VIII.A.6 Fuel Cell Powered Front-End Loader Mining Vehicle*

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CANMET, Ottawa, Ontario, Canada
Caterpillar Inc., Peoria, Illinois
Hatch, Sudbury, Ontario, Canada
HERA Hydrogen Storage Systems, Longueuil, Québec, Canada
Modine Manufacturing, Racine, Wisconsin
Nuvera Fuel Cells, Cambridge, Massachusetts
Southwest Research Institute, San Antonio, Texas
Stuart Energy Systems, Mississauga, Ontario, Canada
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Caterpillar-Elphinstone, South Burnie, Tazmania, Australia
DRS Technologies, Hudson, Massachussetts
Newmont Mining, Carlin, Nevada
Placer Dome Technical Services, Vancouver, British Columbia, Canada

Start Date: October 2001
Projected End Date: December 2006

**Congressionally directed project*

Objectives

- Develop a mine loader powered by a fuelcell
- Develop associated metal-hydride storage and refueling
- Demonstrate 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 Research, Development and

Demonstration Plan:

- A. Vehicles
- B. Storage
- C. Hydrogen Refueling Infrastructure

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE technology validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 5: *Validate fuel cell demonstration vehicle range of ~200 miles and durability of ~1,000 hours.* The underground fuelcell mine loader will demonstrate an active life span of 1,000 hours to be demonstrated in mining operations in Nevada.

Approach

- Perform a cost/benefit analysis of fuelcell mine vehicles including cost of producing hydrogen, method of hydrogen transfer, mine recurring costs, and ventilation savings
- Determine power requirements (duty cycle), drive system, whether a hybrid, and onboard energy storage for a Caterpillar-Elphinstone R1300, 165 hp (123 kW), 3.5 cu. yd. 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

- Complete the detailed engineering design started in Phase 2
- Completed fabrication of fuel cell powerplant, drive system components, hydraulic components, operating controls, and cooling components
- Battery pack successfully integrated into powerplant module
- Began integration of fuel cell-powerplant and associated components into R1300 base vehicle
- Performed a formal design review on all systems
- Completed preliminary risk assessment
- Test fuel cell systems against baseline diesel-powered performance parameters
- Completed preliminary risk assessment and presented draft risk assessment and underground certification to MSHA and Nevada Mines Safety
- Powerplant electronics testing completed
- Finalize specifications and requirements

Future Directions

- Complete installation of fuel cell powerplant, metal hydride storage, drive system components, hydraulic components, operating controls, and cooling components
- Continue to collect fuel cell stack longevity and performance data
- Evaluate performance and durability in an underground mine in Nevada

Introduction

Underground mining is the most promising application in which fuel cell vehicles can compete strictly on economic merit. 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 the 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 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 3 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.

The first phase of the project performed a cost/benefit analysis comparing diesel and fuel cell vehicle recurring costs, fuel costs, energy efficiency, and ventilation costs that determined the feasibility of commercialization. Different refueling concepts were verified by manufacturing an electrolyzer and using Vehicle Projects' fuel cell powered mine locomotive. To understand all the power requirements, a duty cycle, under real operating conditions, was established. This assisted in determining the type of drive motor, onboard energy storage, and that the powerplant would be a fuelcell-battery hybrid. Software modeling was 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 designed the powerplant, metal-hydride storage, hydraulic interface, cooling system, system controls, and layout. Engineering drawings and bill of materials will be the deliverables.

The final phase involves fabricating the powerplant, metal-hydride storage, and all subsystems, integration into the base vehicle, testing of all systems, completion of risk assessment and certification for underground evaluation, and testing in a production mine in Nevada.

Results

Due to the nature of the duty cycle, the fuel cell powerplant module is designed as a fuel cell-battery hybrid as shown in Figure 2. The module consists of 3 PEM fuel cell stacks rated at 290V, 300A, 87 kW gross power along with 112 nickel metal-hydride (NiMH) batteries capable of an additional 65 kW for about 2 minutes. Peak power is thus about 140 kW net for short durations such as loading the bucket with ore and tramming up an incline.

Included in the fuel cell power module is a system controller that will monitor power,

