Demonstration of Fuel Cell Auxiliary Power Unit to Power Truck Refrigeration Units in Refrigerated Trucks

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

Project Start Date: June 1, 2012
Project End Date: September 30, 2018

Overall Objectives

- Demonstrate the technical 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.
- Use the demonstration data and market assessment to develop a business case that will determine if life cycle cost parity can be achieved with incumbent technologies.

Fiscal Year (FY) 2018 Objectives

- Direct subcontract teams led by Nuvera Fuel Cells and Ballard Power Systems as they each develop a fuel cell-based TRU for a refrigerated Class 8 trailer.
- Complete Phase I of the Ballard subcontract team development effort by producing a business case, a safety plan, and a preliminary design.
- Complete Phase II of the Nuvera subcontract team development effort by performing an 8-hour integrated laboratory demonstration of the fuel cell system, power electronics, and transport refrigeration unit.

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[1]:

- High hydrogen fuel infrastructure capital costs for polymer electrolyte membrane fuel cell applications
- Inadequate private sector resources available for infrastructure development
- A lack of cycle cost and performance data to demonstrate low investor risks
- Inadequate user experience for fuel cell applications.

Contribution to Achievement of DOE Market Transformation Milestones

This project contributes to achievement of DOE milestones from the Market Transformation section 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 TRU market. This niche market will increase hydrogen usage, reduce hydrogen cost, and further establish the hydrogen infrastructure at food distribution centers.

These demonstrations provided valuable data on the performance of the technology in real-world operations and can be used to benchmark the benefits of the technologies. Both the TRU manufacturers and demonstrators provided input into the business case to create a clear picture of the value proposition of this new technology.

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

FY 2018 Accomplishments

- Nuvera integrated the fuel cell system (including stack, packaged balance of plant, and power electronics) with a Thermo King Precedent TRU and tested it in a laboratory environment at both refrigeration and freezer temperature conditions.
- Nuvera completed the Phase II go/no-go decision and wrote a final report describing the results of Phase II development and testing achieved during Phase II.
- Ballard completed the Phase I go/no-go decision and wrote a final report describing the system design and market assessment results achieved during Phase I.
- Pacific Northwest National Laboratory prepared a final summary report describing the results of project.

INTRODUCTION

A TRU is a high-powered air conditioning system used in cooling cold goods during loading, on-road transport, and delivery. 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 distribution 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 was to perform two demonstrations of fuel cell-based TRUs using two separate fuel cell teams as shown in Table 1. These demonstrations could 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 TRU Demonstration Teams

Project Role	Nuvera Team	Ballard Team
Fuel Cell Supplier, System Integrator	Nuvera	Ballard
TRU Supplier	Thermo King	Carrier Transicold
Demonstration Partner	H-E-B	Walmart

APPROACH

Each team consisted of a fuel cell system supplier and integrator, a TRU system manufacturer, and a demonstration site. During FY 2018, Ballard completed Phase I of the development effort. Phase I involved the development of a preliminary business case, a safety plan, and the design of the fuel cell system. Nuvera completed Phase II of the development effort. Phase II involved an 8-hour test of the integrated fuel cell system, power electronics, and TRU. Phase II also included an updated business case analysis. Although not performed by either team, Phase III of the project was to include a demonstration of 800 to 1,000 hours duration that would include actual deliveries of cold goods at the demonstration partner's site.

RESULTS

FY 2018 was the conclusion of the project. The Nuvera team completed Phase II and the Ballard team completed Phase I. In both cases, a "no-go" decision was made to progress this work further. The work that was performed during FY 2018 is described in more detail below.

Nuvera Fuel Cell System Development

The Nuvera team completed their packaging of the fuel cell system using an existing shell of a Thermo King SGSM 3000 diesel genset that is undermounted on a Class 8 trailer as the equipment enclosure. The fuel cell stack and balance of plant was packaged in this shell and the system controls, software, and communication were finalized to allow its integration with the Thermo King Precedent C-600 TRU. This particular TRU is a plug-in hybrid system that allows the use of either the diesel-generated power or 480 VAC 3-phase shore power during operations.

One significant challenge that was successfully overcome during the Nuvera design was the power electronics. Conversion from the fuel cell's DC power to 480 VAC power requires inverters and boost converters. It also requires signal conditioning components such as filters to prevent premature failure of the electrical components. The integrated test setup with the Nuvera fuel cell, power electronics (inverter), and Thermo King TRU are shown in Figure 1.

