# Fuelcell Risk Assessment, Regulatory Compliance, and Implementation of the World's First Fuelcell-Powered Mining Equipment at Placer Dome – Campbell Mine

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ABSTRACT

The successful implementation of a new technology in an underground production mine requires many challenges to be overcome. These challenges include mine hardening of new technology, mitigation of safety risks and hazards, mine operation support, and technology transfer to mine staff. In the end, the majority of these challenges relate to the human aspects of implementation. The approach selected to overcome these challenges must be customized and appropriate for each unique situation.

This paper will outline the approach used to address these challenges as part of successful implementation and resulting demonstration of the hydrogen fuelcell locomotive at the Placer Dome – Campbell Mine.

# 1. Introduction

This paper outlines the regulatory and implementation approach utilized in the successful demonstration of the world's first hydrogen fuelcell powered locomotive at the Placer Dome – Campbell Mine. The fuel cell locomotive demonstrated in Figure 1, is the result of a large team effort of 12 companies listed in Tables 1 and 2 (Miller and Barnes, 2002).

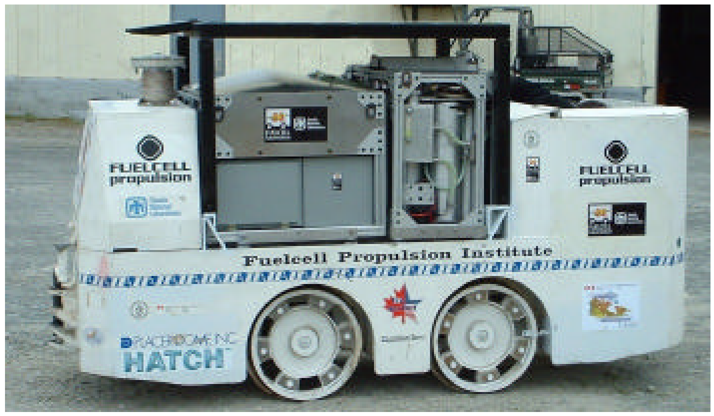


**Figure 1- Hydrogen Fuelcell locomotive**

**Table 1 – Fuelcell Locomotive Risk Assessment Team**

| 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, Regulatory compliance in Canada, Mechanical Engineering, Process Control and Automation 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. | Demonstration Mine Site, Technical Services Group |
| RA Warren Equipment Ltd. | Locomotive Manufacturer |

**Table 2 – Additional Locomotive Project Partners**

| Organisation | Area of Involvement |
|---|---|
| University of Nevada | Surface testing in Nevada |
| Stuart Energy Systems Inc | Vehicle refuelling |
| Nuvera Fuel Cells Europe | Fuelcell stacks |
| Kappes, Cassiday & Associates | Surface test site in Nevada |
| Fuelcell Propulsion Institute | Industry advising |

The Placer Dome, Campbell Mine was the selected site for the demonstration and is an underground narrow vein gold mine located in northwestern Ontario, Canada. The mine and mill currently employs approximately 350 people and produced 178,139 ounces of gold in 2001.

The objectives of the fuelcell demonstration at the Placer Dome – Campbell Mine were as follows:

- Safely demonstrate the successful operation of a hydrogen powered fuelcell locomotive in a production situation;
- Determine the regulatory and operational requirements for incorporation into future fuelcell mining equipment;
- Determine technical and soft issues critical for future fuelcell applications; and
- Determine the level of market acceptance for a fuelcell in an underground mine.

Prior to testing the fuelcell locomotive at Campbell Mine a great deal of effort was completed. This effort and results of Campbell tests are outlined in the following papers…………..also presented at the 2003 CIM AGM in Montreal.

As with the development and introduction of any new technology into a mining operation, there are many challenges to overcome to improve the probability of success. Challenges include mine hardening of new technology, mitigation of safety risks and hazards, mine operation support, and technology transfer to mine staff. In the end, the majority of these challenges relate to the human aspects of implementation with safety being paramount in all areas. The approach selected to overcome these challenges must be customized and appropriate for each unique situation with the specifics for the locomotive outlined in the following sections.