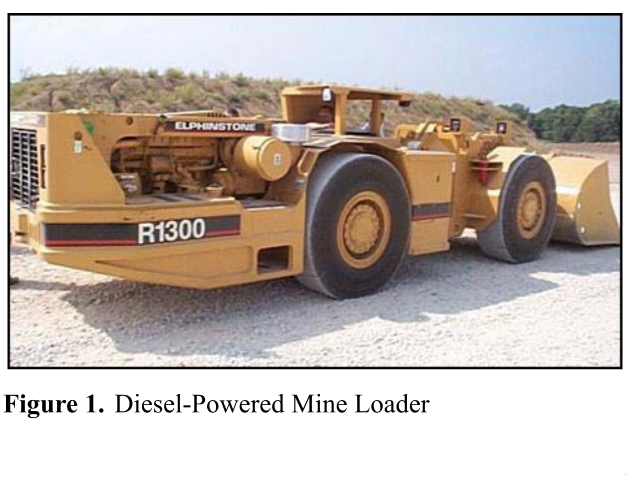

Figure 1. Diesel-Powered Mine Loader

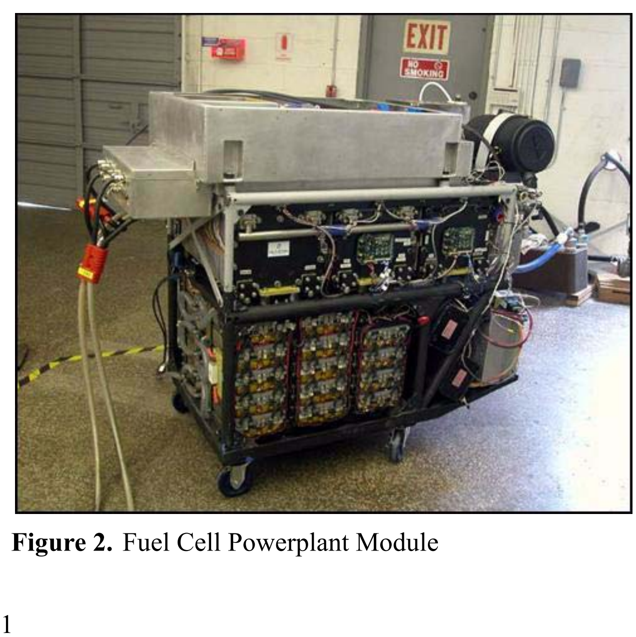

Figure 2. Fuel Cell Powerplant Module

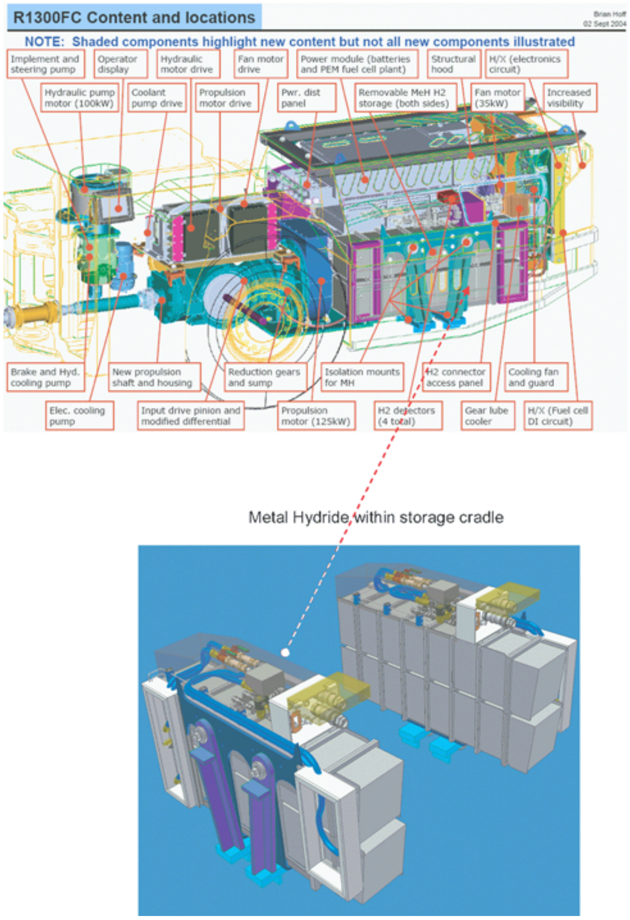

Figure 3. Fuel Cell Powered Loader Layout

temperature, pressures, and flow rates; an 80 kW DC/DC boost converter; an 8 kW bi-directional DC/DC power module capable of handling 24 V to 400 V; and a data acquisition system that will monitor every cell of the 402 total cells of the fuel cell stacks.

The air compressor is a centrifugal supercharger design rotating at 171,000 rpm and delivering nearly 4,700 SLM at 1.8 bar (absolute). The fuel cell stacks are cooled with de-ionized water flowing at 150 LPM to maintain the stack temperature between 65° C and 75° C. The cooling loop interfaces with the metal-hydride storage to supply heat to desorb the hydrogen from the metal-hydride.

Figure 3 shows the overall layout of the fuel cell powered loader. The fuel cell powerplant module sits in the middle of the metal-hydride storage which is in a saddlebag configuration. The metal-hydride storage is removable so that in shaft mines the metal-hydride can be taken to surface for refueling. Another major addition is the traction motor (situated in front of the fuelcell powerplant module). This is a brushless permanent magnet (BPM) motor rated at 450 hp (335 kW). This is more than the original diesel engine rating of 165 hp (123 kW) and we will limit the power to the motor so as not to overpower the loader. The traction motor will direct-drive the propulsion shaft to the front wheels through the rear differential.

A preliminary risk assessment, facilitated by a professional engineering firm specializing in risk assessments and mine equipment, was performed to identify potential health and safety hazards. This extensive risk assessment covers all aspects of operation and will provide valuable information to the regulatory agencies such as the Mine Safety and Health Administration (MSHA). The risk assessment is ongoing and will conclude with the acceptance of the loader being demonstrated underground.

Conclusions

Great strides have been made in the detailed design of the fuel cell powerplant, metal-hydride storage, vehicle hydraulics and cooling subsystems, and the risk assessment. Project members are starting the fabrication phase as the vehicle integrator finalizes the layout and placement of critical components. Because of the harsh operating environment of underground mines, special design considerations have been taken into account to minimize any release of hydrogen. The heating of the metal-hydride storage to desorb hydrogen will be closely monitored and controlled in order to have the amount of free hydrogen needed for the fuelcells to be at a minimum at any given time. This will mitigate the possible release of hydrogen to an acceptable and manageable level. Because of the stringent regulations for underground mines, metal-hydride storage is an ideal technology for the loader.

Presentations

1. 2005 DOE Hydrogen Program Review: "*Fuel Cell Powered Underground Mine Loader Vehicle*" by David Barnes, May 25, 2005, Arlington, VA.