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

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Vehicle Projects LLC
27 May 2004
Objectives

Project Objectives

• Develop a metal-hydride, fuelcell-powered mine loader equivalent to a Caterpillar-Elphinstone R1300.

• Evaluate the vehicle in an underground mine in Nevada

Past Year Objectives

• Complete Reports Including:
  – Demonstration of an Electrolysis System for Fuelcell Mining Vehicles
  – Best Methods of Hydrogen Transfer
  – Operating Costs of Hydrogen Production
  – Ventilation Benefit Analysis for Canadian Mines
  – Cost Benefit Analysis of US Underground Mines
  – Capital and Recurring Cost Benefit Analysis for Canadian Mines
Objectives – Continued

Past Year Objectives – con’t

• Determine Traction Motor
  – Induction versus Brushless Permanent Magnet (BPM)
• Determine Battery-Hybrid Configuration
  – Sizing of batteries to support duty cycle
• Determine Metal-Hydride Amount and Configuration
  – Weight limitation
• Complete Engineering Design
## Budget

<table>
<thead>
<tr>
<th>Phase</th>
<th>Amount</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Phase 1</td>
<td>$926,670</td>
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<td>Phase 2</td>
<td>$3,165,400</td>
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<td>Phase 3</td>
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<td><strong>Total:</strong></td>
<td><strong>$8,617,373</strong></td>
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<thead>
<tr>
<th>Source</th>
<th>Amount</th>
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<tbody>
<tr>
<td>Total DOE Funds</td>
<td>$4,239,198</td>
<td>49.2%</td>
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<tr>
<td>Total NRCan Funds</td>
<td>$599,500</td>
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<td>Placer Dome Funds</td>
<td>$225,000</td>
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<td>Newmont Mining Funds</td>
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<td><strong>Total In-Kind Cost Share:</strong></td>
<td><strong>$3,453,675</strong></td>
<td>40.0%</td>
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| FY04 DOE Funds        | $1,550,000 | 46.7%     |
| FY04 Contractor Funds | $1,770,000 | 53.3%     |
| **FY04 Total:**       | **$3,320,000** |         |
Technical Barriers and Targets

- DOE Technical Barriers for Technology Validation
  - A. Vehicles
    Demonstration of complete system
  - B. Storage
    On-board metal-hydride storage
  - C. Hydrogen Refueling Infrastructure
    On-site hydrogen production by electrolysis
Approach

- Perform cost-benefit analysis
- Determine operational duty cycle
- Conceptual design
- Detailed engineering design
- Risk assessment
- Fabricate subsystems
- Vehicle integration and test
- Demonstration of vehicle underground
Project Safety

- Risk assessment to identify operational safety and health risks
- Individual failure mode and effects analysis (FMEA) on subassemblies
- Regulatory review including MSHA acceptance
- Lessons learned from DOE Fuelcell-Powered Underground Mine Locomotive Project Risk Assessment
# Project Timeline

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
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<td>10/01 – 2/03</td>
<td>2/03 – 3/04</td>
<td>3/04 – 12/05</td>
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</table>

1. **Phase 1 - Cost Benefit Analysis and Preliminary Design**
   - Demonstrate electrolyzer refueling station

2. **Phase 2 – Detailed Engineering Design**
   - Receive R1300 diesel loader
   - Select battery-hybrid configuration and regenerative braking
   - Receive 87 kW gross continuous fuelcell stacks

3. **Phase 3 – Fabrication, Integration, and Demonstration**
   - Deliver 150 kW battery-fuelcell hybrid powerplant
   - Deliver metal-hydride storage (15kg H₂)
   - Vehicle integration and test
   - Underground demonstration (3 mines)
Technical Accomplishments/Progress

Detailed design includes:

- Fuelcell-battery hybrid powerplant
- 70 kW continuous, 140 kW peak (net)
- Removable metal-hydride storage
- Regenerative braking
- 340 kW (450 hp) DC BPM traction motor
- Separate 100 kW hydraulic BPM motor
Technical Accomplishments/Progress