# 2. Risk Management

As with all aspects of mining operations, health and safety is the number one priority. One of the more challenging aspects of implementing a new technology is addressing both the perceived and actual health and safety risks. Addressing the perceived risks early in a project is critical such that knowledge and facts are considered instead of initial incorrect perceptions.

For new equipment such as a fuelcell locomotive, existing regulations and standards for underground mines usually do not specify requirements. In cases such as this, significant effort is required for hazard identification, risk assessments, reviewing pertinent legislative requirements, available industry standards and codes, and ensuring good engineering practice. These investigations, reviews, and consultations include input from a wide range of people in fields including research and development, manufacturing, mining operations, regulatory bodies, and engineering consulting. Through this multi-discipline approach all aspects of design, safety and operations of the equipment can be addressed. This handles both the perception and actual risks.

## 2.1 Overview of risk management process

Project risk management utilized follows the framework and process defined by the Project Management Institute (Project Management Institute 2000), and consists of the following steps:

- **Risk Management Planning** focuses on deciding how to approach and plan the risk management activities for a project. It establishes the context by defining the objectives, identifying the stakeholders, defining the criteria against which risks will be evaluated and defines the structure for the analysis.
- **Risk Identification** involves identifying which risks might affect a project and documenting their characteristics. Basically risk identification answers the questions what can happen and how could it happen.

- **Qualitative Risk Analysis** consists of performing a qualitative analysis of the risks identified during risk identification to prioritize their effects on project objectives. The risks are analyzed in terms of existing controls, likelihood of occurrence, severity of impact, precision with which the risk is understood, intervention difficulty, and risk level.
- **Quantitative Risk Analysis** involves estimating the probability of occurrence and severity of impact of hazards in quantitative terms and estimating their implications for project objectives. During quantitative hazard analysis, the risks are evaluated and ranked and minor risks are screened out.
- **Risk Response Planning** develops procedures and techniques and defines activities to respond to risks threatening project objectives. For major risks, risk response options are identified, the best option is selected and detailed risk response plans are developed and implemented. Low priority risks are accepted and monitored.
- **Risk Monitoring and Control** is the ongoing monitoring of residual risks (after implementation of risk response plans), identification and analysis of new risks, execution of risk response plans and evaluation of the effectiveness of the risk response plans throughout the project life cycle.

## 2.2 Project Risk Management Activities

Placer Dome Technical Services initiated the planning for risk management. During the summer of 2001, Placer Dome organized a facilitated risk-planning workshop to identify risks, qualitatively assess the risks, and develop a risk response plan. Note, this workshop did not include a quantitative risk analysis. The workshop participants listed in Table 1, had the required range of expertise to consider all aspects of the locomotive, fuelcell, regulatory, and mining. The workshop was conducted over a two-day period with additional follow-up teleconferences.

First workshop requirement was for participants to agree on the project-specific risk management parameters. These parameters are used throughout the analysis and form the basis of the qualitative scales. The critical project success factor to be considered was Health and Safety of test operators and mine personnel during the locomotive demonstration at Campbell Mine. The probability or likelihood was described as either a "times per year" frequency or a probability. The Health and Safety impact was described as ranging from "first aid" to "multiple fatalities." The assessment scale used for the workshop is shown in Table 3.

**Table 3 – Risk Analysis Assessment Scales**

| **Risk Analysis Assessment Scales** | | | | | |
|---|---|---|---|---|---|
| **Numerical Rank** | **1** | **2** | **3** | **4** | **5** |
| Qualitative Description | Very low | Low | Possible | High | Very High |
| **Probability / Likelihood** | | | | | |
| Qualitative Description | Rare, very unlikely | Unlikely, but not impossible | Moderate, just as likely as unlikely | Likely | Almost certain, will probably arise |
| Frequency (times/year) | <1/100 | 1/100-1/10 | 1/10-1/1 | 1/1-10/1 | >10/1 |
| Probability | 0.0-0.2 | 0.2-0.4 | 0.4-0.6 | 0.6-0.8 | 0.8-1.0 |
| **Health and Safety Consequences/Impact** | | | | | |
| Qualitative Description | Negligible | Minor, easily remedied | Moderate, some objectives affected | Major, most objectives threatened | Catastrophic, most objectives will not be met |
| People | First aid | Medical aid | Disabling injury | Single fatality | Multiple fatalities |

