


The Green Mining Vehicle – Green Energy Road Map


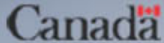

M.C. Bétournay

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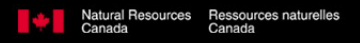

Immediate Issues and Opportunities

Underground

- Green House Gases (GHG): 1.0 MT/year of underground CO₂ eliminated from the 3.7 MT/year underground + open pit mining
- Health: Fuel cells offer a total solution, noise generation, vehicle heat load in deep mines, as well as eliminating all emissions
- Operating Costs
 - ventilation costs (savings of 10% in site electrical and energy bill, ~0.3-1.9 \$M/year)
 - diesel equipment, maintenance, downtime, automation vs fuel cell lower maintenance costs, higher reliability
 - automation, tele-remote operation improved
- Momentum is building for all-electric mining vehicles

Surface

- Reduce contaminant load (DPM, NO_x, SO₂), improve air quality
- Compliance with EPA Tier 4



Road Map Objectives

- Within 3 years provide industry with proven and regulated turnkey electric power replacements for underground diesel mining vehicles
- Take advantage of related energy efficiencies (ventilation, vehicle controls, electric motors)
- Address mine type and mine specific energy mix options
- Pre-competitive partnerships between equipment manufacturers
- Carry out consultations with regulatory agencies and trade unions



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Main Issues With Clean Energy Solutions

Clean Diesel	
Low capital cost	Pollutants
Universally accepted	High ventilation
Flexible application	Highest heat release


Diesel-Battery	
Low pollutants	Moderate capital cost
Reduced diesel consumption	Moderate ventilation
Flexible application	Moderate heat release

Fuel Cell-Battery	
No pollutants	Safety issues
Lower ventilation	Fuel cost
Flexible application	High capital cost
Little heat release	


Lithium-Ion Battery	
No pollutants	Maintaining charge
Lower ventilation	Time in service
Flexible application	Highest capital cost
Little heat release	Limited industrial application


Clean Energy Application Readiness




Fuel cell-battery




Lithium ion battery



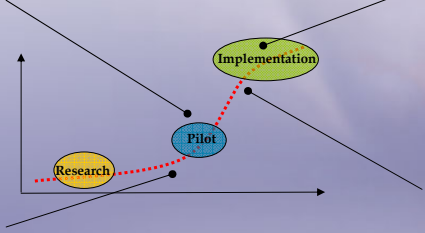
Clean diesel




Diesel Hybrids




Research Pilot Implementation





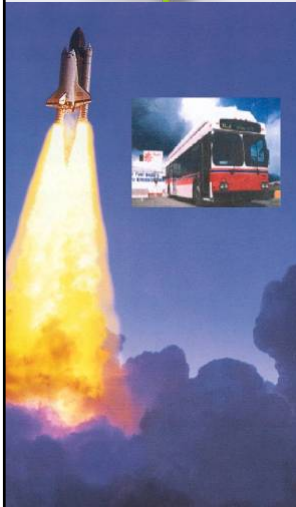
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Hydrogen Technology - Current Applications



- space missions
- submarines
- city buses
- large power plants
- residential
- fork lifts, switchyard trains



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Hydrogen Mine Initiative, Underground

Proof of Concept Projects

- Impact of underground environment on fuel cells (C)
- Mine vehicle duty cycles (C)
- Risk evaluation methodology (C)
- Cost-benefit analysis (C)
- Mine production locomotive \$2.4M (C)
- Locomotive automation design, long-term testing (C)
- Mine production loader \$13M (C)
- Light duty mine vehicle

Introduction Projects


- Hydrogen production and delivery (S)
- Commercial hydrogen production
- Mining regulation development (S)
- Partial fleet testing at a mine site
- Maintenance training program

C=completed S=started

POWER RANGE


Underground Vehicles

- Mine loco 15-75 kW
- Light duty 50-100 kW
- LHD 150-300 kW
- Truck 300-500 kW









Open Pit Hydrogen Power Application Considerations

Proof of concept studies:

- Storage and refuelling infrastructure
- Risk, safety, regulations
- Cost-benefit

Power plant aspect studies:

- Duty cycles
- Hybrid architecture
- Regenerative braking
- Power train and motor configurations
- Hydrogen storage
- Operation period
- Refuelling time

↔


Test Vehicle (retrofit):

- Production application

↓

Final mine regulations:


- Test vehicle performance
- Supplement u.g. regulations
- Safety and training



POWER RANGE

Open Pit Vehicles

Light duty	200 - 300 kW
Loader	200 - 1,100 kW
Tractor	185 - 630 kW
Truck	745 - 3,000 kW





