

## IX.6 Fuel Cell-Based Auxiliary Power Unit for Refrigerated Trucks

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### Overall Objectives

Demonstrate the viability of fuel cell-based transport refrigeration units (TRUs) for refrigerated Class 8 trucks by:

- Identify companies and partnerships to support multiple demonstrations.
- Develop system designs that meet or exceed the cooling capacity of the current diesel engine-based devices.
- Evaluate the value proposition for such systems by developing business cases for their use.
- Demonstrate the fuel cell-based TRUs with multiple 400-hour commercial demonstrations with food distribution companies making actual deliveries at a variety of locations and with varying routes.
- Analyze the data resulting from these demonstrations and provide an independent assessment of the technology.

### Fiscal Year (FY) 2014 Objectives

- Compete and place subcontracts with two fuel cell vendors
- Develop business cases to analyze the system's market viability
- Size the systems to provide adequate power to meet the expected door openings and ambient temperatures
- Develop prototype systems and test over the expected range of conditions
- Address interfaces with trailer, refueling system, and TRU

### Technical Barriers

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

- (E) Inadequate private funds available for new projects
- (F) Inadequate user experience for fuel cell applications
- (H) Lack of awareness of applications

### FY 2014 Accomplishments

- Set up subcontracts with Nuvera and Plug Power as the two system integrators. These subcontracts also include TRU manufacturers and demonstration partners.
- Both Nuvera and Plug Power teams have accomplished the following:
  - Developed business cases assessing the market, interviewing customers, and demonstrating the economics of the value proposition.
  - Defined the power requirements for the fuel cell-powered TRU system either with data collection at potential sites and modeling anticipated ambient temperatures and door openings.
  - Addressed the interface issues of refueling and electrical connections with the TRU.
  - Prepared safety plans including either a preliminary hazards analyses or a design failure modes and effects analysis.
  - Performed initial testing on a bench-top system.



### INTRODUCTION

Fuel cells can provide clean, efficiency auxiliary power for vehicles that have significant power demands when the primary motive-power engines are not running. Currently, primary engines are often kept running solely to provide electrical power for those auxiliary loads, an inefficient practice that wastes fuel, increases emissions, and results in increased engine wear. Fuel cell-based auxiliary power units represent a possible solution to replace the need for operating a diesel engine. Heavy-duty refrigerated trucks are one such application that uses a diesel engine to power the TRU. By replacing the diesel engine in the TRU with a fuel cell, recent environmental mandates can be addressed, noise restrictions in urban areas, especially at night can be overcome, and the uncertainty of diesel prices can be resolved.

## APPROACH

As part of DOE’s Fuel Cell Technologies Office, Market Transformation seeks to increase the number of commercial products that use fuel cells, expand the fuel cell market, and promote early adoption of hydrogen and fuel cell technologies. One application that appears promising is the use of fuel cells to power the TRUs on refrigerated heavy-duty trucks. PNNL has been tasked to identify and subcontract with two fuel cell vendors and assist them in developing fuel cell-based auxiliary power unit prototypes that will power such TRUs. The demonstration systems will not be a final sellable product, but the project will demonstrate the feasibility of such systems by developing a business case and testing each demonstration system.

This project involves the major players in the TRU and food distribution arena, allowing them to become familiar with fuel cell technologies. The two major producers of TRUs in the U.S., Carrier Transicold and Thermo King, are partners with the subcontracts on this project. Significant players in food distribution, Sysco and HEB, are the demonstration partners. Four demonstrations are currently proposed in New York and Texas. These partners have been involved in the development of the business cases. They have assisted in sizing the system power to ensure that it provides similar levels as that produced by the diesel engine. This power data was developed by experimental measurements or modeling. Each team is required to address the issues with infrastructure, compliance with applicable regulations, and road worthiness. This aspect of the work is still ongoing.

