Vehicle Projects LLC

Final Technical Report
For the

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Golden Field Office
Hydrogen, Fuel Cells and Infrastructure Technologies Program

Advanced Underground Vehicle Power and Control; the Locomotive Research Platform

Cooperative Agreement: DE-FC36-99GO10458

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Prepared by

David L. Barnes, General Manager, Vehicle Project LLC
Arnold R. Miller, President, Vehicle Projects LLC

Contact

David L. Barnes
General Manager
Tel: 303.296.4218
Fax: 303.296.4219
E-mail: david.barnes@vehicleprojects.com

Vehicle Projects LLC
621 17th Street, Suite 2131
Denver, CO 80293

Project Lead:

Vehicle Projects LLC

Project Title:

Advanced Underground Vehicle Power and Control; the Locomotive Research Platform

Project Objectives:

Develop a fuelcell mine locomotive with metal-hydride hydrogen storage. Test the locomotive for fundamental limitations preventing successful commercialization of hydride fuelcells in underground mining.

General Information:

The Fuelcell Propulsion Institute (FPI) was the prime contractor for Phase 1 of this project. Phase 1 was a collaborative effort between FPI and Sandia National Laboratories/CA (SNL) with SNL being funded separately by DOE. Vehicle Projects LLC, at the request of DOE, was established as the prime contractor for the work of Phase 2. The proposal was submitted in response to the Department of Energy, Office of Power Technologies, Office of Energy Efficiency and Renewable Energy Broad Based Solicitation No. DE-PS36-99GO10383.

Project Partners:

Battery Electric Ltd – Motor controller
Canada Centre for Mineral and Energy Technology (CANMET) – Underground testing
Fuelcell Propulsion Institute (FPI) – Industry advising and stakeholder education
Hatch Associates Ltd – Safety and risk analyses
Kappes, Cassiday & Associates (KCA) – Surface test site in Nevada
Mine Safety and Health Administration (MSHA) – Risk evaluation of vehicle
Nuvera Fuel Cells Europe – Fuelcell stacks
Ontario Ministry of Labour – Risk evaluation of vehicle
Placer Dome Inc – Underground production test site
RA Warren Equipment Ltd – Base vehicle
Sandia National Laboratories/CA (SNL) – Powerplant and hydrogen storage development
University of Nevada at Reno (UNR) – Surface testing in Nevada
Vehicle Projects LLC – Prime contractor and project management.

Introduction:

The Fuelcell Propulsion Institute (FPI) was awarded a 25 month, $465,954 contract by the DOE Office of Energy Efficiency and Renewable Energy, Golden Field Office effective 1 September 1999. The complete project was later revised to a 38 month, $1,189,949 contract on 5 May 2002, to include evaluation, engineering enhancements, and testing in an underground mine. This research will benefit the metal mining industry, and American industry in general, through improved health and safety, enhanced economic competitiveness, reduced energy consumption, and reduced environmental impacts.

The project was completed in two phases. Phase 1 of the project involved Sandia National Laboratories/CA developing a 14.4 kW fuelcell powerplant, including 3 kg of metal-hydride storage, all of which was funded separately by DOE. The powerplant was integrated into an existing battery electric base vehicle. Phase 1 was completed in January 2002. Phase 2 included preliminary power tests, enhanced engineering design to accommodate mine conditions and control automation, installation of new technology fuelcell stacks increasing the power output to 17 kW, and successfully testing the locomotive underground in a gold mine in a production environment. The overall project was completed in October 2002.

Background:

Underground mining is the most promising application in which fuelcell 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. Tethered vehicles are power-dense and clean, but the tether is unsafe and interferes with mobility and productivity. Diesel vehicles are more mobile and theoretically more productive, but their compliance with government emissions regulations reduces actual productivity. Emissions and noise regulations in the process of implementation will further increase vehicle capital and operating costs and lower mine productivity. Battery vehicles are clean, but their low energy capacity restricts productivity.

Solution of this problem by fuelcells would provide powerful cost offsets to their current high capital cost. Lower recurring costs, reduced ventilation costs, and higher vehicle productivity could make the fuelcell vehicle cost-competitive several years before surface applications. A fuelcell type well-suited to underground mining, as well as other heavy-duty applications, is the "hydride fuelcell" — a coupling of a fuelcell system with metal-hydride onboard energy storage. Benefits of traction fuelcells include zero emissions, low noise, high power density, low temperature/pressure operation, and long life. The PEM (Proton Exchange Membrane) fuelcell type, coupled with hydride storage, provides additional benefits critical to heavy-duty, underground applications: safety, compactness, simplicity, and ruggedness. Although hydride storage is heavy, weight is of minor consequence in mine vehicles.

Summary:

During Phase 1 of the DOE-EERE sponsored project, FPI and its partner SNL, completed work on the development of a 14.4 kW fuelcell powerplant and metal-hydride energy storage. An existing battery-electric locomotive with similar power requirements, minus the battery module, was used as the base vehicle. In March 2001, Atlas Copco Wagner of Portland, OR, installed the fuelcell powerplant into the base vehicle and initiated integration of the system into the vehicle. The entire vehicle returned to Sandia in May 2001 for further development and integration. Initial system power-up took place in December 2001.

A revision to the original contract, Phase 2, at the request of DOE Golden Field Office, established Vehicle Projects LLC as the new prime contractor,. Phase 2 allowed industry partners to conduct surface tests, incorporate enhancements to the original design by SNL, perform an extensive risk and safety analysis, and test the fuelcell locomotive underground under representative production mine conditions. During the surface tests one of the fuelcell stacks exhibited reduced power output resulting in having to replace both fuelcell stacks. The new stacks were manufactured with new and improved technology resulting in an increase of the gross power output from 14.4 kW to 17 kW.

Further work by CANMET and Hatch Associates, an engineering consulting firm specializing in safety analysis for the mining industry, both under subcontract to Vehicle Projects LLC, established minimum requirements for underground testing. CANMET upgraded the Programmable Logic Control (PLC) software used to monitor and control the fuelcell powerplant, taking into account locomotive operator's needs. Battery Electric, a South Africa manufacturer, designed and manufactured (at no cost to the project) a new motor controller capable of operating the higher rpm motor and different power characteristics of the fuelcells.

In early August 2002, CANMET, with the technical assistance of Nuvera Fuel Cells and Battery Electric, installed the new PLC software, installed the new motor controller, and installed the new fuelcell stacks. After minor adjustments, the fuelcell locomotive pulled its first fully loaded ore cars on a surface track. The fuelcell-powered locomotive easily matched the battery-powered equivalent in its ability to pull tonnage and equaled the battery-powered locomotive in acceleration.

The final task of Phase 2, testing the locomotive underground in a production environment, occurred in early October 2002 in a gold mine. All regulatory requirements to allow the locomotive underground were completed and signed off by Hatch Associates prior to going underground. During the production tests, the locomotive performed flawlessly with no failures or downtime. The actual tests occurred during a 2-week period and involved moving both gold ore and waste rock over a 1,000 meter track. Refueling, or recharging, of the metal-hydride storage took place on the surface. After each shift, the metal-hydride storage module was removed from the locomotive, transported to surface, and filled with hydrogen from high-pressure tanks. The beginning of each shift started with taking the fully recharged metal-hydride storage module down into the mine and re-installing it onto the locomotive. Each 8 hour shift consumed approximately one half to two thirds of the onboard hydrogen. This indicates that the fuelcell-powered locomotive can work longer than a similar battery-powered locomotive, which operates about 6 hours, before needing a recharge.

Major Project Tasks

Vehicle Specifications:

The base vehicle is a commercial four-ton battery locomotive manufactured by project partner RA Warren Equipment. The battery vehicle employs a 52-cell lead-acid battery (104 V nominal), series traction motor with interpoles, smart motor controller, double-enveloping gear drive, hydraulically assisted disc brakes, and unitized body/chassis. A design objective of the fuelcell powerplant was for it to fit into the same volume as the battery.

Although low-temperature metal-hydride storage is generally considered too heavy for light-duty vehicles, it is substantially lighter than lead-acid batteries. Our hydride-fuelcell locomotive is 30% lighter than the battery version. To bring the locomotive up to its specification weight of 4 tons, 1,100 kg of ballast had to be added.

Comparison of Battery and Fuelcell Locomotives		
Parameter	**Battery**	**Fuelcell**
Power, rated continuous	7.1 kW (gross)	17 kW (gross)
Current, rated continuous	76 A	135 A
Voltage at continuous rating	94 V (estimated)	126 V
Energy capacity, electrical	43 kWh	48 kWh
Operating time	6 h (available)	8 h
Recharge time	8 h (min)	1 h (max)
Vehicle weight	3,600 kg	2,500 (without ballast)

Figure 1. Battery and Fuelcell Specifications

Powerplant Design and Fabrication:

The locomotive's fuelcell power system uses proton-exchange membrane (PEM) fuelcells. No traction battery is employed, and the vehicle is thus a pure fuelcell vehicle. The stacks, manufactured by Nuvera Fuel Cells Europe, are a rugged design using metal bipolar plates. Two stacks in electrical series provide 126 V and 135 A at the continuous rated power of 17 kW gross. Each stack, with integral humidifier, weighs 30 kg and has a volume of 25 L. The air cathode operates at 0.5 bar above ambient pressure using a modified Roots-type air pump. Waste heat from the stacks provides the heat to desorb hydrogen from the metal-hydride bed. A heat exchanger links two isolated thermal systems: (a) the hydride-bed heating/cooling loop and (b) stack cooling loop. The bed loop uses a circulating anti-freeze medium, whereas the stack loop uses de-mineralized water. Stack cooling water also passes through a forced-air excess-heat radiator. Coolant pumps and the stack air pump are powered at system startup by an auxiliary battery recharged by the stacks. Total parasitic losses are less than 10%, a very good design result.

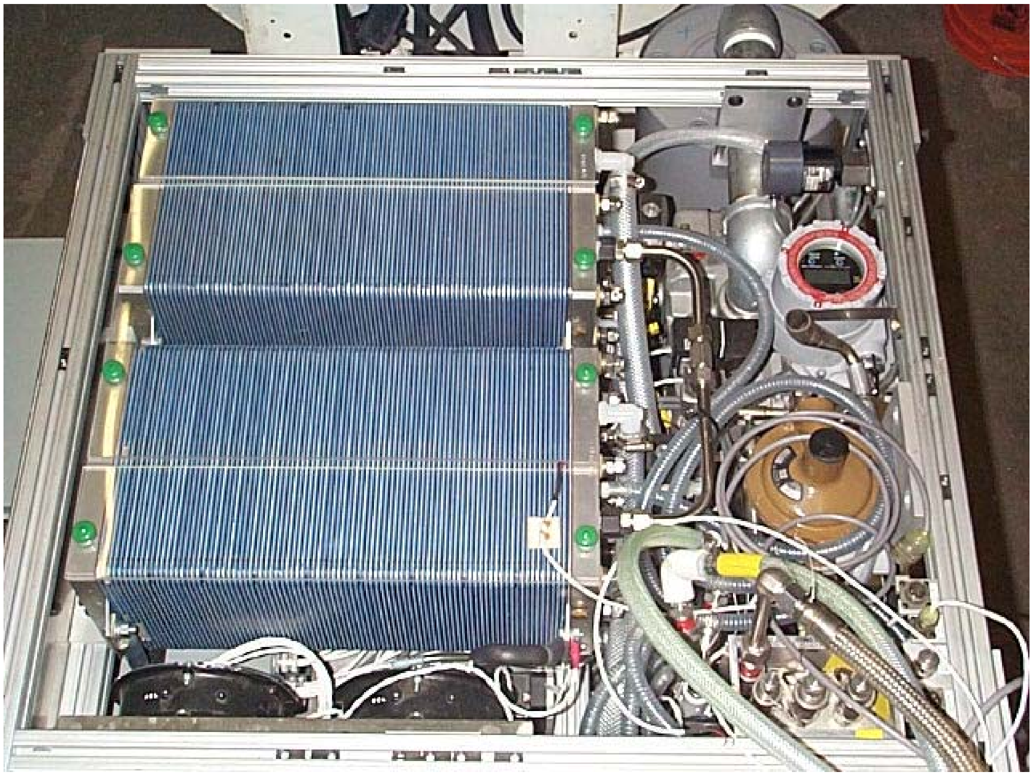

Figure 2. Fuelcell Stacks and Balance of Plant - Top View

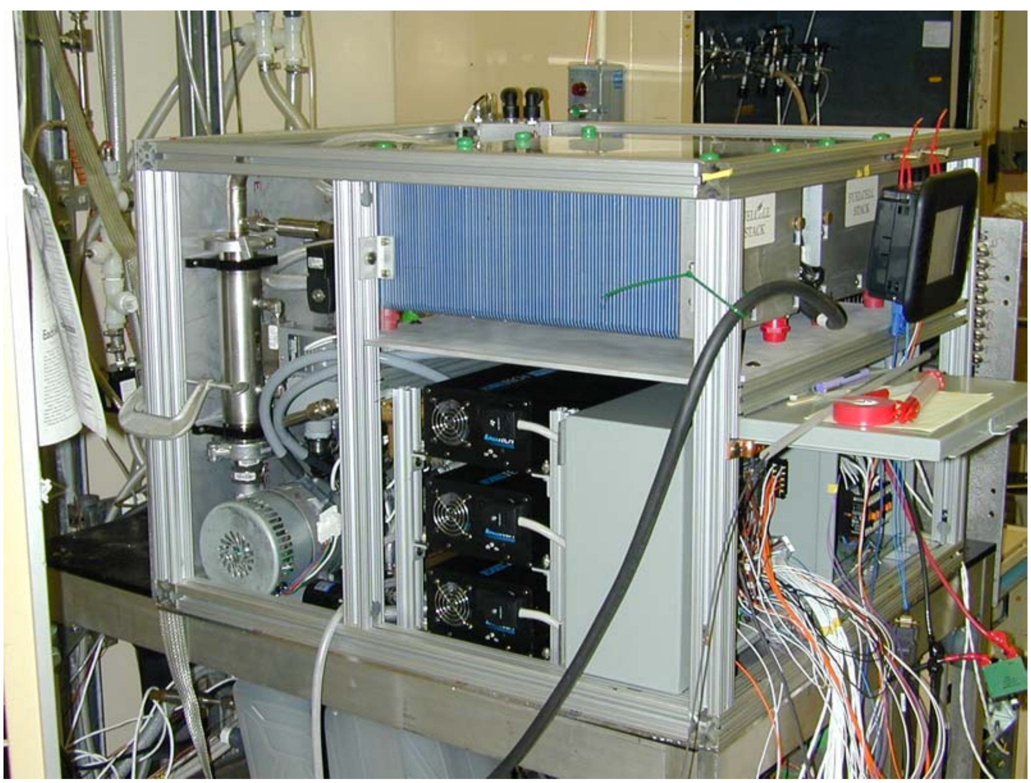

Figure 3. Powerplant – Side View

Metal-Hydride Storage Design and Fabrication:

In a metal hydride, hydrogen chemically bonds to the metal atoms while occupying the interstices. Ferrous metals, among others, form hydrides that are readily reversible and constitute a safe, solid storage medium for hydrogen. By removing low-temperature heat from the crystal, hydrogen atoms enter the channels and *charge* the metal. Conversely, by providing low-temperature heat to a charged crystal, the process is reversed and the crystal is *discharged*. The gas pressure remains approximately constant during the process and can be very low, even below atmospheric.

Unlike liquid or gaseous fuels, metal hydrides are of low flammability. They are of low flammability because the hydrogen is trapped in the metal matrix, or crystal lattice, and the rate at which hydrogen atoms can file through the channels, recombine into hydrogen molecules, and be released is limited by the rate of heat transfer into the crystal. Rupture of a hydride system is self-limiting: As hydrogen escapes, the bed automatically cools and lowers the rate of escape. The metal matrix, moreover, forces the hydrogen atoms unusually close together, as close as in liquid hydrogen, and is responsible for the high volumetric energy density.

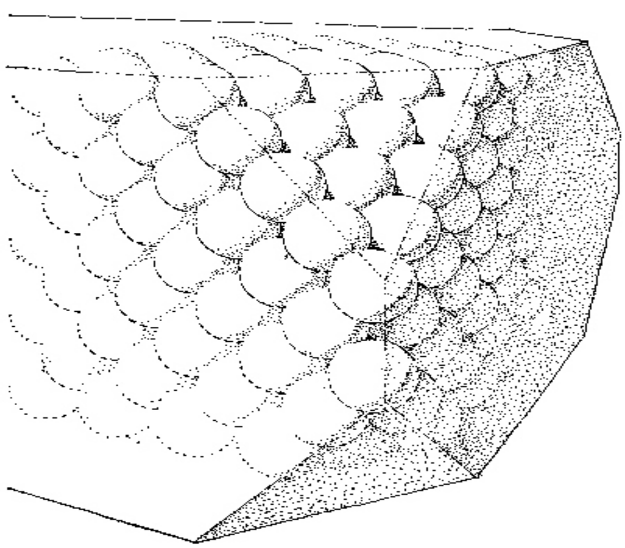

Figure 4. Crystal Lattice

The hydride storage system, designed and fabricated by project partner Sandia National Laboratories/CA, stores 3 kg of hydrogen, sufficient for eight hours of locomotive operation at the predicted 6 kW average power of its duty cycle. The bed uses 213 kg of C-15 alloy (an alloy of manganese, titanium, zirconium, iron, and other constituents from GfE in Germany) and has an operating pressure of 1-2 bars above atmospheric. Measured bed capacity is 1.4 weight percent of hydrogen. Hydride subsystem design allows for rapid change-out (swapping) of a discharged bed with a freshly charged unit. Recharging utilized gaseous hydrogen at seven bars and has been measured at approximately one hour.

Figure 5. Metal-Hydride Storage Module

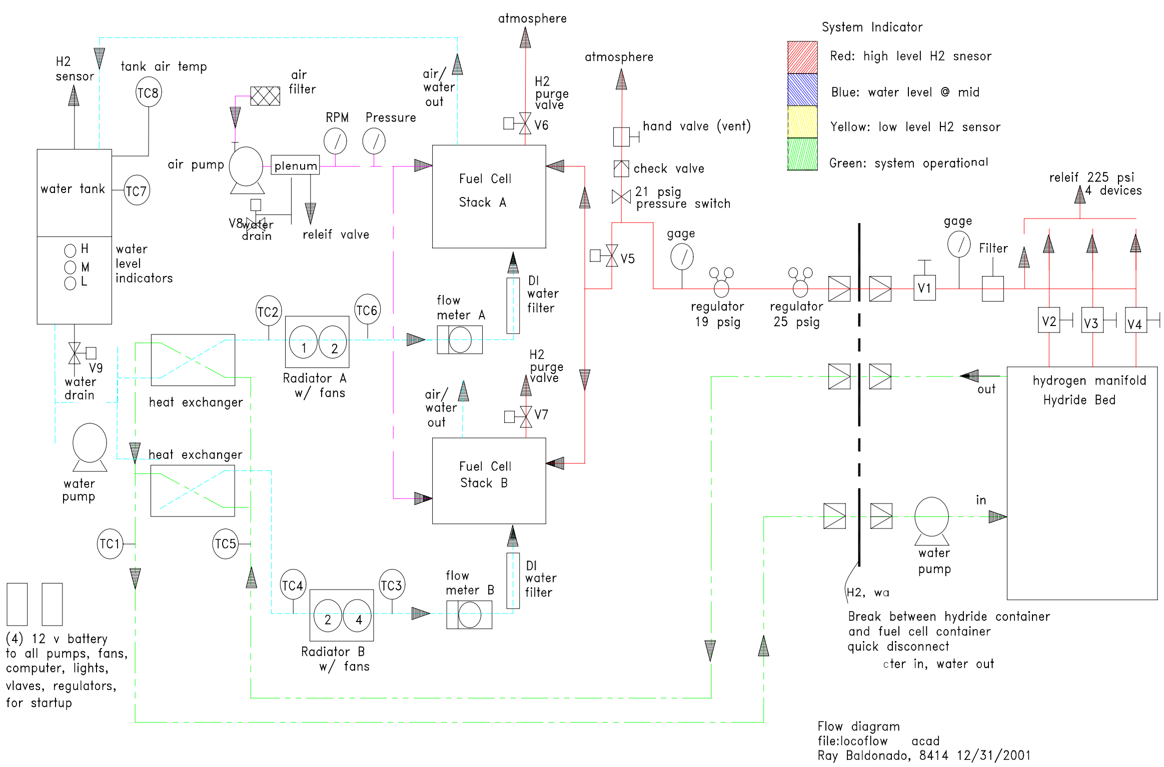

Figure 6. Schematic Layout of Fuelcell Powerplant and Metal Hydride Storage

System Test, Debug, and Final Integration:

The locomotive was first functionally tested on a surface track in Reno, NV. The results were positive but also revealed additional enhancements that would be needed to make the locomotive a practical machine for underground mining. Prior to these first tests, one of the fuelcell stacks exhibited reduced power output effectively reducing the total output of the powerplant by 35%. The final system evaluation resulted in extending the project to procure a newly designed motor controller to interface properly with the higher rpm traction motor, further automation of the Programmable Logic Controller (PLC) to increase monitoring and control of powerplant parameters, simplify operator controls, incorporate new fuelcell stacks to replace the existing, lower performing ones, and to extend the risk assessment and safety analysis to provide adequate data to meet regulatory requirements for underground testing. The Mine Safety and Health Administration (MSHA) also conducted sound tests establishing baseline noise. The noise from the steel wheels on the track during tramming easily surpassed the powerplant noise.

Average Sound Levels for the Locomotive	
Location / Position	dBA
Operator Position/Traveling Forward, Run #1 (Full Throttle)	75.3
Operator Position/Traveling Forward, Run #2	76.6
Operator Position/Traveling in Reverse, Run #1 (Full Throttle)	76.6
Operator Position/Traveling in Reverse, Run #2	76.2
Operator Position/Idle	74.4
6 Inches from Blower on Right Side/Idle	78.9
6 Inches from Top Vent on Right Side/Idle	80.0
6 Inches from Control Panel on Left Side/Idle	79.5
1 Foot in Front of Locomotive/Idle	75.3
Background Near Area of Tests	73.4

Figure 7. Results of Sound Tests as Taken by MSHA, US Department of Labor

In a 5 month period, CANMET personnel developed new PLC software and identified and implemented additional safety controls. The water and air management systems for the fuelcell stacks were changed to improve output power response to changing power requirements. Battery Electric of South Africa, at no additional cost to the project, developed and manufactured a new smart motor controller. The new design better matched the increased induction of the higher rpm traction motor to the fuelcell stack's ability to provide power on demand. In the equivalent 4 ton battery-electric locomotive, the batteries are capable of delivering an overload current of up to 350 amps during initial acceleration. The new fuelcell stacks were designed to provide continuous current of 135 amps. Since fuelcells exhibit overload capabilities less than batteries, the smart motor controller limited any surges to a maximum of 180 amps. This proved to be more than adequate during acceleration, apparently matching the acceleration of the battery locomotive while providing smoother acceleration.

Final integration was supervised by CANMET with no problems encountered. Two days after final integration, the fuelcell locomotive was pulling three fully loaded four-ton (each) ore cars on a surface track at their facilities. The locomotive would eventually pull 5 fully loaded 4 ton ore cars with enough reserve power to pull 7 fully loaded 4 ton ore cars. The maximum trailing load is limited by wheel adhesion rather than power of the fuelcell powerplant.

Figure 8. Fuelcell Locomotive After Final Integration

Figure 9. Fuelcell Locomotive Pulling 3 Fully Loaded 4 Ton Ore Cars

Underground Production Field Tests:

Project partner Hatch Associates was the lead on completing the risk and safety assessments, as well as documentation needed for regulatory approval, that allowed the fuelcell locomotive to go underground in a metal mine for testing. Project partner Placer Dome provided access to a gold production mine, the Campbell Mine in Red Lake, ON. The particular level of the mine where the tests were conducted was inspected for site-specific safety considerations prior to testing. All participating mine personnel were educated on the fuelcell locomotive and the refueling of the metal-hydride storage. Recharging of the metal-hydride took place on the surface after each day-shift was completed.

Two weeks of underground production testing resulted in the fuelcell locomotive passing all tests without any failures or downtime. The fuelcell locomotive is capable of outperforming the equivalent battery locomotive due to extended operating time.

Figure 10. Fuelcell Locomotive Underground

Conclusions:

The problems of vehicle emissions and noise have negative economic consequences for underground vehicle applications. Fuelcells coupled with reversible metal-hydride storage, by solving these problems, offer cost offsets — higher productivity and lower operating costs — that can make underground fuelcell-vehicles cost-competitive sooner than surface applications. Our hydride-fuelcell locomotive, like the battery version, is a zero-emissions vehicle. However, the fuelcell locomotive has greater net power, greater energy storage, higher gravimetric and volumetric energy and power density, higher volumetric power density, and substantially faster recharging. It is slightly noisier than the battery vehicle but is still very quiet, the vehicle noise being lower than track noise. Because weight is not an issue, safe and compact metal-hydride storage is an ideal storage technology for underground locomotive applications.

Figure 11. Final Version of Fuelcell Locomotive, Reno, NV

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FUELCELL POWERED LOCOMOTIVE PERFORMANCE EVALUATION

Final Report

by Gaétan Desrivières, Pierre Laliberté, Marc Bétournay and Marcel Laflamme
Mine Mechanization and Automation Program
Val-d'or, Québec

Work performed for:
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Version: December 2002

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1.0 Introduction

The Fuelcell Propulsion Institute (FPI), an international technical consortium, is proposing and analysing fuelcells as a solution to the growing problem of providing alternate power for the benefit of industrial vehicle users. The mining industry is poised to take advantage of the benefits of fuelcell applications to address pressing issues, such as underground air quality, greenhouse gas emissions, and productivity.

Several projects planned and managed by FPI's Vehicle Projects LLC will demonstrate the safe and economic use of fuelcells for underground mining vehicles. One of these, the subject of this report, has for objective to evaluate the performances of the first fuelcell powered underground locomotive both on surface and underground test sites. This project has been managed by prime contractor Vehicle Projects LLC whose corporate offices are based in Denver Colorado.

This report describes the tests which have been carried out on a R.A. Warren Equipment fuelcell-powered 4.5 ton underground mine production locomotive in collaboration with project partners, on both above ground and underground test sites in Reno Nevada, Val-d'Or Québec and the Campbell Mine in Red Lake, Ontario. The purpose of these tests were several fold: establish fuelcell vehicle performance to ensure that it was ready for underground evaluation, demonstrate its operability and safety to project stakeholders and Ministry of Labour, and verify the suitability of the power plant design and assembly. A complete list of project partners can be found on the fuelcell propulsion institute web site: http://www.fuelcellpropulsion.org.

2.0 Objectives

The main objective of this project was to ensure that the fuelcell locomotive vehicle built by the client meets the performances required to undertake productivity tests in an underground mining environment, and is demonstrated as being safe and viable for a mine production vehicle. In order to achieve this, observations and measurements were made to quantify/qualify the performance of the locomotive under surface and underground conditions and define the mine operating requirements to host such a vehicle.

To achieve this, two distinct phases were first undertaken:

Phase 1: Stakeholder Tests

At a surface rail siding, in Reno Nevada owned by the Union Pacific Railroad, the locomotive was tested and studied to establish its overall performance based on the following:

- Power
  - Power plant voltage
  - Power plant current
  - Motor voltage
  - Motor current
- Fuel consumption
- Resistor bank function
- Refuelling time
- Warm up time

Phase 2: Mine Site Tests

The locomotive was evaluated in production mode at two Canadian mine sites: CANMET-MMSL's experimental mine site (surface and underground), and Placer Dome's Campbell Red Lake Mine (underground).

Performances were evaluated based on the following parameters:

Surface tests:

- Tractive effort
- Power
- Power plant voltage
- Power plant current
- Motor voltage
- Motor current
- Fuel consumption
- Resistor bank function
- Refuelling time
- Warm up time

Underground tests: (locomotive & locomotive + one, three, five loaded cars)

- Continuous push/pull effort monitoring
- Power curves in acceleration & deceleration
- Hydrogen consumption rate
- Recharging aspects
- Noise level
- Vibration level
- Warm up time
- Hydrogen escape monitoring
- Troubleshooting, reliability, maintenance
- General safety aspects

Other assessments included productivity, reliability, availability, practicality, and safety (the latter considering the conclusions derived from tests addressing specific risks, performed ahead of Phase 1) in real and representative underground mine production conditions.

After completing the stakeholder tests in Reno itemized in Phase 1, it was apparent that additional work was needed on the unit in order to upgrade and refine the locomotive to meet the minimum requirements for underground testing in a full production environment. The additional work was carried out under a separate project with Vehicle Projects LLC but performed in both Phase 1 and Phase 2 by CANMET-MMSL's staff at its facilities in Val-d'Or. The detail of this additional work is provided later in this report.

3.0 Monitoring Equipment

The ISAAC V 6.1 professional system was the basic monitoring system used throughout all of the sessions carried out. All the necessary parameters such as: Volts, Amps, pressures, temperatures and speeds have been collected on a one sample/second rate using ISAAC sensors. The collected date was downloaded on a Panasonic CF-27 Laptop for further analysis.

4.0 Phase 1: Stakeholder Tests in Reno Nevada

The fuelcell powered locomotive was tested for the first time on a 100 m (300 feet) tracked site at the Kappes, Cassiday & Associates facility in Reno Nevada from February 18th to March 1st, 2002. These tests marked the first time that the locomotive was self-propelled using the Sandia fuelcell power plant. They were conducted jointly by Sandia and CANMET personnel. This testing process also allowed technology and knowledge transfer from Sandia, the fuelcell power plant manufacturer to CANMET-MMSL's testing representative.

The organizational members involved were: Dan Trujillio, Don Meeker and Ray Baldonado from Sandia, and Gaetan Desrivières and Pierre Laliberté from CANMET-MMSL.