Fuel Cell-Rechargeable Loader Testing

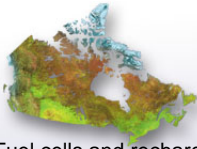


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Loader Design Basis

- Fuel cells and rechargeable batteries
- 14 kg, 8 hour shift duration
- Metal hydride hydrogen storage
- Programmable PLC's for functions, central operator control
- 15 min. refueling
- 15% ramp travel
- Continuous and peak power availability
- Resistance to dust, shock and vibration

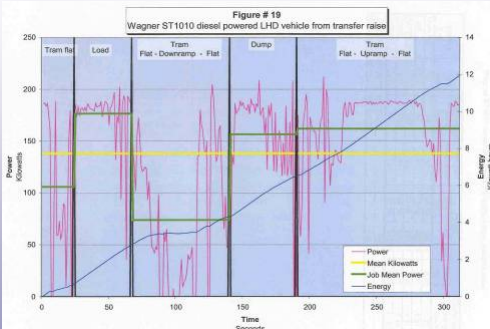
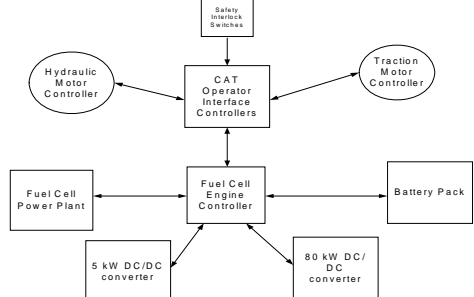



Figure # 19
Wagner ST1010 diesel powered LHD vehicle from transfer raise



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    graph TD
      FC[90 kW Fuel Cell Stacks, 400-280 V, 0-300 A] --> B400[400 V Bus]
      B400 --> B800[800 V Bus]
      B800 --> T[Traction and Hydraulic Motors, 150 kW peak]
      B400 --> B24[24 V Bus]
      B24 --> B_start[24 V start-up battery]
      B24 --> B_vehicle[Vehicle Aux loads: lights, horn, etc]
      B_start --> B24
      B_vehicle --> B24
      B24 --> B_converter[Boost/Buck DC/DC, 24 V to 400 V]
      B_converter --> B400
      B_converter --> B_boost[80 kW boost DC/DC converter]
      B_boost --> B800
      B_converter --> B_battery[Battery Pack, 150 kW peak, 18 kWh, 600-800 V]
      B_battery --> B_converter
      B_converter --> B_5kW[5 kW DC/DC converter]
      B_5kW --> B_controller[Fuel Cell Engine Controller]
      B_battery --> B_80kW[80 kW DC/DC converter]
      B_80kW --> B_controller
      B_controller <--> FC
      B_controller <--> B_battery
      B_controller --> B_cat[CAT Operator Interface Controller]
      B_cat --> B_hydraulic[Hydraulic Motor Controller]
      B_cat --> B_traction[Traction Motor Controller]
      B_cat --> B_safety[Safety Interlock Switches]
      B_safety --> B_cat
  
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Comparative Operating and Capital Costs for Underground Mine Loaders (2011)

Annual operating cost comparison 8 LHD's, Louvicourt.


	Diesel	Fuel cell-hybrid	Difference between diesel and fuel cell-hybrid
Operation			
maintenance, fuel, hydride bed cooling	\$ 2,722,390	\$ 3,016,500	\$ (513,760)
ventilation	\$ 2,194,800	\$ 1,640,000	\$ 553,800
TOTAL	\$ 4,917,190	\$ 4,657,500	\$ 259,690

Diesel loader capital costs 8 LHD's, Louvicourt.


Tanks, delivery system, pumps, stations, excavations, extinguishing systems, ventilation systems	\$ 666,100
8 LHD's, 8yd ³	\$ 5,842,000
TOTAL	\$ 6,508,100

