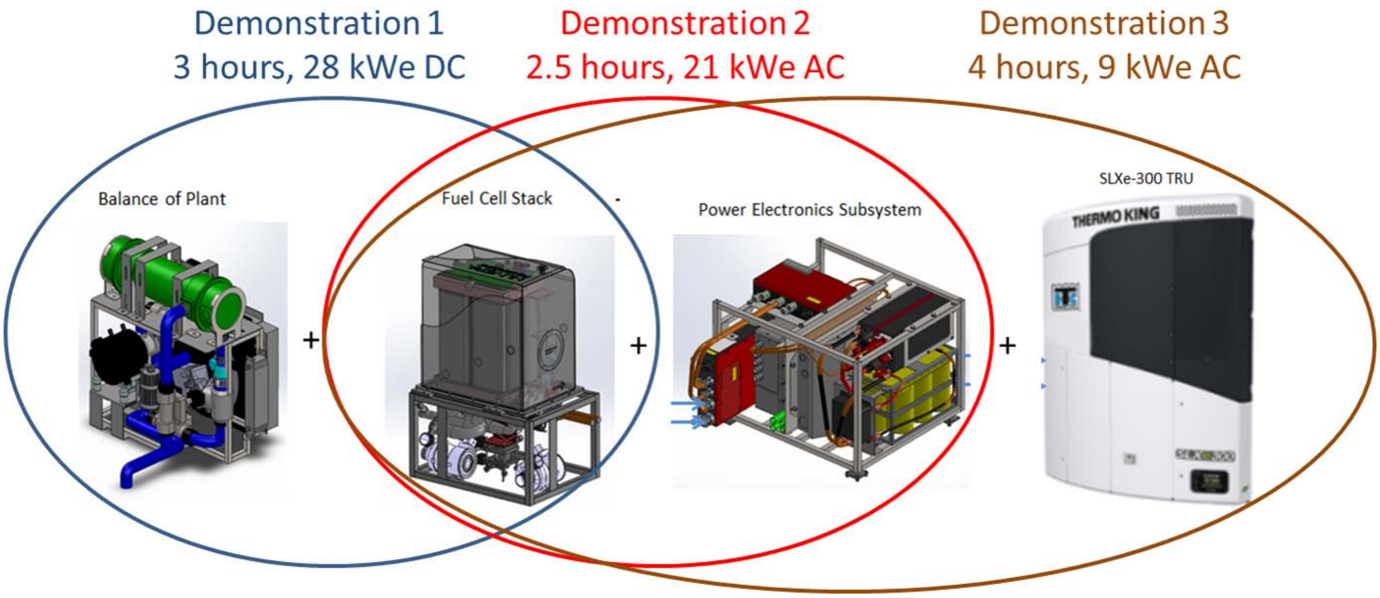

FIGURE 2. Laboratory integration demonstration performed with the Nuvera team fuel cell system

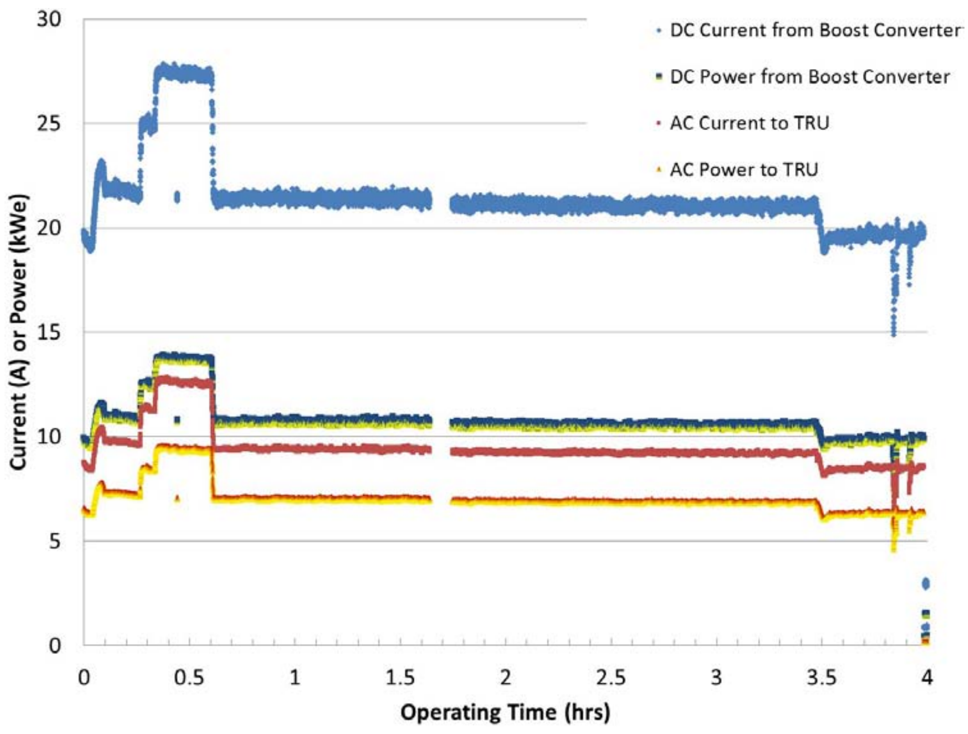

FIGURE 3. Results of the Nuvera team fuel cell system integration with a SLXe-300 TRU

Work performed to this point includes the development of a business case and assembly of a fuel cell system for the Nuvera team. It also includes the selection of the Ballard team to begin their development and demonstration.

Future Nuvera work in FY 2017 includes the completion of the fuel cell/TRU integration for on-road demonstration. Two 400 h demonstrations will be performed with actual deliveries of refrigerated and frozen goods from the H-E-B grocery distribution center in San Antonio, Texas. Fuel cell and TRU data will be collected and analyzed for system technical and economic performance.

The Ballard team future work will develop a preliminary business case, design the system and complete safety documentation as part of Phase I to be completed early in FY17. If they pass the DOE go/no-go decision, they continue into Phase II where they will develop the appropriately sized system and package it for on-road operation.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Brooks, K., G. Block, T. Lutkauskas, 2016, "Demonstration of Fuel Cell Auxiliary Power Unit (APU) to Power Truck Refrigeration Units (TRUs) in Refrigerated Trucks," 2015 Fuel Cell Seminar & Energy Exposition, November 18, 2015, Los Angeles, CA.

2. Brooks, K., G. Block, T. Lutkauskas, 2016, "Development and Demonstration of Fuel Cell-Powered Transport Refrigeration Units for Refrigerated Trucks," Advanced Automotive Battery Conference, June 17, 2016, Detroit, MI.