Fuel Cell-Powered Front-End Loader Mining Vehicle

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Objectives

- Develop a mine loader powered by a fuel cell
- Develop associated metal-hydride storage and refueling
- Demonstrate the loader in an underground mine in Nevada

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Vehicles
- B. Storage

Approach

- Perform a cost/benefit analysis of fuel cell mine vehicles including cost of producing hydrogen, method of hydrogen transfer, vehicle manufacturer costs, mine recurring costs, and ventilation savings
- Develop an electrolysis refueling station and demonstrate refueling concepts in Nevada
- Determine power requirements (duty cycle), drive system, hybridization options, and onboard energy storage for a Caterpillar-Elphinstone R1300, 165 hp (123 kW), 3.5 cubic yard mine loader
- Perform a detailed engineering design of powerplant, metal-hydride storage, drive system, and control system
- Fabricate powerplant and metal-hydride storage and bench test
- Integrate powerplant, metal-hydride storage, and system components into base vehicle
- Complete risk assessment and certify for underground demonstration
- Test entire vehicle and demonstrate in an underground mine in Nevada

Accomplishments

- Completed manufacturing of electrolyzer and demonstrated refueling concepts in Nevada with a fuel cell-powered locomotive
- Completed final reports for cost/benefit analysis including "Best Methods of Hydrogen Transfer", "Operating Costs of Hydrogen Production", and "Ventilation Benefit Analysis"
- Completed preliminary design identifying duty cycle, single electric drive motor, battery hybrid configuration, and amount of metal hydride storage
- Received diesel-powered R1300 from manufacturer for verification of detailed component layout
- Ordered 100 kW fuel cell stacks from manufacturer

Future Directions

- Complete detailed engineering design for powerplant, metal-hydride storage, drive system, hydraulics, and operating controls
- Fabricate and test powerplant, metal-hydride storage, drive system components, hydraulic components, operating controls, and cooling components
- Integrate associated fuel cell powertrain components into R1300 base vehicle
- Test fuel cell system and compare to baseline diesel-powered performance parameters
- Complete risk assessment and underground certification with the Mine Safety and Health Administration (MSHA)
- Evaluate performance and durability in an underground mine in Nevada

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Introduction

Underground mining is the most promising application in which fuel cell vehicles can compete strictly on economic merit (1). The mining industry, one of the most regulated, faces economic losses resulting from the health and safety deficiencies of conventional underground traction power. Conventional power technologies - tethered (including trolley), diesel, and battery - are not simultaneously clean, safe, and productive. Solution of this problem by fuel cells would provide powerful cost offsets to their current high capital cost. Lower recurring costs, reduced ventilation costs, and higher vehicle productivity could make the fuel cell vehicle cost-competitive several years before surface applications. The diesel-powered version of the test loader is shown in Figure 1.

Approach

A joint venture between the Fuelcell Propulsion Institute (a nonprofit consortium of industry participants) and Vehicle Projects LLC (project management) provided the basis for this three-phase project, a key production element of underground mining. To ensure the design meets industry needs, various mining industry participants will evaluate and provide input regarding performance, productivity, and operator ergonomics.

Figure 1. Diesel-Powered Mine Loader.

The first phase of the project will perform a cost/benefit analysis comparing diesel and fuel cell vehicle recurring costs, fuel costs, energy efficiency, and ventilation costs that will determine the feasibility of commercialization. Different refueling concepts will be verified by manufacturing an electrolyzer and using Vehicle Projects' fuel cell-powered locomotive. To understand all of the power requirements, a duty cycle based on real operating conditions, will be established. This will assist in determining the type of drive motor, onboard energy storage, and whether a standalone fuel cell or hybrid powerplant will be used. Software modeling will be used to understand the energy requirements needed to satisfy the duty cycle over an entire operating shift.

In Phase 2, detailed engineering design, project partners will design the powerplant, metal-hydride storage, hydraulic interface, cooling system, system controls, and layout. Engineering drawings and the bill of materials will be the deliverables.

The final phase involves fabricating the powerplant, metal-hydride storage, and all subsystems; integrating them into the base vehicle; testing all systems; completing the risk assessment and certifying the vehicle for underground evaluation; and testing in a production mine in Nevada.

Results

The cost/benefit analysis indicates substantial savings in ventilation costs of anywhere from 24% to 53%, depending on the type of mine operation. This can result in up to $1.5 million a year in savings in primary ventilation system costs if the existing diesel-powered loader fleet were replaced with fuel cell power. This is a substantial cost savings that could offset higher fuel cell-power capital costs. In addition, the cost of producing hydrogen via electrolysis is under $5.00 per kg based on $0.06 per kW for electricity. With the fuel cell powerplant being almost twice as efficient as a diesel engine, the cost of hydrogen approaches the cost of diesel.

Two methods of refueling the metal-hydride storage, recharging directly onboard and swapping of storage modules, were successfully demonstrated with the use of Vehicle Projects' fuel cell-powered locomotive in Nevada. Recharging of 3 kg of hydrogen can be accomplished in under one hour.

Ongoing detailed design, based on the established duty cycle shown in Figure 2, has identified a hybrid powerplant design. In conjunction with using 100 kW (continuous) proton exchange membrane fuel cell stacks, an additional 70 kW, stored in lead-acid batteries, will be available to provide enough power to handle the peak-power requirements. Regenerative braking will not be used in this design due to the complexity and reliability.

Conclusions

The problems of vehicle emissions and noise have negative economic consequences for underground vehicle applications. Fuel cells coupled with reversible metal-hydride storage, by solving these problems, offer cost offsets - higher productivity and lower operating costs - that can make underground fuel cell vehicles cost-competitive sooner than surface applications. Our fuel cell-powered, electric drive loader with metal-hydride storage will exhibit greater torque characteristics than the diesel equivalent and is anticipated to be more productive, while emitting zero emissions and lower noise. Because of the stringent regulations for underground mines, metal-hydride storage is an ideal technology that has been proven with Vehicle Projects' fuel cell-powered locomotive.

References

A. R. Miller, Tunneling and Mining Applications of Fuel Cell Vehicles. *Fuel Cells Bulletin*, July 2000, pp. 5-9.

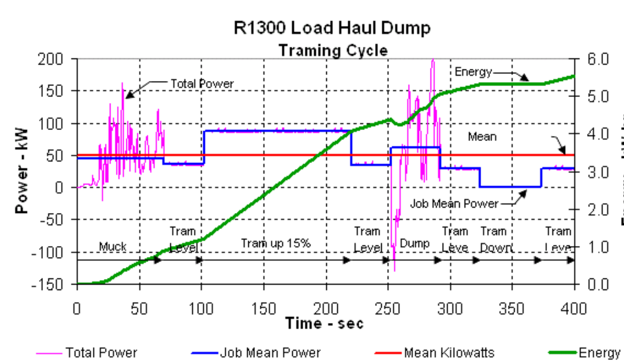

Figure 2. Duty Cycle for the Fuel Cell-Powered Loader

Presentations

1. R. Sage, "Fuelcell Mine Loader and Prototype Locomotive", Canadian Institute of Mining Annual Conference & Exhibition, Vancouver, British Columbia (2002)

2. A.R. Miller, "The Fuelcell Mining Vehicles Development Program: An Update", Canadian Institute of Mining Annual Conference & Exhibition, Montreal, Quebec (2003)