X.5 Demonstration and Deployment of a Fuel Cell-Electric Refuse Truck for Waste Transportation

Abas Goodarzi
US Hybrid Corporation
445 Maple Avenue
Torrance, CA 90503
Phone: (310) 212-1200
Email: abas@ushybrid.com

DOE Manager
Pete Devlin
Phone: (202) 586-4905
Email: Peter.Devlin@ee.doe.gov

Contract Number: DE-SC00011854

Subcontractor
Mitch Ewan, Honolulu, HI

Project Start Date: June 9, 2014
Project End Date: March 8, 2015

Overall Objectives

- Design and technical analysis of zero emission, fuel cell-powered refuse powertrain system architectures for refuse truck operation in Honolulu, Hawaii
- Evaluate its environmental benefits in terms of reducing emissions and fossil fuel consumption
- Explore the commercial viability of a zero emission, fuel cell-powered, heavy-duty, electric hybrid truck for waste hauling applications

Fiscal Year (FY) 2015 Objectives

- Analyze best route of refuse truck operation based on existing fueling infrastructure
- Evaluate commercial viability and next steps for Phase II demonstration build and deployment
- Establish a commercialization plan for Phase II deployment containing market analysis and commercialization strategy

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:

(D) Market uncertainty around the need for hydrogen infrastructure versus timeframe and volume of commercial fuel cell applications

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

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

Technical Targets

No specific technical targets have been set.

FY 2015 Accomplishments

- Proposed deployment route from Honolulu Collection Yard to neighborhood collection area based on existing hydrogen infrastructure
- Calculated total energy use for route is 53.17 kWh, with 3.9 kWh/mi energy consumption
- Determined that total hydrogen consumption is 2.7 kg, with 0.2 kg/mi fuel consumption
- Designed packaging in conjunction with refuse truck body original equipment manufacturer (OEM)
- Projected a cost analysis indicating that the cost premium for commercial volume production could have a payback time of five years based on a hydrogen cost of $6/kg

✧ ✧ ✧ ✧ ✧

INTRODUCTION

Urban refuse collection is a major industry in North America, with a fleet estimated at approximately 179,000 waste-hauling trucks. Due to the continuous start and stop behavior of waste collection, refuse trucks, which are typically diesel fueled, operate at low speeds. This results in significant greenhouse gases (GHG) and exposure to diesel exhaust, which is comprised primarily of particulate matter (PM) and oxides of nitrogen (NOx). The refuse truck duty cycle engine operation translates to a very poor fuel economy averaging 3 miles per gallon (mpg) and hearing-damaging noise exceeding decibel levels of 100. Nationally, refuse trucks use 1 billion gallons of diesel fuel annually, representing 3% of the United States' total diesel fuel consumption. As such, US Hybrid Corporation teamed with Hawaii Center for Advanced Transportation Technologies (HCATT) and Hawaii Natural Energy Institute to perform a

Phase I analysis to explore the potential of a fuel cell electric system for refuse truck propulsion.

Based on the initial technical and economic analysis and performance data, the fuel cell-powered zero emission refuse truck is a viable product for refuse truck operators that want to experience lower lifetime operating cost, significant noise reductions, better acceleration and handling, and zero tailpipe GHG or criteria pollutant emissions. In the short run, the fuel cell refuse truck may initially be focused on niche markets, where eliminating emissions or the operating noise is critical, due to its higher capital cost. Eventually, economies of scale will reduce the cost, so the zero emission truck will provide a lower lifetime operating cost while eliminating emissions and allowing full utilization of renewable energy for transportation.

APPROACH

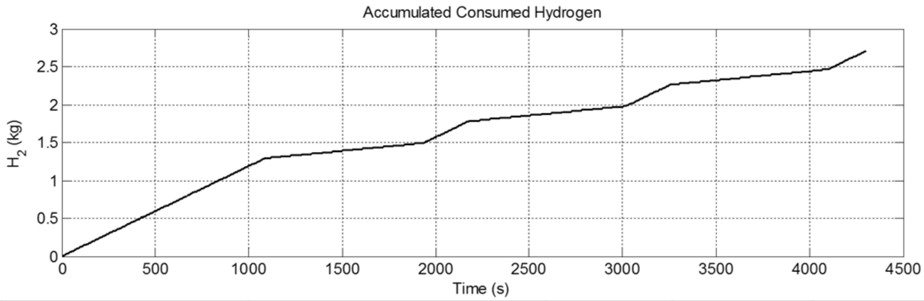
This project explored the technical and commercial viability of a zero emission, fuel cell-powered, heavy-duty, electric hybrid truck for waste hauling application. The scope of the project included the design and technical analysis of zero emission, fuel cell-powered refuse powertrain system architectures for refuse truck operation in Honolulu, Hawaii. This incorporated both analytical and computational evaluation, that latter of which was done with a simulation that measured performance and energy consumption. Our analysis of performance characteristics of various refuse drive cycles identified the required fuel cell, energy storage capacity, electric powertrain, and the electrohydraulic drive system component size required to meet or exceed the performance criteria set for conventional refuse trucks. Using the component sizing results, we were able to do a preliminary packaging study with OEM body builder, Heil. We also explored ways to establish a business case and an optimized route for the refuse hauler based on current station development.