Risk identification was performed using the what-if/checklist technique (The Center for Chemical Process Safety 1992). This technique combines the creative, brainstorming features of the what-if analysis technique with the systematic features of the checklist analysis technique. It takes advantage of the strengths and reduces the impact of the weaknesses of the separate techniques. Participants at the workshop created a list of risks on a flipchart. Examples of risks identified included "derailment", "rail-wheel sparking", and "control system failure". A total of 127 Health and Safety risks were identified.

For each risk, the Health and Safety impact and the likelihood of occurrence were estimated using the scales agreed to during risk management planning. Three risk examples are outlined in the following table:

**Table 4 – Examples of risks from workshop**

| Risk | Impact | Likelihood |
|---|---|---|
| Derailment | 4 | 2 |
| Rail Wheel sparking causing ignition | 5 | 1 |
| Control System Failure | 4 | 2 |

Following the workshop and subsequent teleconferences, the risks and the qualitative analysis data were presented in a matrix format using specialised software. As with any risk management software, the use of it allows for improved tracking, reporting, and maintenance of risks.

**Table 5 – Likelihood and Impact Matrix**

| **Likelihood-Impact Matrix** | | | | | | |
|---|---|---|---|---|---|---|
| **Likelihood** | | **Impact** | | | | |
| | | **1** | **2** | **3** | **4** | **5** |
| | | **Negligible** | **Minor** | **Moderate** | **Major** | **Catastrophic** |
| **5** | Almost Certain | Medium | Major | Major | Extreme | Extreme |
| **4** | Likely | Minor | Medium | Major | Major | Extreme |
| **3** | Moderate | Minor | Medium | Medium | Major | Extreme |
| **2** | Unlikely | Minor | Minor | Medium | Medium | Major |
| **1** | Rare | Negligible | Minor | Minor | Medium | Major |
| (green) | No action required | | | | | |
| (yellow) | Manage as second priority, | | | | | |
| (red) | Immediate action required prior to proceeding with demonstration, manage as first priority | | | | | |

Based on the risk matrix, the project management team was able to develop Risk Response Plans to mitigate risks deemed unacceptable. Of the 127 risks identified, 40 required action plans to mitigate the potential risks. These action plans were appropriate to the severity of the risk and realistic to the project context. Depending on the nature of the risk, some of the actions required design changes to the equipment, some required procedures to be developed, and some required further investigation.

The following risk assessments were completed as part of the Pre-development Review (PDR) process;

- Fuelcell Unit and Hydride Bed;
- Fuelcell Operating Procedures such as start-up, shutdown, and maintenance;
- PLC control logic onboard the fuelcell unit.

Once the action plans were completed, the risks were revisited to ensure that the consequences, likelihood, and risk ranking had, indeed decreased the risks to acceptable levels. Risk monitoring and control was performed during the on-site implementation detailed in the following Section 4.

# 3. Regulatory

The Ontario Occupational Health and Safety Act (OHSA) Regulations for Mines and Mining Plants requires that a mine perform a PDR before new technology is implemented. The review must include a review of the design, plus a review of the pertinent existing regulations, codes, and standards.

Hatch undertook investigations and consultations to assess the applicable regulations and industry standards for the introduction of this new technology into mining. The participants of the risk analysis workshops identified a number of standards to consider, with additional standards identified during an extensive investigation.

The following regulations were determined to be applicable:

- 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".

Standards from the following organizations were reviewed:

- Compressed Gas Association (CGA);
- National Fire Protection Association (NFPA);
- Society of Automotive Engineers (SAE);
- US Government Code of Federal Regulations (CFR);
- American National Standards Institute (ANSI); and
- American Society of Mechanical Engineers (ASME) – Boiler and Pressure Vessel Code.

