

Fuel Cell Powered Underground Mine Loader Vehicle **DE-FC36-01GO11095**

Arnold R. Miller, PhD
Vehicle Projects LLC
Denver, CO
17 May 2006



Project ID # TVP 10



OVERVIEW

Timeline

- Start – October 2001
- End – December 2006
- 90% Complete

Budget

- Total project funding
 - DoE - \$4,901,731
 - Industry - \$4,894,653
- Funding received FY05
 - \$2,161,695
- Funding for FY06
 - \$1,462,204

Barriers

- Vehicles
- Storage

Partners

AeroVironment, Inc., *Monrovia, CA*
Caterpillar, Inc., *Peoria, IL*
HERA USA, *Ringwood, NJ*
Nuvera Fuel Cells, Inc., *Cambridge, MA / Milan, Italy*
Modine Manufacturing Company, *Racine, WI*
Hatch, *Sudbury, Ontario*
CANMET-MMSL, *Val d'Or, Quebec*
Washington Safety Management Solutions, *Aiken, SC*
DRS Technologies, *Hudson, MA*
Southwest Research Institute, *San Antonio, TX*
University of Nevada, *Reno, NV*
Placer Dome Ltd., *Vancouver, British Columbia*
Newmont Mining Corporation, *Carlin, NV*
MSHA, *Triadelphia, WV*
Agnico-Eagle Mines Ltd., *LaRonde Mine, Quebec*
Fuelcell Propulsion Institute, *Denver, CO*
Vehicle Projects LLC, *Denver, CO*



OBJECTIVES

Overall

Technology Validation - develop and evaluate a fuelcell mine loader vehicle for an application with high commercial potential.

FY 2005

- Fuelcell-battery hybrid power module
Fabrication and assembly
- Metal-hydride storage
Fabrication and assembly
- Modify base platform
Hydraulics, traction motor, wiring, frame modification

FY 2006

- Vehicle integration
- Debug and test
- Demonstration



APPROACH

> Task 1 100% Complete

Perform cost/benefit analysis of fuelcell mine vehicles, including cost of producing hydrogen, method of hydrogen transfer, mine recurring costs, and ventilation savings

> Task 2 100% Complete

Determine power (duty cycle) and drive system requirements, and onboard energy storage for a Caterpillar-Elphinstone R1300, 165 hp (123 kW), 3.5 cu. yd. mine loader

> Task 3 100% Complete

Perform detailed engineering design of power plant, metal-hydride storage, drive system, and control system

> Task 4 100% Complete

Fabricate power plant and metal-hydride storage and bench test

> Task 5 80% Complete

Integrate power plant, metal-hydride storage, and system components into base vehicle

> Task 6 90% Complete

Complete risk assessment and certify for underground demonstration

> Task 7 0% Complete

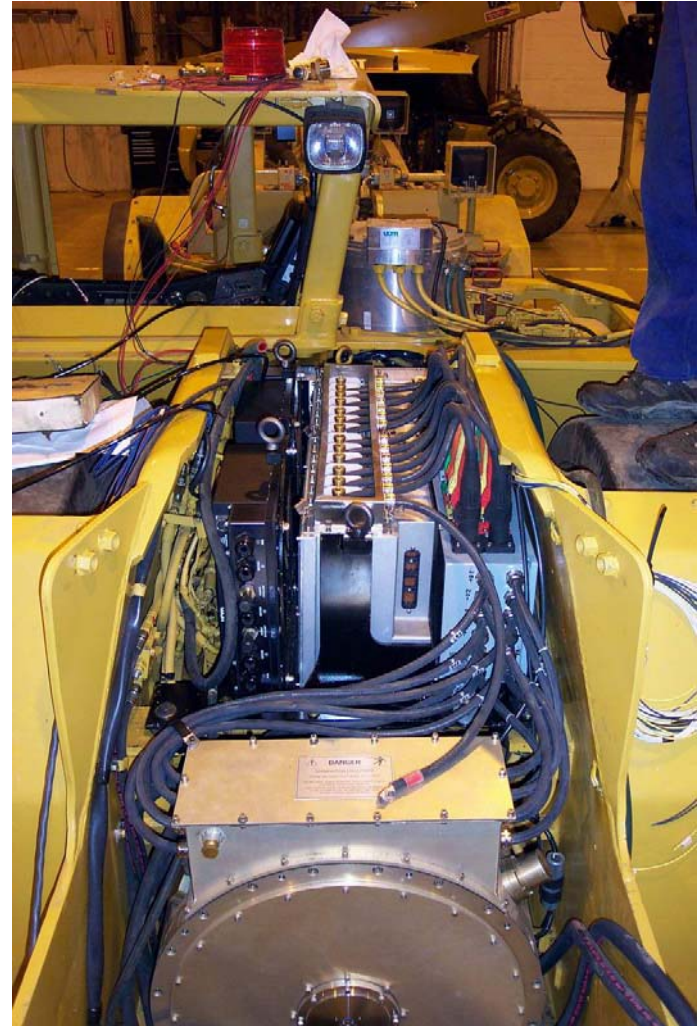
Test entire vehicle and demonstrate in an underground mine in Nevada



TECHNICAL ACCOMPLISHMENTS

Traction Motor

DRS Technologies' PA44 brushless DC traction motor installed along with a custom designed Saminco motor controller. The motor is rated at 450 hp, 335 kW but will be limited to 125 kW to match the original R1300 diesel.