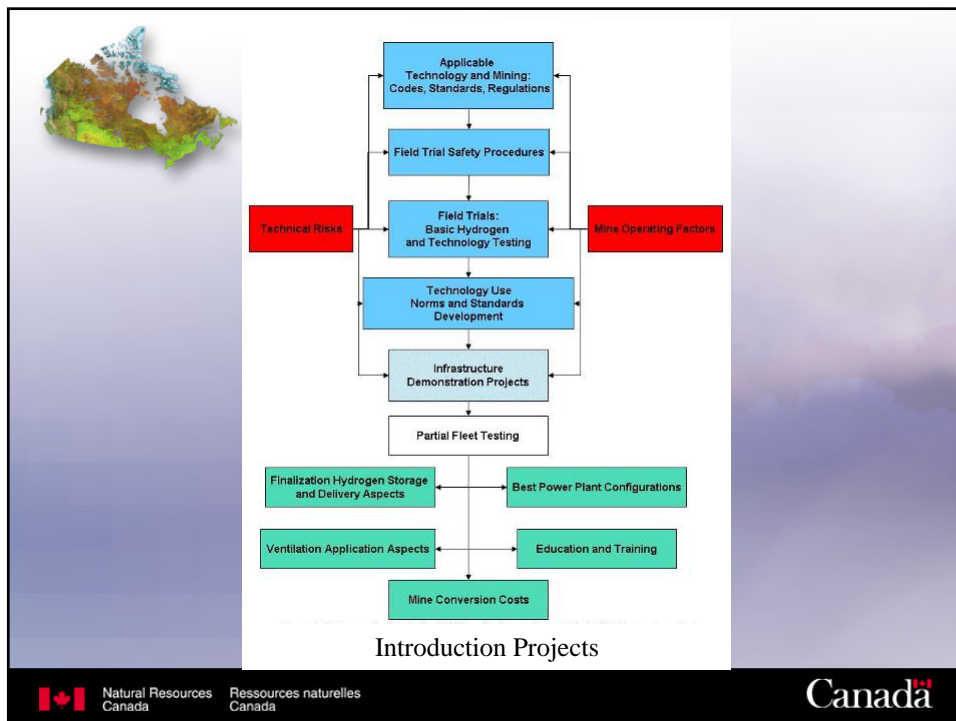
Fuel cell hybrid loader capital costs, 8 LHD's Louvicourt

Surface storage tanks, delivery system, monitoring equipment, filling stations, excavations, extinguishing systems, ventilation systems	\$ 338,280
8 LHD's, 8yd ³	\$ 9,521,788
TOTAL	\$ 9,860,068



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Hydrogen Mine Introduction Initiative Consortium

Funding: \$800K
In-Kind: \$625K (industry & stakeholders)

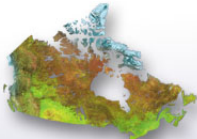
Technical Committee	Advisory Committee	Stakeholders
Barrick Goldcorp IAMGOLD Vale INCO Xstrata Nickel Raglan Hydro-Quebec Air Liquide	AECOM Hydrogen Research Institute URS Paceas Technologies A.V. Tchouvelev and Associates NRCan Transportation Energy program	Chief Inspectors of Mines, Canada Mine Safety and Health Administration, USA Trade Unions Equipment manufacturers
Facilitators SOREDEM CANMET-MMSL		

* Other Technical Committee membership under discussion: Newmont Gold, Mosaic Potash, Atlas Copco, IRSST Quebec, Anglo American



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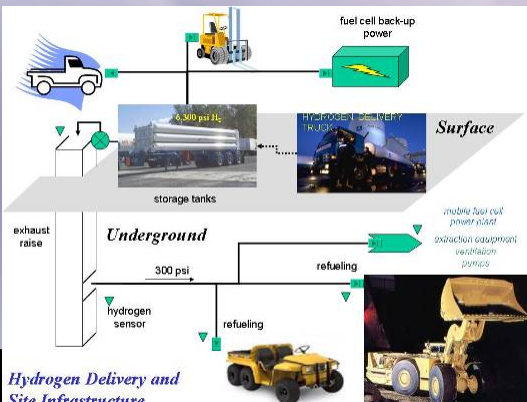


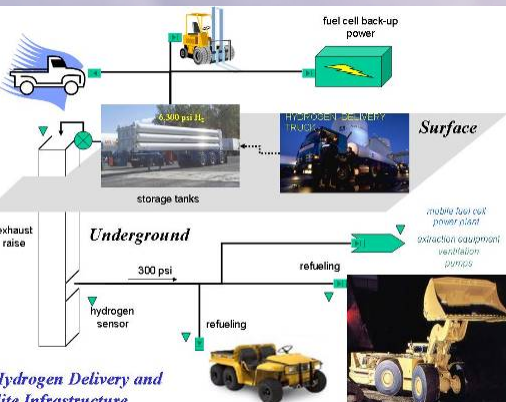



HMII Projects

- 1- Applicable norms and standards, expertise, mining regulations (completed)
>Go
- 2- Risk management, safety for project 3 tests (completed)
>Go
- 3- Hydrogen behaviour in confined areas, ventilation, ignition, (underground minesite) (started, end December 2012)
>Go/no go
- 4- Evaluation of results and first version of best practices for mining regulation (not started, end – April 2013)