All applicable regulations and standards were reviewed and compliance documented. The regulations and standards compliance documentation were compiled with the risk assessments to complete the PDR (Hatch 2002) as required by the Ontario Occupational Health and Safety Act and Regulations for Mines and Mining Plants.

This work formed the initial basis for the implementation of the tests on site at Campbell Mine.

# 4. Implementation

Implementation does not need to be the most challenging aspect of a project as it typically is when introducing new technology, approach or equipment into a mining operation. The success of an implementation depends on how the following factors are approached:

- Support of mine staff and management,
- Perception of project,
- Safety aspects,
- Timing of mine involvement,
- Knowledge of technical aspects,
- Understanding and buy-in to goals of project,
- Ability of project to add value to operation,
- Communication between overall team, and
- Planning and support.

The challenges of implementing technology is well documented by others including (Willis and Campbell 2001; and Dessureault et al. 2000).

The following sections outline how the above factors and others were considered for the Placer Dome - Campbell Mine demonstration.

## 4.1 Early Preparations

### *4.1.1 Selection of Mine for Demonstration*

The Placer Dome - Campbell Mine was selected for many reasons including support from mine management, and support from mine staff based on early involvement, support from Corporate Technical Services Group, and the mine presently use the same size locomotive and track gauge.

The involvement of the mine at a very early stage was a contributing factor to the success of the project. Terry MacKinnon, Health and Safety Supervisor for Campbell Mine participated in the initial risk analysis workshop at the beginning of the risk assessment process. He in turn became the site champion and maintained the communication with the mine staff about project developments and voiced their concerns.

### *4.1.2 Consistent and informed team*

As previously highlighted, one of the key factors to a successful demonstration is the health and safety knowledge and preparations that formed the basis of the PDR. By maintaining the same team that completed the PDR for the Campbell Mine demonstration, the information and knowledge in the PDR about the standards, engineering “best practices”, risks, and risk mitigation plans was vital to answer questions and alleviating concerns of Campbell Mine staff. If the continuity wasn’t present, the lack of familiarity with the PDR could have inadvertently caused doubts about the safety of the new technology. These doubts could cause false perception to become fact in the minds of some staff and incorrectly reduce project support.

## 4.2 Preparations for tests at Campbell Mine

### *4.2.1 Initial visit to Campbell Mine*

Six months prior to the scheduled test of the locomotive, the Hatch PDR team conducted the initial site review and meetings with Campbell staff. This visit included:

- Hatch presented overview to Campbell team of fuelcell locomotive project along with remaining action items,
- Hatch PDR team discuss project Campbell team and answer questions and concerns,
- Identified procedures required,
- Mine tour and review of potential test sites and surface refueling locations,
- Specific requirements for tests discussed such as ventilation, etc.,
- Preferred location for test and refueling selected,

Following this initial visit, there were a number of action items for both Hatch and Placer Dome in preparation for the hazard assessment.

### *4.2.2 Hazard Assessment of Campbell Mine test location*

Two months prior to the tests, a hazard assessment workshop (HAZOP) was conducted on-site at Campbell Mine. This workshop included Campbell team members in the following areas: maintenance staff, hoistman, cage tender, production supervisor, and health-safety. This workshop started with a detailed presentation on the project and the PDR that was in process along with any preliminary information about the test plan at Campbell Mine. The workshop included all aspects of the locomotive demonstration starting from arrival of the equipment, operation, storage, refueling, dismantling, transport of equipment in cage and suspended in shaft, and finally dismantling and shipping equipment off site.

Following the HAZOP, Hatch and Placer Dome continued to work closely in resolving outstanding action items, confirming logistics, and test schedule. A PDR was completed for the overall test demonstration and submitted to the Ministry of Labor.

It is important to state that communications between the site meetings and workshops is critical both in terms of keeping information up to date but also to maintain the project momentum.

Initial testing of the locomotive was completed prior to shipment to the Campbell Mine. This initial testing reduced the number of commissioning problems with the prototype prior to arrival at Campbell Mine.