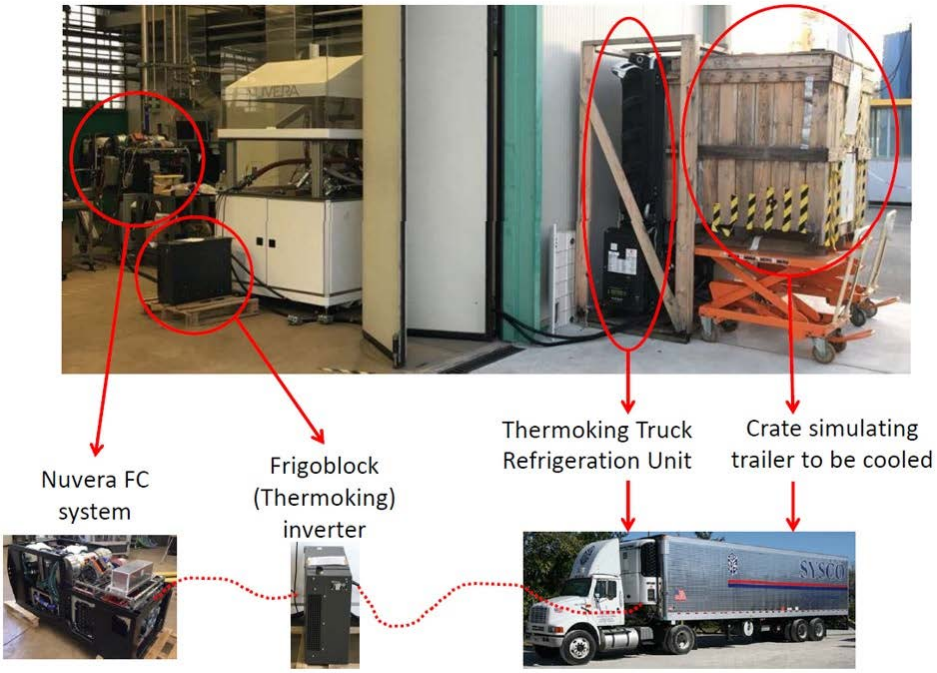

Figure 1. Nuvera integrated test setup

The test was done using a crate to simulate an actual trailer (box) to be cooled. The use of a test crate causes the TRU to cycle (because without the crate, the TRU would run at maximum power continuously). This crate methodology is a standard method commonly used by Thermo King for endurance testing and allowed Thermo King to compare the performance to their internal testing of non-fuel-cell-powered units. Although the crate was insulated, the insulation effectiveness was less than what would be installed in a typical well-insulated refrigerated trailer, resulting in more ambient heat flowing into the test crate than would flow into a conventional refrigerated trailer. Because of this, temperature cycling is more frequent using the test crate; therefore, the test is more severe than a test performed using a standard trailer.

The integrated laboratory demonstration was performed successfully for 8 hours. The test consisted of operations at a setting of 1°C (34°F) cooling temperature for the first 4.5 hours and then –20°C (–4°F) for the remaining 3.5 hours. During the entire duration of this testing, the temperature set point was reached and maintained as seen in Figure 2. The fuel cell system produced up to 15 to 23 kW maximum power with a resultant system efficiency of approximately 47% (lower heating value). It should be noted that the peaks in the data correspond to defrost and heat events generated by the TRU that will drive the crate temperature above and below the set point. These peaks are a result of excessive cycling caused by the box configuration of the test and would be eliminated in a full-sized trailer.

In addition to the integrated test, Nuvera also provided an updated economic analysis comparing a Thermo King diesel-powered TRU with a fuel cell-powered version. The analysis identified the "tipping point" between positive, marginal, and negative net present values (NPVs) as shown in Figure 3. With the 30% investment tax credit, the diesel fuel cost at $3/gallon (February 2018 price), and the incremental cost of the fuel cell at $33,600 (i.e., best case scenario), the NPV is positive only when the cost of hydrogen is $6/kg or less. As diesel prices rise, the NPV becomes positive as hydrogen costs fall.

As a result of the negative estimated NPV life cycle cost comparison to the diesel engine TRU, the Nuvera team decided to not continue the project into Phase III nor perform their originally planned demonstration. Instead, they wrote a final report and closed out the subcontract.