4.1 Reno Experimental Site

A 100 metre (300 foot) length of track, property of the Union Pacific Railway, adjoining the Kappes, Cassiday & Associates facilities located at 7950 Security Circle Dr. in Reno Nevada, was used. The site features indoor mineral processing facilities and a machine shop. It offered indoor space, mechanical and welding services as well as locomotive handling devices.

4.2 Tests Performed in Reno

4.2.1 Hydride bed refuelling

Filling the hydride bed with hydrogen is a heat generating chemical reaction which tends to raise the temperature of the hydride material; whenever the hydride material overheats, it's hydrogen bonding and storage properties tend to lessen. A proper heat dissipating system is therefore needed to cool the hydride material in order to fill the vessel to its maximum capacity. Water jackets around the 16 hydride material canisters were built and an on-board pump added in order to dissipate the heat buildup; this, coupled with an adequate external heat exchanger would allow refuelling to be achieved in a one hour time frame.

The heat exchanger used in Reno, made of a wrapping copper tube linked to a garden hose in which tap water ran, was immerged into a bucket of anti-freeze to ensure the coolest temperature flow through the hydride bed pump. The efficiency of this hand made heat exchanger did not provide proper cooling to ensure refuelling to hydride bed's maximum capacity within the hour target. Refuelling was therefore first carried out by allowing the hydride bed to cool off overnight after filling at two thirds capacity, and then adding the remaining third the next morning. It was agreed upon that a more efficient external heat exchanger would be needed to reach the one hour refuelling to full capacity target.

4.2.2 Start-up, operating, shut-down procedure of the power plant

Start-up, operating and shut-down procedure of the fuelcell power plant were adapted from the laboratory for locomotive application. The first start-up - operating - shut-down sessions of the power plant were done using an electrical artificial load (re: Dynaload) to ensure proper functioning of the unit. The whole cycle needed around two hours to complete. Because of a defect condition in one of the two stacks, it was not possible to draw more than 7.4 Kilowatts from the power plant without jeopardizing this weak stack's survival. The normal operation of the power plant required constant attention and manual flow adjustments were frequently needed. Furthermore, Sandia's procedure required that the fuelcell stacks reach 30°C before drawing more than 30 amps, which in an underground production environment, doubled by this highly transient application and the other already mentioned flaws, was, by all means, an unreasonably demanding task.

4.2.3 Propulsion tests and electric controller

Propulsion tests were conducted on the 300 foot long outdoor track. The on-board computer used to monitor proper vital operation of the power plant was experiencing major difficulties. It was decided to nonetheless perform a few propulsion tests. The locomotive was driven up and down the whole length of the track successfully 3.5 times starting from the neutral position and smoothly accelerating to half speed, and in one cycle ramped up to full speed (11 km hour).

Brutal acceleration was then tried without success, the Safecon controller tripped out as soon as the throttle handle reached full throttle position.

Because of a lack of proper power plant monitoring capability and traction power, and of the controller's behaviour, the performance monitoring of the unit was agreed not worthwhile.

4.3 Analysis and Comments

It was agreed by the client that further work was needed to ensure the locomotive could meet all requirements to undergo underground performance tests in a full production manner. The following had to be addressed:

- A proper heat exchanger was needed to achieve refuelling at maximum vessel capacity within an hour;
- That the fuelcell stacks, in this condition, do not deliver the power required by the locomotive's working cycle;
- Operational issues were to be integrated into the onboard PLC to ensure automatic flow adjustments according to energy variations as well as proper heat management and safety features.
- Electric controller problems were to be solved;
- Mine hardening protective covers were to be sought.

5.0 Additional Work Required on the Unit

An amendment was added to the initial proposal of the project to address all the operational, safety and power related issues from the aforementioned Phase1 Reno tests. The following summary illustrates the adjustments/modifications done on the unit by CANMET-MMSL’s staff in the Val-d'Or facilities in the time frame May - September 2002:

- Installation of two new fuelcell stacks;
- PLC/FPD operator interface features added:
- PID loop for automatic control of water and air flow according to the energy output;
- All monitoring signals from the former Windaq system rerouted to PLC and a snapshot feature that will record all operational parameters to facilitate troubleshooting;

- Trending features allowing graphic views of operating parameters;
- Many start-up and shut-down features and interlocks integrated;
- A full failsafe alarm and emergency shutdown system that ensures nominal and safe operation at all times including onboard hydrogen detectors;
- All preset operational parameters are easily accessible and changeable; a fuel gage as well as an hour meter;
- Added electrical components and rewiring as necessary;
- Updated schematics and drawings delivered by the power plant manufacturer;
- The Safecon controller is replaced by the Icon controller, also from Battery Electric;
- Accessories (lights and horn) control panel;
- Added mine hardening devices, inclined hood;
- Auxiliary antifreeze reservoir placed on the hydride bed to ensure proper heat transfer from fuelcell power plant to hydride bed;
- Adaptations of the start-up/operating/shut-down procedure to the system.

After this work was completed, a four-day primary start-up and integration work session was held involving major critical component manufacturer such as NUVERA's and Battery Electric technical representatives and CANMET-MMSL’s key staff. This work session united all necessary knowledge to rapidly overcome the previous primary start-up glitches that usually appeared in all integration related work. The locomotive started hauling its first fully loaded cars of material a few days later. It is important to note that fuelcell stack manufacturer highly recommended that a 200 amps draw from the stacks was a limit. Therefore, a pre-set was input in the Icon controller limiting the maximum draw from the fuelcell power plant at 200 amps. This pre-set remained for the entire performance tests using the fulcell power plant.

6.0 Phase 2: Mine Site Tests

6.1 Val-d'Or Experimental Mine Performance Tests

Performance tests at CANMET's Experimental Mine were conducted on the locomotive, first on a surface track site then on an underground track site. The purpose of the tests was to ensure that the unit meets all power, operational and safety in preparation for underground tests in a full production environment. The following parameters were being evaluated:

- Tractive effort
- Continuous push/pull effort monitoring
- Power curves in acceleration/deceleration
- Refuelling time & fuel consumption
- Warm up time
- Vibration levels
- Noise levels
- Resistor bank function
- Troubleshooting, reliability and maintenance

The surface track is 60 m (200 foot) long, with a gauge of 30 inches and slight 0.5% downward slope towards the east. The underground track site is 200 m (650 foot) long, with a gauge of 30 inches with a 0.6% downward slope towards the south-east. It is located on the 70 metre level and accessible via a 15% incline ramp in which the locomotive was hauled using a 2 yard Wagner LHD on one end and sitting on a wheel axle on the other.

6.1.1 Test Performed in Val-d'Or

Refuelling

Refuelling was carried out after the hydride bed was emptied, using a manifold linked to six 5.44 m³ pressurized hydrogen bottles and following the procedure outlined for the heat exchanger, to properly cool the vessel. A pressure sensor and a thermocouple installed on the hydride bed unit allows monitoring of pressure and temperature in a real time mode while refuelling (see refuelling graph in Appendix 1). The whole process was done in 56 minutes, and 450 psi of hydrogen pressure remained in the bottles.

Warm up time

Because of automated functions in the start-up/operation/shut-down procedure, it was possible to initiate locomotive use after about only 10 minutes after start-up. The operation of the unit required adding demineralized water on occasion whenever the blue status light of the tower light system started blinking. All other operational and safety parameters were monitored by the PLC-based flat panel display and an alarm or a shut-down process would be automatically initiated if ever a malfunction, hydrogen leak or overheating occurred. The shut-down process required 15 minutes to complete.

Surface performance tests

The locomotive was driven up and down the 200 foot surface track followed by pulling one, then two, and up to five fully loaded 4 ton cars (weight of rock). A new monitoring period was started when the locomotive was standing still at the west end of the track: the throttle was then pushed to maximum allowing the unit to accelerate at full power at the peak speed it could reach before applying electric brake (E-brake) to decelerate and stop at the east end of the track. The performance parameters recorded for analysis were: speed, power drawn from power plant, power dissipated in the resistor bank when E-braking, temperature of the resistor bank and continuous push/pull effort. It is important to notice that the surface track was dry, maximizing traction capability compared to an underground track which would be moist, wet and muddy.

Surface performance results and analysis

Data compilation is shown in graph form where the different curves illustrates the parametric variations during the different recordings. This is also provided in spreadsheet format (Table 1). These figures are based on the mean of all available curves going upgrade then downgrade.

Table 1. Val d'Or surface performance tests compilation

	Acceleration	Deceleration	Distance Travelled (m)		Power (kW) Cons. Acc. Gen. Dec.		Mean Tractive Effort (kg)	
			Acc.	Dec.	Mean	Peak	Acc.	Dec.
Loco	0 - 14.5 km-h/ 9.5 sec	14.5 - 0 km-h/ 3.5 sec	23	4.8	12 7.82	17.3 25.9		
Loco + 1 car	0 - 12.4 km-h/ 11 sec	12.4 - 0 km-h/ 3.0 sec	28	4.2	12.6 6.21	18.2 16.4	211	395
Loco + 2 cars	0 - 11 km-h/ 13 sec	11 - 0 km-h/ 7 sec	25	8.5	14.9 2.97	18.2 11.9	329	394
Loco + 3 cars	0 - 10.1 km-h/ 15 sec	10.1 - 0 km-h/ 7 sec	26	8.3	15.2 2.7	17.7 11.1	423	444
Loco + 4 cars	0 - 8.9 km-h/ 17 sec	8.9 - 0 km-h/ 5.5 sec	28	5.5	15.2 3.24	17.5 9.39	482	588
Loco + 5 cars	0 - 8.4 km-h/ 16.5 sec	8.4 - 0 km-h/ 7.5 sec	24	5.7	15.1 1.75	18.7 9.39	536	443

Underground performance tests

The locomotive was driven up and down the 650 foot underground track sequentially pulling one, then two and up to five fully loaded 4 ton cars. A new monitoring period was started when the locomotive was standing still at the north-west end of the 70-110-N track on the 70 m level. The throttle was then pushed to maximum allowing the unit to accelerate at full power at whatever speed it could reach before applying electric brake to decelerate and stop at the south-east end of the track. The different monitored performance parameters recorded for analysis were speed, power drawn from power plant, power dissipated in the resistor bank when E-braking, temperature of the resistor bank and continuous push/pull effort. It is important to notice that the underground track was moist/wet, minimising traction capability compared to the surface track which was dry.

Underground performance results and analysis

Data compilation is shown in graph form where the different curves illustrates the parametric variations during the different recordings. This is also provided in spreadsheet format (Table 2). These figures are based on the mean of all available curves going upgrade then downgrade.

6.1.2 Vibration level monitoring

Vibration level readings were performed using a Bruel & Kjaer model 2513 accelerometer on the hydride bed chassis, as well as directly on the locomotive's chassis. The accelerometer was linked into a portable computer via the sound card line-in plug and the SpectraPlus software was used for data recording and analysis. Monitoring was recorded at a 48,000 readings/second rate.

Table 2. Val d'Or underground performance tests compilation

	Acceleration	Deceleration	Distance Travelled (m)		Power (kW) Cons. Acc. Gen. Dec.		Mean Tractive Effort (kg)	
			Acc.	Dec.	Mean	Peak	Acc.	Dec.
Loco + 1 car	0 - 15.6 km-h/ 17.3 sec	15.6 - 0 km-h/ 5.2 sec	43	6.5	12.3	17.4	164	284
					3.74	22.2		
Loco + 2 cars	0 - 14.1 km-h/ 20.3 sec	14.1 - 0 km-h/ 6.8 sec	46	7.3	13.5	18	304	540
					4.59	19.2		
Loco + 3 cars	0 - 13.2 km-h/ 19.3sec	13.2 - 0 km-h/ 7.3 sec	36	8.1	14.2	18.2	403	549
					3.6	21.2		
Loco + 4 cars	0 - 11.8 km-h/ 20.8 sec	11.8 - 0 km-h/ 5.2 sec	33	4.5	14.7	18	495	458
					1.94	14.1		
Loco + 5 cars	0 - 11.5 km-h/ 25.8 sec	11.5 - 0 km-h/ 5.2 sec	38	5.9	14.7	18.2	536	584
					2.03	13.3		

Vibration monitoring methodology

Recording of the vibration data was carried out at the underground 650 foot long track site. The recording of each axis began when the locomotive was sitting at the north-west end of 70-110-N rail with three fully loaded cars attached. The throttle was pushed to maximum, to simulate real operation conditions, the locomotive accelerated to maximum speed (± 13 km/h), then the electric brake was applied decelerating the unit to a full stop at the south-east end of the track; it was ramped up to full speed again going uphill (± 9 km/h) to return to the start point, accelerating and decelerating in the same manner. The recorded data was then saved to file, each window containing from 125 to 150 seconds worth of data. Recording was systematically done in the X,Y, Z axis on the hydride bed frame then directly on the locomotive's chassis in the same acceleration/deceleration pattern.

Vibration results and analysis

The recorded data is presented in a graph showing the vibration amplitudes on a real time basis, the y axis expressed as gravity (G) and the x axis expressed as time (seconds). A Fourrier transformation was then extracted from the raw data to present a mean frequency spectral for each axis comparing both hydride bed collected data (blue trend) and locomotive's chassis collected data (yellow trend) (see graphs in Appendix 2).

The vibration amplitude graphs shows a tendency to generate maximum amplitudes at the end of each recorded trend corresponding to the unit in E-brake mode, decelerating to a stop. Maximum accelerations in the 4G, 5G, and 8G range on the locomotive's chassis, and in the range of 1G, 1G and 1.5G on the hydride bed chassis respectively on the vertical, lateral side-side and lateral front-rear axis. The difference between the results obtained at the hydride bed and chassis locations indicate a damping effect of the rubber mounted fixture on which, the hydride bed and the fuelcell power plant are sitting on.

The mean frequency spectral graphs shows a peak in the 4.5 kHz range in every axis which corresponds to the frequency generated by the wheel-track steel on steel vibration generating effect on this type of vehicle.

6.1.3 Noise level monitoring

The sound level recording session was not done according to internationally recognised standards for sound level monitoring methodology. Therefore, results have to be pondered accordingly.

Noise level readings were done using a Bruel & Kjaer model 2236 soundmeter in the locomotive operator's cab at operator's ear level. Monitoring was recorded at a 1 reading/second speed and each recorded window was saved for every different frequency and contains in the range of 50 to 60 seconds of recording.

Noise monitoring methodology

Recording of the noise data was done on the underground 650 foot long track site at the same time as vibration data was recorded. The recording of each frequency namely: 31.5 Hz, 125 Hz, 250 Hz, 500 Hz, 1 KHz, 2 KHz, 4 KHz, 8 KHz, RMS A, RMS C, began when the locomotive was sitting at the north-west end of the 70-110-N opening, 2.5 m^2 in cross-section, with three fully loaded cars attached. The throttle was pushed to maximum, to simulate real operating conditions, the locomotive accelerated to maximum speed (± 13 km/h), then, with the electric brake applied, the unit decelerated to a full stop at the south-east end of the track. It was ramped up to full speed again in the other direction going upgrade (± 9 km/h) towards the start point, accelerating and decelerating in the same manner. Each and every frequency was recorded in the same acceleration/deceleration pattern. Background sound was negligible and unaccounted for.

Noise results and analysis

As previously stated, recorded data reflect 50 to 60 seconds of monitoring in each aforementioned frequency range. The following sound related reference expressions were extracted from the raw data files:

- MaxP: maximum peak level since last reset;
- MaxL: maximum sound pressure since last reset;
- MinL: minimum sound pressure since last reset;
- Leq: continuous equivalent acoustic level;
- LEXd: daily sound level exposure (7.5 hours);
- L10: acoustic pressure exceeding 10% of recorded data;
- L50: acoustic pressure exceeding 50% of recorded data;
- L90: acoustic pressure exceeding 90% of recorded data.

The Leq values, which is the most relevant for sound exposure levels, range from 69.1 dBA to 98.6 dBA depending on the frequencies, the average being 90.4 dBA.

The highest noise generation level in this case comes from the steel on steel wheel/track application and not from the fuelcell powerplant.

6.1.4 Comments on the Val-d'Or tests

Based on the above results, it was decided that all the operational, performance and safety issues had been dealt with. The fuelcell powered locomotive did meet the basic requirements to undergo tests in a full production environment, namely the Placer Dome Campbell Mine in Balmertown Ontario.

6.2 Placer Dome Campbell Mine Performance Tests

The locomotive was brought for testing to the 27th level at the Campbell Mine in Balmertown Ontario. The level is at about 1200 m deep (4000 feet) and accessible via a shaft. Performance tests were conducted between October 5th to 13th 2002 on day shift. A battery bay, on the level, equipped with an overhead crane, was used for a locked over-night parking space and power plant and hydride bed units transfer area. The hydride bed refuelling facility was on surface in an opened, well vented quonset. The following performance parameters were monitored while the locomotive was subjected to its production duties:

- Continuous push/pull effort monitoring
- Power consumption in real time
- Speed
- Refuelling process & fuel consumption
- Warm up & shut-down time
- Resistor bank function
- Troubleshooting, reliability and maintenance

6.2.1 Placer Dome Campbell Mine performance tests methodology

The typical test day began with retrieving the filled up hydride bed from the outdoor quonset and then sent underground on the cage to the transfer area on 27th level. The hydride bed was then installed on the locomotive, followed by the mine hardening protective cover using the on site overhead crane. The start-up procedure was then initiated and the unit was ready to perform its daily hauling duties. Usually the unit was ready to work at around 7:45 and was sent back into the transfer area at 14:00, for refuelling purposes, which allowed for about 6.5 hours of daily production time; taking out 0.5 hour for lunch, leaving 6.0 hours of daily production time. The mine hardening protective cover and the hydride bed were then removed from the unit and the latter directed to surface via the cage for refuelling. Refuelling of the hydride bed was usually done around 15:00 and took about an hour. A monitored production day was done last using the unit's traditional battery on October 12th for performance comparison purposes. The cars used were side dump cars triggered by a pneumatic cylinder at both ore pass and waste pass dump sites.

6.2.2 Placer Dome Campbell Mine tramming routes

Different tramming routes were used throughout the 7 days of monitoring. Of course, length, grade, loading method, track conditions and number of cars used on each of these routes resulted in different energy signature required by the locomotive. The three official routes commonly used were:

"Chute A 2 cars": located in the 2756 E drift in the south-east end of 27th level this location was trammed using two 4 ton cars and dumped in the ore pass. Load is done under a pneumatically activated chute. Total length of 561 m (1850 feet) and a grade of 0.6% (1150 feet at 0.76%).

"Chute B 3 cars": located in the 2720 S X-cut this location was trammed using three 4 ton cars and dumped in the ore pass. Loading was done under a pneumatically activated chute. Total length of 335 metres (1100 feet) and a grade of 0.5% (365 feet at 0.8%).

"Rse bore 3 cars": located near the main X-cut, in front of the mechanical shop on 27th level, this location was trammed using three 4 ton cars and dumped in the waste pass. A small diesel-hydraulic LHD was used for loading. The loader did not have the space to back into in order to turn around and dump into the cars. Therefore, the train was hauled out then backed in each time so the loader would cross the track to dump into the cars, 14 to 15 buckets were needed to fill the three cars. The total length was 190 m (625 feet) and a grade of 0.4%.

The main factor determining the number of cars used in each tramming routes was traction capabilities. For mine water management reasons an upward grade is usually applied when mining underground headings. The results of this was that a tramming unit will work against the grade while hauling empty cars towards the loading point and downgrade while hauling the load to the dumping point. This is of course an advantage for tramming efficiency compared at what it would be the other way around, however, it does result in a limited traction capability. The steel on steel contact of the locomotive wheel and the damp/wet/muddy underground railway is the hauling limitation when tramming upgrade towards the loading point. Gross power of the locomotive is rarely an issue as for hauling limitation.

6.2.3 Campbell Mine tests performed

Refuelling process and fuel consumption

After finishing the production duty, the hydrogen vessel needed to be refuelled; typically, the whole process at the Campbell Mine is listed below:

- drive the fuelcell powered locomotive into the transfer area (0 min);
- initiate shut-down process;
- remove the mine hardening protective cover and the hydride bed using the overhead crane;
- store the hydride bed in its transportation box (0 + 25 min);
- install H.B. on a flat car and drive to the station;
- load in the cage and send to surface;
- use forklift to travel to the quonset (0 + 50 min);
- plug-in heat exchanger, plug onto H_2 bottles, purge and initiate refuelling (0 + 60 min); and
- refuelling complete, unplug and lock-up (0 + 120 min).

While refuelling is in progress, the pressure and temperature of the H.B. were monitored in real time.

All the hydrogen needed for the tests came from 7.24 m^3 bottles pressurized at 2200 psi. A manifold was linked on 6 bottles at a time and fuel was fed to the H.B. through a regulator at 160 psi pressure. A total of approximately 67.2 m^3 (67 200 litres) was used from 12 of these bottles for the 5 days (29.7 hours) of fuelcell operation.

An onboard fuel metre, which calculates fuel consumption based on the following mathematical equation (0.42 x "current" x 96 cells x 1 (stoich factor) x 2 stacks) according to total energy produced, states the fuel consumption to be at 46,000 litres. It would be a fair assessment to say that the remaining 21,200 litres of hydrogen was used through the purge system.

Warm up and shut-down time

The fuelcell power plant, equipped with PLC controlled features, requires around 10 minutes to go through the start-up procedure and around 15 minutes to perform shut-down. Half that time in the shut-down process is used to allow the voltage in the stacks to dissipate.

Resistor bank function

Electric brakes are available through the Icon controller on the unit by means of reversing the traction motor into a generator and the energy is dissipated through this resistor bank. Monitoring equipment was therefore installed on this circuit in order to read the energy generated (see E-brake kilowatts curve in graphs). E-brake is observed as having generating capabilities to peaks reaching up to over 18 kilowatts. This however does not represent a great amount of energy because these peaks do not last for a very long time (1-2 seconds). This recoverable energy, even it is a relatively small amount, should nonetheless be banked in devices such as ultra capacitors, and fed into traction when needed.

Troubleshooting, reliability and maintenance

In the Campbell Mine performance tests, the unit operated for 29.7 hours with the fuelcell power plant and for 6.5 hours with the traditional battery. In the process, the only reliability related issue that has been encountered was a blown fuse on the hydride bed pump circuit discovered on a morning fuelcell power up ritual. The fuse had been replaced in five minutes and power up completed. A total of 50 litres of demineralized water were added throughout the whole testing period. It would be recommended that condensing devices be sought in order to recover as much demineralized water as possible from the steaming air/water outlet. A positive water balance of the fuelcell power plant would not require any water addition and therefore be more efficient.

Underground performance results and analysis

Data compilation are shown in a form of a graph where the different curves illustrates the level and the behaviour of the different recordings. A spreadsheet is also presented outlining the relevant observations. A graph and spreadsheet, presenting the recording of the parameters, illustrates a typical cycle for every tramming route used by the fuelcell powered locomotive and two tramming routes are covered by the battery powered locomotive. Two graphs are also constructed to compare the speed under battery power and fuelcell power on two tramming routes. A compilation of the data is shown in Table 3.

Table 3. Speed data compilation

	Cycle time (seconds)	Top speed (Mean speed) (When vehicle is in motion) km-h	Distance Travelled Metres (feet)	Power (kW)		Mean Tractive Effort (kg)
				Mean	Peak	
Fuelcell Powered Chute A 2cars	635	15.2 (8.2)	561 (1850)	5.13	17	187.9
Fuelcell Powered Chute B 3cars	449	12.8 (7.5)	335 (1100)	5.38	18.1	256.9
Fuelcell Powered Rse Bore 3 cars	898	12.4 (5.5)	190 (625)	3.97	18.9	295
Battery Powered Chute B 3 cars	442	12.1 (7.5)	335 (1100)	5.75	16.1	146.2
Battery Powered Rse Bore 3 cars	903	10.7 (5.9)	190 (625)	3.5	21.9	177.2

As for gross power, it is important to know that the Icon controller allows the limitation of operating parameters. As recommended by the fuelcell stack manufacturer, maximum amps to the motor is limited to 200 A when operating with the fuelcell power plant.

According to the manufacturer, this limitation is necessary to keep the stacks from being severely damaged. Consequently, the battery powered locomotive (amp limitation set at 350 A) will tend to accelerate faster from a stop position when loaded (re: this is usually where the amps level peaks). However, because the fuelcell outputs a higher voltage (100-170 volts compared to 90-110 volts) compared to battery, speed, in normal travelling mode, tends to be higher.

Because the battery powered locomotive uses stored energy and the fuelcell manufactures energy on demand from a consumable fuel, it is foreseeable that performances of the battery powered vehicle will tend to lessen after a certain given amount of time while the performances of the fuelcell powered unit will not decrease as long as the right amount of fuel is available.

With the present unit, and for the present tests, an average of 6.5 hours of operation per day is done using the fuelcell power plant. The one day of operation using the battery operated for 6.5 hours as well. The daily hydrogen consumption rate while operating with the fuelcell power plant is around 20,000 litres which is 2/3 the hydrogen containing capacity of the on board vessel. By extension, it is therefore predictable that the unit would have enough fuel on board to achieve production for another 1/3 of that time for a total of 8.5 hours without affecting performances. The battery has around 7 hours of operation storage capacity at its best condition and performances will tend to decrease as it is used. This is not reflected in the present performance data because of underground daily time limitation which allowed only 8 hours of work wall to wall. It was therefore impossible to operate the fuelcell based locomotive until running out of hydrogen, nor the battery powered locomotive until battery completely run out of energy. The above statements regarding total performance availabilities are based on operator's prior experiences with battery powered locomotive and common sense.

7.0 Mine Site Tests Conclusions

The locomotive in both surface and underground tests at CANMET's Experimental Mine and at Placer Dome's Campbell Mine, accumulated a total of 43 hours of operation in fuelcell mode and 6.5 hours in traditional battery mode for a grand total of almost 50 hours of monitored operation. The Val-d'Or tests were designed for specific acceleration/deceleration performance on both the 60 m long surface track site and then 200 m long underground track site. Vibration and noise tests were also performed using the underground test site. Campbell Mine tests were oriented in production capability in real tramming routes in a fully operational underground context. In this fully productive environment, over 1000 tons (760 tons on fuelcell and 240 tons on battery) of material were hauled covering a total cumulative distance of over 65 kilometres going up and down the Campbell Mine's different tramming routes.

The fuelcell powered locomotive proved to be as reliable and productive as the battery powered version, on a one fuelcell powered tramming cycle compared to any one battery powered tramming cycle. The maximum 200 motor amps pre-set in the Icon controller (highly recommended by fuelcell stack manufacturer) using the fuelcell power plant compared to the 350 motor amps same pre-set for the battery power unit, tends to give greater acceleration power in the lower vehicle speeds when fully loaded for the battery powered version. However, because the fuelcell power plant works at a greater voltage, maximum speed is higher than the battery powered unit. It is also foreseeable, even if not properly demonstrated in the included performance data because of daily time window limitation, that the fuelcell powered version will give steady, 100% power availability for around 8.5 hours of operation, compared to the battery powered version, because running on stored energy, will give a steady decreasing performance curve for around 7 hours of operation.

The noise and vibration levels are not greater than the battery powered locomotive, the greater noise and vibration generation coming from the steel on steel wheel track contact.

It takes roughly three hours for refuelling the hydride bed including handling/transportation up and down the shaft. It is obvious that different refuelling technics need to be addressed to have the proper answers, but refuelling has the potential to easily being achieved within an hour time frame if a proper underground hydrogen refuelling area can be sought compared to the 7-8 hours needed to fully recharge a traditional locomotive battery.

Based on these performance tests, this prototype fuelcell powered underground locomotive proves to be as effective, as the same battery powered unit regarding power generation/tractive effort/daily production basis for a continuous 6.5 hour production window. However, the potential of increasing daily production levels are much greater using the fuelcell powered unit. It is not an overstatement to say that off the shelf manufactured fuelcell power plant will be more efficient as for power/volume ratio and therefore will prove to be much more productive on a long term basis than battery powered locomotives. If the fuelcell power locomotive outperforms the battery power locomotive based only on production issues, one must also take into consideration the advantages compared to an underground diesel powered locomotive when adding ventilation related economies, noise, health, etc.

8.0 Recommendations

The locomotive experience did enhance our collective knowledge on what are the requirements to effectively and safely operate fuelcell powered equipment in an underground mining environment. It is important to use this newly acquired knowledge to apply positively to other similar projects with regards to fuelcell power plant development and integration in an existing piece of equipment. The one lesson that needs to be remembered is that absolutely all power as well as operational requirements and limitations needs to be known and addressed ahead of time, and this list of requirements/limitations has to follow the unit’s development at each and every step.

Therefore, based on our experience with this prototype locomotive, some technical issues need to be addressed in order to improve power plant efficiency:

- More than 30% of the 67,200 litres of the total hydrogen consumption at the Campbell Mine tests have been ejected in the atmosphere via the fuelcell stacks purge system. In order to enhance fuel efficiency, it is important to optimize this purging system.
- Air and direct water injection were fed into both stacks using a single blower and water pump. An uneven distribution is therefore observed for the different feedings. A greater flow resistance in one line compared to the other, even the slightest one, caused unbalanced feeding. A more proper, evenly distributed feeding system, is needed for the air and water circuits.
- The direct water injection circuit is used to cool the stacks and keep membranes moist. However, whenever the stack temperature reaches a higher level (40-60°C) the systems water balance becomes negative, because of the evaporation effect, it is necessary to add demineralized water from time to time. A condenser should be installed to recover as much water possible from the air/water outlet keeping a constant positive water balance in the system. In the same Campbell mine performance tests, no less than 50 litres of water was added to the system.
- Many electric related issues, from design to component selection, needs to be addressed.

Some answers still need to be provided, especially regarding refuelling issues, but based on the performance curves illustrated in the present report, using fuelcell technology to power underground mining equipment is, without a doubt, a very promising alternative to battery or hardwired electric vehicles as well as diesel powered equipment.

