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Largest Fuelcell Land Vehicle: A Hybrid Shunt Locomotive for Los Angeles

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Abstract

A North American public-private project partnership is developing a fuelcell-hybrid shunt (switch) locomotive for urban rail applications. This prototype is intended to lead to commercial locomotives, including freight, that will (1) reduce air and noise pollution in urban railyards, (2) increase energy security of the rail transport system by using hydrogen as fuel, (3) reduce atmospheric greenhouse-gas emissions, and (4) serve as a mobile backup power source for critical infrastructure on military bases and during civilian disaster-relief operations. The railyard demonstrations will be executed at the Commerce and Hobart railyards in the Los Angeles, California, metro area. At 127 tonne (280,000 lb), continuous net power of 240 kW from its PEM fuelcell prime mover, and transient power well in excess of 1 MW, the hybrid locomotive is the heaviest and most powerful fuelcell land vehicle yet built. Its fourteen carbon-fiber composite compressed-hydrogen storage tanks, located at the roofline, have a combined storage of 70 kg at 350 bar. The system provides fuel for a rigorous 8-10 hour shunt-locomotive duty cycle. The locomotive is complete at the time of this writing, and it will soon commence exhaustive testing at the US Department of Transportation rail-vehicle proving grounds in Pueblo, Colorado. It will then begin its demonstration phase in Los Angeles around 1 August 2009. This paper focuses on the locomotive's potential to reduce air and noise pollution in the Los Angeles Basin.

Keywords: Fuel cell locomotive; hybrid vehicle, hydrogen storage; urban rail; zero emissions

1 Introduction

A fuelcell locomotive would provide the advantages of its competitors – catenary-electric and diesel-electric locomotives – while avoiding their disadvantages. It would have the environmental advantages, at the vehicle, of a catenary-electric locomotive but higher overall energy efficiency and lower infrastructure costs similar to that of a diesel [1]. The natural fuel for a fuelcell is hydrogen, which can be produced from many renewable energies and nuclear energy, and thus a hydrogen-fuelcell locomotive will not depend on fossil fuels for its energy supply. Hydrogen produced from renewable primary energies or nuclear energy would additionally be a totally zero-emissions vehicle, that is, with zero carbon in the energy cycle.

A North American public-private project partnership comprised of Vehicle Projects Inc, BNSF Railway Company, and the U.S. Army Corps of Engineers' Engineer Research and Development Center Construction Engineering Research Laboratory (ERDC-CERL) is developing

Figure 1: The fuelcell shunt locomotive, the largest fuelcell land vehicle yet built, nearing completion on 1 August 2008

a prototype fuelcell-powered shunt (switch) locomotive (see Fig. 1) for urban rail applications. This prototype is intended to lead to commercial locomotives that will (1) reduce air and noise pollution in urban railyards, including seaports, (2) increase energy security of the rail transport system by using a fuel independent of imported oil, (3) reduce atmospheric greenhouse-gas emissions, and (4) serve as a mobile backup power source ("vehicle-to-grid" or "power-to-grid") for critical infrastructure on military bases and for civilian disaster relief efforts. The railyard demonstrations will be executed at the Commerce and Hobart yards in the Los Angeles, California, metro area.

This paper focuses on the locomotive's potential to reduce chemical (primarily diesel particulates and nitrogen oxides) and acoustic noise emissions in the Los Angeles Basin.

2 Background

This fast-paced project commenced in May 2006, and at the time of this writing the vehicle is complete and will begin exhaustive vehicle testing at the US Department of Transportation railway proving grounds operated by TTCI in Pueblo, Colorado. It will arrive in Los Angeles (LA) for testing under working conditions by 1 August 2009.

Contributing to the fast pace are: (1) the platform of the fuelcell-hybrid locomotive is based on a 127-tonne commercially available diesel-battery hybrid shunt locomotive manufactured by RailPower Hybrid Technologies, (2) both the fuelcell powerplant and the compressed-hydrogen storage system are related to those of the Citaro™ fuelcell transit bus, and (3) private funding (BNSF Railway) supported project startup. Citaro fuelcell buses, widely used in European cities, have a combined operating experience of more than 1.5 million kilometers.