R1300 Duty Cycle

Power - kW

Energy - kW-hr

Time - sec

Total Power
Job Mean Power
Mean Kilowatts
Energy

Muck
Tram Level
Tram up 15%
Tram Level
Dump
Tram Level
Tram Down 15%
Tram Level

0.0
1.0
2.0
3.0
4.0
5.0
6.0

0.0
1.0
2.0
3.0
4.0
5.0
6.0

0 50 100 150 200 250 300 350 400

200 meters 100 meters 200 meters 100 meters

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Technical Accomplishments/Progress

- 87 kW gross (total)
- 290 V, 300 A full load
- Air pressure 2.0 bara
- H₂ pressure 2.2 bara
- Air stoichiometry 2.0
- Operating temp 60-75° C
- Air RH = 80-100% @ 70° C
- External air humidification
- Fuel loop dead-end mode
- Weight 280 kg
- Volume 220 L

Fuelcell Stacks Manufactured by Nuvera Fuel Cells Inc.
Technical Accomplishments/Progress

Fuel cell stacks bench tested at AeroVironment Inc.

Photo Courtesy Vehicle Projects LLC
**Technical Accomplishments/Progress**

- DAQ monitors all 402 FC cells
- 112 NiMH batteries, H$_2$O cooled
- Stack full-load 290 V, 300 A (gross)
• Battery configuration
  – Cobasys (formerly Ovonics) NiMH batteries
  – Single battery rated at 12 V, 8.5 AH
  – 56 in series of 2 each in parallel
  – Module rated at 672 V, 17 AH, 11.42 kWh nominal
  – Maximum battery power up to 2 minutes will provide additional 65 – 70 kW
Technical Accomplishments/Progress

Motor torque requirements (N*m) (125kW)

- Required Motor torque (N*m)
- Max rated motor torque (N*m)

125kW constant power region (800 to 3600 rpm)
Assume battery is cycled from 20 to 80% during each cycle. 80% leaves head-room for regen braking.
## Interactions and Collaborations

### Engineering and Manufacturing

- AeroVironment Inc. - Balance of Plant
- Caterpillar Inc. - Vehicle Integration
- Caterpillar-Elphinstone - R1300 LHD Loader
- DRS-Technologies - Traction Motor
- HERA Hydrogen Storage - Metal-Hydride Storage
- Modine Manufacturing Co. - Heating and Cooling
- Nuvera Fuel Cells Inc. - Fuelcell Stacks
- Stuart Energy - Hydrogen Refueling Station
## Interactions and Collaborations

### Engineering and Consulting

- Hatch: Risk Assessment, Regulatory
- Placer Dome Technical Services: End-User Oversight
- Southwest Research Institute: Duty Cycle / Energy Modeling
- WSMS: Hydrogen Risk Analysis

### Academia

- University Nevada – Reno: Ventilation Evaluation
- Carleton University: Software Simulation
Interactions and Collaborations

Government

- CANMET (Canadian) Tech. Transfer, Demo Oversight
- MSHA Regulatory Oversight

End-Users

- Agnico-Eagle Mines Ltd. Mine Demonstration
- Newmont Mining Corporation Mine Demonstration
- Placer Dome Ltd. Mine Demonstration
Responses to Previous Year
Reviewer’s Comments

Project not presented last year
Future Work

• Remainder of FY 2003
  – Fabrication/Assembly of Fuelcell Powerplant, Metal-Hydride Storage
  – Loader Teardown and Preparation
  – Test Traction Motor and Reduction Gear
  – On-going Risk Assessment and Regulatory Review

• FY 2004
  – Vehicle Integration
  – Vehicle Commissioning
  – Complete Risk Analysis and Regulatory Review
  – Underground Mine Demonstrations (3 mines)