At each stage of the system development, PNNL and DOE have Go/No-Go decisions to ensure the design is adequate. Once the systems have completed their acceptance testing and commissioning on the trailers, they will be evaluated in real-life delivery routes with the food distributors. Data on the fuel cell, TRU, route, and environmental conditions will be collected and analyzed by PNNL to provide an independent assessment of the systems’ performance.

## RESULTS

As part of the business case development of a “Voice of the Customer” was conducted. It involved interviews with six food service distribution and grocery companies, representing the functions of warehousing, fleet operations and maintenance, engineering, and senior management. These interviews provide indications of what is important to the customer and some of the important considerations in developing a fuel-cell based TRU. The results indicate that “return on investment is the biggest driver after safety”—the commercial product must be cost effective. Additionally, they found that “being a sustainability leader is critical to corporate image”—such reductions in fossil fuel use are expectations of the customers. The study also elucidated that

“noise from diesel engines is unacceptable in an increasing number of settings where food is delivered, including densely residential areas, underground parking, hotels, hospitals and nursing homes.” In addition, diesel price uncertainty is a major concern.

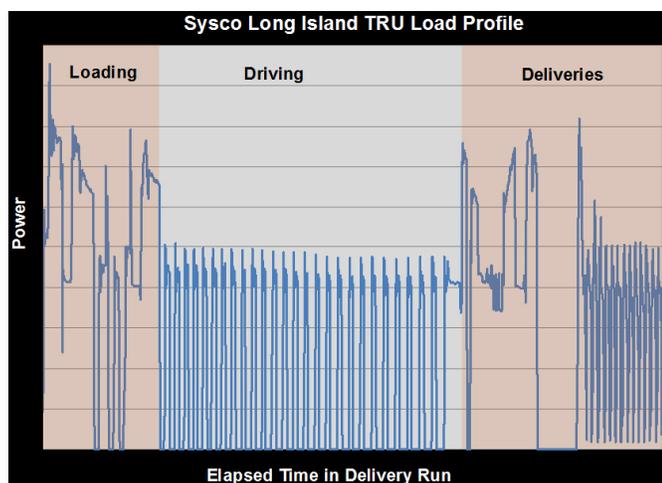
The business case also evaluated the economics of the system by comparing a current diesel-powered TRU with the fuel cell-powered version. The parameters of fuel cell incremental cost, diesel pricing and hydrogen pricing were evaluated assuming a 20-kW fuel cell with a 12-year trade cycle and 2,000 hours of operation. Federal investment tax credit for fuel cell systems is also included in Table 1. As can be seen in the results of the table, the price per unit of hydrogen is a major driver in making the system economical. This can be achieved as the overall consumption of hydrogen is increased, thus spreading the high cost of its infrastructure across a larger number of systems.

**TABLE 1.** Sample Value Proposition Analysis for the Fuel Cell TRU System

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)

The maximum power requirements for the systems were estimated based on data logging of actual deliveries or based on modeling. Plug Power collected data at Sysco Long Island and Sysco Houston to during loading, driving and deliveries to determine the maximum power required for the systems. A sample data collection log for Sysco Long Island is shown in Figure 1. Nuvera in contrast developed a model with assistance from Thermo King to evaluate the maximum power requirements. The model was impacted by ambient temperature and includes loading, initial pull-down and then a series of door openings. In both cases, the output requirements for these systems were determined to be ~20 kWe.

Both the Carrier and Thermo King have selected systems that have an electric standby option that allows the compressor to be run either with a diesel engine or with external 480 VAC power. Power from the fuel cell would be fed to the TRU through this 480 VAC line. Both designs for the demonstrations will leave the diesel engine in place and install the fuel cell system underneath the belly of the trailer. By leaving the diesel engine in place, it can act as a backup in the event there is an issue with the fuel cell and prevent damage to the temperature-sensitive cargo being distributed during the demonstrations. With a commercial fuel cell



**FIGURE 1.** Sample TRU Load Profile developed by Sysco Long Island for Plug Power

product, the fuel cell and its ancillary equipment would replace the diesel engine. Early indications are that there is sufficient space for such an exchange.