At 127 tonne (280,000 lb), continuous net power of approximately 240 kW from its PEM (proton exchange membrane) fuelcell powerplant, and transient power well in excess of 1 MW, the hybrid locomotive will be the heaviest and most powerful fuelcell land vehicle yet. Its prime mover is a modular design based on Ballard P5™ stacks. For energy storage, fourteen lightweight carbon-fiber composite tanks are located above the traction battery (see Fig. 2). The 14 tanks have a combined storage of 70 kg of compressed hydrogen at 350 barg (5100 psig). This storage system provides fuel for a rigorous 8-10 hour shunt-locomotive duty cycle. Fig. 3 shows a CAD model of the fuelcell prime mover and Fig. 4 shows it installed in the locomotive.

Based on engineering design by Vehicle projects Inc, the BNSF Topeka System Maintenance Terminal in Topeka, Kansas, fabricated most of the fuelcell powerplant replacement for the diesel genset and integrated the prime mover into the vehicle. Subsystem and complete powerplant testing was executed by Vehicle Projects Inc. The fuelcell stack modules were purchased from Ballard Power Systems. Because the combined weights of fuelcell powerplant and carbon-fiber hydrogen storage system are substantially lighter than the diesel genset and diesel fuel tank they replace, a steel-plate ballast of approximately 9000 kg is placed in the undercarriage bay (see Fig. 2). (A locomotive has a fixed operating weight in order to maintain wheel adhesion to the rails.)

Previous papers have discussed the theory [2-4] and engineering design [1, 5-6] of the hybrid locomotive. While the BNSF locomotive is the largest and possibly the most sophisticated fuelcell land vehicle to-date, it is not the first fuelcell locomotive. The first fuelcell-powered locomotive was an underground mine locomotive successfully completed and demonstrated in a working gold mine by Vehicle Projects Inc (formerly Vehicle Projects LLC) in 2002 [7,8].

3 Emissions and the Los Angeles Basin

Population of the Los Angeles metro area is 13 million people, and the city measures about 130 km from east to west and 60 km north to south. Because of the low population density, and consequent reliance on the automobile for transportation, and location in a basin partly surrounded by mountains, it has historically had air-quality problems. It is also the site of the adjacent ports of Long Beach and Los Angeles, the largest seaports in the United States, which contribute to air pollution from trucks, trains, and ships. In part, because the size of the economy of the State of California exceeds that of many nations, the state has substantial influence and has taken a leadership role in setting US Government air-quality regulations. Planned regulations in California are far more stringent than federal air-quality regulations; for example, California intends to regulate carbon dioxide as an air pollutant, whereas the federal government has resisted such a classification. The State of Massachusetts sued the US Government over the issue and won in a 2007 US Supreme Court ruling, and accordingly the US Environmental Protection Agency (EPA) has in April 2009 declared carbon dioxide to be a harmful air pollutant. Thus, consistent with the historical leadership role of California, the federal government is following the lead of California (and Massachusetts).