9.0 Acknowledgements

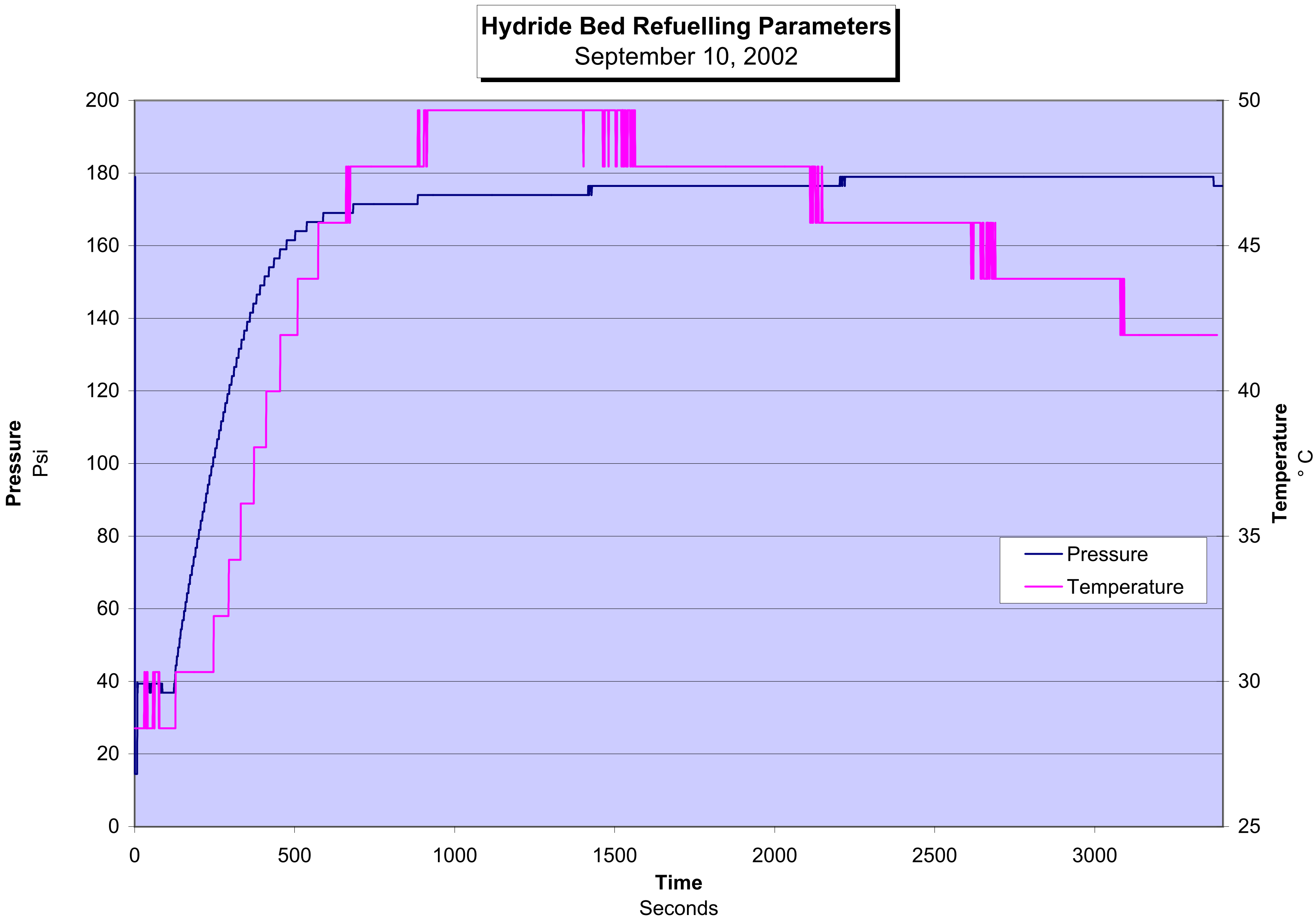
This project would not have been possible without the participation of mining companies, equipment manufacturers and the Fuelcell Propulsion Institute which provided the impetus and technical knowledge to initiate the project. Furthermore, the project would not have been carried out without the financial support of the United States Department of Energy and Natural Resources Canada Energy Emerging Technology Program and Climate Change Program. This project has been driven by Vehicle Projects LLC acting as main management authority.

Special thanks are given to Tim Doyles from the Campbell Mine in Balmertown Ontario whom dedicated innumerable efforts and a total on site commitment to make the Campbell's Mine performance tests as effortless as possible.

Dr. Arnold Miller of FPI is also acknowledged for the organization of the project and the advice he has brought to bear.

Appendix 1

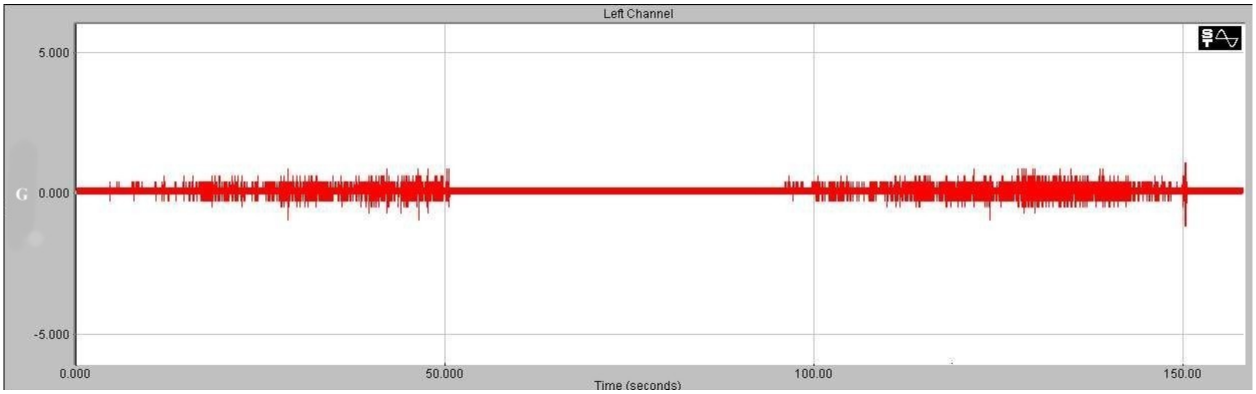
Refueling data graphs


Hydride Bed Refuelling Parameters
September 10, 2002
Pressure
Psi
Temperature
° C
Time
Seconds
Pressure
Temperature
200
180
160
140
120
100
80
60
40
20
0
50
45
40
35
30
25
0
500
1000
1500
2000
2500
3000

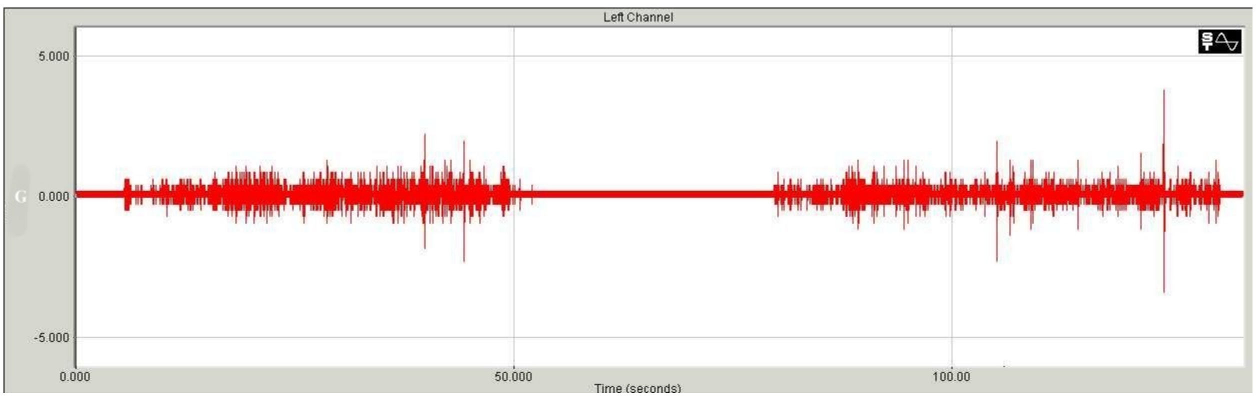
Appendix 2

Vibration monitoring data

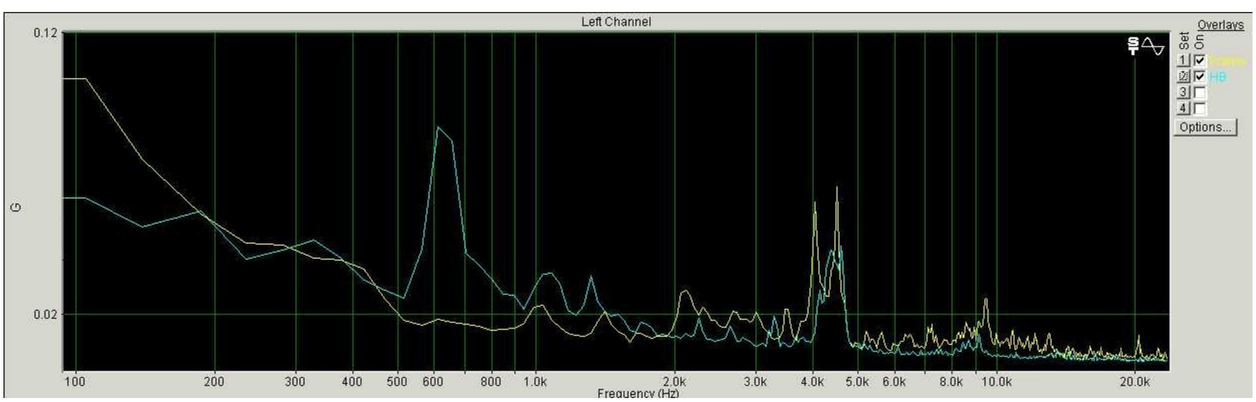
Top hydride bed real time monitoring



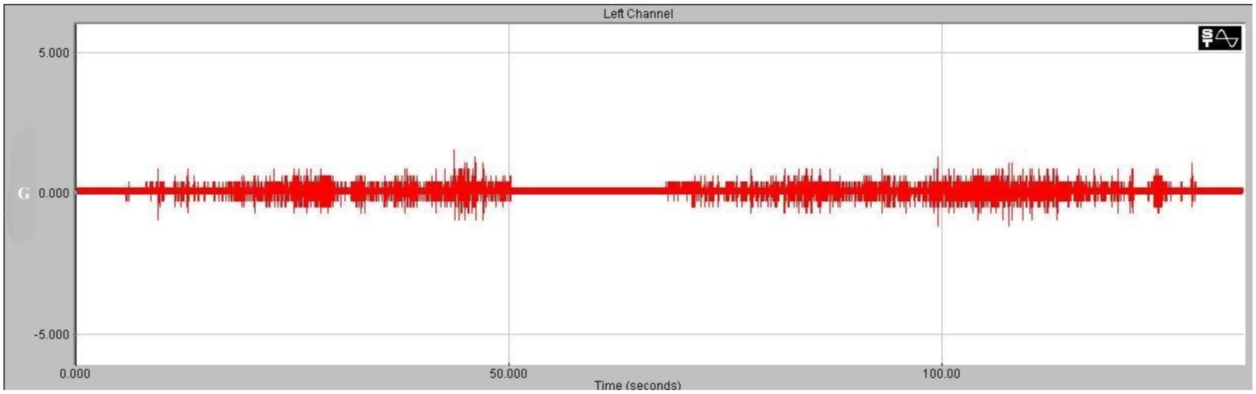
Top locomotive chassis real time monitoring



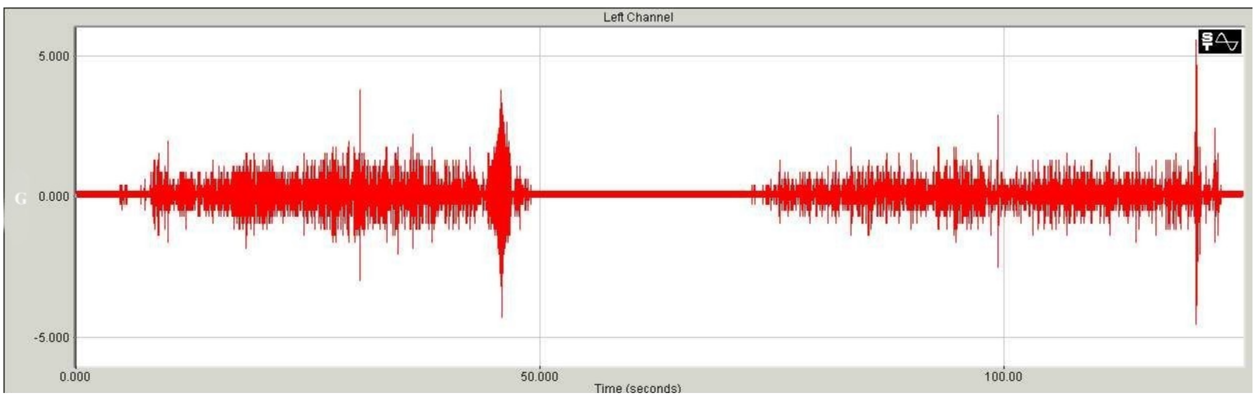
Top mean frequency spectral



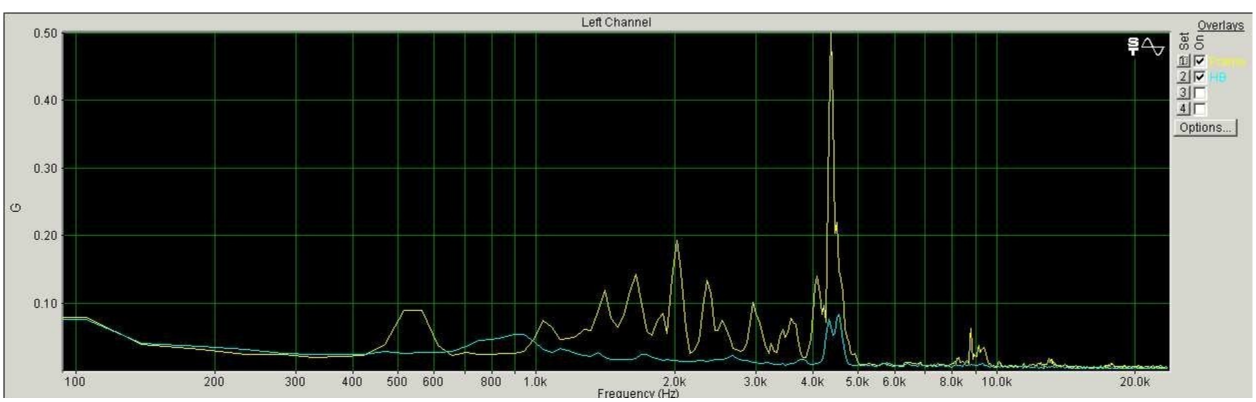
Lateral side to side hydride bed real time monitoring



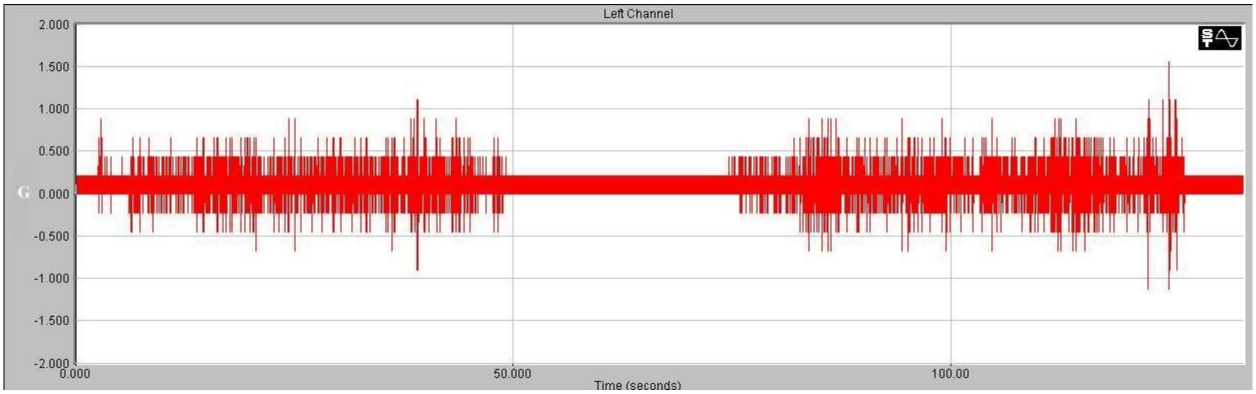
Lateral side to side locomotive chassis real time monitoring



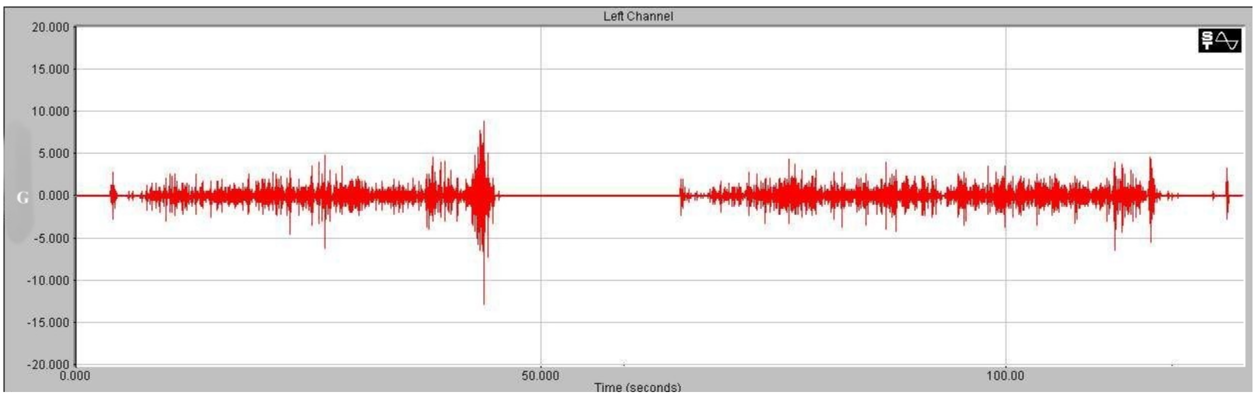
Lateral side to side mean frequency spectral



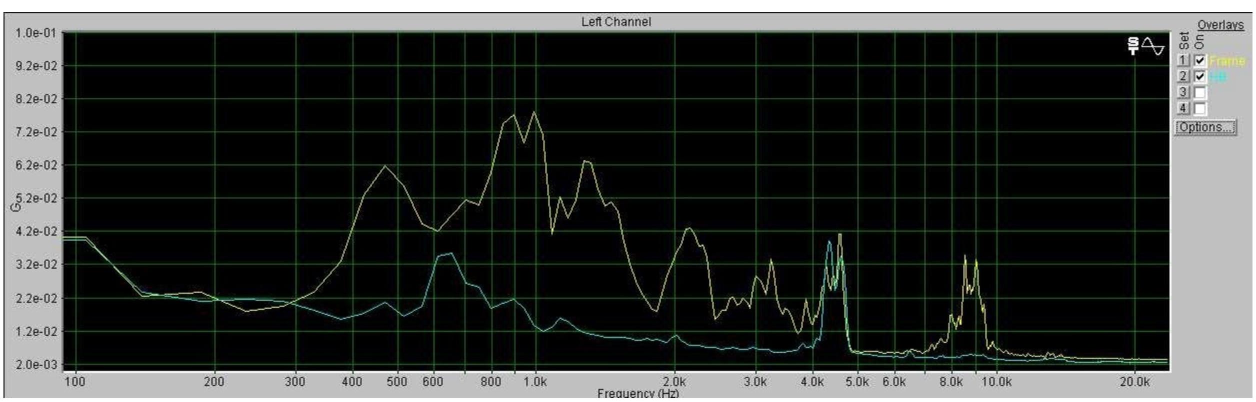
Lateral front-rear hydride bed real time monitoring



Lateral front-rear locomotive chassis real time monitoring



Lateral front-rear mean frequency spectral



1. Introduction

As requested, Hatch has conducted a Pre-development Review (PDR) of the prototype Fuelcell Locomotive to be tested at the CANMET Experimental Mine (Val-d'Or, Québec) in August-September 2002 and the Placer Dome Campbell Mine (Balmertown, ON) in September-October 2002.

The review has been carried out in accordance with the Health and Safety Guidelines for Pre-development Reviews, as required by the Ontario Occupational Health and Safety Act and the Regulations for Mines and Mining Plants, O. Reg. 854. This review documents the work undertaken with respect to hazard identification, risk assessments, pertinent legislative requirements, and available standards and codes.

The project consists of the following:

- Sandia National Laboratories (Livermore, CA) has designed and manufactured a fuelcell power plant (the "Fuelcell Unit") and a hydrogen storage unit using metal hydride (the "Hydride Bed");
- The Fuelcell Unit and the Hydride Bed have been installed on a standard underground mining locomotive provided by RA Warren Equipment. The Fuelcell Unit and Hydride Bed have replaced the standard rechargeable batteries; and
- The Fuelcell powered locomotive is to be tested in underground mines located in Quebec (CANMET Experimental Mine, Val-D'Or, QC) and Ontario (Campbell Mine, Balmertown ON).

2. Regulatory Assessments and Reports

Investigations and consultations were undertaken to assess which regulations and industry standards were applicable to the introduction of this new technology to mining. The assessment and compliance reports specific to the locomotive and fuelcell equipment are detailed in Appendix A. As there is a hazardous gas, hydrogen, present onboard the locomotive, a Hazardous Locations Classification has been performed on the equipment in accordance with the Canadian Electrical Code, see Appendix B.

3. Contributors

The Pre-Development Review process for this project consists of substantial effort on the part of several organisations. The project has included participants from organizations involved in hydrogen fuel development, mining, mine safety, mining technology, and government research. The organisations and their specialties are listed in Table 1 below:

Table 1: Organisations

Organisation	Expertise
Sandia National Laboratories	Hydrogen Fuelcell Integration
Mine Safety and Health Administration (MSHA)	Mine Safety (United States Department of Labor)
Hatch	Mining Technology Implementation, Mechanical Engineering, Process Control Engineering
CANMET (Natural Resources Canada)	Mining and Mineral Sciences Laboratories (Natural Resources Canada) – Test Site
Vehicle Projects LLC	Prime Contractor, Project Management
Placer Dome Ltd.	Operating Mine - Demonstration Site
RA Warren Equipment Ltd.	Locomotive Manufacturer

3.1 Engineering Personnel

The following Engineers from Hatch have contributed to this Pre-Development Review. A summary of each Engineer's relevant experience is included below, and complete resumes are attached.

3.1.1 Doug Eastick, P.Eng

Twelve years experience in mechanical engineering related to underground mining equipment design, manufacturing, and quality assurance and regulatory compliance.

3.1.2 Christopher Graves, P.Eng

Seven years experience in industrial instrumentation, communication, process control, and electrical design (under 600V). This expertise includes experience with a high pressure acid leach plant which produced hydrogen gas as a by-product.

3.1.3 Fred Delabbio, Ph.D, P.Eng

Ten years of experience as a consultant in the mining industry. This expertise includes the development of prototype mining equipment, tele-operation, automation, rock excavation technologies, technology implementation, and industrial engineering applied to mining processes.

3.1.4 Keith Robinson, P.Eng

Twenty-two years experience in mechanical engineering related to the Ontario Boilers and Pressure Vessel Act, pressure piping standards, system design and quality assurance. Gas experience includes oxygen, chlorine, hydrogen sulphide, sulphur dioxide, ammonia, and tetra-chloroethylene.

3.1.5 David Peters, P.Eng

Nine years experience in electrical engineering related to electrical, instrumentation and controls, including operating in hazardous zones. Previous work in hazardous zone classification, static protection, and hazardous locations equipment installation specifications. Two years experience working in the area of standards and certification in the safety testing of equipment used in gas detection.

4. Risk Assessments

The risk assessments have been extensive in their scope and have included:

- Fuelcell Unit and Hydride Bed;
- Fuelcell Operating Procedures such as startup, shutdown, and maintenance;
- Control logic onboard the fuelcell unit;
- Site assessments at the CANMET Experimental Mine (Val d'Or, QC) and Campbell Mine (Balmertown, ON). These assessments include verifying the Site Specification requirements are met, and a risk/hazard analysis of the site specific procedures.

All risk assessment reports are included in Appendix F.

5. Summary

Based on this review and subject to the following qualifications, we consider that the equipment and systems meet the intent of the Ontario Occupational Health and Safety Act and Ontario Regulation 854 if the Fuelcell Locomotive is operated in accordance with the documented procedures and associated documentation.

It is required under Ontario Regulation 854 that a copy of this report be kept at or near the workplace at which the equipment and systems are located.

It is noted that while Hatch will conduct a field check to ensure that the installation meets the design intent, adherence of the final installation to the Occupational Health and Safety Act rests with the Owner of the mine and with the test operators, CANMET.

6. Revision History

Revision Number	Date	Description
0	2002-06-19	Draft for comment to Ontario Ministry of Labour.
1	2002-07-11	Interim release to Ontario Ministry of Labour.
2	2002-09-09	Final Release for Vehicle Projects/Placer Dome

D. Eastick, P.Eng. C. Graves, P.Eng.

DE:de
Attachments
Resumes:

- Fred Delabbio
- Doug Eastick
- Christopher Graves
- David Peters
- Keith Robinson

Project Report

August 28, 2002

Vehicle Projects LLC
Fuelcell Locomotive Assistance

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Regulatory Requirements

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If you disagree with any information contained herein, please advise immediately.

1. Introduction

As part of the Pre-Development Review for the Fuelcell Locomotive to be demonstrated at the CANMET Experimental Mine and Campbell Mine, Hatch has reviewed the applicable government regulations and applicable industry standards. This document outlines the applicability and compliance of each.

2. Applicability of Regulations and Industrial Standards

2.1 Regulations and Guidelines

The following regulations and guidelines are applicable to the fuelcell locomotive and have been reviewed for compliance:

- Ontario Occupational Health and Safety Act;
- Ontario Occupational Health and Safety Act; Regulation 854 – Mines and Mining Plants;
- CSA B51-97; Boiler, Pressure Vessel, and Pressure Piping Code;
- CSA C22.1-02; 2002 Canadian Electrical Code; and
- CSA M421-93; "Use of Electricity in Mines".

2.2 Industrial Standards

The Fuelcell Locomotive utilises an approved standard battery locomotive as a base to assemble the overall hydrogen fuelcell locomotive. The only modification to the standard locomotive systems is the replacement of the battery energy source with a hydrogen fuelcell.

Only the regulations and industrial standards which affect the design and construction of the hydrogen fuelcell system are considered applicable for this review. The following sections itemize the industrial standards reviewed and considered either relevant or non-relevant to the operation of the Fuelcell Locomotive.

2.2.1 Relevant Industrial Standards

The locomotive has been found to comply with the following industrial standards. (Note: the electrical standards are considered to be superseded by the Canadian Standards Association (CSA) documents; C22.1-02, 2002 Canadian Electrical Code, and M421-93, "Use of Electricity in Mines"). 1

- Air Products Co. Safetygram No. 4;
- Air Products Co. Safetygram No. 11;
- Air Products Co. Safetygram No. 15;

- Air Products Co. Safetygram No. 23;
- Brookhaven National Laboratory X-4259, Hydrogen Systems;
- CGA G-5.4: Standard for Hydrogen Piping Systems at Consumer Locations;
- CGA G-5.5-1996 Hydrogen Vent Systems;
- DOE/CE/50389-502, Hydrogen Vehicle Safety Report (FORD);
- DOT-FTA-MA-26-7021-98-1, Clean Air Program: Design Guidelines for Bus Transit Systems using Hydrogen as an Alternate Fuel (TMS);
- Fire Marshall Act;
- NFPA 122, Fire Prevention in Metal and non-metal mines; and
- WSRC-TR-98-00331, Preliminary Safety Evaluation for Hydrogen-fuelled Underground Mining Equipment (Westinghouse-Coutts).

2.2.2 Non-Relevant Industrial Standards

The following industrial standards have been reviewed but are not considered relevant to the hydrogen fuelcell locomotive for one of the following reasons:

1. The topic the standard covers has been addressed or superseded by a separate standard listed previously. Principles of these standards are covered by other applicable regulations and standards; or
2. The standard is applicable to the design and construction of the standard components of an underground locomotive only and are not specific to the use of a hydrogen fuelcell; or
3. The standard is specific to applications which are significantly different than that of the locomotive. All of the general safety considerations are covered by the listed applicable standards; or 1
4. The standard is applicable to parts of the fuelcell locomotive which are standard design components. The manufacturer of the each component is assumed to have ensured that they have been constructed to meet the applicable standard.

The following industrial standards are not considered relevant to the locomotive as per **Reason 1**:

- NFPA 123, Fire Prevention in Coal Mines (refer to NFPA 122);
- API 2003, Protection Against Ignitions Arising Out of Static, Lighting, and Stray Currents (refer to C22.1-02);
- CGA G-5, Hydrogen (refer to MSDS and Air Products Co. Safetygrams);

- CGA SB-22, Al Cylinders – Guidelines for a heat exposure indicating system (refer to B54-97);
- CGA TB-9, Ultra High Integrity Service Connections (refer to B54-97);
- FMVSS 303, Fuel System Integrity (refer to B54-97);
- FMVSS 304, Container Integrity (refer to B54-97);
- NFPA 30A, Service Stations – applies to motor fuel dispensing facilities (refer to C22.1-02 & M421-93);
- NFPA 50 A, Hydrogen Systems, applies to gaseous hydrogen systems (refer to C22.1-02, M421-93, & B54-97);
- NFPA 50 B, Hydrogen Systems, applies to liquid hydrogen systems (refer to NFPA 50A);
- NFPA 52, Vehicle Fuel Systems – applies to CNG fuelled vehicles (refer to C22.1-02, M421-93, & B54-97);
- NFPA 70, National Electrical Code (refer to C22.1-02 & M421-93);
- NFPA 77, Static Electricity (refer to C22.1-02 & M421-93);
- NFPA Art. 691, Electrical Requirements (refer to C22.1-02 & M421-93);
- 49CFR 173.301, Compressed Gas Cylinders (refer to B54-97);
- 49CFR 178.46, Seamless Al Cylinders (refer to B54-97);
- 49CFR 178.68, Cylinder Specifications (refer to B54-97); and
- 29CFR 1910.103, Hydrogen (refer to C22.1-02, M421-93, & B54-97).