Currently both subcontractors have developed their fuel cell systems and have tested them over the range of conditions expected for the TRU. These prototype systems are bench-top units as shown in Figure 2. They have not been packaged, but work is underway to develop these packages and prepare them for the vibration, impacts, and weather extremes expected during commercial operation.

## CONCLUSIONS AND FUTURE DIRECTIONS

The conclusions of the fuel cell TRU development work for FY 2014 are as follows:



- Nuvera and Plug Power have developed business cases that indicate positive rates of return are possible with sufficient hydrogen usage volume.
- Nuvera and Plug Power have determined the power requirements for their systems at approximately 20 kW<sub>e</sub>. Based on available experimental and modeling data, these systems appear to be adequate to support TRU operation over a range of ambient conditions and anticipated door opening scenarios.

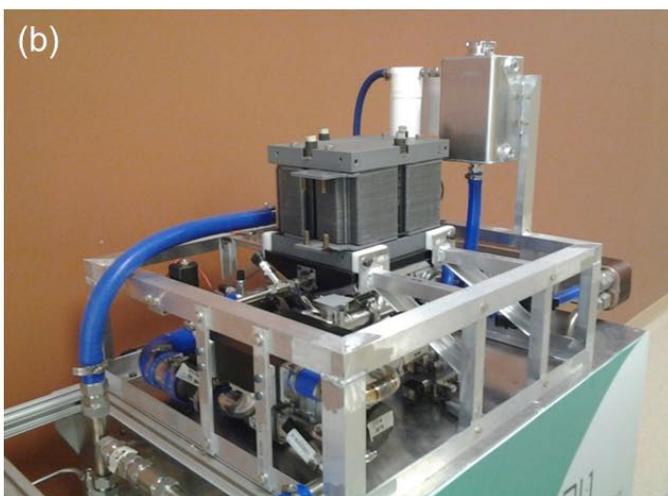
The future work for the fuel cell TRU development work in FY 2015 is as follows:

- Future work includes developing the packaged system and addressing on-road issues such as vibration, safety and weather extremes. The systems will then be demonstrated with commercial deliveries.

## FY 2014 PUBLICATIONS

### Media Interest Articles

1. Burke, Jack; "Future Cooling Trend?" Diesel Progress, October 2013.
2. Piellisch, Rich; "Hydrogen Fuel Cells for Reefer Trucks," Fleets & Fuels, August 2013.
3. Flatt, Courtney; "A Greener Way To Cool Your Foods On The Way To The Grocery Store," NPR, The Salt, September 2013, <http://www.npr.org/blogs/thesalt/2013/09/03/218592685/a-greener-way-to-cool-your-foods-on-the-way-to-the-grocery-store>.
4. Beaudry, David; "Cool that's Also Clean: Fuel Cells for Refrigerated Trucks," TruckingInfo.com, November 2013, <http://www.truckinginfo.com/channel/products/article/story/2013/11/cool-that-s-also-clean-fuel-cells-for-refrigerated-trucks.aspx>



**FIGURE 2.** Prototype Testing Systems for (a) Plug Power and (b) Nuvera

5. Phys.org, “Refrigerated trucks to keep their cool thanks to fuel cell technology” (8/23/2013) <http://phys.org/news/2013-08-refrigerated-trucks-cool-fuel-cell.html>

6. EcoSeed, Hydrogen & Fuel Cells, “Fuel cell powered refrigeration trucks being developed and tested by P.N.N.L.” (8/29/2013) <http://www.ecoseed.org/renewables/hydrogen-fuel-cells/16961-fuel-cell-powered-refrigeration-trucks-being-developed-and-tested-by-p-n-n-l>

7. Work Truck Magazine, “Fuel-Cell Technology Keeps Refrigerated Trucks from Losing Their Cool” (9/6/2013) <http://www.worktruckonline.com/channel/green-fleet/news/story/2013/09/fuel-cell-technology-keeps-refrigerated-trucks-from-losing-their-cool.aspx?prestitial=1>