RESULTS

Our analysis of performance characteristics of various refuse drive cycles identified the required fuel cell, energy storage capacity, electric powertrain, and the electrohydraulic drive system component size required to meet or exceed the performance criteria set for conventional refuse trucks. The baseline vehicle assumed for the analysis was a 54,000 lb gross vehicle weight restriction model built on a Navistar WorkStar® with a Heil body with a 370 hp MaxxForce® engine. The study indicated that the minimum traction motor power is 240 kW, fuel cell power is 68 kW and the hydraulic drive power is 80 hp. The vehicle also included 24 kWh of battery storage to provide transient power and fully recover braking energy on a typical Honolulu route and other refuse routes. The refuse truck's duty cycle is characterized by high power demand and relatively low energy demand. The energy needs on a typical route are under 45 kWh with a peak power of up to 240 kW. The fuel efficiency of the fuel cell refuse truck was simulated using the actual Honolulu residential district route profile provided by the City and County of Honolulu.

The refuse truck starts its day at the Honolulu Collection Yard and commences its refuse route in Waikiki. As shown in Figure 1, Joint Base Pearl Harbor-Hickam (JPBHH) is in

FIGURE 1. JBPHH hydrogen station location relative to Honolulu Collection Yard and neighborhood for refuse collection (image courtesy of Google Maps)



Total energy used (kWh)	Energy used per mile (kWh/mile)	H_2 (kg)	H_2 (Kg/mile)	H_2 (Kg/hour)
53.17	3.9	2.7	0.2	2.26
Distance=13.7 miles, Time=4300 seconds (1.2 hours)				

FIGURE 2. Performance data and energy efficiency and consumption for 24,500 kg refuse truck

close proximity to the yard. This study concluded that the preferred operation would consist of driving the refuse truck from the Honolulu Collection Yard and fuel it at the HCATT hydrogen production and fueling station at JBPHH. The truck would then complete its daily operations and then return to the Honolulu Collection Yard in the evening.

The results of the simulations indicated that the fuel cell hybrid electric refuse truck consumes about 3 kg of hydrogen per hour. Given 20 kg of hydrogen storage, this provides about seven hours of continuous operation, which is much longer than a full day's operation of current diesel trucks. This represents more than 42 gallons of diesel fuel saving per day. The current average fuel use is about 31 gallons per day. The performance data and energy efficiency and consumption for the fuel cell hybrid electric truck are shown in Figure 2.

The economic analysis of the viability of the fuel cell electric hybrid refuse truck accounted for the cost of the additional components, development costs, and increased labor to integrate the system into the vehicle. The cost analysis indicated that the cost premium for commercial volume production has a payback time of five years based on a hydrogen cost of $6/kg. Such prices will arise with matured hydrogen generation technologies. In the long run, fuel cell hybrid electric systems may offer lower costs and shorter payback times and better return on investments, while improving truck productivity by continuous compacting, better truck and hydraulic performance, lower noise, simpler packaging, and reduced hydraulic equipment load with an electrically driven pump.

CONCLUSIONS AND FUTURE DIRECTIONS

Based on the initial technical and economic analysis and performance data, the fuel cell-powered, zero emission refuse truck is a viable product; however, it may initially be focused on niche markets, where eliminating emissions or the operating noise is critical, due to its higher capital cost. Eventually, economies of scale will reduce the cost, so the zero emission truck will provide a lower lifetime operating cost while eliminating emissions and allowing full utilization of renewable energy for transportation.

Future work includes:

- Phase II prototype build and deployment
- Determine logistical and environmental impact of actual vehicle fuel cell powertrain development, modeling, and fabrication
- On site commissioning and training with refuse truck operator
- Begin deployment testing and collect operational and cost data
- Phase III technical and business discussions with OEMs and distributors for deployment beyond initial demonstration

FY 2015 PUBLICATIONS/PRESENTATIONS

1. G.A. Goodarzi, "Demonstration and Deployment of a Fuel Cell-Electric Refuse Truck for Waste Transportation," presented at the DOE Annual Merit Review, Washington, DC, June 8–12, 2015.

REFERENCES

1. Inform (2003). Greening Garbage Trucks: New Technologies for Cleaner Air [Online]. Available: http://www.informinc.org/reportpdfs/st/GreeningGarbageTrucks.pdf.

2. U.S. Energy Information Administration. (2015). Hawaii Profile Overview [Online]. Available: http://www.eia.gov/state/?sid=HI.