The following industrial standards are not considered relevant to the locomotive as per **Reason 2**;

- SAE J 1163, Seat Index Point;
- SAE J 899, Operator's Seat Dimensions;
- SAE J 297, Operator Controls;
- SAE J 153, Operator Precautions;
- SAE J 98, Operator Protection;
- SAE J 386, Operator Restraint;

- SAE J 1042, Operator Protection;
- SAE J 185, Access Systems; and
- SAE J 1362, Symbols for Control.

The following industrial standards are not considered relevant to the locomotive as per **Reason 3**:

- ANSI Z21.83, Fuel Cell Power Plants;
- NFPA 853, Stationary Fuel Cell Power Plants;
- RMA IP-3-3, Static Conducting V-belts;
- NFPA 88B, Repair Garages; and
- SAE J 1718, Hydrogen Emissions.

The following industrial standards are not considered relevant to the locomotive as per **Reason 4**:

- CGA S1.1, Pressure Relief Device Standard; and
- CGA SB-20, Use of Quick Connect Couplings for Compressed Gas Service

3. Review of Regulations and Guidelines

3.1 Occupational Health and Safety Act and Regulations for Mines and Mining Plants, Reg. 854 Ontario Ministry of Labour

The introduction of a fuelcell-powered locomotive to an underground mine is considered an **alteration of technology**. The relevant difference between a standard battery powered locomotive and the Fuelcell powered locomotive is the power plant itself and the potential introduction of hydrogen to an underground environment. The applicable sections of the regulation are those related to haulage of material, ventilation, flammable gases, and good electrical practices. The regulations specific to normal mine activities and equipment are considered outside the scope of this review. All test sites are assumed to be compliant with these regulations.

3.1.1 Haulage -- Standard Locomotive Equipment

The locomotive has been supplied by RA Warren Equipment Ltd.. As standard equipment it includes a mechanical brake calliper that acts as a parking brake, and a hydraulic brake calliper that is used as a service brake. The locomotive is also supplied with an operating horn and headlights. This is in compliance with R.R.O. 1990, Reg. 854, s. 103 (1).

Requirements for haulage drift dimensions and safety bays have been included in the Site Specification in Appendix E. Existing mine procedures at the mines for the operation of battery powered locomotives, fire hazards, and operator clearances will be applied to the operation of the Fuelcell Locomotive.

3.1.2 Section 35, Flammable Gas

The fuelcell locomotive has installed two hydrogen detection units which constantly monitor the concentration of hydrogen on-board the locomotive. The locomotive's control system (PLC) has been configured to de-energise the electrical components upon the detection of 12.5% of hydrogen's lower explosive limit (LEL). 12.5% of the LEL is 0.5% hydrogen in air by volume which exceeds the requirements laid out in this regulation.

The area in which the locomotive will be operated and refuelled will be clearly marked as a fire hazard area. All operators in the area will be given clear written communication as to the precautions required for the area.

3.1.3 Section 155, Good Electrical Practices

CSA C22.1-02, the 2002 Canadian Electrical Code, and CSA M421-93, "Use of Electricity in Mines", have been referenced for good electrical practices. See sections 3.2.2 and 3.2.3 for details.

3.1.4 Section 156, Notification of Electrical Installations

This is neither a major electrical installation nor an alteration to an existing electrical installation. The health and safety representatives have been notified of the planed operation of the locomotive underground.

3.1.5 Section 159, Working on or near live equipment

All the provisions required for working on or near live equipment will be followed.

3.1.6 Section 163, Fire Precautions

Fire extinguishers are provided on-board the locomotive.

3.1.7 Section 164, Ground Fault Protection on Mobile Equipment

The locomotive's maximum theoretical voltage produced is 190V thus does not exceed the 300V cut-off for this regulation.

3.2 Ontario Regulation 220/01 – Boilers and Pressure Vessels

The locomotive includes piping used for the supply of hydrogen from the Hydride Bed to the Fuelcell Unit. The supply of hydrogen is an integral part of the generation of electricity for this system to power the locomotive. In this context, the fuelcell power plant is considered a "generator" or "engine". The Ontario Technical Standards and Safety Authority, who is responsible for registering pressure piping systems in Ontario, has agreed that this system is exempt from registration. The exemption is stated O. Reg. 220/01, s. 2(2): ⚠1

```
2. This Regulation does not apply to, [...]
```

(m) pressure containers that form an integral part of or that are a component of rotating or reciprocating mechanical devices, including pumps, compressors, turbines, **generators, engines** and hydraulic or pneumatic cylinders where the primary design considerations or stresses, or both, are derived from the functional requirements of the device;

The same exemption is stated, verbatim, in the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. Clause U-1(c)(3).

(c) The following classes of vessels are not considered to be within the scope of this Division: [...]

(3) pressure containers that form an integral part of or that are a component of rotating or reciprocating mechanical devices, including pumps, compressors, turbines, **generators, engines** and hydraulic or pneumatic cylinders where the primary design considerations or stresses, or both, are derived from the functional requirements of the device;

Hatch has also reviewed the piping components and piping material, in regards to allowable working pressures and suitability for hydrogen use and found the system is consistent with good engineering practice. Additionally, Sandia National Laboratories performed a design review of the hydride cylinders and concluded that *"[…] the tanks as designed […] are safe for the 150 psi design limit pressure for many cycles without concern for slow crack growth problems*[1]*."* The design of the hydride cylinders meets the ASME Boiler and Pressure Vessel Code, Section VIII, Division I.

The refuelling system piping will be purchased from the hydrogen gas supplier with the requirement it be suitable for hydrogen use. The selection of the components has been consistent with standard engineering practice and the overall assembly and procedures used are consistent with CGA G-5.4-2001 (Standard for Hydrogen Piping Systems at Consumer Locations), and CGA G-5.5-1996 (Hydrogen Vent Systems). Consideration has been given to the fact that the piping system is portable, temporary, and procedural control will be used in place of design conditions for permanent installations (i.e. adverse weather conditions). 1

3.3 C22.1-02, 2002 Canadian Electrical Code

The fuelcell locomotive is compliant with all the regulations noted in the 2002 Canadian Electrical Code. Please refer to Appendix C for the hazardous location classification of the prototype hydrogen fuelcell locomotive.

Each section of the 2002 Canadian Electrical Code listed here includes a brief summary of the sections applicability, relevance, and any design considerations made;

3.3.1 Section 0, Object, Scope, and Definitions

The hydrogen fuelcell locomotive is compliant with Section 0.

3.3.2 Section 2, General Rules

The hydrogen fuelcell locomotive is compliant with Section 2.

[1] Sandia National Laboratories – Project Memo: Yih-Renn, Kan. January 26, 2000.

3.3.3 Section 4, Conductors

The hydrogen fuelcell locomotive is compliant with Section 4 except for the following:

- The colour convention of the locomotive system wiring does not follow the standards indicated in section 4.

3.3.4 Section 6, Services and Service Equipment

The hydrogen fuelcell locomotive is compliant with Section 6.

3.3.5 Section 8, Circuit Loading and Demand Factors

The hydrogen fuelcell locomotive is compliant with Section 8.

3.3.6 Section 10, Grounding and Bonding

The hydrogen fuelcell locomotive is compliant with Section 4 with the following engineering design considerations; 1

- The hydrogen piping of the hydrogen fuelcell is of stainless steel and electrically bonds all components of the fuelcell system to a common electrical potential. In addition, each of the two compartments (hydride bed and fuelcell stacks) is bolted to the frame of the locomotive which electrically bonds each compartment to the electric potential of the whole locomotive.
- The electrical system on board the locomotive is a 2 wire DC system and is not grounded. The regulation requiring ground fault protection devices is not required for the locomotive. The locomotive's electrical system is fitted with breakers as protection from short-circuiting.

3.3.7 Section 12, Wiring Methods

The hydrogen fuelcell locomotive is compliant with Section 12.

3.3.8 Section 14, Protection and Control

The hydrogen fuelcell locomotive is compliant with Section 14 with the following engineering design considerations;

- The electrical system on board the locomotive is a 2 wire DC system and is not grounded. The regulation requiring ground fault protection devices is not required for the locomotive. The locomotive's electrical system is fitted with breakers as protection from short-circuiting.

3.3.9 Section 18, Hazardous Locations

3.3.9.1 Hazardous Location Classification

Refer to Appendix C for the Hazardous Locations Classification requirements of the fuelcell locomotive.

3.3.9.2 Adequate Ventilation

The provision of adequate ventilation for the locomotive is a key requirement for mitigation of several risks associated with high hydrogen concentrations. Sandia National Laboratories has calculated the required ventilation to dissipate a full line-break from the Hydride Bed to 20% of the Lower Explosive Limit (LEL) shown in Figure 1. The value of 20% was chosen as being half of that required by the Canadian Electrical Code for de-energisation of electrical equipment in the presence of hydrogen.

Figure 1: Ventilation Calculation

```
We do not have free flow desorption measurements on an assembled
hydride bed.  However, we have measured the free flow of hydrogen of a
fully loaded single canister, during our development stage.  Based on 7
test results, the initial peak flow rate is approximately 125 L/min.
The hydride bed is consists of 16 canisters, to scale up one can simply
multiply that number by 16,

          125 x 16 = 2000 L/min

Although the 16 canisters were manifold together and hydrogen flows
thru a single line, the net flow rate should be reduced in the HB
configuration.  However, due to lack of measured data, we would
recommend to use this number, but please keep in mind that it's a very
conservative estimate.

To provide adequate ventilation to disperse and dissipate the hydrogen
to less than 20% of its LEL [4% in air], the required airflow will be:

   2000 / 0.04 / 0.20 = 250,000 L/min (8829 cu.ft/min)

Jennifer P. C. Chan
SMTS, Systems Engineering
Sandia National Labs
P.O. Box 969
Livermore, CA 94551
(925)294-2043
```

As a result, the minimum ventilation in order to operate the locomotive has been specified at 9000 cu.ft/minute. This is specified in the Site Requirements for operation of the Fuelcell Locomotive in Appendix E, and is compliant with R.R.O. 1990, Reg. 854, s. 261.

3.3.10 Section 26, Installation of Electrical Equipment

The hydrogen fuelcell locomotive is compliant with Section 26.

3.3.11 Section 28, Motors and Generators

The hydrogen fuelcell locomotive is compliant with Section 28.

3.3.12 Non-Relevant Sections

Sections 20 through 24 and sections 30 through 86 of the 2002 Canadian Electrical Code are not considered relevant.

Review of the fuelcell locomotive in regards to the 2002 Canadian Electrical Code has been via the following:

1. Visual inspection in Reno, Nevada (February 2002); and

2. Visual inspection in Val d'Or, Québec (June 2002); and

3. Review of the hydrogen fuelcell's electrical drawings.

The final electrical drawings reviewed are those produced by Sandia National Laboratories, and revised by CANMET (with approval of revisions by Sandia and Hatch).

3.4 CSA Standard M421-93, "Use of Electricity in Mines"

The fuelcell locomotive is compliant with the regulations noted in this standard except where the regulations apply to systems with the following conditions:

1. Voltages in excess of 300V.

The maximum theoretical voltage produced by the hydrogen fuelcell is 190V.

2. Trailing or overhead power supply lines; or

Neither the fuelcell locomotive nor the test site locations have requirements for trailing or overhead power supply lines as the fuelcell locomotive has a self-contained power supply.

3. The regulations specific to normal mine activities or equipment unrelated to the fuelcell locomotive and thus outside the scope of this review.

The selected test sites are assumed to be compliant with standard site-specific regulations.

4. The equipment type/size/rating specifically referenced within the regulation is not found on-board the fuelcell locomotive.

All other items in this section apply and are complied with except for the special treatment required of a prototype system. The following issue must be considered for this prototype system:

➤ Due to the sensitive nature of this prototype system, direct washing of the fuelcell locomotive will not be allowed.

D. Eastick, P.Eng.
Mechanical, Senior Engineer

C. Graves, P.Eng.
Controls, Automation and Electrical, Engineer

CG:ka
Attachments

HATCH

Project Report

PR92038.005, Rev.1
FL92038.201

September 16, 2002

Vehicle Projects LLC
Hydrogen Fuelcell Locomotive

DISTRIBUTION

B. Deck - MOL
D. Barnes - Vehicle Projects
F. Delabbio - Hatch
D. Eastick - Hatch

Hazardous Location Classification

Table Of Contents

If you disagree with any information contained herein, please advise immediately.

1. Introduction

This project involves the operation and testing of an existing prototype hydrogen fuelcell powered locomotive for underground (U/G) service in Canada. The locomotive is a standard U/G battery powered locomotive adapted to accept the electrical power provided from a hydrogen fuelcell.

The presence of compressed hydrogen gas powering this locomotive necessitates the hazardous location classification of the system.

This document, along with enclosed GA's and sketches, illustrates the reasoning behind the hydrogen fuelcell's Hazardous Location Classification.

2. Introduction to Hazardous Material/Fuelcell Operation

2.1 Hazardous Material

Hydrogen gas is the only hazardously explosive material on board the fuelcell, which is being added to the standard U/G battery powered locomotive.

2.1.1 Hydrogen gas

The total fuelcell is divided into two halves for ease of transportation and remote re-fuelling. The first half, the hydride bed container, holds the Hydride Bed (HB), which acts as the fuel tank for the fuelcell's "engine", the fuelcell stacks. This container is to be routinely unbolted from the locomotive's chassis and transported to surface for refuelling.

The second half, the fuelcell container, holds the Fuelcell stacks (FC) which consumes the hydrogen gas to produce the electricity required to power the electric motors on the locomotive. Also on board the fuelcell container are the heating/cooling systems, consumption air blower, exhaust systems, and the fuelcell electrical and control systems.

Onboard the hydride bed container, the hydrogen gas is stored within 16 canisters which at 20 °C provides a pressure of approximately 170 psi. The pressure in the canisters remains relatively constant, depending only on the temperature of the hydride material. At 28 °C the hydrogen pressure increases to 225 psi at which pressure the pressure relief valves on the system release hydrogen gas to atmosphere (via a hydrogen detector). The piping collecting the hydrogen from the 16 containers is grouped into three sections. Sections are grouped in sets of 5, 6, and 5 containers respectively and all three groups are manifolded together and pass the hydrogen gas through a solenoid-actuated valve (V5) on route from the hydride bed container to the fuelcell container. Note that each section of the hydrogen gas manifold is isolatable with a manual valve (V2, V3, & V4). Each of the three manifold sections and the piping between the manual valves (V2, V3, & V4) and the solenoid valve (V5) have pressure relief vents (which release at a pressure of 225 psi as noted above).

From the hydride bed container the hydrogen gas is piped in a combination of welded ½" stainless steel tubing, wire braided rubber hose, and a Swagelok quick-disconnect fitting to the fuelcell container. On entering the fuelcell container the hydrogen gas is regulated down to 21 psi for supply to the fuelcell stacks (FC) for consumption.

The total volume of hydrogen gas present is = 9,560 usg @ standard T & P (36200 l)

The maximum pressure is = 225 psi (1551 kPa)

The flow rate of hydrogen between HB and FC is = approx. 22.5 usg nominal, 45 usg max. @ standard T & P (85 l/min nominal, 170 l/min max.).

Once the hydrogen gas is supplied to the fuelcell stacks it is consumed in combination with oxygen (from air) through a non-permeable wetted membrane. During the normal operation of the fuelcell the concentration of water vapour increases in both the air and hydrogen gas sides of the membrane. On the air side of the membrane the water vapour is continuously purged to atmosphere. On the hydrogen gas side of the membrane if the increase in water vapour concentration is un-restrained it will reduce the efficiency and cause permanent damage to the fuelcell stack. To avoid the danger of damaging the fuelcell stack the moisture content in the hydrogen gas must be reduced by purging. During these purge cycles the hydrogen gas and water vapour is released from the fuelcell to atmosphere through a sintered metal vent filter. The sintered metal filter is engineered to restrict the flow of hydrogen gas from the purge such that the maximum concentration of hydrogen gas outside the filter is below 12.5% of the LEL.

3. Hazardous Location Classification

3.1 Existing Fuelcell and Locomotive Electrical Equipment

Note : the majority of the existing electrical and instrumentation equipment is unclassified. Notable exceptions to this statement are the hydrogen gas detectors.

Please refer to drawing C-14214-LH040702 (Fuel cell 1 line (U)) for indication of the major electrical and instrumentation components of the fuelcell system.

3.2 Operating/Safety Procedures

Please refer to the enclosed operating procedures (appendix A).

3.3 2002 Canadian Electrical Code - Section 18, Hazardous Locations;

3.3.1 Rule 18-002 Special Terminology

The 2002 Canadian Electrical Code defines "Adequate Ventilation" as follows;

> *"Adequate ventilation – means natural or artificial ventilation that is sufficient to prevent the accumulation of significant quantities of vapour-air or gas-air mixtures in concentrations above 25% of their lower explosive limit."*

As per the attached calculation sheet from Sandia National Laboratories (appendix B), 9,000 cfm of ventilation is provided while underground and has been calculated to provide “adequate ventilation”.

3.3.2 Rule 18-004 Classification

As per the following definition this system falls into the Class I classification. Class II and Class III refer to explosive atmospheres of dust and fibres respectively.

The 2002 Canadian Electrical Code defines the classes of hazardous locations as follows;

> *“Hazardous locations shall be classified according to the nature of the hazard…(a) Class I locations are those in which flammable gases or vapours are or may be present in the air in quantities sufficient to produce explosive gas atmospheres;”*

3.3.3 Rule 18-006 Division of Class I Locations

The 2002 Canadian Electrical Code defines the sub-divided zones of Class I hazardous locations as follows;

> *“Class I locations shall be further divided… …based on frequency of occurrence and duration of an explosive gas atmosphere as follows:”*

> *“(a) Zone 0, comprising Class I locations in which explosive gas atmospheres are present continuously or are present for long periods;”*

In regards to item (a); No, neither continuous nor long periods of explosive atmospheres are expected from this system. The system engineered to retain hydrogen gas concentrations above 12.5% of the LEL.

> *“(b) Zone 1, comprising Class I locations in which;*
>
> *(i) Explosive gas atmospheres are likely to occur in normal operation; or*
>
> *(ii) Explosive gas atmospheres may exist frequently because of repair or maintenance operation or because of leakage; or*
>
> *(iii) The location is adjacent to a Class I, Zone 0 location, from which explosive gas atmospheres could be communicated.”*

In regards to item (b), point (i); No, the system is engineered not to release explosive atmospheres of hydrogen during normal operation. Only in the case of damaged equipment (canister, piping or fuelcell membrane) will the system discharge hydrogen at explosive concentrations.

In regards to item (b), point (ii); No, no leakage of hydrogen will be permitted to exist. Any detected leakage of hydrogen gas will restrict the fuelcell locomotive from operation until the hydrogen leak source is found and repaired. All repair or maintenance work will only be performed once the system, to be maintained, has been completely purged. All repair and maintenance work on hydrogen gas piping in the hydride bed will be performed in a surface maintenance shop (purging of the hydride bed can only be performed on surface). The fuelcell container can be maintained while underground as the volume of hydrogen gas stored in minimal (once disconnected from the hydride bed). Procedural checks of the system's integrity must be performed before operating the fuelcell locomotive.

In regards to item (b), point (iii); No, explosive atmospheres of hydrogen gas cannot be communicated from the fuelcell to the surrounding area under normal operating conditions.

"(c) Zone 2, comprising Class I locations in which;

(i) Explosive gas atmospheres are not likely to occur in normal operation and, if they do occur, they will exist for a short time only; or

(ii) Flammable volatile liquids, flammable gasses, or vapours are handled, processed, or used, but in which liquids, gases, or vapours are normally confined within closed containers or closed systems from which they can escape only as a result of accidental rupture or breakdown of the containers or systems or the abnormal operation of the equipment by which the liquids or gases are handled, processed, or used; or

(iii) Explosive gas atmospheres are normally prevented by adequate ventilation but may occur as a result of failure or abnormal operation of the ventilation system; or

(iv) The location is adjacent to a Class I, Zone I location, from which explosive gas atmospheres could be communicated, unless such communication is prevented by adequate positive-pressure ventilation from a source of clean air, and effective safeguards against ventilation failure are provided."

In regards to item (c), point (i); No, explosive gas atmospheres are not likely to occur in normal operation but would exist for short periods of time if released. The Hydride Bed and Fuelcell containers are fitted with hydrogen gas detectors which will de-energize the entire locomotive (including the PLC) upon detection of 12.5% of the LEL and isolate the flow of hydrogen gas before leaving the Hydride Bed container. If hydrogen gas is detected the detectors and PLC will de-energize the locomotive systems.

Note : The de-energization of the locomotive and fuelcell is immediate except for the PLC and explosion proof blower which are stopped after a 2 second delay due to the potential of the blower motor controller sparking from back-emf from the blower motor if it is shut down uncontrolled.

In regards to item (c), point (ii); Yes, the hydrogen gas in the system is contained within a closed system from which it can escape only as a result of accidental rupture or breakdown of the system or the abnormal operation of the equipment.

In regards to item (c), point (iii); Yes, the system is normally well ventilated but this does not affect the classification of the system. The ventilation of the system applies to the de-classification of the hazardous location, please refer to section 4.

In regards to item (c), point (iv); No, there is no Class I, Zone I area from which explosive gas atmospheres can be communicated.

As a result of the preceding logic the Hazardous Location Classification of the existing system has been evaluated to be Class I, Zone 2. No engineering controls have been taken into account, refer to section 4 for declassification of the fuelcell system.

4. Engineered Controls

The following indicates the engineered controls which are present on the locomotive or are required while operating the locomotive; 1

1. Hydrogen gas detectors (2)
2. Forced Ventilation

Hydrogen gas detection is present in both the hydride bed container and the fuelcell container. The control system is configured to activate an emergency shutdown of the locomotive (total power shutdown) if the hydrogen gas concentration is detected at or above 0.5% in air (12.5% of the LEL).

A requirement for operating the prototype fuelcell locomotive underground is that a minimum of 9,000 cfm (rounded up from the calculated 8,829 cfm, see appendix B for the adequate ventilation calculation) of ventilation is present at all times. Procedures are in place to;

- Notify the locomotive operator if the mine ventilation fails, and
- To use a hand-held air linear velocity meter to verify the rate of ventilation during operation.

As stated in both 1998 and 2002 Canadian Electrical Code, the combustible gas detection system must be able to;

- Activate adequate ventilation at a concentration of 20% of the LEL
- De-energize the equipment at a concentration of 40% of the LEL

The systems have been engineered with controls which provide adequate ventilation 100% of the time the locomotive is underground. The concentration level at which the equipment is de-energized has been reduced from 40% of the LEL (1.6% hydrogen in air) to 12.5% of the LEL (0.5% hydrogen in air).

In addition the system has been engineered to collect and concentrate hydrogen gas in the hydride bed and fuelcell containers at the point of detection (before being vented to atmosphere). As escaped hydrogen rises in the containers it encounters a ceiling plate. The ceiling plate is angled such that the hydrogen gas (rising faster than air) will reach the vent to atmosphere (point of detection) at a higher concentration than is present in the body of the container. This provide heightened detection of any escaped hydrogen.

4.1 1998 Canadian Electrical Code - Section 18, Hazardous Locations;

4.1.1 Rule 18-070 Combustible Gas Detection Instruments

The 1998 Canadian Electrical Code defined the potential declassification of Class I hazardous locations via implementation of a combustible gas detector as follows;

> *"Where a deviation is allowed in accordance with Rule 2-030, electrical equipment suitable for non-hazardous locations shall be permitted to be installed in a Class I, Zone 2 hazardous location and electrical equipment suitable for Class I, Zone 2 hazardous location shall be permitted to be installed in a Class I, Zone 1 hazardous location, provided that the location is continuously monitored by a combustible gas detection instrument that:*
>
> *(i) Will actuate ventilating equipment or other means designed to prevent the concentration of gas from reaching the lower explosive limit when the gas concentration reaches 20% of the lower explosive limit; and*
>
> *(iii) Will automatically de-energize the equipment being protected when the gas concentration reaches 40% of the lower explosive limit; and*
>
> *(iv) Will automatically de-energize the equipment being protected upon failure of the gas detection instrument."*

Note : Rule 2-030 restricts the deviation from the Rules only if written permission is obtained from the proper authorities.

4.2 2002 Canadian Electrical Code - Section 18, Hazardous Locations;

4.2.1 Rule 18-070 Combustible Gas Detection

The 2002 Canadian Electrical Code defines the potential declassification of Class I hazardous locations via implementation of a combustable gas detector as follows;

> *"Electrical equipment suitable for non-hazardous locations shall be permitted to be installed in a Class I, Zone 2 hazardous location and electrical equipment suitable for Class I, Zone 2 hazardous locations shall be permitted to be installed in a Class I, Zone 1 hazardous location provided that:*
>
> *(a) No specific equipment suitable for the purpose is available; and*
>
> *(b) The equipment, during its normal operation, does not produce arcs, sparks, or hot surfaces, capable of igniting an explosive gas atmosphere, and*
>
> *(c) The location is continuously monitored by a combustible gas detection system that:*

(i) *Will activate an alarm and actuate ventilating equipment or other means designed to prevent the concentration of gas from reaching the lower explosive limit when the gas concentration reaches 20% of the lower explosive limit; and*

(ii) *Will automatically de-energize the equipment being protected when the gas concentration reaches 40% of the lower explosive limit; and*

(iii) *Will automatically de-energize the equipment being protected upon failure of the gas detection instrument."*

4.2.2 Intent for Rule 18-070

The 2002 Canadian Electrical Code describes the intent behind the changes in Rule 18-070 (combustable gas detection) as follows;

> *"This Rule intends to permit the installation of electrical equipment approved for Class I, Zone 2 hazardous locations in Class I, Zone 1 hazardous locations. The Rule limits this permission to Zone 2 equipment and does not permit non-hazardous equipment to be installed in a hazardous location because if a sudden concentration of explosive atmosphere should be released in the location, the ordinary location type equipment could produce an arc and create an explosion in less time than the gas detection equipment could respond and shut the equipment down. The Rule requires the gas detection system to actuate the ventilation equipment when the gas concentration reaches 20% of the LEL and de-energize the equipment when the gas concentration reaches 40% of the LEL. The rule also calls for continuous monitoring of the efficacy of the gas detection system and the de-energizing of the equipment if the gas detector system fails."*

Combustable gas detection under the 1998 Canadian Electrical Code, the classification of Class I, Zone 2 could be declassified to allow for non-hazardous locations. Under the 2002 Canadian Electrical Code, the declassification of a Class I, Zone 2 location to an non-hazardous location is not possible. The intent for the change in Rule 18-070 is due to the concern that if a sudden concentration of an explosive atmosphere should be released, the hydrogen gas detector might not be able to activate adequate ventilation nor de-energizing the electrical equipment in time.

Taking into account the following engineered controls;

a. Presence of adequate ventilation at all times while underground, and

b. Presence of hydrogen gas detection in both containers, and

c. Restriction of the trip point to a lower, more stringent 12.5% of the LEL, and

d. Concentration of the more buoyant hydrogen gas (the density of hydrogen is only 10% that of air)

and the following procedural controls;

e. Operating/safety procedures, and

f. Well trained and well qualified operators

the concerns indicated in the intent of the modifications to the regulations have been addressed and mitigated. With the implementation of the engineered and procedural controls it is our opinion that the existing Class I, Zone 2 hazardous location classification can be declassified to a non-hazardous location.

5. Summary

As per the 2002 Canadian Electrical Code, the fuelcell locomotive would require a classification of Class I, Zone 2 if operating independent of any engineered controls. The following are engineered controls present during operation of the fuelcell locomotive;

1. The addition of steady forced ventilation of 9,000 cfm while in the drift U/G;
2. Monitoring of the hydrogen gas concentration on-board both the Fuelcell (FC) and Hydride Bed (HB);
3. Collection and concentration of hydrogen gas (via. Peaked roof on FC and HB containers);
4. The entire locomotive be de-energized on detection of 12.5% of hydrogen gas's Lower Explosive Limit (LEL).

Due to the engineered controls the fuelcell locomotive system it is our opinion that this system and application can be declassified from a Class I, Zone 2 hazardous location to a non-hazardous location.

Note: This fuelcell locomotive is a prototype and therefore not designed or constructed for long service or commercial applications. Rigorous control over the proper operator training, operational/safety procedures, and the operating conditions are required to safely operate this fuelcell locomotive.

C. Graves P. Eng.
Controls, Automation and Electrical, Engineer

D. Peters P.Eng.
Power and Electro-technology, Sr. Engineer

CG:pc:cg
Attachments
Appendix A Procedures
Appendix B Adequate ventilation calculation
Appendix C Fuelcell and Hydride Bed electrical single line (Sandia)
Appendix D Hydride Bed and Fuelcell process flow diagram (Sandia)
Appendix E Hydrogen gas MSDS

APPENDIX A
Procedures

Locomotive Fuel Cell Operating Procedure

LFC-OP-01

Rev-L

August 5, 2002

Prepared by: Kenneth L. Black
Exploratory Systems Technologies
Sandia National Laboratories

Reviewed: Canmet; Gaetan Desrivieres, Pierre Laliberte

IMPORTANT NOTICE

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THE FUEL CELL LOCOMOTIVE, ITS COMPONENTS, AND ITS OPERATIONS ALL INVOLVE INHERENT HAZARDS. ONLY COMPETENT ENGINEERING PERSONNEL, WHO HAVE A THOROUGH UNDERSTANDING OF THE HAZARDS AND OPERATIONAL CONSIDERATIONS OF THE SYSTEM, SHOULD BE INVOLVED IN FUEL CELL LOCOMOTIVE OPERATIONS.