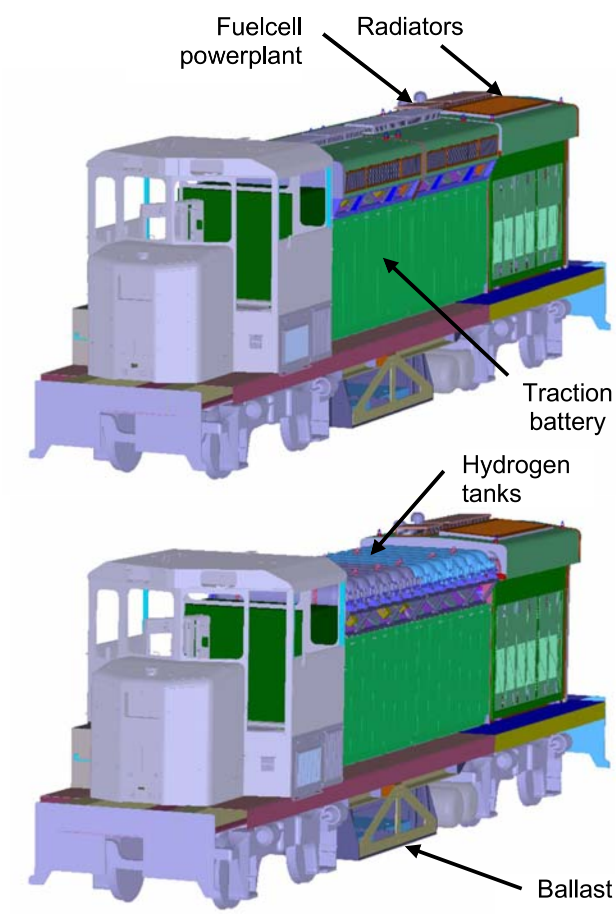

Figure 2: CAD model of the complete locomotive. Bottom view shows the hydrogen-storage hood removed. The fuelcell powerplant is located behind the traction battery on the right side of the vehicle.

The driving force of the fuelcell-hybrid shunt locomotive project is to demonstrate that fuelcell locomotives are practical solutions to reducing chemical and noise emissions in the LA Basin. Shunt locomotives, which assemble and disassemble trains in railyards, account for about five percent of all rail emissions, but they have a disproportionate impact on the air quality and health risks in the communities surrounding large urban railyards. The California Air Resource Board's (CARB's) 2004 assessment of diesel particulate matter (PM) risk levels near the Roseville, California, railyard revealed localized risks in excess of 500 potential cancer cases per million people exposed and that over 155 thousand people living in the vicinity of the railyard faced an elevated cancer risk due to rail operations [9]. In contrast, line-haul locomotives that travel throughout California emit over 95 percent of rail emissions but distribute their emissions over a much larger area.

In March 2008, although not yet addressing carbon-dioxide emissions, the US EPA finalized a three-part national program that will reduce emissions from diesel locomotives of all types – line-haul freight, shunt, and passenger rail [10]. The standards for locomotives are divided into *Tier Groups* based on their date of original manufacture and apply to rebuilt as well as new locomotives. The rule will reduce PM emissions by as much as 90 percent and nitrogen oxide (NOx) emissions by as much as 80 percent when fully implemented. The EPA projects that by 2030, the program will reduce annual emissions of PM and NO_x by 27 thousand tons and 800 thousand tons, respectively. EPA projects these reductions will annually prevent up to 1,100 PM-related premature deaths, 280 ozone-related premature deaths, 120 thousand lost work days, 120 thousand school-day absences, and 1.1 million minor restricted-activity days. The annual monetized

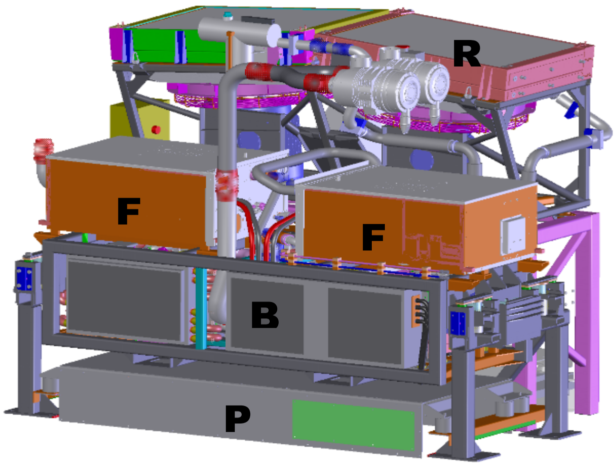

Figure 3: CAD model of the locomotive's fuelcell powerplant. R = radiator module, F = fuelcell stack modules, B = balance of plant, P = power electronics.

health benefits of this rule in 2030, or conversely the annual social cost of not implementing the program, will range from $9.2 billion to $11 billion.

Diesel engines may be able to meet the EPA standards by employing after-treatment technologies such as high-temperature or catalytic exhaust filters for PM and urea injection, followed by ammonia scrubbing, for NOx emissions. However, these technologies increase capital cost, lower reliability, and lower availability due to their complexity or nature of operation.