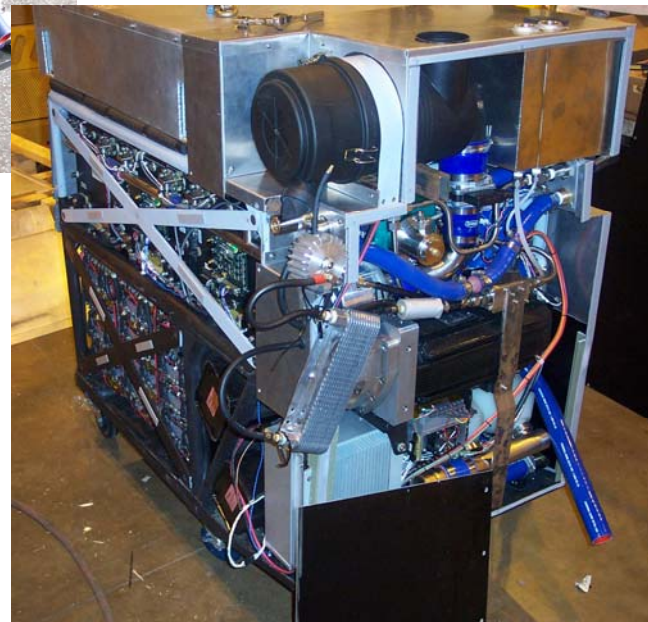




TECHNICAL ACCOMPLISHMENTS

Power Module

- 108 NiMH batteries (12 kWh) liquid cooled
- Data Acquisition (DAQ) monitors all 402 cells
- Stacks full-load 87 kW (gross)
- 20% parasitic losses
- Rotrex centrifugal supercharger air compressor
- Power module tested against duty cycle
- 80 kW DC-DC converter fully tested
- Control system fully tested
- SOC of batteries between 25% and 85%





TECHNICAL ACCOMPLISHMENTS

Metal-Hydride Storage

- 2 modules, leak tested and fully cycled with hydrogen
- Total hydrogen capacity of 13.6 kg
- State-of-the-art safety due to low pressure operation of less than 7 bar
- Modules are removable for surface refilling
- Superior heat transfer design demonstrated fast refill in less than 15 minutes with partial cooling water flow; full water flow will enable refill in less than 10 minutes
- Factory performance tested with power module
- Modular tube design lends itself to low cost mass production