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Safety and Operational Precautions

The fuel cell locomotive is a demonstration vehicle only. It has not been designed to stand up to the rigors of routine daily mine operations. Test personnel should afford it tenderness appropriate for a prototype vehicle.

Hydrogen has a lower explosive limit (LEL) of 4% in air. Take appropriate precautions and safety measures.

The fuel cell develops in excess of 100 volts. Appropriate precaution should be exercised whenever it is operating.

The fuel cell system must not be exposed to freezing conditions. Water and other moisture in the plumbing and in the cell stacks can freeze, causing serious damage to the hardware.

The hydride bed must not be exposed to excessive ambient temperatures. Extended exposure to hot weather, direct sunlight, or other conditions that would raise the bed significantly above room temperatures can result in hydrogen release through the vent valve. This situation is most likely when the hydride bed has a full load of hydrogen.

By its very nature, the hydride material tends to self-limit hydrogen release when it is not heated. The rate of hydrogen liberation is directly related to the temperature of the hydride. Desorption results in lower hydride temperatures. If the hydride bed ruptures or develops a large leak, it would significantly limit the flow of hydrogen compared to a traditional high-pressure bottle, but would continue to release for a longer period of time.

The fuel cell system contains damaged fuel cell stacks. As a result, the manufacturer has recommended limiting the current draw. In particular, care should be taken not to introduce large current spikes with sudden starts of the locomotive. Further, the power control system of the locomotive has not been adequately tested with the motor and the power plant. Care must be exercised in determining appropriate starting torque values.

After shipping the locomotive to another site, check all electrical wires and cables to ensure the integrity of the system.

1.0 GENERAL

1.1 Scope

This document provides procedures for operation of the locomotive fuel cell and its support subsystems, including the hydride bed, the cooling system and the air supply system. This procedure does not address operation of the locomotive vehicle.

1.2 Hazards

Hydrogen gas
High voltage
Pressurized gas systems
High temperatures
Kinetic motion

1.3 System Description and Overview

The fuel cell system consists of several major components or subsystems, including the fuel cell stack, the hydride bed, the air supply system, the hydrogen distribution system, the cell stack cooling system, the hydride heating system, and the controls system. Each of these is briefly described below.

The fuel cell stack generates the electrical power to operate the locomotive. Several individual cells are packaged together and connected in electrical series to provide the necessary voltage. The cell stack is supplied with fuel (hydrogen), an oxidant (oxygen from air), cooling lines for temperature maintenance, and power lines connected to the electrical load.

The hydride bed provides a steady supply of hydrogen during system operation. The hydride material stores large quantities of hydrogen at near-ambient pressures. Hydrogen gas is liberated when the hydride bed is heated. This approach provides significant improvements in safety over traditional hydrogen storage methods.

The air supply system provides a steady supply of fresh air to the cell stack. An air pump sends filtered air into the fuel cell where the air acts as an oxidant. Exhaust air is mixed with the cell stack cooling water and is subsequently releasing into and vented from the coolant holding tank.

The hydrogen distribution system delivers hydrogen gas to the fuel cell stack. The gas is derived by heating the hydride bed. The distribution system consists of a manifold connected to the hydride bed, plus gauges, valves and regulators for controlling gas flow. Additional provisions allow for recharging the hydride bed with gaseous hydrogen. A fuel purge valve in the cell stack periodically vents small quantities of excess hydrogen and water droplets, venting them directly to the atmosphere.

The cell stack cooling system draws heat out of the fuel cell during operation, thus maintaining an optimal operating temperature. Cooling water is pumped from a tank, through a filter and into the cell stack. After leaving the cell stack, the heated water passes through a heat exchanger that provides heat to the hydride bed. A second heat exchanger with fans further cools the water before it returns to the holding tank.

The hydride heating system heats the hydride bed, thus liberating the hydrogen to supply a steady flow of hydrogen gas. Circulating water passes through a heat exchanger where it is heated by the coolant in the cell stack cooling system. The water enters the bed heating jackets, imparting heat to the hydride material. Return water from the bed goes back through the heat exchanger.

The controls system manages the various elements of the complete fuel cell system. It monitors the various parameters to ensure operations are within prescribed limits. The operator interacts with both a laptop computer and a touch-screen Flat Panel Display (FPD).

2.0 DOCUMENTS

2.1 Reference Documents

NUVERA FUEL CELLS EUROPE S.r.l.
Instruction Manual For Stack Mod.
D-Integrated Water Management, Revision 3, 7/23/2001

Flow diagram for fuel cell system, SNL Dwg. 2/15/2001,
Ray Baldonado, file: locoflow

Locomotive Fuel Cell System Operation, PHS & HA #:
SNL1A00110-004

2.2 Required Documents

None

3.0 EQUIPMENT

3.1 Standard Equipment

None.

3.2 Special Equipment

Complete fuel cell system
Hydrogen gas recharge system
Recharge cooling system

4.0 OPERATING CONDITIONS

4.1 Authorized Personnel

This procedure should be executed only by knowledgeable and suitably-qualified personnel.

4.2 Special Requirements

Verify the presence of sufficient ventilation prior to venting hydrogen.

4.3 Calibration Requirements

Flow, temperature and pressure sensors and controllers should be kept calibrated.

5.0 OPERATING PROCEDURE

5.1 Preliminary Data

______ Record the name of the person conducting this operation.

____

______ Record the date of this operation.

____

______ Record the purpose of this operation.

____

______ Record the location of this operation.

____

5.2 Startup of Fuel Cell System

Pre-start Checks

______ Open valves V2,V3,V4

______ Verify that the hydride bed has been properly charged with hydrogen (HB pressure). ________________
(Do not operate under 25 psi)

______ Verify that the hydride bed cooling antifreeze tank is at a proper level.

______ Verify that the water hoses are connected at the Q-D interface, and that all the adjacent electrical cables have been connected.

Control System Start

______ Push "START" green button on FPD enclosure and hold until FPD screen appears.

______ Observe and record the following temperatures from the FPD:

Parameter	Measured T
Air out of stack	
Water tank	
Water from HB	
Water to HB	
A Radiator In	
A Radiator Out	
B Radiator In	
B Radiator Out	

Note: a reading of 0.0 indicates an open circuit.

______ Check the FPD to verify the presence of air and hydrogen pressure readings. Record the values:

__________ psia air (atm. Pressure)

________ psia hydrogen (from atm.to 22 psi)

______ Record the water tank level from the FPD: __________.
(between M and H)

Add demineralized water if necessary. Ensure that the adjacent electrical connectors are capped before adding water.

______ Push "ON" start mode .
Note : From this point to the beginning of the next section of the procedure, battery power is being used to power all system functions. To conserve battery power, this section should be completed expeditiously.

______ Verify the illumination of the green indicator on the light stack.

______ Perform light integrity test

Membrane Integrity Test

______ Ensure that Hydride Bed valves V1, V2, V3 and V4 are closed.

______ Push "OPEN" (H2) Valve via the FPD.

______ Plug in the hydrogen line from the Hydride Bed at the Quick-Disconnect interface.

______ Open Hydride Bed valves V2, V3 and V4.

______ Open Hydride Bed valve V1.

______ Verify that the FC regulator hydrogen pressure is less than 22 psia.

______ Close valves V1.

______ Observe the yellow or red light for any presence of hydrogen, which may indicate a leak in a membrane.

Halt further testing. (The presence of voltage on the cell stacks at this point is normal and expected.)

______ Perform automatic stack integrity test on FPD
A "SUCCESS" is expected in the results
Record H2 pressure difference:_______________

______ Push "Close" H2 valve on the FPD.

System Battery-Powered Start

______ Open HB valves V1.

______ Push "ENABLE" blower and set on automatic (min.130 l/min.)

______ Verify proper blower operation.

______ Record the following data:

Parameter	Measured	Expected
Air pressure		~ 16 psia
Hydrogen pressure		~ 20 psia
Blower flow		130 l/min

______ Based on the above measurements, verify that the system is ready to receive hydrogen and begin generating power.

______ Push "OPEN" (H2) valve, allowing hydrogen to flow to the FC stacks.

______ Record stack voltages:

Stack A voltage		85 – 95 volts
Stack B voltage		85 – 95 volts

______ Momentarily activate the hydrogen purge valves.

______ Start the automatic purge cycle. Wait for two purge cycles to be completed.

Switch To Fuelcell power

______ Push "ON" Run mode, which will transfer the power load from the batteries to the FC supply.

______ Push " ON" H Bed pump. Verify that water is flowing.

Push "ON" power out .

______

______ Push "ON" stack pump, (DI water) and set on automatic (min 0.2 l/min).

5.3 Continuous Operation of Fuel Cell System

______ Monitor all system parameters to ensure nominal operational status.

______ Ensure that both stack voltages stay within 10 volts difference and don't drop less than 40 volts each.

______ Begin shutdown of the fuel cell system if the hydride bed pressure drops down to 25 psi.

______ Add DI water whenever blue light turns on .

5.4 Interim Shutdown of Fuel Cell System

Power Reduction Phase

______ Decrease the electrical load.

______ Push “OFF” power out

______ Turn off the cell stack cooling water pumps from the FPD DI WATER.

______ Turn off the hydride bed water pump.

______ Turn off the radiator fans.

Switching To Battery Power

______ Check and record the open circuit voltage on the FC stacks:

_________ volts Stack A __________ volts Stack B

______ Continue to operate the blower for 5 minutes, allowing the air and hydrogen to dry the fuel cell stacks, and ;

______ During the 5minutes interval, open the plenum drain valve (on the FPD) and drain any water from the plenum. Close drain valve.

______ Push “DISABLE” blower.

______ Push “OFF” Run mode.

______ Allow 5 to 10 minutes for energy to dissipate (2 – 3 volts)

______ Push "Close" H2 valve, isolating the hydrogen supply from the cell stacks.

______ Push "OFF" purge cycle.

Safing the FC System

______ Close HB valves V1, V2, V3, and V4.

Control System Shutdown

______ Push "OFF" start mode.

______ Push PLC shutdown

5.5 Complete Shutdown of Fuel Cell System

Note: This procedure should also be completed when the system will be left unprotected or will be non-operational for several days.

______ Drain the DI water from the FC water tank and associated plumbing using the proper hand valve.

5.6 Hydride Bed Removal, Recharging, & Replacement

Preparation

______ Verify that the fuel cell system is completely shut down. (No voltage and no live systems).

______ Verify that valves V1, V2, V3 &V4 of the Hydride Bed are closed.

______ Demate both hydride bed water heating lines at the quick-disconnect fittings.

______ Disconnect all electrical lines as required.

______ Demate the hydride bed hydrogen line at the quick-disconnect fitting.

______ Remove 6 Bolts from Hydride Bed .

______ Remove and transport the hydride bed to the recharge location as required.

______ Mate both hydride bed water heating lines to the recharge cooling system at the quick-disconnect fittings.

______ Ensure that there is nothing but hydrogen in the hydrogen fill lines and associated hardware. Purge all lines in Hydride Bed from Argon or air if any.

______ Mate the hydride bed hydrogen line to the hydrogen gas recharge system at the quick-disconnect fitting.

______ Start the recharge cooling system and start the pump on the Hydride Bed.

______ Ensure that valve V1 is closed.

______ Open valves V2, V3 and V4.

______ Observe and record the pressure on the hydride bed:

_______________ psig

______ Observe and record the temperature on the hydride bed:

_______________ ° C

______ Ensure that all the bottle valves and the main valve on the hydrogen six-pack have been opened.

______ Set the recharge regulator (on the hydrogen six-pack) at 175 psig.

______ Open the hydrogen gas recharge system main regulator valve.

______ Observe and record the pressure on the hydrogen six-pack:

_______________ psig

Charging

______ Open the hydride bed valve V1.

______ Record the time: _______________

______ Charge the hydride bed as required. This typically takes 30 to 60 minutes. Over-charging may result in subsequent venting of hydrogen. Charging is considered complete when one of the following conditions exists:
a) one hour has passed (if the cooling system is adequate)
b) pressure on the six-pack no longer decays (175 psi)
c) when the HB temperature falls to near 25° C

______ Close the hydride bed valve V1.

______ Record the time: _______________

Completion

______ Close the hydrogen gas recharge regulator main valve.

______ Observe and record the pressure on the hydrogen six-pack:

_______________ psig

______ Turn off the recharge cooling system.

______ Observe and record the pressure on the hydride bed:

______________ psig

______ Observe and record the temperature on the hydride bed:

______________ ° C

______ Close the hydride bed valves V2, V3 and V4.

______ Demate both hydride bed water heating lines from the recharge cooling system at the quick-disconnect fittings.

______ Demate the hydride bed hydrogen line from the hydrogen gas recharge system at the quick-disconnect fitting.

______ When required, transport and reinstall the hydride bed into the locomotive.

______ Mate both hydride bed water heating lines to the fuel cell system at the quick-disconnect fittings.

______ Close all the valves on the 6 packs hydrogen

5.7 Hydride Bed Shipment Preparation (abbreviated)

______ Vent the hydrogen while heating the bed to 35° – 40° C. Note that failure to maintain a positive hydrogen flow during this step can lead to irreversible contamination and deterioration of the hydride material.

______ When hydrogen pressure reaches 5 psig, connect the bed to argon supply.

______ Fill hydride bed with argon to approximately 20 psig.

______ Vent argon from bed until pressure reaches 5 psig.

______ Fill hydride bed the second time with argon to approximately 20 psig.

______ Vent argon from bed the second time until pressure reaches 5 psig.

______ Fill hydride bed the third timee with argon to approximately 20 psig.

______ Vent argon from bed the third time until pressure reaches 5 psig.

______ Fill hydride bed with argon to 15 psig.

______ Close valves and disconnect argon.

______ Package the hydride bed in a suitable container for shipment.

5.8 Hydride Bed Post-Shipment Processing (abbreviated)

______ Vent the argon until the bed pressure reaches approximately 2 psig. Note that failure to maintain a positive argon flow during this step can lead to irreversible contamination and deterioration of the hydride material.

______ Connect the hydrogen supply to the hydride bed.

______ Fill the hydride bed with hydrogen to 20 psig.

______ Vent hydrogen from the bed until the pressure reaches 5 psig.

______ Fill the hydride bed the second time with hydrogen to approximately 20 psig.

______ Close the valves and disconnect the hydrogen.

6.0 EMERGENCY AND BACK-OUT PROCEDURE

6.1 Emergency Procedures

This portion of the procedure has not yet been developed.

7.0 RECORDING REQUIREMENTS AND TABLES

7.1 Data Retention

This document shall be retained with other project records as deemed appropriate by project management.

7.2 Data Recording

Data shall be recorded as indicated in section 5 of this document.

7.3 Changes From Previous Revision

Not Applicable for this version.

Locomotive Refueling Procedure

LFC-OP-02

Rev-B

May 28, 2002

Prepared by: Kenneth L. Black
Exploratory Systems Technologies
Sandia National Laboratories

Reviewed by: Jennifer Chan
Sandia National Laboratories

Locomotive Refueling Station

Requirements & Procedures

1.0 General Site and Equipment Requirements

This document identifies the minimum requirements for the locomotive hydride bed refueling station, including hydrogen venting, lifting equipment, and the cooling system. It also includes basic operational procedures. This document does not cover any site-specific hazards, safety requirements or procedures.

1.1 Hydrogen Safety and Ventilation

The hydride bed should be refueled in an outdoor open air environment whenever possible. In the case where it's required to refuel in a confined space, adequate ventilation must be provided. A hydrogen leak detector must be used at all times during refueling.

1.2 Hydride Bed Transporting Equipment

An adequate lifting hoist is required for removal and reinstallation of the hydride bed (approx. 1100 pounds, or 500 kilos) on to the locomotive. An adequate forklift or other equipment may be required to transport the hydride bed to and from the refueling station. The hydride bed should be transported in a specially made container that provides adequate ventilation, protection from falling objects, forklift puncture, etc.

1.3 Cooling Requirements

A cooling system with a cooling capacity of approximately 14 KW should be used for refueling. Use the system supplied by Sandia National Laboratories or another suitable substitute.

1.4 Other Equipment

A 24-VDC power supply is required to power the hydride bed water pump.

1.5 Hydrogen Specification

Gaseous hydrogen supplied to the hydride bed should have a purity level of 99.99% or better.

2.0 Hydride Bed Removal, Recharging, & Replacement Procedures

2.1 Preparation
(Refer to attached figures)

______ 1. Verify that the fuel cell system is completely shut down (no voltage and no live systems). Verify that all three electrical breakers are open.

______ 2. Verify that valves V1, V2, V3 &V4 of the hydride bed are closed.

______ 3. Demate both hydride bed water lines at the quick-disconnect fittings. Cap the fittings and safely stow the lines.

______ 4. Disconnect all hydride bed electrical lines as required. Cap the connectors and safely stow the cables.

______ 5. Demate the hydride bed hydrogen line at the quick-disconnect fitting. Cap the fittings and safely stow the lines.

______ 6. Remove the six mounting bolts from the Hydride Bed .

______ 7. Remove and transport the hydride bed to the recharge location as required.

Ensure that there is nothing but hydrogen in the hydrogen fill lines and associated hardware by doing steps 8 through 14. Refer to Figure 1.

______ 8. Ensure that vent valve, the six-pack main valve, and the fill line main valve is closed.

______ 9. Ensure that the special purge valve is closed. Attach the special purge valve assembly to the fill hose Q-D fitting,

______ 10. Open all the bottle valves and the main valve on the hydrogen six-pack.

______ 11. Set the recharge regulator (on the hydrogen six-pack) at 175 psig.

______ 12. Open the hydrogen gas recharge system fill line main valve.

______ 13. Using a portable leak detector, check for the presence of any leaking hydrogen. Correct as needed.

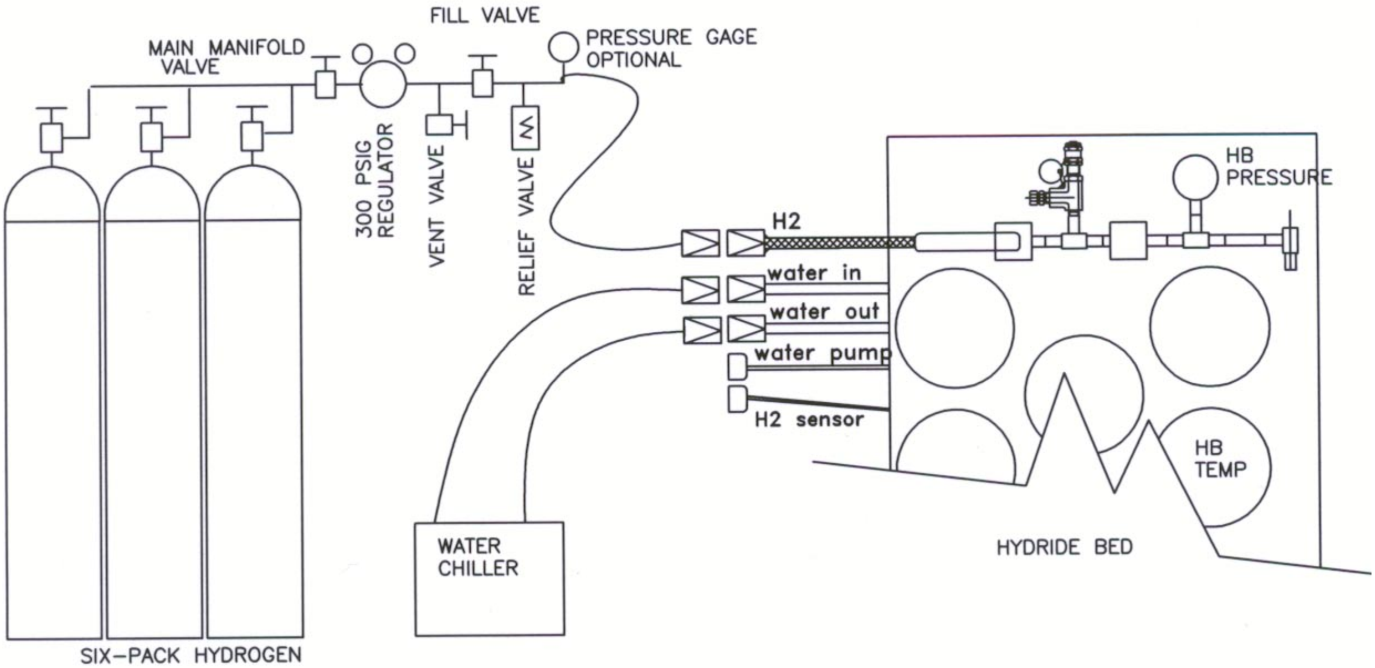


Figure 1
Hydrogen Recharge System

______ 14. Open the special purge valve long enough to bleed any non-hydrogen gas from the hose, then close the valve,

______ 15. Close the gas recharge system fill line main valve.

______ 16. Remove the special purge valve assembly from the fill line.

______ 17. Mate the hydride bed hydrogen line to the hydrogen gas fill line at the quick-disconnect fitting.

______ 18. Using a portable leak detector, check for the presence of any leaking hydrogen. Correct as needed.

______ 19. Connect the hydride bed water pump cable to a suitable power source.

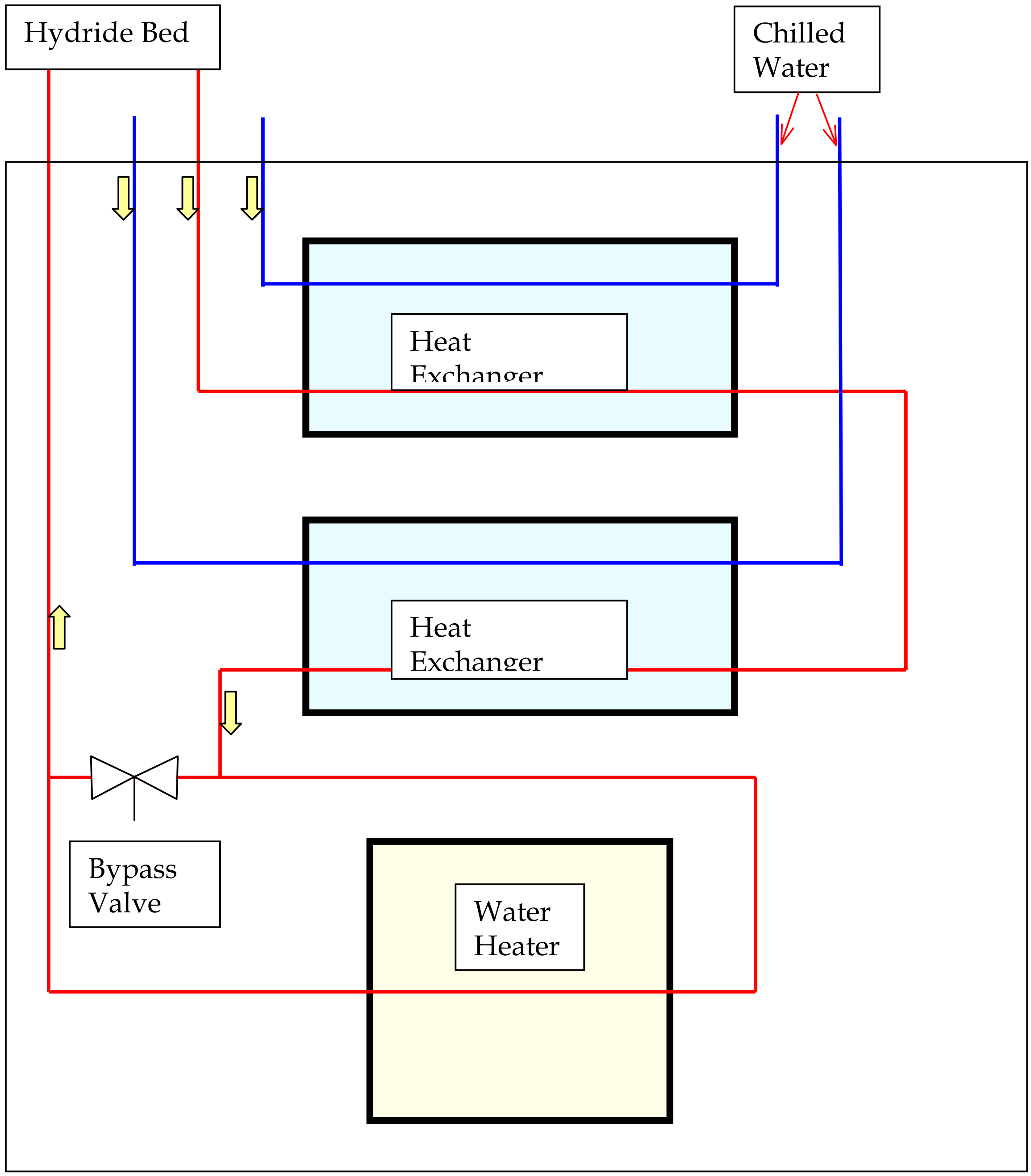
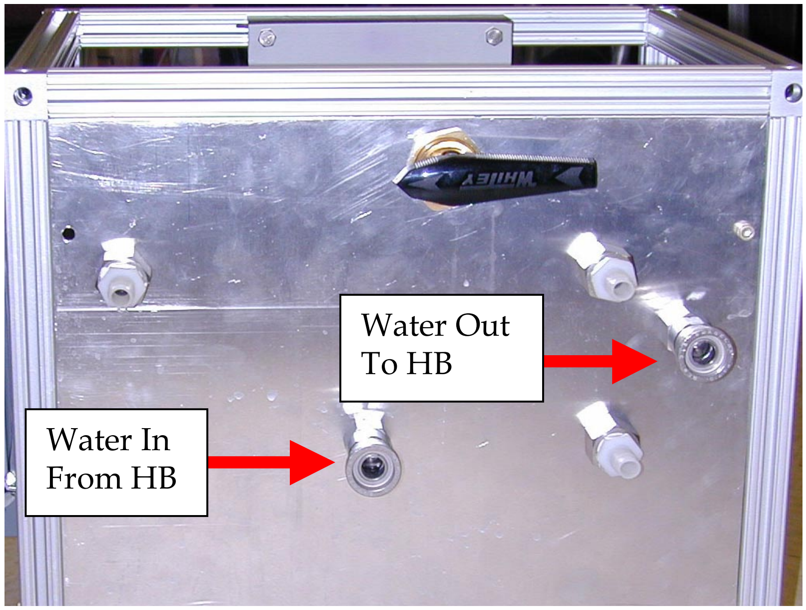
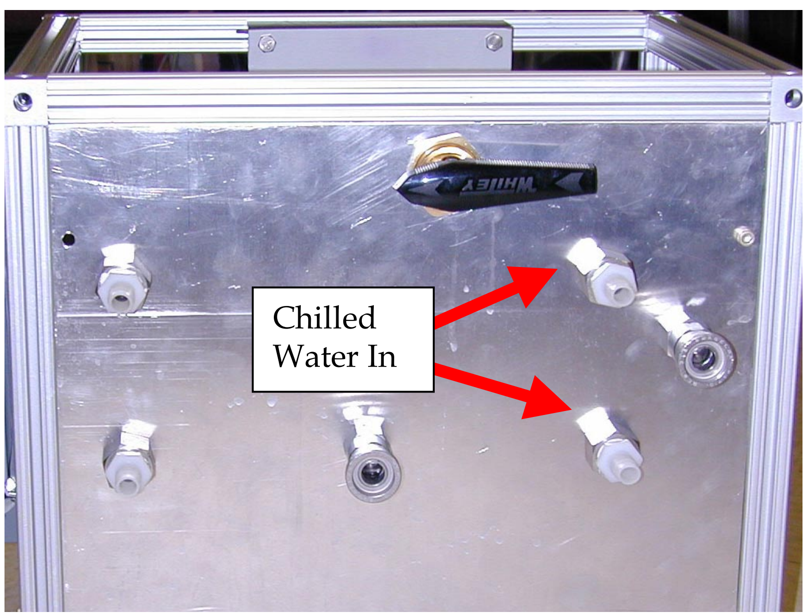


Figure 2
Heat Exchange Panel

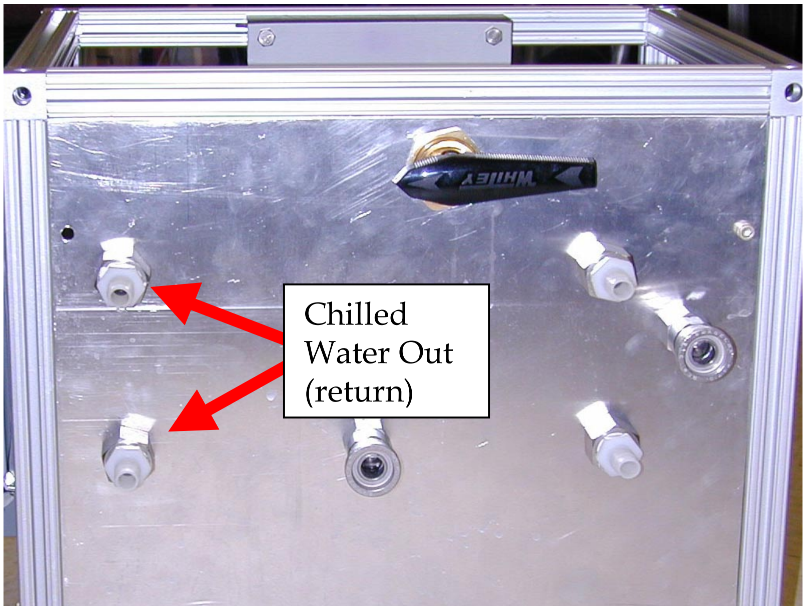
______ 20. Connect two water lines between the hydride bed quick-disconnect fittings and the heat exchanger panel quick-disconnect fittings.