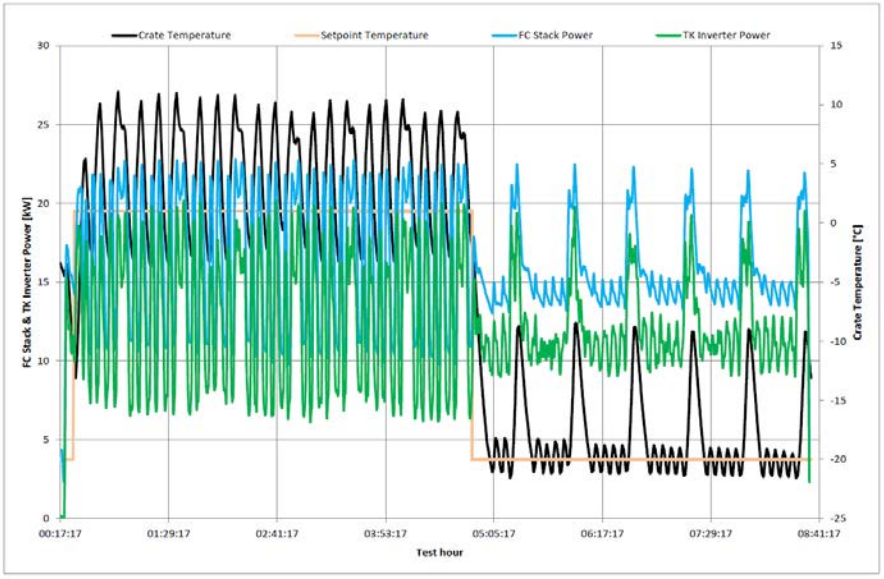

Figure 2. Power and temperature results from the Nuvera laboratory integrated 8-hour test

			$ 3.00	$ 4.00	$ 6.00	$ 8.00
INC. COST $ 33,600	HYDROGEN ($/kg)	$ 2.50	45,432	71,482	123,581	175,680
		$ 4.00	25,669	51,719	103,818	155,917
		$ 6.00	(681)	25,368	77,467	129,566
		$ 8.00	(27,032)	(982)	51,117	103,216
		$10.00	(53,382)	(27,332)	24,767	76,866
		$12.00	(79,732)	(53,683)	(1,584)	50,515
INC. COS $ 42,000	HYDROGEN ($/kg)	$ 2.50	36,563	62,612	114,711	166,811
		$ 4.00	16,800	42,850	94,949	147,048
		$ 6.00	(9,550)	16,499	68,598	120,697
		$ 8.00	(35,901)	(9,851)	42,248	94,347
		$10.00	(62,251)	(36,202)	15,897	67,996
		$12.00	(88,602)	(62,552)	(10,453)	41,646
INC. COS $ 50,400	HYDROGEN ($/kg)	$ 2.50	27,694	53,743	105,842	157,941
		$ 4.00	7,931	33,980	86,079	138,178
		$ 6.00	(18,420)	7,630	59,729	111,828
		$ 8.00	(44,770)	(18,721)	33,379	85,478
		$10.00	(71,120)	(45,071)	7,028	59,127
		$12.00	(97,471)	(71,421)	(19,322)	32,777

Figure 3. NPV of fuel cell vs. diesel-powered TRU developed by Thermo King and Nuvera

Ballard Fuel Cell System Development

During FY 2017, the Ballard team completed their Phase I milestones including a preliminary design, safety strategy, and market assessment. The market assessment performed by Ballard resulted in a similar negative NPV life cycle cost comparison to the diesel engine TRU. As a result of the negative estimated NPV life cycle cost comparison to the diesel engine TRU, the Ballard team (including Walmart and Carrier) decided not to continue the project into Phase II. Instead they wrote a final report and closed out the subcontract.

Final Fuel Cell TRU Report

The results of the development work performed by both Nuvera and Ballard were summarized in a final report. This report compared the designs of the two teams. The initial designs exhibited many similarities, suggesting that the lessons learned would be applicable to any potential TRU system. These included the approach to power conditioning, the required electrical power to the TRU, the use of an electric hybrid architecture for the TRU, and the decision for an underslung location on the trailer of the fuel cell system.

The report also enumerated both the market drivers and the remaining challenges of successful market penetration of a fuel cell-powered TRU from the two teams. Once again, the drivers and challenges from the market assessments were similar. The negative NPV identified by both teams under current conditions and the lack of strong environmental regulations were the largest challenges that led both teams not to continue. Given the high costs and lack of strong customer pull for a zero-emission TRU alternative, TRU manufacturers selected not to embark on further development programs.

The report concludes that the project provided TRU manufacturers an opportunity to understand fuel cell technology: both its benefits and the areas of needed development. Through the development of a business case, specific metrics have been established for evaluating the market for its readiness to implement the technology. Finally, the project has given the fuel cell companies an opportunity to interface with the TRU manufacturers and potential customers to better understand their needs and value propositions.

CONCLUSIONS AND UPCOMING ACTIVITIES

Pacific Northwest National Laboratory agreed with the assessment of the manufacturers. The fuel cell-powered TRU technology is sound and has the potential to be implemented into existing TRUs to create a new, efficient, and environmentally friendly product offering. However, the business case is not yet strong enough to be implemented across the grocery and cold food distribution market. As the cost of the hydrogen, the fuel cell, and power conditioning decrease and regulatory drivers strengthen, this market should be revisited. It is also possible that niche markets, such as small specialty food distributors like organic produce and seafood, may exist now that are less sensitive to cost where these systems could be implemented.

At this point there are no plans for upcoming activities in FY 2019 with this scope.

FY 2018 PUBLICATIONS/PRESENTATIONS

1. K.P Brooks and D.T. Howe, *Fuel Cell Transport Refrigeration Unit Report*, PNNL-27809 (Richland, WA: Pacific Northwest National Laboratory, 2018).