Hydrogen Delivery and Site Infrastructure







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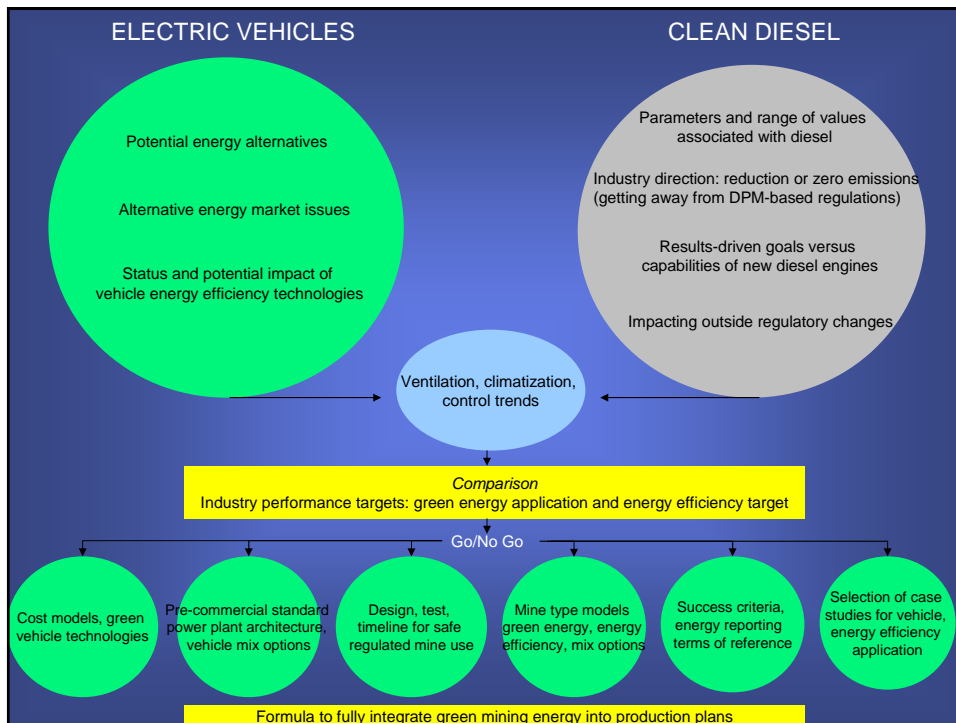
Road Map Activities


- Concordance with corporate strategies
- Status and gaps clean diesel vehicles projects
- Industry performance targets, selective directions
- Adaptation projects, green energy application
- Mine operation integration projects (retrofit current vehicles)



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Road Map Initiative Structure

- Main participant management committee
- Subcommittees for each theme (including advisors)
- Mine site testing, Val d'Or
- Operations technology implementation task force


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Initial Targeted Mining Companies



- Agnico Eagle
- Anglo American
- Barrick Gold
- Goldcorp
- Iamgold
- Kinross
- Mosaic Potash
- Newmont
- PCS
- Rio Tinto
- Vale
- Xstrata Nickel
- Xstrata Nickel Raglan Mine

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Presentations to Date

GOLDCORP
IAMGOLD
SOREDEM
Vale
Xstrata Nickel Raglan Mine
Hydro-Quebec (Lithium ion battery program, high efficiency electric motor program)
Hydrogenics


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Feedback from the Chief Inspectors (Underground Application)



- Comments are favorable for carrying out this work in the continued effort to provide alternatives to diesel for underground vehicle power
- Chief Inspectors ready to play a consultative role and, given the availability of data, norms, standards, emergency response, training, the chief inspectors are in favour of developing the required regulation for hydrogen power and other alternative power application in underground metal mines

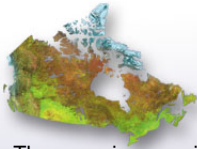
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Considerations and Conclusions


- Alternative power technologies are routinely used in surface vehicles
- There is a limit as to the toxic emissions reductions possible from carbon-based fuels
- Alternative power addresses four important industry issues
 - improved health benefits
 - automation, higher productivity, lower mine costs
 - reductions in emissions, GHG's
 - reduction in energy consumption (electricity, natural gas, diesel)
- Open pit application has not been studied and basic studies are required to identify areas of application and benefits
- Fuel cell technology is being applied to power underground mine production vehicles
- Mine stakeholders, mine regulators, technology developers and application experts would be participating
- Planned projects show high potential for general underground use


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Considerations and Conclusions (ctd)

- There are issues with all alternate technologies but these can be addressed in the short- to medium-term
- Current material research is producing more efficient and cheaper alternate energy systems which will match clean diesel engine cost in the timeframe required for alternate energy application regulatory development
- All relevant technologies have or can theoretically be configured to power existing mine production vehicles for current production needs
- Alternate technologies will meet or exceed EPA Tier 4 regulations, and significant ventilation savings are possible for the alternative energies
- The regulatory approval process for alternate energy application will be longer than the configuration and testing of pre-commercial power plant design
- Studies are required to the best power application for various types of mining methods, depths and mine types, to optimise the mix energy options
- There is currently insufficient alternate energy power plant manufacturing capacity to meet mine production vehicle requirements


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