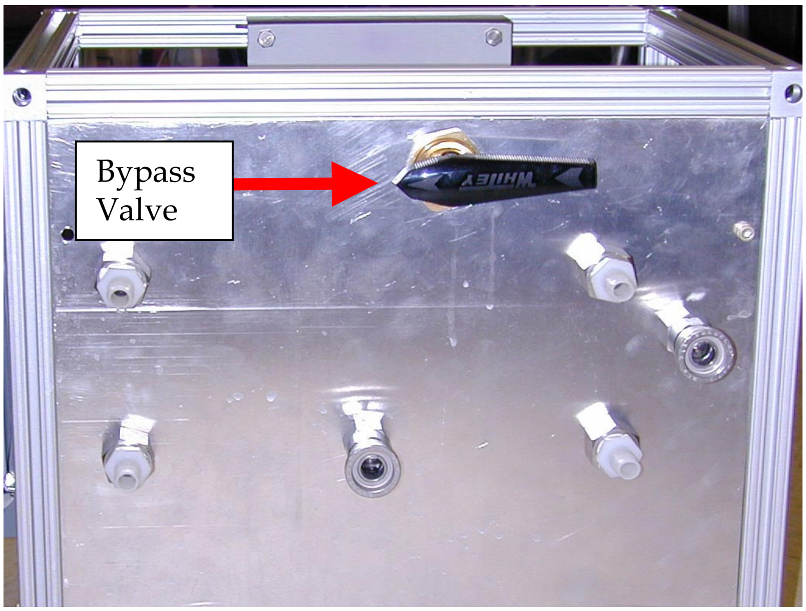
______ 21. On the heat exchange panel, connect the two lines bringing the chilled water from the chilled water source (if not previously connected).



______ 22. On the heat exchange panel, connect the two lines taking the chilled water to the drain or back to the chilled water source (if not previously connected).



______ 23. Ensure that the Bypass Valve is in the open position (horizontal) as shown in the photo below.



______ 24. Start the pump for the Hydride Bed.

______ 25. Ensure that HB valve V1 is closed.

______ 26. Open HB valves V2, V3 and V4.

______ 27. Observe and record the pressure on the hydride bed:

_______________ psig

______ 28. Observe and record the temperature on the hydride bed:

_______________ ° C

______ 29. Ensure that all the bottle valves and the main valve on the hydrogen six-pack have been opened.

______ 30. Ensure that the recharge regulator (on the hydrogen six-pack) is set at 175 psig.

______ 31. Open the gas recharge system fill line main valve.

______ 32. Using a portable leak detector, check for the presence of any leaking hydrogen. Correct as needed.

______ 33. Observe and record the pressure on the hydrogen six-pack:

_______________ psig

2.2 Charging

______ 1. Connect grounding cables from the hydride bed and the six-pack to a good ground.

______ 2. Open the hydride bed valve V1.

______ 3. Record the time: ____________

______ 4. Charge the hydride bed as required. This typically takes 30 to 60 minutes. Over-charging may result in subsequent venting of hydrogen. Charging is considered complete when one of the following conditions exists:
a) one hour has passed (if the cooling system is adequate)
b) source pressure on the six-pack no longer decays
c) when the HB temperature falls to near 25° C

______ 5. Close the hydride bed valve V1.

______ 6. Record the time: ___________

2.3 Completion

______ 1. Close the hydrogen gas recharge regulator main valve.

______ 2. Observe and record the pressure on the hydrogen six-pack:

______________ psig

______ 3. Turn off the power to the hydride bed pump.

______ 4. Observe and record the pressure on the hydride bed:

______________ psig

______ 5. Observe and record the temperature on the hydride bed:

______________ ° C

______ 6. Close the hydride bed valves V1, V2, V3 and V4.

______ 7. Disconnect the two water lines between the hydride bed quick-disconnect fittings and the heat exchanger panel quick-disconnect fittings.

______ 8. As necessary, disconnect the four chilled water lines from the heat exchange panel.

______ 9. Disconnect the hydride bed water pump cable and the grounding straps.

______ 10. Demate the hydride bed hydrogen line from the hydrogen gas fill line at the quick-disconnect fitting.

______ 11. Cap all connectors and fittings. Stow all cables and hoses.

______ 12. Close all the bottle valves on the hydrogen six-pack.

______ 13. Reduce the recharge regulator (on the hydrogen six-pack) to 0 psig.

______ 14. Vent the recharge system line pressure by opening and then closing the vent valve.

______ 15. Close the recharge system fill line main valve.

______ 16. When required, transport and reinstall the hydride bed into the locomotive using the six mounting bolts.

______ 17. Mate the hydride bed hydrogen line to the fuel cell system at the quick-disconnect fitting.

______ 18. Reconnect all hydride bed electrical lines as required.

______ 19. Mate both hydride bed water lines to the fuel cell system at the quick-disconnect fittings.

______ 20. Using a portable leak detector, check for the presence of any leaking hydrogen. Correct as needed.

APPENDIX B
Adequate Ventilation

Adequate Ventilation Calculation

We do not have free flow desorption measurements on an assembled hydride bed. However, we have measured the free flow of hydrogen of a fully loaded single canister, during our development stage. Based on 7 test results, the initial peak flow rate is approximately 125 L/min. The hydride bed is consists of 16 canisters, to scale up one can simply multiply that number by 16,

$$125 \times 16 = 2000 \text{ L/min}$$

Although the 16 canisters were manifold together and hydrogen flows thru a single line, the net flow rate should be reduced in the HB configuration. However, due to lack of measured data, we would recommend to use this number, but please keep in mind that it's a very conservative estimate.

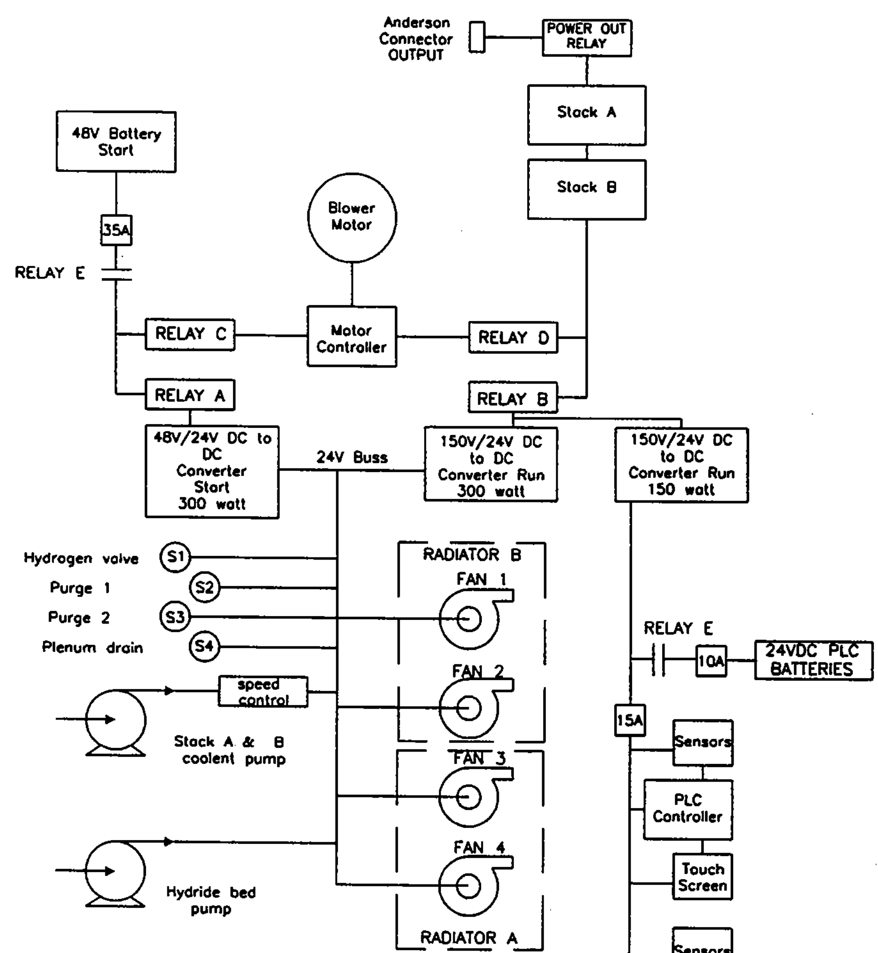
To provide adequate ventilation to disperse and dissipate the hydrogen to less than 20% of its LEL [*4% in air*], the required airflow will be:

$$2000 / 0.04 / 0.20 = 250{,}000 \text{ L/min (8829 cu.ft/min)}$$

Jennifer P. C. Chan
SMTS, Systems Engineering
Sandia National Labs
P.O. Box 969
Livermore, CA 94551
(925)294-2043

APPENDIX C
Single Line Drawing

DESIGN AGENCY PART OR CONTROL NO.	ISSUE	DESCRIPTION / PREPARED BY	DATE	CHKR	ENGR
	A	D. TRUJILLO 8120/L. HOFFA 8243 MODIFIED BY: PIERRE LALIBERTÉ / CANMET	07/15/02		



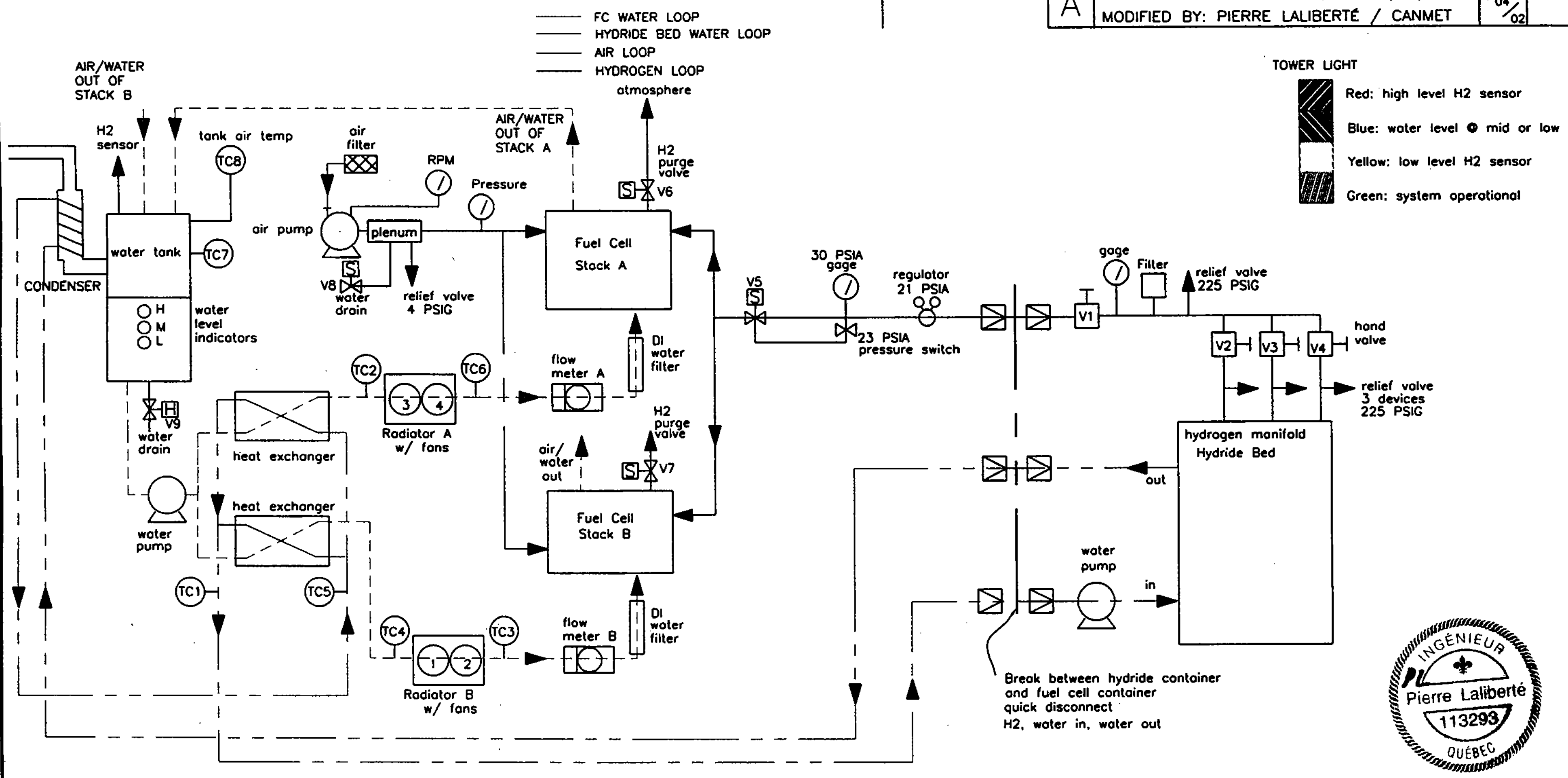
CAD FILE NO. LH040702(MOD).DWG

AGENCY APPROVALS			SHEET INDEX	TITLE
ORG	DATE	INITIALS	SHEET 1 / ISSUE A	(U) TITLE CLASSIFICATION
			PART CLASSIFICATION: UNCLASSIFIED	FUEL CELL 1 LINE DIAGRAM MODIFICATION
			DWG. CLASSIFICATION: UNCLASSIFIED	SIZE C — DWG. NUMBER LH040702(MOD)
				SCALE —— SHEET 1 OF 1

AutoCAD-2002

APPENDIX D
Fuelcell Flow Sheet

DESIGN AGENCY PART OR CONTROL NO.	REVISIONS				
	ISSUE	DESCRIPTION	PREPARED BY	DATE	ENGR
	A	CREATED BY: RAY BALDONADO, 8243 4/29/2002 MODIFIED BY: PIERRE LALIBERTÉ / CANMET		09/04/02	



CAD FILE NO. FLOW DIAGRAM.DWG

AGENCY APPROVALS			SHEET	1
ORG	DATE	INITIALS	ISSUE	A
			SHEET INDEX	
			PART CLASSIFICATION: UNCLASSIFIED	
			DWG CLASSIFICATION LEVEL: UNCLASSIFIED	

(U) TITLE CLASSIFICATION

TITLE: FUEL CELL LOCOMOTIVE FLOW DIAGRAM

SIZE	CAGE	DWG NUMBER
B		FLOW DIAGRAM
SCALE ———		SHEET 1 OF 1

AutoCAD-2002

APPENDIX E
Hydrogen Gas MSDS

MATERIAL SAFETY DATA SHEET

SECTION 1 CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

MDL INFORMATION SYSTEMS, INC.

1281 Murfreesboro Road, Suite 300

Nashville, TN 37217-2423

1-615-366-2000

EMERGENCY TELEPHONE NUMBER

1-800-424-9300 (NORTH AMERICA)

1-703-527-3887 (INTERNATIONAL)

SUBSTANCE: **HYDROGEN**

TRADE NAMES/SYNONYMS:
HYDROGEN GAS; HYDROGEN COMPRESSED; HYDROGEN (H2); DIHYDROGEN; HYDROGEN, NORMAL HYDROGEN; HYDROGEN IN BULK; UN 1049; STCC 4905746; H2; OHS11120; RTECS MW8900000

CHEMICAL FAMILY: inorganic, gas

CREATION DATE: Mar 12 1985
REVISION DATE: Jun 02 1999

SECTION 2 COMPOSITION, INFORMATION ON INGREDIENTS

COMPONENT: HYDROGEN
CAS NUMBER: 1333-74-0
EC NUMBER (EINECS): 215-605-7
EC INDEX NUMBER: 001-001-00-9
PERCENTAGE: 100.0

SECTION 3 HAZARDS IDENTIFICATION

NFPA RATINGS (SCALE 0-4): HEALTH=1 FIRE=4 REACTIVITY=0

EC CLASSIFICATION (ASSIGNED):
F+ Extremely Flammable

R 12

EC Classification may be inconsistent with independently-researched data.

EMERGENCY OVERVIEW:
COLOR: colorless
PHYSICAL FORM: gas
ODOR: odorless
MAJOR HEALTH HAZARDS: difficulty breathing
PHYSICAL HAZARDS: Flammable gas. May cause flash fire. Electrostatic charges may be generated by flow, agitation, etc.

POTENTIAL HEALTH EFFECTS:
INHALATION:
SHORT TERM EXPOSURE: nausea, vomiting, dizziness, tingling sensation, suffocation, convulsions, coma
LONG TERM EXPOSURE: no information on significant adverse effects
SKIN CONTACT:
SHORT TERM EXPOSURE: blisters, frostbite
LONG TERM EXPOSURE: no information is available
EYE CONTACT:
SHORT TERM EXPOSURE: frostbite, blurred vision
LONG TERM EXPOSURE: no information is available
INGESTION:
SHORT TERM EXPOSURE: frostbite
LONG TERM EXPOSURE: no information is available

CARCINOGEN STATUS:
OSHA: N
NTP: N
IARC: N

SECTION 4 FIRST AID MEASURES

INHALATION: When safe to enter area, remove from exposure. Use a bag valve mask or similar device to perform artificial respiration (rescue breathing) if needed. Keep warm and at rest. Get medical attention immediately.

SKIN CONTACT: Wash if needed. If frostbite, freezing, or cryogenic burns occur, warm affected area in warm water. If this is not available, gently wrap affected parts in blankets. Allow circulation to return naturally. Get medical attention immediately.

EYE CONTACT: It is unlikely that emergency treatment will be required. Wash with large amounts of water or normal saline until no evidence of chemical remains (at least 15-20 minutes). Get medical attention immediately.

INGESTION: It is unlikely that emergency treatment will be required. Get medical attention, if needed.

NOTE TO PHYSICIAN: For inhalation, consider oxygen.

SECTION 5 FIRE FIGHTING MEASURES

FIRE AND EXPLOSION HAZARDS: Severe fire hazard. Severe explosion hazard. Vapor/air mixtures are explosive. Containers may rupture or explode if exposed to heat. Electrostatic discharges may be generated by flow or agitation resulting in ignition or explosion.

EXTINGUISHING MEDIA: carbon dioxide, regular dry chemical

Large fires: Flood with fine water spray.

FIRE FIGHTING: Move container from fire area if it can be done without risk. Cool containers with water spray until well after the fire is out. Stay away from the ends of tanks. For fires in cargo or storage area: Cool containers with water from unmanned hose holder or monitor nozzles until well after fire is out. If this is impossible then take the following precautions: Keep unnecessary people away, isolate hazard area and deny entry. Let the fire burn. Withdraw immediately in case of rising sound from venting safety device or any discoloration of tanks due to fire. For tank, rail car or tank truck: Stop leak if possible without personal risk. Let burn unless leak can be stopped immediately. For smaller tanks or cylinders, extinguish and isolate from other flammables. Evacuation radius: 800 meters (1/2 mile). Do not attempt to extinguish fire unless flow of material can be stopped first. Flood with fine water spray. Cool containers with water spray until well after the fire is out. Apply water from a protected location or from a safe distance. Avoid inhalation of material or combustion by-products. Stay upwind and keep out of low areas. Evacuate if fire gets out of control or containers are directly exposed to fire. Evacuation radius: 500 meters (1/3 mile). Consider downwind evacuation if material is leaking. Stop flow of gas.

LOWER FLAMMABLE LIMIT: 4.0%
UPPER FLAMMABLE LIMIT: 75%
AUTOIGNITION: 932 F (500 C)

SECTION 6 ACCIDENTAL RELEASE MEASURES

OCCUPATIONAL RELEASE:
Avoid heat, flames, sparks and other sources of ignition. Do not touch spilled material. Stop leak if possible without personal risk. Reduce vapors with water spray.

Keep unnecessary people away, isolate hazard area and deny entry. Remove sources of ignition. Ventilate closed spaces before entering.

SECTION 7 HANDLING AND STORAGE

Store and handle in accordance with all current regulations and standards. Subject to storage regulations: U.S. OSHA 29 CFR 1910.103. Store in a cool, dry place.
Store in a well-ventilated area. Store outside or in a detached building. Keep separated from incompatible substances. Grounding and bonding required. Keep separated from incompatible substances.

SECTION 8 EXPOSURE CONTROLS, PERSONAL PROTECTION

EXPOSURE LIMITS:
HYDROGEN:
No occupational exposure limits established.

VENTILATION: Provide local exhaust ventilation system. Ventilation equipment should be explosion-resistant if explosive concentrations of material are present.
Ensure compliance with applicable exposure limits.

EYE PROTECTION: For the gas: Eye protection not required, but recommended. For the liquid: Wear splash resistant safety goggles. Contact lenses should not be worn. Provide an emergency eye wash fountain and quick drench shower in the immediate work area.

CLOTHING: For the gas: Protective clothing is not required. For the liquid: Wear appropriate protective, cold insulating clothing.

GLOVES: Wear insulated gloves.

RESPIRATOR: Under conditions of frequent use or heavy exposure, respiratory protection may be needed. Respiratory protection is ranked in order from minimum to maximum. Consider warning properties before use.
For Unknown Concentrations or Immediately Dangerous to Life or Health -
Any supplied-air respirator with full facepiece and operated in a pressure-demand or other positive-pressure mode in combination with a separate escape supply.
Any self-contained breathing apparatus with a full facepiece.

SECTION 9 PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL STATE: gas
COLOR: colorless

ODOR: odorless
TASTE: tasteless
MOLECULAR WEIGHT: 2.0
MOLECULAR FORMULA: H2
BOILING POINT: -423 F (-253 C)
FREEZING POINT: -434 F (-259 C)
VAPOR PRESSURE: 760 mmHg @ -253 C
VAPOR DENSITY (air=1): 0.07
SPECIFIC GRAVITY: Not applicable
DENSITY: 0.0899 g/L @ 0 C
WATER SOLUBILITY: 1.82% @ 20 C
PH: Not applicable
VOLATILITY: Not applicable
ODOR THRESHOLD: Not available
EVAPORATION RATE: Not applicable
VISCOSITY: 0.008957 cP @ 26.8 C
COEFFICIENT OF WATER/OIL DISTRIBUTION: Not applicable
SOLVENT SOLUBILITY:
Slightly Soluble: alcohol, ether

SECTION 10 STABILITY AND REACTIVITY

REACTIVITY: Stable at normal temperatures and pressure.

CONDITIONS TO AVOID: Avoid heat, flames, sparks and other sources of ignition. Minimize contact with material. Containers may rupture or explode if exposed to heat.

INCOMPATIBILITIES: metals, oxidizing materials, metal oxides, combustible materials, halogens, metal salts, halo carbons

HYDROGEN:
ALKALINE METALS: Ignition at elevated temperatures.
CALCIUM CARBONATE + MAGNESIUM (POWDER): Explosion on heating.
CHLORINE DIOXIDE: Detonates when sparked or on contact with platinum sponge.
COPPER (II) OXIDE: Violent explosion when heated.
DICHLORINE OXIDE: Detonates on ignition.
DIFLUORODIAZENE: Explosive reaction above 90 C.
DINITROGEN OXIDE: Sensitizes hydrogen-oxygen mixtures.
DINITROGEN TETRAOXIDE: Sensitizes hydrogen-oxygen mixtures.
DIOXANE + NICKEL (CATALYST): Explosive reaction above 200 C.
FLUORINE PERCHLORATE: Ignition.
HALOGENS: Ignition or explosive reaction.
INTERHALOGENS: Ignition or explosive reaction.
ISOPROPYL ALCOHOL + PALLADIUM: Ignition.

NITROANISOLE + NICKEL (CATALYST): Explosion.
NITROGEN (LIQUID) + ALKENES: May form explosive products.
NITROGEN OXIDE: Sensitizes hydrogen-oxygen mixutres.
NITROGEN TRIFLUORIDE: Explosive reaction on ignition.
NITROSYL CHLORIDE: Causes ignition in hydrogen-oxygenmixtures.
NITRYL FLUORIDE: Explosion @ 200-300 C.
OXIDIZERS: Ignition or explosion.
OXYGEN: Flammable, explosive mixtures, particularly in the presence of a catalyst.
OXYGEN DIFLUORIDE: Explodes if ignited.
OZONE (SOLID): Highly explosive mixtures with liquid hydrogen.
PALLADIUM(II) OXIDE: Incandesces on contact.
PALLADIUM TRIFLUORIDE: Reduces with incandescence.
1-PENTOL: Explosive reaction on heating.
POLY(CARBON MONOFLUORIDE): Deflagration above 400 C.
1,1,1-TRIS(AZIDOMETHYL)ETHANE + CATALYST: Possible explosion.
1,1,1-TRIS(HYDROXYMETHYL)NITROMETHANE + CATALYST: Possible explosion.
UNSATURATED HYDROCARBONS: Hydrogenation of unsaturated hydrocarbons in the
presence of a catalyst may proceed with explosive violence if conditions are not properly controlled.
XENON HEXAFLUORIDE: Violent reaction.

POLYMERIZATION: Will not polymerize.

SECTION 11 TOXICOLOGICAL INFORMATION

HEALTH EFFECTS:
INHALATION:
HYDROGEN: See information on simple asphyxiants.

ACUTE EXPOSURE:
SIMPLE ASPHYXIANTS: The symptoms of asphyxia depend on the rapidity with which the oxygen deficiency develops and how long it continues. In sudden acute asphyxia, unconsciousness may be immediate. With slow development there may be rapid respiration and pulse, air hunger, dizziness, reduced awareness, tightness in the head, tingling sensations, incoordination, faulty judgement, emotional instability, and rapid fatigue. As the asphyxia progresses, nausea, vomiting, collapse, unconsciousness, convulsions, deep coma and death are possible.

CHRONIC EXPOSURE:
SIMPLE ASPHYXIANTS: No data available.

SKIN CONTACT:
ACUTE EXPOSURE:
HYDROGEN: No adverse effects have been reported from the gas. Due to rapid evaporation, the liquid may cause frostbite with redness, tingling and pain or numbness. In more severe cases, the skin may become hard and white and develop blisters.

CHRONIC EXPOSURE:
HYDROGEN: No data available.

EYE CONTACT:
ACUTE EXPOSURE:
HYDROGEN: No adverse effects have been reported from the gas. Due to rapid evaporation, the liquid may cause frostbite with redness, pain and blurred vision.

CHRONIC EXPOSURE:
HYDROGEN: No data available.

INGESTION:
ACUTE EXPOSURE:
HYDROGEN: Ingestion of a gas is unlikely. If liquid is swallowed, frostbite damage to the lips, mouth and mucous membranes may occur.

CHRONIC EXPOSURE:
HYDROGEN: No data available.

SECTION 12 ECOLOGICAL INFORMATION

Not available

SECTION 13 DISPOSAL CONSIDERATIONS

Subject to disposal regulations: U.S. EPA 40 CFR 262. Hazardous Waste Number(s): D001. Dispose in accordance with all applicable regulations.

SECTION 14 TRANSPORT INFORMATION

U.S. DOT 49 CFR 172.101 SHIPPING NAME-UN NUMBER:
Hydrogen, compressed-UN1049

U.S. DOT 49 CFR 172.101 HAZARD CLASS OR DIVISION:
2.1

U.S. DOT 49 CFR 172.101 AND SUBPART E LABELING REQUIREMENTS:
Flammable gas

U.S. DOT 49 CFR 172.101 PACKAGING AUTHORIZATIONS:
EXCEPTIONS: 49 CFR 173.306
NON-BULK PACKAGING: 49 CFR 173.302
BULK PACKAGING: 49 CFR 173.302, 314

U.S. DOT 49 CFR 172.101 QUANTITY LIMITATIONS:
PASSENGER AIRCRAFT OR RAILCAR: Forbidden
CARGO AIRCRAFT ONLY: 150 kg

LAND TRANSPORT ADR/RID:
SUBSTANCE NAME: Hydrogen, compressed
UN NUMBER: UN1049
ADR/RID CLASS: 2
ITEM NUMBER: 1(b)/1F
WARNING SIGN/LABEL: 3/3; 13
HAZARD ID NUMBER: 23

AIR TRANSPORT IATA/ICAO:
CORRECT TECHNICAL NAME: Hydrogen, compressed
UN/ID NUMBER: UN1049
IATA/ICAO CLASS: 2.1
LABEL: Flammable gas

MARITIME TRANSPORT IMDG:
CORRECT TECHNICAL NAME: Hydrogen, compressed
UN/ID NUMBER: UN1049
IMDG CLASS: 2(2.1)
EmS No.: 2-02
MFAG Table No.: none
MARINE POLLUTANT: N

SECTION 15 REGULATORY INFORMATION

U.S. REGULATIONS:
TSCA INVENTORY STATUS: Y

TSCA 12(b) EXPORT NOTIFICATION: Not listed.
CERCLA SECTION 103 (40CFR302.4): N
SARA SECTION 302 (40CFR355.30): N
SARA SECTION 304 (40CFR355.40): N
SARA SECTION 313 (40CFR372.65): N

SARA HAZARD CATEGORIES, SARA SECTIONS 311/312 (40CFR370.21):
ACUTE: Y
CHRONIC: N
FIRE: Y
REACTIVE: N
SUDDEN RELEASE: Y
OSHA PROCESS SAFETY (29CFR1910.119): N
STATE REGULATIONS:
California Proposition 65: N
EUROPEAN REGULATIONS:
EC NUMBER (EINECS): 215-605-7

EC RISK AND SAFETY PHRASES:
R 12
Extremely flammable.
S 2
Keep out of reach of children.
S 9
Keep container in a well-ventilated place.
S 16
Keep away from sources of ignition - No smoking.
S 33
Take precautionary measures against static discharges.