The State of California's program is more stringent and includes regulation of green-house gases (GHGs), and accordingly its savings in social costs of diesel-engine use is much higher than the EPA program. Because California's standards include regulation of GHGs, they could spell the demise of the diesel engine in low-attainment areas such as the LA Basin. Diesel-powered trains conceivably could be stopped at the edge of the metro area, and a non-diesel locomotive – for example, battery-electric, fuelcell, or catenary-electric locomotive – would pull the train through the city. If (1) the residual social costs of diesel locomotives (with after treatment), (2) the higher costs and lower reliability of diesels with after treatment, and (3) the high infrastructure cost (estimated at $6 million/km in the city) for catenary-eclectic locomotives are considered, we hypothesize that the fuelcell locomotive is cost competitive with the other options.

California was chosen for this demonstration, in part, because of available emissions data from studies initiated by CARB to quantify the emissions impact from rail. In the demonstration, we will compare existing emissions data from CARB and projected improvements to air quality through implementation of fuelcell-powered rail transportation. Data collected during the demonstration will include acoustic noise data during standard work operations in the railyards. We have already measured the locomotive's powerplant noise during testing, without any noise absorption facilities in place, and it lies in the range of 70-80 db, depending on where the measurement is taken on the vehicle.

It is apparent – through increasing regulation, public demand for cleaner transportation, concerns over national energy security, energy independence, and global environment and health concerns – that fuelcell rail technology has a potentially significant role in the future of the rail industry.

4 Conclusions

The fuelcell-hybrid shunt locomotive for operation in the LA metro area combines the environmental advantages of a catenary-electric locomotive with the higher overall energy efficiency and lower infrastructure costs of a diesel-electric locomotive. Its energy source is hydrogen, which can be produced from many renewable energies and nuclear energy and thus does not depend on imported oil. Depending on the primary energy

Figure 4: Right-rear view of the locomotive with the installed fuelcell prime mover in the foreground (31 July 2008)

source, it can be a totally zero-emissions vehicle, that is, with zero carbon in the energy cycle. Utilization of fuelcell shunt locomotives in urban railyards can prevent many cases of diesel emissions-based illnesses because such yards are frequently surrounded by residential housing that receives a high concentration of diesel particulates and nitrogen oxides; line-haul locomotives, in contrast, tend to disperse their emissions over much broader geographic areas.

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Authors

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Until founding Vehicle Projects Inc in 1998, Dr. Miller was a research professor at research universities, including the University of Illinois. From 1994 to 1998, he was founding Director of the Joint Center for Fuel-Cell Vehicles at Colorado School of Mines. As an academician, Prof. Miller published numerous papers in refereed journals such as the Journal of the American Chemical Society. As President of Vehicle Projects, besides leading the company, he frequently presents its work at leading international conferences. He received his PhD degree in chemistry from the University of Illinois, Urbana.

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Prior to joining the Vehicle Projects team in 2006, Mr. Hess worked at the General Motors Technical Center from 1998 in various positions in advanced vehicle development. These included subsystem design engineer, concept-vehicle lead engineer, and concept-vehicle program manager. This diverse background has provided the experience to successfully execute projects at both the technical level and total vehicle integration level. As Design Engineer at Vehicle Projects, Mr. Hess is responsible for engineering design, CAD modeling, and engineering integration with project partners. He received his BS degree in mechanical engineering from the University of Michigan-Ann Arbor and MS degree from Purdue University.

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Prior to joining Vehicle Projects, Mr. Erickson spent 10 years working as a software engineer designing intelligent process control systems utilizing impedance sensing technology. Prior positions include working as a control systems engineer for a system integration company as well as six years as a submarine officer in the United States Nuclear Navy. As Controls Engineer at Vehicle Projects, Mr. Erickson is responsible for working closely with the Design Engineer and implementing the control systems that run fuelcell vehicles. He received his B.S. degree in electrical engineering with a computer science minor from the Colorado School of Mines.

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Mr. Dippo joined Vehicle Projects Inc in 2007 and is project manager for the fuelcell-hybrid shunt locomotive. His previous employers include the National Renewable Energy Laboratory and TDA Research. His experience is broadly based in laboratory chemistry, especially research in gas-phase catalytic reactors. Reactor projects include (1) a hydrogen-fueled IC-engine automobile that employed onboard reforming of methanol feedstock and (2) endothermic dissociation of methyl cyclohexane, to hydrogen and toluene, as a fuel for hypersonic ramjets; heat absorption by the reactor would provide engine and vehicle-skin cooling.