## 4.3 Demonstration of Fuelcell Locomotive

During the days leading up to the start of the actual demonstration tests at Campbell, Hatch conducted presentations and discussions with all underground crews including service and maintenance at Campbell Mine. These sessions included all crews for both day and afternoon shifts for a total of approximately 10 sessions (Graves and Eastick, 2002). The reason for these sessions were to increase awareness of the tests and provide answers to questions and concerns.

During the demonstration period, CANMET staff operated the locomotive with Placer Dome and Hatch team members providing logistic support. This support was through integration with operations along being available should a technical or safety issue arise. A picture of the locomotive underground at Campbell Mine during the demonstration is shown in Figure 2.

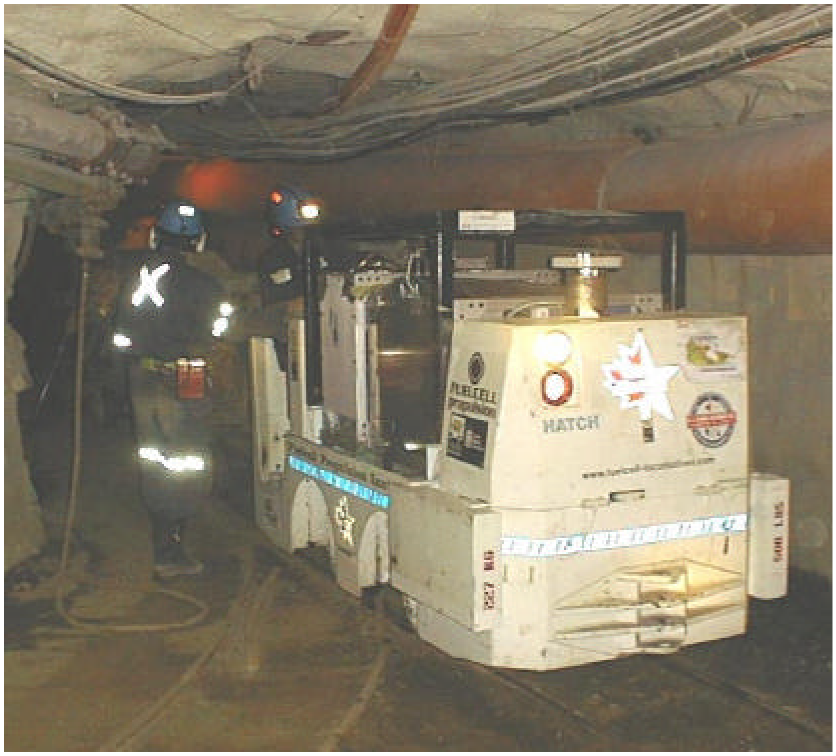


**Figure 2– Hydrogen Fuelcell locomotive underground at Placer Dome – Campbell Mine.**

As outlined in (…test result paper???……..2003) the tests were a success both technically and with no safety incidents. The greater than expected muck tramming rate resulted in a "lack of muck" situation. It should be stated that the safety and ventilation aspects of the selected location were a priority compared to selecting a location based on availability of muck for transport.

## 4.4 Opportunities for Improvements

Overall the regulatory review and implementation was successful. However, with any R&D project such as this there should always be possible improvement suggested for future such projects.

- Effort for regulatory review and compliance could have been reduced if it was considered earlier in the project;
- The ability to refuel hydride bed underground would have been a closer comparison to present day locomotive operations.
- Reduced ventilation requirements through design modifications would have resulted in a greater number of potential test areas.

# 5. Conclusion

As outlined in this paper, there are many critical aspects to consider when introducing an R&D project into a mining operation such as Campbell Mine. The success of the implementation was largely based on how the following aspects where handled, mine hardening of new technology, mitigation of safety risks and hazards, mine support, communications between team members, and technology transfer to mine staff. The approach selected to overcome these challenges must be customized and appropriate for each unique situation. In the end, it is clear that successful implementation depends probably more on human aspects then the technical performance.


# 6. Acknowledgements

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