TECHNICAL ACCOMPLISHMENTS

System Integration

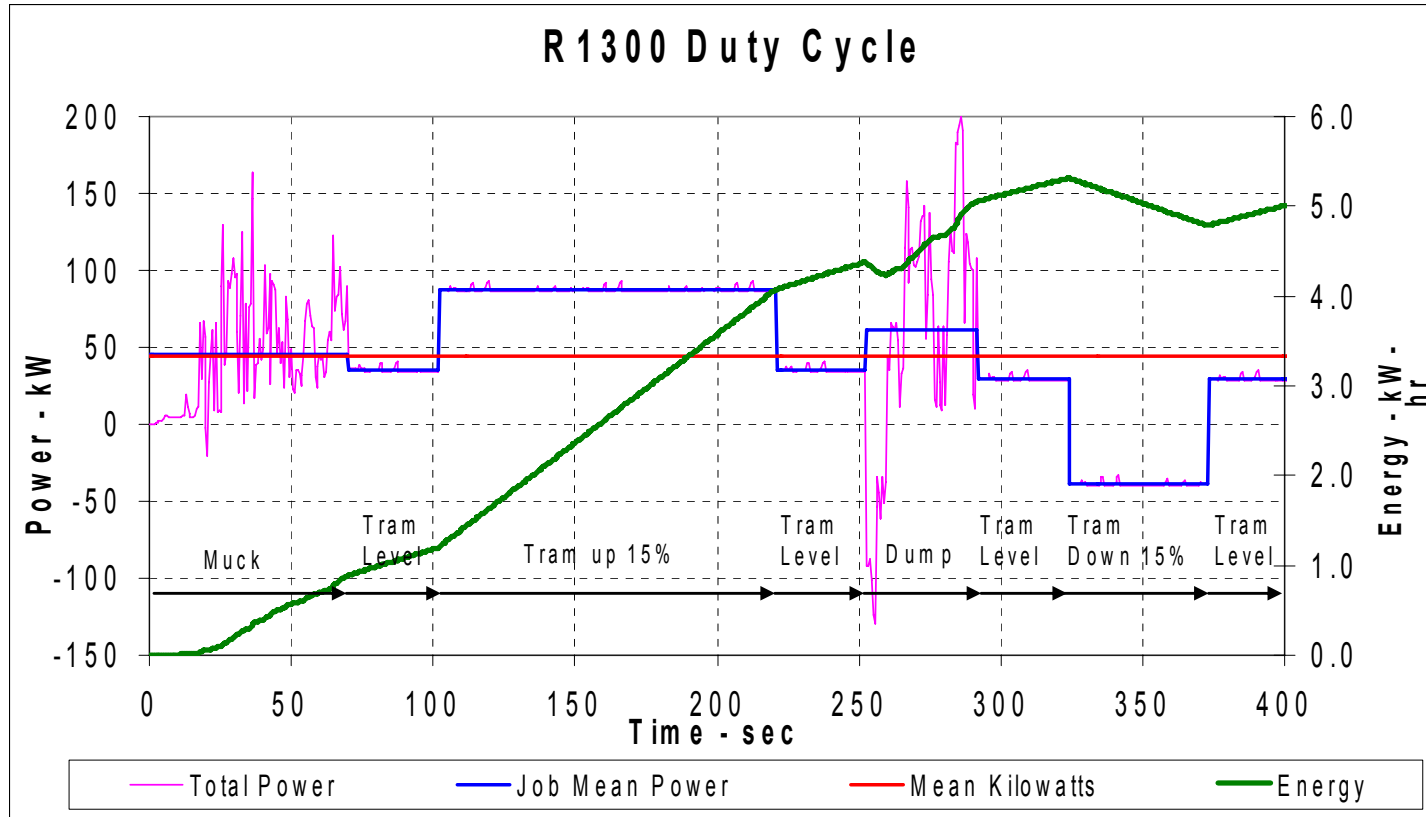
- Hydraulics complete
- Frame modification complete
- Electrical wiring complete
- Power Module fit confirmed
- Metal-hydride fit confirmed





TECHNICAL ACCOMPLISHMENTS

Acceptance Test Requirements



Power Module successfully tested against duty cycle





FUTURE WORK

FY06 – FY07

- Refurbish some cells in two of the stacks

- Integrate associated fuelcell-power components into R1300 base vehicle
 - Debug and test
 - Qualification baseline testing

- Evaluate performance and durability at an underground mine in Nevada and Ontario



PROJECT SUMMARY

- **Importance:** Improves performance, worker health and safety, as well as advancing market opportunities
- **Approach:** Retrofit an existing diesel loader, a well-known key production vehicle for mines, and improve performance
- **Accomplishments:** Completed all sub-assemblies and tested individually. Extreme packaging requirements met
- **Collaborations:** Large project team with many contributors including:
 - Caterpillar – system integrator
 - HERA USA – metal-hydride storage
 - AeroVironment – power module development
 - Vehicle Projects – project management
- **Future Work:** Complete integration, test, and demonstrate to finish project



INNOVATIONS

- High power density, compact design
- Electrically-powered centrifugal blower operating at 170,000 rpm
- Powerplant is a fuelcell-battery hybrid
- Regenerative braking
- Hydraulic and traction systems operate independently
- Record recharge time for the metal-hydride storage system



RESPONSE TO REVIEWER'S COMMENTS

- The technical approach is reasonable considering the poor (relative to HFCIT goals) vehicle application choice
 - Extreme operating conditions help accelerate technology validation and allow a more comprehensive approach to failure analysis
- Collaboration does not appear to extend beyond project participants
 - The Fuelcell Propulsion Institute, a project participant, is a collaboration of members with different disciplines involved in multiple fuelcell projects. There is an inherent sharing of project information for both dissemination and project improvement
- The project has not yet accomplished much relative to the fraction of total project funds consumed
 - Feasibility studies and conceptual designs
 - Complete refurbishment of base vehicle
 - Development and manufacture of power module and metal-hydride storage under extreme packaging requirements and specifications
 - Development of DC traction motor and custom motor controller drive system



CRITICAL ISSUES

- **Hydrogen purging**
 - Use of catalytic converter to burn hydrogen
 - Alternatively, dilute purged hydrogen into cathodic air exhaust
- **Air management system**
 - Packaging constraints limit air compressor availability
 - Use of new centrifugal supercharger to increase air stoichiometry
- **Low pressure hydrogen storage**
 - Metal hydride storage modules couple low pressure with small flow channels to limit the hydrogen release rate in the even of an accident
 - Shake test to verify manufacturing process