GERMAN REGULATIONS:
WATER HAZARD CLASS (WGK): 0 (Official German Classification)

SECTION 16 OTHER INFORMATION

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Project Report

July 12, 2002

Vehicle Projects LLC
Fuelcell Locomotive Assistance

DISTRIBUTION

G. Desrivières	- CANMET
P. Laliberté	- CANMET
D. Barnes	- FPI
F. Delabbio	- Hatch
D. Eastick	- Hatch
C. Graves	- Hatch
J. Angel	- MSHA
R. Baldonado	- Sandia
W. Replogle	- Sandia
D. Trujillo	- Sandia

Mine-Hardening Assessment

Table Of Contents

If you disagree with any information contained herein, please advise immediately.

1. Introduction

During the hazards and operability assessment sessions in Reno, Nevada (February 2002) an opportunity to observe the fuelcell locomotive's (LOCO) readiness for underground (U/G) service was provided. This report details the observations and points of concern regarding the LOCO's U/G readiness. 1

2. Mechanical Mine-Hardening

The following observations were made during the assessment of the locomotive:

2.1 Drive System

The underside of the Fuelcell and Hydride Bed units are exposed to the drive system of the locomotive.

RECOMMEND: Installing a ¼" thick, A36 plate, to the frame of the locomotive to physically separate the units from the drive system.

2.2 General Fittings

A hose clamp on the hydride bed water system was loose. The water line was not leaking, but was not secured in place. The hose clamp was tightened by P. Laliberte of CANMET. The cause is unknown.

2.3 Process Piping

An elbow pipe to the water pump protrudes from the front of the hydride bed unit. There is potential for this pipe to be damaged during insertion and removal of the hydride bed unit to/from the locomotive.

RECOMMEND: Modify the piping such that all pipes are contained within the unit

2.4 Containment of Hydride Bed

The front of the hydride bed unit is open (i.e. not closed) and the potential for damage to the hydride canisters exists during loading/unloading of the unit.

RECOMMEND: Mount vertical aluminum bars to the front of the hydride bed unit – may require assessment of clearances.

2.5 Hydrogen Manifold Support

The hydride bed manifold is supported by bolts in one location of each pipe as well as self-supporting. The manifold piping is vulnerable to vibration during shipping and usage.

RECOMMEND: Installing lockwashers or removable loctite on manifold support bolts.

2.6 Hydrogen Piping

The grade and specifications for the hydrogen piping are unknown. Welded and fabricated fittings have been used.

RECOMMEND: To determine grade, specifications, non-destructive tests performed on hydrogen piping for regulatory assessment.

2.7 Hydrogen Sensor

The hydrogen sensor unit on the hydride bed has four hoses from the hydrogen manifold pressure relief devices directly inserted into the sensor. This will result in 225 psi of hydrogen directly into the sensor. It is unknown if the physical installation of the hoses in the sensor will resist the pressure, or if the hoses will be ejected from the sensor.

RECOMMEND: To determine if Sandia performed any functionality tests on the assembly.

3. Instrumentation and Controls Mine-Hardening

3.1 Instrument Mounting

Instrument hardware support was noticed to be lacking on hydrogen piping (specifically pressure transmitters). Due to the potential for rough handling during shipping and/or operation this was noted as a threat for preventable stresses on the process piping.

Recommend: To review and improve general instrumentation support to reduce the risk of stress on hydrogen piping during operation and transportation.

3.2 Electrical Connections

Some electrical cable terminations were noticed to be supported with resin while other cable terminations were supported with proper cable support (as would be supplied with original connector kit).

Recommend: To consider replacing or adding mechanical support on cable terminations to adequately prevent damage to cable terminations due to inadvertent “rough” handling of the cables during operation or transport.

3.3 Locomotive DC Motor

The locomotive motor will spark regularly and sufficiently to ignite explosive concentration of hydrogen in the motor’s area. The locomotive’s motor is physically located lower than any process line containing hydrogen and thus hydrogen is unlikely to exist in the motor’s area. However unlikely the presence of an explosive concentration of hydrogen is, there is no guarantee of a zero chance of the hydrogen concentration (in the motor area) ever reaching the LEL. Upon detection of 40% of hydrogen’s LEL the control system should de-energize the locomotive’s motor to prevent the chance for an ignition source to be produced in the presence of an explosive concentration of hydrogen.

Recommend: To confirm this action is already programmed into the PLC controller and it's testing. If the de-energizing of the DC motor cannot be confirmed, consideration must be made to ensure the drive can be de-energized by the control system on detection of 40% of the LEL.

3.4 Hydrogen Purge Exhaust

During the purge of the fuel-cells the purge exhaust line will contain 100% hydrogen. With the present configuration, explosive concentrations of hydrogen are guaranteed to exist in the exhaust line during the normal operation of the fuelcells.

The approach to safe handling of explosive gases/vapours assumes that a source of ignition is present at all times. Under this constraint the existing exhaust system is deemed hazardous.

Recommend: To consider adding forced ventilation on the purge manifold to ensure sufficient dilution of the purged hydrogen below 25% of the LEL. The purge valves (and thus the operation of the fuelcell) should be interlocked such that the purge valves can not open unless the ventilation fan is running

Note that if this condition is not rectified regulatory approval could prove to be difficult with the existing electrical and instrumentation hardware classifications for explosive environments.

3.5 General Instrumentation in Hazardous Locations

It was noted that the instrumentation, cabling, and enclosures installed on the fuelcell locomotive are not classified as intrinsically safe. This is thought to be acceptable provided effective hydrogen monitoring is provided in the region where the electrical equipment is located. Hydrogen sensors have been mounted in both the hydride-bed compartment and the fuel-cell compartment to detect against hydrogen leaks. It is thought that the fuelcell locomotive will not require intrinsically safe instrumentation but regulatory approval may prove different or require proof of effective detection of hydrogen by the installed sensors.

Recommend: To perform documented tests to indicate if the sensors can effectively detect a hydrogen from the furthest location of the process containing hydrogen. Ensure the hydrogen detection system has the ability to de-energize all electrical equipment on the locomotive.

Testing and documentation of the success of the detection system is recommended (the conditions in which the tests were performed, i.e. rate of ventilation, rate of hydrogen addition, etc… should be documented).

3.6 Hydrogen Sensors

The effectiveness of the hydrogen sensors to detect hydrogen leaks (in still or well ventilated conditions) is questionable. This concern is confirmed by a comment from Sandia that the hydrogen sensors located in the ceiling of the lab (the room's high point) generally detected concentrations of hydrogen before hydrogen sensors mounted locally on the fuelcell and hydride-bed.

In addition the location of the hydrogen sensors does not ensure the detection of the presence of a hydrogen leak. The specific installation of the hydrogen sensor on the fuelcell compartment is questionable as it was mounted beside the fuelcell purge vent. This could trip the sensor without need (i.e. backfeed from purge) or provide a vent point for hydrogen before detection. In either case the location is thought to be ineffective.

Recommend: To consider improving the effectiveness of hydrogen detection by mechanical modification of hydride bed and fuelcell compartments. The mechanical modifications (e.g. hydrogen collection hood) would be designed to direct rising hydrogen through a collective high-point, before venting to atmosphere, where the hydrogen detection would be re-installed.

This mechanical modification should keep in mind the following potential mechanical restrictions:

- The requirement to operate the manual hydrogen isolation valves (V1, V2, V3, & V4);
- The 8-inch clearance allowed from the top of the hydride bed compartment to the protective cover;
- The fuelcell purge vent (existing or modified design);
- Process and electrical connections between the hydride-bed and fuelcell; and
- Relocation of the fuelcell purge vent.

3.7 Operating Procedure

One assumption for operating the fuelcell locomotive is there will be sufficient ventilation. It has been noted that local ventilation could fail in the presence of the fuelcell locomotive while unattended. This is an opportunity for a hydrogen leak, which has remained undetected under ventilation, to produce a hazardous concentration.

Recommend : Modify the operating procedure to de-energize the control system (10A breaker) and power distribution (35A breaker) if the fuelcell locomotive is to be left alone for any period of time.

3.8 H2 Pressure Relief (225 PSI) on Hydride-bed

See mechanical section 2.7.

4. Summary

The above noted items are thought to be necessary modifications to the existing fuelcell system to improve the probability of successful transport and trials.

Although there are concerns listed here which have bearing on the regulatory approval this is not an indication that these are the only issues, which will require attention for regulatory approval. The issues, which may have bearing on regulatory approval, have been indicated here to give forewarning and reduce future effort for regulatory approval.

D. Eastick/C. Graves

DE:pc:cg

Revision Note: 1

- Rev 1 -- July 12, 2002 – Actions identified in this report were followed up in a teleconference documented in Meeting Minutes (MM92038.001) in Appendix F of the Pre-Development Review.

Minutes of Meeting

May 17, 2002

Vehicle Projects LLC
Fuelcell Locomotive Assistance

DISTRIBUTION

Those present +
G. Desrivières - CANMET
F. Delabbio - Hatch

Minutes of Meeting

DATE: May 16, 2002

LOCATION: Teleconference

PRESENT:	CANMET	FPI	Hatch	MSHA	Sandia
	M. Bétournay	D. Barnes	D. Eastick	J. Angel	J. Chan
	P. Laliberté		C. Graves	B. Boring	R. Baldonado
					W. Replogle
					D. Trujillo

PURPOSE: Reno Risk Assessment - Action Assignment

ITEM	ACTION BY:

1. Introduction

The purpose of the meeting was to assign actions to the high risk items identified during the Reno Risk assessment of the operating procedures as well as items identified during the Mine-Hardening report.

2. Reno Risk Assessment

Please refer to the attached document "Risk Log – Reno May16.xls" for assignments and descriptions of agreed action items.

3. Mine-Hardening Assessment Review

Each Item will be examined below as per the numbering in the Mine-Hardening report "PR92038.003".

If you disagree with any information contained herein, please advise immediately.

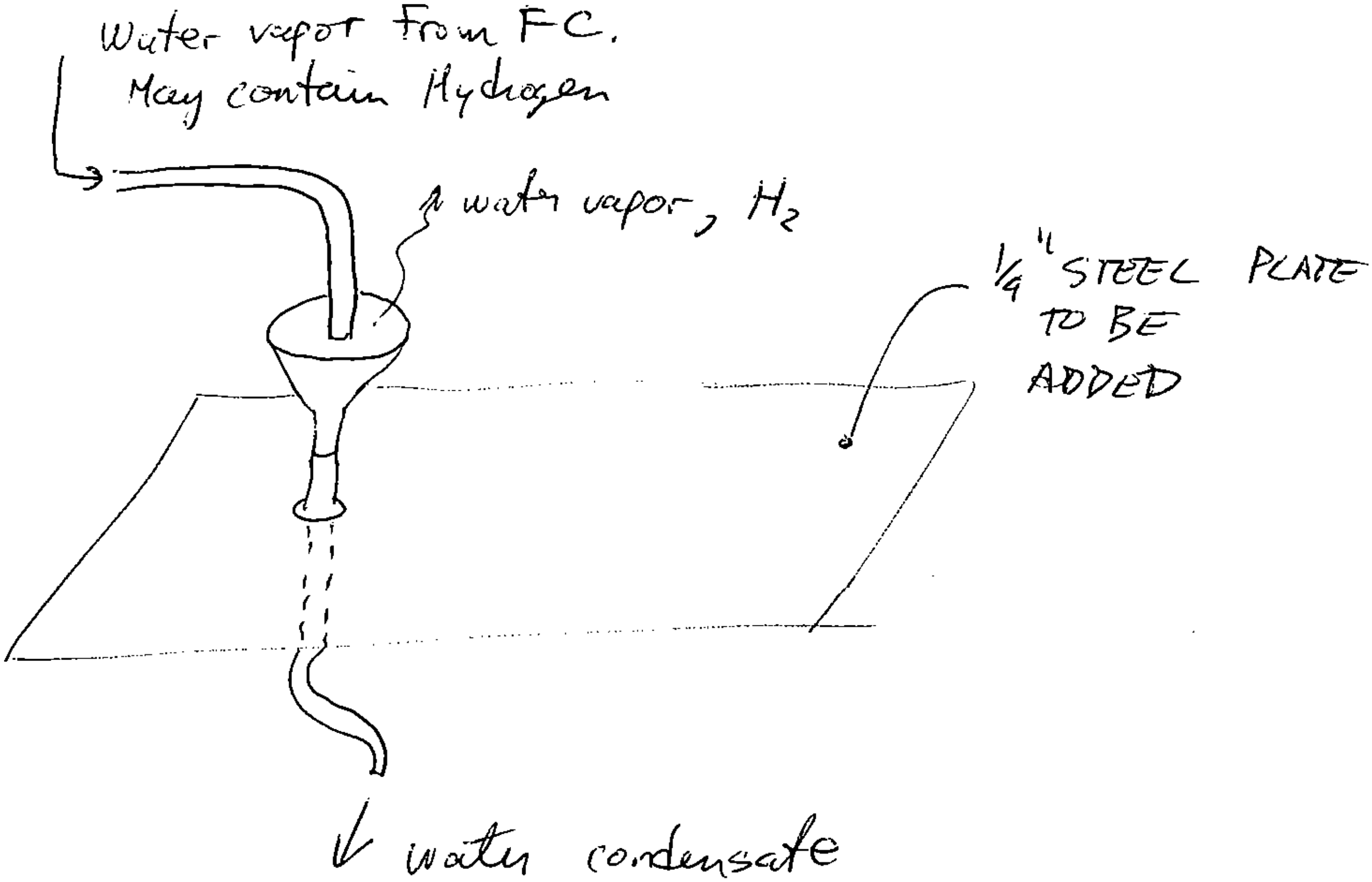
ITEM		ACTION BY:
Ref. 2.1	**Drive System – Cover Plate** A ¼" steel plate (approx 22" x 48") will be installed under the FC/HB units to act as a protective barrier between the drive system and the FC/HB units. Subsequent calculations for ballast should take this into account.	CANMET
Ref. 2.2	**Fittings** Maintenance procedures are to include checking electrical connections and hose connections regularly.	CANMET
Ref. 2.3	**Process Piping** Pierre will investigate if the piping from the water pump can be modified to be contained within the HB aluminum frame box.	CANMET
Ref. 2.4	**Containment of HB** Pierre will add vertical bars to help with the guidance and prevent damage.	CANMET
Ref. 2.5	**Hydrogen Manifold Support** Pierre will either add loctite or lock-washers to the manifold support bolts. Checking these bolts will be made part of maintenance procedures. Evaluate if second support position is feasible.	CANMET
Ref. 2.6	**Hydrogen Piping** Sandia has provided all piping specs for the HB and FC. HB pressure test results have also been provided. R. Baldonado assures that a helium leak test was performed on the FC hydrogen piping (operating pressure = 7 psig).	None
Ref. 2.7	**HB Hydrogen Sensor Piping** Jim Angel suggested the piping be modified to vent away from the operator after it passes thru/by the detector. Doug Eastick questioned the integrity of the plastic piping to withstand +225 psig. Doug will check the pipe specs supplied by Sandia and advise CANMET of a piping change.	Hatch CANMET
Ref. 3.1	**Instrument Mounting** P. Laliberté will check if it is possible to add external supports to reduce the effects of long term vibration	CANMET
Ref. 3.2	**Electrical Connections** Sandia assures that he use of resin is standard practice for securing electrical connections.	none
Ref. 3.3	**Locomotive DC Motor** All agreed that ventilation, elevation, and the plate to be installed	ALL

ITEM		ACTION BY:
	from Item 2.1 (above) will provide a physical barrier to prevent hydrogen from getting near the DC motors. The condensate discharge exhaust underneath the loco may occasionally contain Hydrogen. Hatch has sketched a possible solution – please comment.	
Ref. 3.4	**Hydrogen Purge Exhaust** Chris explained the electrical regulatory requirements and zone classifications. The purge piping must be modified to reduce the hydrogen concentration before discharge. Sandia will provide a solution using a combination of sintered metal and forced air. As well, CANMET should check the purge requirements for new stacks.	W. Replogle - Sandia CANMET
Ref. 3.5	**General Instrumentation – H2 Sensing** All agreed that testing will be performed to ensure that the Hydrogen sensors detect and can shut down in a static ambient environment. Sandia to provide notes on the tests they performed in the lab. These can be used as a basis for new tests.	D. Trujillo - Sandia
Ref. 3.6	**H2 Sensing** All agreed that the location of the FC sensor could be relocated to increase reliability. Hatch will provide a concept sketch for sensor relocation and lid modification	Hatch
	All agreed that the sensors/PLC will be programmed for the following levels: - Warning at 25% LEL - Shutdown at 40% LEL	CANMET
Ref. 3.7	**Operating Procedure** Modify the operating procedure for long-term shutdown to open the 10A breaker and 35A breaker.	CANMET
Ref. 3.8	**H2 Pressure Relief** Same as Item 2.7 above.	

D. Eastick

DE:ka
Attachments
-
-

HATCH	CALCULATION SHEET			SHEET NO. 1 OF 1
DESCRIPTION Mine Harding #3.3		PROJECT NO. 92038	MADE BY WE DATE May 17/2002	CHECKED BY DATE

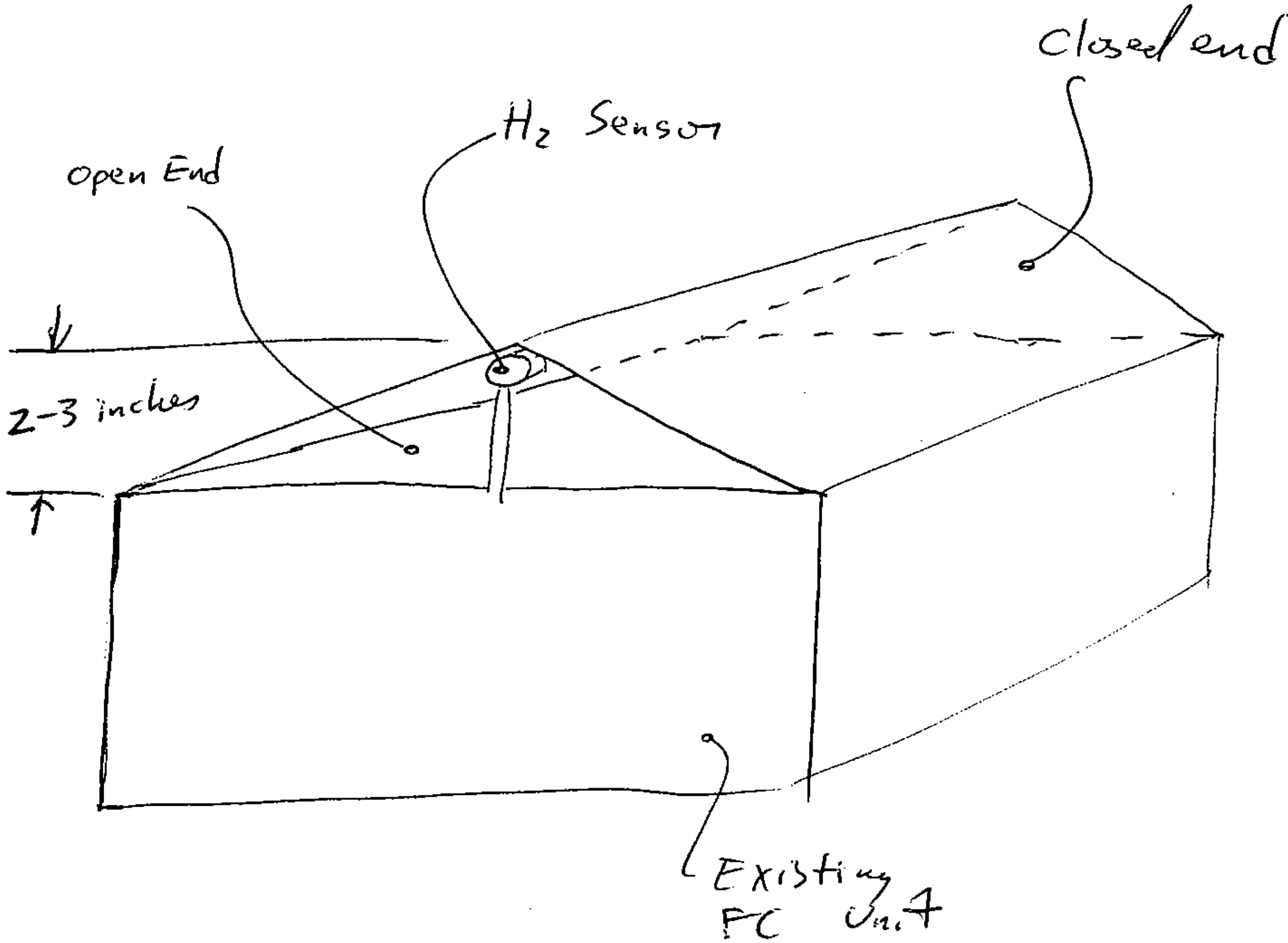


NOTE: FC & HB NOT SHOWN FOR CLARITY.

HATCH	CALCULATION SHEET	SHEET NO. ____ OF ____

DESCRIPTION	PROJECT NO.	MADE BY	CHECKED BY
3.6 Hydrogen Sensors	92038	WE DATE May 17/2002	DATE

REVISED CONCEPT FOR FC COVER (ALUMINUM)



Project Memo

PM92038.005
FL92038.101.03
Rev. 0, Page 1

September 10, 2002

TO: Fuelcell Locomotive PDR File **FROM:** Doug Eastick

Copies: F. Delabbio
C. Graves

Vehicle Projects LLC
Fuelcell Locomotive Assistance

Risk Assessment - Final

1. Introduction

As a final step in the risk assessments undertaken over the course of this project, a re-assessment of the risks identified as requiring action has been performed. This memo and attachments detail the current estimates of the consequence and severity of the risks identified at the following assessments:

- Risk Assessment of Fuel Cell Locomotive Demonstration (Ottawa, July-August 2001); and
- Fuelcell Operating Procedures such as start-up, shutdown, and maintenance (Reno, NV, February 2002).

For each risk assessment, actions were identified as being needed to reduce the likelihood and/or consequence to a lower level. The actions taken and the resulting assessment of likelihood and consequence are detailed in the attached spreadsheets.

This memo is to serve as a matter of record for the reassessment and the actions taken.

DE: ka
Attachments:
- Summer 2001 Risk Log (Revised)
- Operating Procedures Risk Log (Revised)

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Risk Assessment of Fuel Cell Locomotive Demonstration

- Risk Matrix (Revised)

- Risk Log (Revised)

© Hatch 06/2002❖

Project: Fuel Cell Locomotive | Risk Matrix: name | 2002-09-04

Risk #	Risk Name
064	Stray rock from ore chute
104	Sharp edges

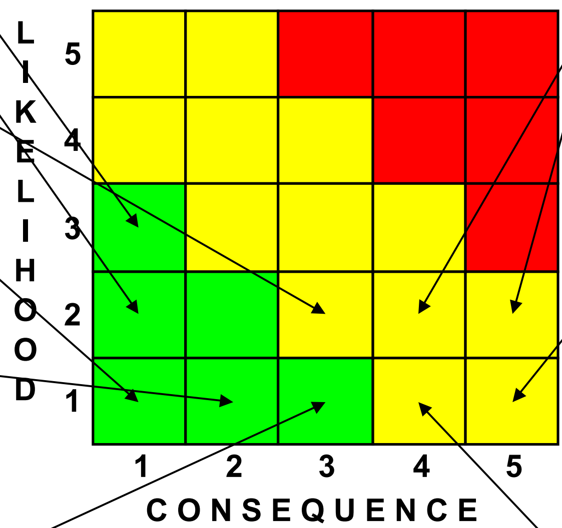
Risk #	Risk Name
042	Hydride bed cooling water system failure during refueling
046	Failure of 48/24 DC/DC converter for start mode.
122	Hydride bed heating water system failure

Risk #	Risk Name
100	Debris in female side of quick disconnect (on fuel cell side) resulting in poor connection and H2 leak
107	Manhandling of hydride bed
108	Pinch points
118	Dropping of the hydride bed causing personal injury

Risk #	Risk Name
024	Black Damp (CO)
030	Vehicle operated in sub 2% methane
052	Transporting in vertical position
063	Magnetic field exposure
095	Emissions from fuel cell due to contaminants in U/G air
098	Noise
101	Personal hazard from vacuum
126	Failure of 24/ +-15 DC DC converter for total stack current monitoring

Risk #	Risk Name
013	Battery acid leaks onto hydrogen system and releases hydrogen
014	Fuel Canisters lead hydride
021	Shrapnel damages fuel cell
025	Exposure to high acid water
026	Flooding of mine
044	Loss of hydride bed to cooling water separation
050	Hydrogen embrittlement of hydrogen supply system
051	Inertial weld failure on manifold aluminum SS/SS connections.
071	Burns from hot surfaces
102	Hot exhaust gases
106	Slippery conditions or burns from water tank overflow
116	Rotating parts

Risk #	Risk Name
005	Battery explosion due to heat or overcharge
012	Explosives damage vehicle and release hydrogen
035	Sparks from muck dumping
048	Air contaminants enter fuel cell system
065	Failure of connection between hydrogen source and hydride bed
069	Physical contact with hydride
082	Failure of power pack ventilation
097	Uncontrolled pressure release (whipping, debris)
124	Failure of 150/48 Dc/DC converter for battery charger
125	Failure of 24/5 DC/DC converter for blower control



Risk #	Risk Name
001	Random Mine Fire
022	Major damage to hydrogen container
027	Roof collapse / Fall of ground
028	Bump / Vibration / Seismic event
034	Sparking from sulphide dust causing hydrogen explosion
038	Smoking near FC or hydrogen tanks
049	Failure of pressure relief of hydride bed
058	Vandalism
092	Effect of prolonged shutdown on startup

Risk #	Risk Name
003	Fire starts in Hydrogen component on locomotive
019	Hydrogen system damaged by welding
023	Vehicle impact damages hydrogen container
036	Locomotive derailment
039	Traction controller failure
041	Loss of power and impact on braking
045	Maintenance of Loco/Power plant while power plant in operation
055	Vibration
056	Temperature cycling
057	Pressure cycling
062	Dropped hydrogen bottle while handling
068	Physical characteristics of fuel cell loco differ from battery loco
070	Contamination by air of the hydride bed
072	Overheating of FC
085	Drying out of the fuel cell membrane
086	Freezing of the fuel cell.
114	Arcing sources
115	Grounding of the stack
123	Failure of 150/24 Dc/DC converter for run mode

Risk #	Risk Name
002	Random Vehicle Fire
004	Methane ignition
006	Random mine fire with hydride cannister burst
007	Random vehicle fire with hydride canister burst
008	Fire in hydrogen components with hydride cannister burst
009	Hydrogen Explosion underground
018	Electrical cable falls on equipment
031	Steel on steel generates sparks (rail or worm gear) and fire starts
032	Static electric sparking during hydrogen re-fueling
033	Sparks with ventilation fans
040	Failure of fuel cell controller
053	Hydrogen buildup in dead air space resulting in explosion.
060	Failure of pressure regulator
066	Connection of wrong fuel to hydride bed
075	Lightning during refueling
076	Reaction of ammonia or afterblast chemicals
077	Failure of air supply to the fuel cell, hydrogen escapes from fuel cell
078	Reaction of H2 with mine environment gases or particles
079	Sparking from handheld radios
081	Failure of mine ventilation
083	Leakage through H2 valve stem packing
084	Impact of Diesel
088	Operator error with interface
089	Failure to follow startup and showdown procedures (isolation valves)
094	Emissions from burning fuel cell
099	Overheating due to air blower plugging up.
105	Poor design of pipe length; diameter ratios.
111	Stray currents
113	Failure to purge FC with nitrogen before maintenance to de-energize it.
119	Sparks with ventilation fans (battery bay)
127	Hydrogen buildup in dead air space resulting in asphyxiation

Risk #	Risk Name
015	Fuel cell electrical short
016	Fuel cell membrane fails and small deflagration occurs
020	Shrapnel damages hydrogen
029	Vehicle left in operation and runs out of fuel
037	Failure of universal joint causing impact with FC
043	Fuel cell cooling water system failure
047	Traction controller feeds current into fuel cell.
054	Hydrogen buildup in loco
059	Maintenance Induced leaks
087	Damage by pressure washing or minewater
090	Ignition of hydride bed
091	Mechanical damage of membrane
093	Nitrogen buildup in dead air space
096	Electrical shocks from fuel cell during operations.
103	Failure of aluminum support structure
109	Blower sucking in hydrogen
112	Electrocution
117	Damage from debris from road travel
120	Sparks with ventilation fans (mine vent fans)
121	Hydride bed cooling water system failure during refueling

Project: Fuel Cell Locomotive   Risk Log: Fuel Cell z   2002-09-10

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
BD	001	Random Mine Fire	Including Other Vehicles and Excludes the Fuel Cell (F.C.) Loco	5	2	med	What is the Campbell mine Fire History; Modify Emerg Resp. plan. Multiple fatalities would result in the recovery efforts, not the initial fire.	No changes
BD	002	Random Vehicle Fire	Fuel Cell Locomotive Only Unrelated to F.C.	5	1	med	Understanding of electrical energy from tract motor to F.C. not sufficient. This item relates to the recovery operation after a fire, not the danger to the operator.	No changes
JA	003	Fire starts in Hydrogen component on locomotive	Jet of Invisible Fire from 1/2" line for about 1 minute. Not Explosion.	4	2	high	Unit is already designed to be enclosed.	Was (4,3). Likelihood of 2 as we now have active detection.
BD	004	Methane ignition		5	1	med	Locomotive will not be near any diamond drilling where most likely to occur	No changes
.	005	Battery explosion due to heat or overcharge	4 Small Lead-Acid Batteries sealed and approved for DOT transportation.	3	1	med	Located underneath the F.C. and enclosed in separate steel box. Westinghouse predicts 7/10,000 years.	
.	006	Random mine fire with hydride cannister burst	Random Mine Fire plus Failure of Pressure Relief Valve	5	1	low		
.	007	Random vehicle fire with hydride canister burst		5	1	low	Need better understanding of how the hydride bed reacts in a fire.	
RB	008	Fire in hydrogen components with hydride cannister burst		5	1	high		Was (5,2). Likelihood of 1 as we now have active detection and pressure releif devices.
BD	009	Hydrogen Explosion underground	Only 1 kg of Free Hydrogen	5	1	med	Rare because low ventilation plus small leak over time	No changes
.	010	Methane Explosion	covered under item 4	0	0	low	Covered under Item 4	
.	011	Coal Dust Explosion (deleted)		0	0	low		

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	012	Explosives damage vehicle and release hydrogen	Recovery operation after an unplanned detonation.	3	1	med	Do not transport explosives with the F.C. Locomotive.	
.	013	Battery acid leaks onto hydrogen system and releases hydrogen	Jet of Invisible Fire from pinhole leak with 1/2m flame.	2	1	high	Should remove batteries for slinging during transport. Plus hydride bed is removed for slinging. Plus batteries are installed below the hydrogen system.	
.	014	Fuel Canisters lead hydride	Hydride alloy is reactive in air, oxidizes and glows red. Inhalation hazard. Will release hydrogen.	2	1	med	40 micron filter in manifold. Toxicity for inhalation not understood. Need MSDS for activated material.	
.	015	Fuel cell electrical short	150 Amp maximum current damaging the membrane causing a hydrogen jet.	4	1	med	Plastic cover over battery terminals should be in place. Sandia looking at fusing the stack.	
RB	016	Fuel cell membrane fails and small deflagration occurs	Includes Item 15 plus dry membrane, failed pressure regulator, age, etc.	4	1	med	Manufacturer of membrane needs to provide information on the membrane.	Was (4,2). Likelihood revised to 1 as we now have sufficient ventilation and H2 detection.
.	017	Coal dust enters and damages fuel cell (deleted)	Not applicable	0	0	low		
JA	018	Electrical cable falls on equipment		5	1	low	No additional risk for operator compared to battery loco. Recovery operation will need to account for F.C. Loco. See item #2.	No changes
.	019	Hydrogen system damaged by welding		4	2	high	See Item #3. Before any welding, the hydride bed should be removed and the system purged with nitrogen. Pressure testing of the entire system.	

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	020	Shrapnel damages hydrogen	From internal or external equipment damage causing flying metal. Generates large jet of fire.	4	1	high	See Item #3 and #12. Roots Blower is 2800 RPM.	
.	021	Shrapnel damages fuel cell	Small Jet fire would occur.	2	1	high	Fuel Cell design is in segments resulting in less damage.	
RB	022	Major damage to hydrogen container	Movement of Hydride Bed causing puncture and immediate release of hydrogen.	5	2	med	See #9. No immediate explosion since hydride bed has no air source. The concern is release of free hydrogen through the puncture into a dead area. Therefore, only transport the hydride bed in well-ventilated area. Ventilated protective frame for transport.	No changes
GD	023	Vehicle impact damages hydrogen container	Runaway condition, operator error when coupling cars, derailment	4	2	med	See Item #3. Vibration effect on F.C. from coupling cars unknown. Rubber mounts are in design as is impact specs (35 mph impact), etc.	No changes
.	024	Black Damp (CO)	Oxygen deficient atmosphere in unventilated headings causing damage to F.C. Or caused by fire using available oxygen.	1	1	low	F.C. is oxygen starved and electrical output will diminish. Need more information from supplier on effect of CO. See #1 for source of CO.	
.	025	Exposure to high acid water	General Corrosion	2	1	med		
.	026	Flooding of mine		2	1	med	See Item #22. Possible shock to personnel. Need more information on flooding at Campbell Mine.	
TD	027	Roof collapse / Fall of ground	Large release of hydrogen resulting in explosion or asphyxiant condition.	5	2	low	Check and scale drift where demo is going to be.	No changes
TD	028	Bump / Vibration / Seismic event		5	2	med	Loco in haulageway which is not in the stress zones.	Was (5,2). Seismic monitoring in place.

Project: Fuel Cell Locomotive Risk Log: Fuel Cell z 2002-09-10

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	029	Vehicle left in operation and runs out of fuel		4	1	low		
.	030	Vehicle operated in sub 2% methane		1	1	med	Campbell Mine has some procedures for virgin ground and measuring Methane, but not for established mine areas.	
BD	031	Steel on steel generates sparks (rail or worm gear) and fire starts		5	1	high	See #9 and #114. Loco has to be moving and H2 rises, so likely that H2 will not buildup.	No changes
.	032	Static electric sparking during hydrogen re-fueling		5	1	med	Must be well-ventilated. Procedure will be to use grounding	
.	033	Sparks with ventilation fans	There are 4 non-sparking radiator fans on the F.C.	5	1	high		
BD	034	Sparking from sulphide dust causing hydrogen explosion		5	2	low	Sulphide explosions are related to blasts, but sulphide dust could be associated with the ore passes.	No change in risk from conventional mining.
.	035	Sparks from muck dumping		3	1	med	See #9. However, the loading/unloading is in ore pass/dumping station which is well-ventilated. Pockets in the back could be set off by sparks causing flash burns.	
.	036	Locomotive derailment		4	2	med	See #23. No rollover (180 deg) potential due to the dimensions of the drift.	
.	037	Failure of universal joint causing impact with FC		4	1	high	See #20. 1/4" aluminum plate under the fuel cell and a 1/2" aluminum plate under the hydride bed.	
TD	038	Smoking near FC or hydrogen tanks		5	2	med	See #9. Human factors are involved resulting in a likelihood ranking of 2.	No changes

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
GD	039	Traction controller failure	Overspeed or loss of braking.	4	2	med	See #23 and #41. Battery Electric Safecon 2000 traction controller from South Africa.	No change. Two manual brakes are available, plus power KILL switch.
RB	040	Failure of fuel cell controller	Small leak of H2 through the F.C.	5	1	low	Fuel Cell is "self healing": if there is no power required, the energy production stops. Purging could happen continuously. Sandia will investigate the amount of H2 released during a purge. See item #9.	No change. PLC review done; KILL switch hardwired.
.	041	Loss of power and impact on braking	Primary brakes are hydraulic and emergency brake is mechanical.	4	2	low	Loco has a mechanical brake for level grades. Need more information on what happens to braking and speed control on loss of F.C. or controller failure from Warren Muir.	
.	042	Hydride bed cooling water system failure during refueling	Can't re-fuel as quickly since the absorption of hydrogen slows down.	1	2	high	Eventually reaches a plateau temperature where the absorption stops.	
JA	043	Fuel cell cooling water system failure	Fuel Cell will burn up if no action is taken.	4	1	high	An operator is essential. Alarms on low water flow and high temperature indication. See #3.	Was (4,2). PLC monitors, controls, and alarms flows.
.	044	Loss of hydride bed to cooling water separation	Could result in vaporizing and venting due to overheating (steam) and overpressurizing .	2	1	low	Canister is jacketed with 1/8" cooling water annulus around the canister. The canister wall is 1/2" thick. See #14.	
.	045	Maintenance of Loco/Power plant while power plant in operation	Shock; H2 Leak; Manifold damage	4	2	med	May need to troubleshoot traction controller with power pack on.	
.	046	Failure of 48/24 DC/DC converter for start mode.	48/24 VDC converter fails during start mode and turns stack into a battery.	1	2	high	Cooling pumps, hydrogen supply solenoid fail and shuts down the system.	

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	047	Traction controller feeds current into fuel cell.	<116V, the traction controller sees the F.C. as a battery and re-charges the battery.	4	1	low		
.	048	Air contaminants enter fuel cell system	Dust; Methane; CO; Sulphide; NOx; Aldehydes; Carbon; Heavy Metals; Ammonia	3	1	low	could foul reaction & vent hydrogen, or could react with hydrogen and cause the fuelcell to overheat. Worste case would cause a small hydrogen fire, or toxic emmisions	
JA	049	Failure of pressure relief of hydride bed	Explosion of Hydride bed during overheating; slow leak if it doesn't re-seat.	5	2	low	Three separate relief vents in parallel.	No change. Three PR devices set at 225 psi.
.	050	Hydrogen embrittlement of hydrogen supply system	Small crack.	2	1	med	Piping is stainless steel; canister is aluminum. See #13 or #21.	
.	051	Inertial weld failure on manifold aluminum SS/SS connections.	Slow Hydrogen leak	2	1	med	Dissimilar metals with different thermal expansion and corrosion properties. Verified with radiography and proof test. In addition, mechanical strength tests have been done.	
.	052	Transporting in vertical position	Battery leaking onto piping - battery is designed to be operated in any position. Fuel cell structure could come loose since there are only 4 bolts holding it down.	1	1	med		
.	053	Hydrogen buildup in dead air space resulting in explosion.		5	1	med	See #9.	
.	054	Hydrogen buildup in loco		4	1	med	Loco must be in well-ventilated area. Casing must be vented. Mechanical ventilation req'd. See #3	
RB	055	Vibration	could cause small hydrogen leak and fire	4	2	high		Was (4,3). Likelihood of 2 as we now have active detection.

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	056	Temperature cycling	same as 55, but less likely	4	2	med		
.	057	Pressure cycling	same as 56, but less likely because low pressure	4	2	med		
TD	058	Vandalism	Could result in violent fire if large leak put into system see #3	5	2	med	Secure unit in off-shift	No changes
TD	059	Maintenance Induced leaks	Probably potential for a small leak fire not a large leak fire	4	1	high	Three types of maintenance: 1) minor piping -- break disconnects and purge system (FC/HB on board) 2) mechanical pumps, etc -- FC/HB removed, work performed on surface 3) Loco problem -- FC/HB removed, secondary source of power	Was (4,2). Mainteance procedures in place, trained personnel will be used.
JA	060	Failure of pressure regulator	Result would be a large explosion of hydride bed?	5	1	med	Regulator set at 5-7 psi. Overpressure release valve set at 7psi. Suggest HAZOP review when P&ID available.	Was (5,2). 23 psia pressure switch set at 20.9 psia in PLC.
.	061	Dropping hydride bed during handling (See #22)		0	0	low	See Item #22. Lifting lugs req'd on HB.	
TD	062	Dropped hydrogen bottle while handling	Potential for Fire	4	2	low	See Item #3	No change.
.	063	Magnetic field exposure		1	1	low	Magnetic fields will likely not impact any of the electronics.	
.	064	Stray rock from ore chute	Could add to vibration, but that really is it as long as use at least battery box protection.	1	3	high		
RB	065	Failure of connection between hydrogen source and hydride bed	Hydrogen leak in open air, possibility for hydrogen fire on surface during refueling.	3	1	high	Surface area to be well ventilated. Tanks should be a distance away according to CGA G5.4. Check on battery capacity indicator.	Was (5,2). Ignition sources outside 5m radius; portable detector; outdoor ventilation; procedures developed.

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	066	Connection of wrong fuel to hydride bed	Could react with bed and possibly generate a fire or explosion	5	1	low	Need to find out what would happen if other fuels like accetyllene contact hydride or are put through fuelcell. Check on different fittings/connectors.	
.	067	Failure of cooling system at refueling station (see #42)		0	0	low	See #42	
TD	068	Physical characteristics of fuel cell loco differ from battery loco	Could cause operator to not stop quick enough, or tip over more easily.	4	2	med	See #23. Use ballast to keep weight and CofG same as original loco.	No change. Ballast installed by CANMET.
.	069	Physical contact with hydride	Could cause burns or damage to eyes.	3	1	low	Hydride canisters are sealed, they would have to be severely damaged to expose hydride material. Need MSDS for HB.	
GD	070	Contamination by air of the hydride bed	Air in the hydride bed could cause the bed to generate heat and release hydrogen causing a fire or explosion	4	2	low	Not sure what would happen to hydride bed. Need MSDS for HB.	No changes. Procedures and training in place to minimize air infiltration to HB.
.	071	Burns from hot surfaces		2	1	high	ANSI Z21.83 1988, p32 indicates max 66 deg. C for metal contact.	
.	072	Overheating of FC		4	2	low	See 16, 43.	
.	073	Invisible hydrogen flame (deleted - not risk)		0	0	low		
.	074	Can't smell hydrogen (deleted - not risk)		0	0	low		
.	075	Lightning during refueling		5	1	med	Obtain portable lightning indicators/detectors.	
GD	076	Reaction of ammonia or afterblast chemicals	could foul reaction & vent hydrogen, or could react with hydrogen and cause the fuelcell to overheat. Worste case would cause a small hydrogen fire, or toxic emmisions	5	1	low	See 48. ACTION: what is effect of chemicals (ammonia, etc) as possible contaminants to cell?	No change

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	077	Failure of air supply to the fuel cell, hydrogen escapes from fuel cell		5	1	low	Sandia - If the hydrogen doesn't react will it leak through the fuelcell and be vented?	
.	078	Reaction of H2 with mine environment gases or particles	Could initiate an explosion	5	1	low	See 76, 48. Can use Hydrogenics as an info resource.	
BD	079	Sparking from handheld radios	Could initiate an explosion	5	1	high	Similar to 9, 31, 32, 33. Methane-safe radios are available in last few years. Check what Campbell mtce people carry.	Was (5,2). Test area will be well ventilated with adequate ventilation.
.	080	Radio wattage (see #79)	?	0	0	low	See 79	
.	081	Failure of mine ventilation	Greater chance of hydrogen explosion	5	1	high	ACTION: calculate/confirm ventilation requirements for the Campbell demo.	
GD	082	Failure of power pack ventilation	Greater chance of hydrogen explosion	3	1	high	See 81. Shutdown fuel cell if ventilation fails.	Was (5, 2). PLC monitors radiator fans, temps, water flows. Failure of ventilation would result in system shutdown.
.	083	Leakage through H2 valve stem packing	Leakage through Teflon seal, but not likely from the stem. Could have a hydrogen flow even with system purged. If solenoid and manifold valve fail, electrocution is possible.	5	1	low	Three ball valves (manual) are hydrogen compatible. See #9 for the slow leak scenario.	
.	084	Impact of Diesel	Diesel particulate and emmisions react in fuelcell cause overheate / hydrogen venting	5	1	low	See 48, 78	
.	085	Drying out of the fuel cell membrane		4	2	low	See #16	

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
GD	086	Freezing of the fuel cell.	Could damage hydride or fuelcell resulting in hydrodgen fire. Damage to membrane and deflagration.	4	2	med	See #16.	No change. Site spec and shipment procedures limit exposure to sub-zero conditions.
TD	087	Damage by pressure washing or minewater	Damage by pressure. Damage by water ingress.	4	1	high	1) Use compressed air and cloths for cleaning. 2) Review system for water resistance.	Was (4,5). No pressure washing allowed. CANMET has defined maintenance procedures.
RB	088	Operator error with interface		5	1	high	Choose competent operators. This is a work in progress by Sandia. Should be fairly automated.	Was (5,2). Interface review done. PLC review done. Only one trained operator will be used.
GD	089	Failure to follow startup and showdown procedures (isolation valves)	Vent hydrogen and cause fire or explosion	5	1	high		Was (5,2). Trained personnel with checklists will be used.
.	090	Ignition of hydride bed	Likely just burn, possible explosion	4	1	med	See #14, 69, 70	
.	091	Mechanical damage of membrane	small hydrogen fire	4	1	high	See #16.	
GD	092	Effect of prolonged shutdown on startup		5	2	med	Shutdown procedure is developed for 2-3 day shutdown, but needs revision to insert and remove plugs that are no good.	No change. Procedures developed for short-term and long-term shutdown.
.	093	Nitrogen buildup in dead air space		4	1	med		
.	094	Emissions from burning fuel cell	Plastic membrane releasing toxic gases	5	1	low		
.	095	Emissions from fuel cell due to contaminants in U/G air		1	1	low	See #48	
.	096	Electrical shocks from fuel cell during operations.		4	1	med		
.	097	Uncontrolled pressure release (whipping, debris)		3	1	med		

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	098	Noise		1	1	med	If blower is noisy, insulate? CANMET to perform sound measurements.	
.	099	Overheating due to air blower plugging up.		5	1	med	See # 2, keep filter clean. Add to daily mtce procedures.	
JA	100	Debris in female side of quick disconnect (on fuel cell side) resulting in poor connection and H2 leak	Large Jet	3	2	high	See #3. The connector design is poor and it is probable that particulate will contaminate the female connector	Was (3,3). H2 detector used on-board, plus portable H2 detection.
.	101	Personal hazard from vacuum		1	1	med	Protected by filter?	
.	102	Hot exhaust gases		2	1	med	Venting underneath loco. Approx exhaust 80C, 100% RH.	
.	103	Failure of aluminum support structure	Dead Short; Manifold weld or line break.	4	1	med	See #15 for short; See #3 for weld break.	
.	104	Sharp edges		1	3	med		
JA	105	Poor design of pipe length; diameter ratios.	Explosion due to hydrogen not dispersing plus an ignition source.	5	1	med	See #9	No changes.
.	106	Slippery conditions or burns from water tank overflow		2	1	high		
.	107	Manhandling of hydride bed		3	2	high	develop procedures. Approx weight 1000 lbs.	
.	108	Pinch points		3	2	high	develop procedures for handling hydride bed. See #107.	
.	109	Blower sucking in hydrogen		4	1	low	Evaluate	
.	110	Location of the discharge vents for dispersion (delete - move to Parking Lot)		0	0	low	Moved to Parking Lot.	
RB	111	Stray currents		5	1	low	ACTION: ensure no stray currents at demo location.	No changes.

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	112	Electrocution		4	1	med	see #96.	
BD	113	Failure to purge FC with nitrogen before maintenance to de-engergize it.		5	1	high	procedures and labels	Was (5, 2). Procedures and training in place.
JA	114	Arcing sources		4	2	med	See #3 - identify and isolate. Ensure HB removed if any welding to be performed.	No changes.
.	115	Grounding of the stack		4	2	low	See #15.	
.	116	Rotating parts		2	1	high	Coupler exposed between blower and blower motor. Covered by shroud.	
.	117	Damage from debris from road travel		4	1	high	Protect during shipping - Inspect and test at arrival. See #37.	
.	118	Dropping of the hydride bed causing personal injury		3	2	med	Handling procedures, see #107, #108	
.	119	Sparks with ventilation fans (battery bay)	Battery Bay (was #33b)	5	1	low	Continuous ventilation required and the fan cannot be in the bay. See Item 53.	
.	120	Sparks with ventilation fans (mine vent fans)	Mine ventilation fans (was #33c)	4	1	low	Vent fans are distant which will allow H2 to dissipate	
.	121	Hydride bed cooling water system failure during refueling	Operator could mis-diagnose problem and cause another problem. (Was the second #42a)	4	1	med		
.	122	Hydride bed heating water system failure	On operating loco, the reaction shuts down. (Was #42b)	1	2	high	See #3, but likelihood of occurrence mitigated since refueling is outside.	

Risk Owner	Risk #	Risk Name	Risk Statement	C	L	Prec	Risk Narrative	2002-09-03 reassessment notes
.	123	Failure of 150/24 Dc/DC converter for run mode	150/24 VDC converter fails in run mode. The blower could keep running at full speed with the cooling water stops. (Was #46b)	4	2	high	Cooling pumps, hydrogen supply solenoid fail and shuts down the system.	
.	124	Failure of 150/48 Dc/DC converter for battery charger	Fuse might fail. Battery may overcharge and explode. (Was #46c)	3	1	high	See #5	
.	125	Failure of 24/5 DC/DC converter for blower control	Fuse might fail. Current limiting. Blower may malfunction. (Was #46d)	3	1	high		
.	126	Failure of 24/ +-15 DC DC converter for total stack current monitoring	Monitor is used for performance monitoring, not control. (Was #46e)	1	1	high		
.	127	Hydrogen buildup in dead air space resulting in asphyxiation	(Was second #53)	5	1	med		
.	128	(unused)		0	0	low		

Risk Analysis of Fuelcell Operating Procedures

- Risk Matrix (Revised)

- Risk Log (Revised)

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Project: Fuelcell Loco Operation   Risk Matrix: All Open Risks   2002-09-06

Risk #	Risk Name	Prec	Owner
039	Add proc. Step to cool H.B	low	.

Risk #	Risk Name	Prec	Owner
016	Move data to be monitored to same F.P.D Screen	high	.
040	Investigate Argon shipment regs.	low	.

Risk #	Risk Name	Prec	Owner
001	Relocate Breaker	high	.
020	Add proc. Step to add D.I. water if blue light	high	.

Risk #	Risk Name	Prec	Owner
003	Add Typical T. Ranges to Procedure	high	.
008	Integrate Meas. Vs Expected	high	.
011	Develop procedure for actions on Bat. Failure	high	.
035	Develop a fuel gauge system	high	.

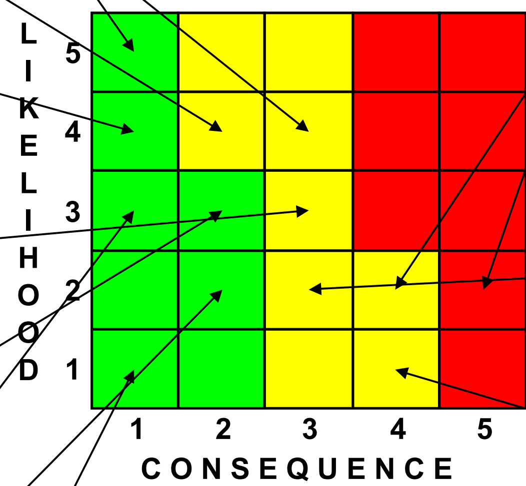
Risk #	Risk Name	Prec	Owner
028	Develop P.P.E. requirements for servicing	med	.
029	Install holders/restraints for connectors	high	.

Risk #	Risk Name	Prec	Owner
017	Enable radiator code in PLC to turn on at 35°C	high	.

Risk #	Risk Name	Prec	Owner
010	Feedback to Operator successful pwr. Switch	high	.

Risk #	Risk Name	Prec	Owner
009	Timed Open on Purge (s) Controlled by PLC button	high	.
018	Investigate effects of transient/throttling loads	low	.
021	Integrate "PWR" shut-off with water pump shutoff (.2 & .3 together)	high	.

Risk #	Risk Name	Prec	Owner
007	Label Battery Do Not Boost	high	.
034	Ensure P(HB) and T(HB) displayed/available to personnel	high	.



Risk #	Risk Name	Prec	Owner
031	Define site refuel requirements (slings, vent, charging, cooling)	low	.

Risk #	Risk Name	Prec	Owner
002	"Mine Harden" Data Historian	high	.
004	Measure Site atm. pressure	high	.
015	Define storage and usage and shipping requirements regarding temp	med	.
022	Develop troubleshooting and maintenance procedures.	high	.
025	Move step 5.4.9 to after 5.4.17	high	.
027	Allow for external voltage check (See 5.4.11)	high	.
032	Develop Q.C. purge tee and procedure	med	.
033	Use H2 detector after all Q.C. connects	high	.
036	Determine press. Rating of Q.C's + hoses.	low	.

Risk #	Risk Name	Prec	Owner
037	Modify procedures to connect: (1) Gas H2 sniff, (2) Elect., (3) water (reverse for disconnect)	med	.
041	Develop suitable H.B. container and shipment procs.	high	.

Risk #	Risk Name	Prec	Owner
005	Label D.I. Water in	high	.
006	Check Light function (step in procedure)	high	.
012	Develop Temp. Control Strategy (ie. 30°C…)	med	.
013	Integrate required water flows into PLC	high	.
014	Integrate water temps into PLC	high	.
019	Define responsibility of who modifies PLC Code	high	.
023	Develop method to "Bleed" elect. From stacks	low	.
024	Modify PLC to empty plenum automatically.	high	.
026	Add overflow port to safe discharge	high	.
030	Investigate spark proof tools	low	.
038	Develop method to heat H.B.	high	.

Project: Fuelcell Loco Operation
Risk Log: All Open Risks

2002-09-06

Project: Fuelcell Loco Operation **Risk Log: All Open Risks** **Date: 17-May-2002**						Closure Method	Closure Status	Closure Comments	Revision Notes 2002-09-05
Risk #	Risk Name	Risk Owner	C	L	Prec				
001	Relocate Breaker	.	2	4	high				
002	"Mine Harden" Data Historian	.	4	2	high				
003	Add Typical T. Ranges to Procedure	.	1	4	high	LOCO Proc	DONE	Effective LFC-OP-01 Rev J. Sec 5.2.12	
004	Measure Site atm. pressure	.	4	2	high	LOCO Proc	DONE	Effective LFC-OP-01 Rev J. Sec 5.2.13	
005	Label D.I. Water in	.	4	1	high				
006	Check Light function (step in procedure)	.	4	1	high				
007	Label Battery Do Not Boost	.	1	1	high				
008	Integrate Meas. Vs Expected	.	1	4	high				
009	Timed Open on Purge (s) Controlled by PLC button	CANMET	2	2	high	LOCO PLC	DONE	Action by: P. Laliberté (CANMET)	Was (4,3). Purge is now time-controlled and purge vent disperses H2 gas
010	Feedback to Operator successful pwr. Switch	.	1	3	high				
011	Develop procedure for actions on Bat. Failure	.	1	4	high				
012	Develop Temp. Control Strategy (ie. 30°C…)	CANMET	4	1	med	LOCO Proc	DONE	CANMET will work with Nuvera to develop a warm up procedure	Was (4,5). Temps now controlled by PLC
013	Integrate required water flows into PLC	CANMET	4	1	high	LOCO PLC	DONE	CANMET will work with Nuvera and program into the PLC	Was (4,5). Temps now controlled by PLC
014	Integrate water temps into PLC	CANMET	4	1	high	LOCO PLC	DONE	To be done with #013	Was (4,5). Temps now controlled by PLC
015	Define storage and usage and shipping requirements regarding temp	Sandia	4	2	med	LOCO Proc	DONE	Effective LFC-OP-01 Rev J. Sec 5.7.16	Was (4,5).
016	Move data to be monitored to same F.P.D Screen	.	3	4	high			Action by: P. Laliberté (CANMET)	
017	Enable radiator code in PLC to turn on at 35°C	.	2	3	high			Action by: P. Laliberté (CANMET)	
018	Investigate effects of transient/throttling loads	VP/CANMET	2	2	low	LOCO Equip	DONE	VP/CANMET replaced controller	Was (4,4). Controller replaced.
019	Define responsibility of who modifies PLC Code	CANMET	4	1	high	LOCO Proc	DONE	CANMET (Pierre Laliberte) with guidance by Sandia.	Was (4,3). PLC logic effectively controlled by CANMET.
020	Add proc. Step to add D.I. water if blue light	Sandia	2	4	high	LOCO Proc	DONE	Effective LFC-OP-01 Rev J. Sec 5.3.5	

Project: Fuelcell Loco Operation
Risk Log: All Open Risks

2002-09-06

Risk #	Risk Name	Risk Owner	C	L	Prec				
021	Integrate "PWR" shut-off with water pump shutoff (.2 & .3 together)	CANMET	2	2	high	LOCO PLC	DONE	CANMET reprogrammed PLC	Was (4,4)
022	Develop troubleshooting and maintenance procedures.	CANMET	4	2	high	LOCO Proc	DONE	Troubleshooting: done. Maintenance: GD supplied copies of procedures to Hatch.	Was (4,4).
023	Develop method to "Bleed" elect. From stacks	CANMET	4	1	low	LOCO Proc	DONE	CANMET added resistive load.	Was (4,4)
024	Modify PLC to empty plenum automatically.	.	4	1	high				
025	Move step 5.4.9 to after 5.4.17	Sandia	4	2	high	LOCO Proc	DONE	Effective LFC-OP-01 Rev J	Was (4,3)
026	Add overflow automated valve to safe discharge	CANMET	4	1	high	LOCO Equip	DONE	CANMET will purchase and install a solenoid to control the overflow valve.	Was (4,4)
027	Allow for external voltage check (See 5.4.11)	.	4	2	high				
028	Develop P.P.E. requirements for servicing	.	3	3	med	LOCO Proc			
029	Install holders/restraints for connectors	.	3	3	high				
030	Investigate spark proof tools	.	4	1	low				
031	Define site refuel requirements (slings, vent, charging, cooling)	Sandia	5	2	low	LOCO Proc	DONE	Sandia procedure supplied. Assigned proc. Number LFC-OP-02, Rev B, May 28, 2002.	Was (5,4). Procedures defined and assessed
032	Develop Q.C. purge tee and procedure	.	4	2	med				
033	Use H2 detector after all Q.C. connects	CANMET	4	2	high	LOCO Proc	DONE	CANMET will use a portable detector after all connections.	
034	Ensure P(HB) and T(HB) displayed/available to personnel	.	1	1	high				
035	Develop a fuel gauge system	CANMET	1	4	high	LOCO PLC			
036	Determine press. Rating of Q.C's + hoses.	Hatch	4	2	low	LOCO Design	DONE	Sandia has supplied all spec sheets. Hatch has reviewed. Sandia will submit piping system to TSSA for registration.	
037	Modify procedures to connect: (1) Gas H2 sniff, (2) Elect., (3) water (reverse for disconnect)	Sandia	3	2	med	LOCO Proc	DONE	Effective LFC-OP-01 Rev J	
038	Develop method to heat H.B.	Sandia	4	1	high	LOCO Equip	DONE	Sandia shipped h/w and procedures to CANMET.	Was (4,4)

Project: Fuelcell Loco Operation
Risk Log: All Open Risks

2002-09-06

Risk #	Risk Name	Risk Owner	C	L	Prec				
039	Add proc. Step to cool H.B	Sandia	1	5	low	LOCO Proc	DONE	Effective LFC-OP-01 Rev J	
040	Investigate Argon shipment regs.	Hatch	3	4	low	LOCO Proc	DONE	Exempt from Transport of Canada Acts and Regulations	
041	Develop suitable H.B. container and shipment procs.	CANMET	3	2	high	LOCO Equip	DONE	Fabricated by CANMET	Was (4,4). Steel box now provided and shipment procs defined.