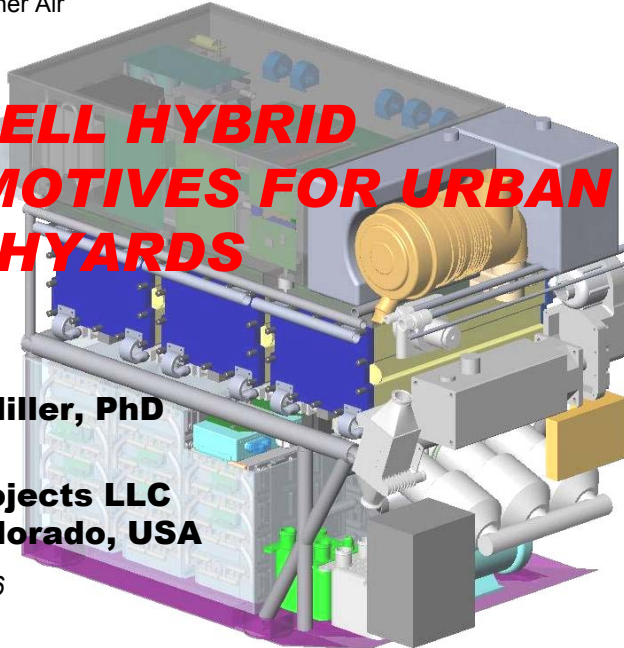


Faster Freight, Cleaner Air

FUELCELL HYBRID LOCOMOTIVES FOR URBAN SWITCHYARDS

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President
Vehicle Projects LLC
Denver, Colorado, USA

31 January 2006



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Background

FUELCELL MINE LOADER

- 23 metric tons
- 160 kW (max) fuelcell-battery hybrid
- 90 kW (cont) PEM fuelcells
- 14 kg hydrogen as metal hydride
- Refuel in 15 min



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Background

FUELCELL MINE LOCOMOTIVE

- Completed in 2002
- 3.6 metric tons
- 17 kW PEM fuelcells
- 3 kg hydrogen as metal hydride
- Not hybrid



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Overview

FUELCELL LOCOMOTIVE

- 109 tonne road-switcher
- 1.2 MW fuelcell powerplant – in 8 modules
- 250 kg hydrogen as metal hydride
- Not hybrid



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PROTOTYPE POWER MODULE FOR LOCOMOTIVE

- **165-kW prototype module (150 kW required)**
- **Rugged metal plates for rail applications**
- **Prototype is being sold to offshore customer**
- **Delivery in January 2006**



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POTENTIAL BENEFITS OF HYBRID RAIL POWER

- **Enhancement of transient power and tractive effort**
- **Regenerative braking**
- **Reduction of capital cost**

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AUXILIARY POWER/STORAGE DEVICES

- Rail application requirements
 - Ruggedness
 - High energy density
 - Provide or absorb power over relatively long period
- Two plausible devices for rail: batteries or flywheels

TRACTIVE EFFORT

Type of Service	Qualitative Benefits	Packaging Difficulty	Comments
Switcher	Low	High	Wheel adhesion limits power
Light Rail	Medium	High	Power equipment must reside under floor
Mass Transit	High	High	Similar to light rail but uses third rail
Commuter Rail	High	Low	Good benefits. Space less of an issue (tender car can be used if necessary)
Inter-city Passenger	High	Medium	Same as commuter rail but tender car less desirable
High-speed Rail	Medium	High	Continuous power rating dominated by aerodynamics
Line-haul Freight	Low	Medium	Duty cycle dominated by long periods at full power

REGENERATIVE BRAKING

Type of Service	Qualitative Benefits	Implementation Difficulty	Comments
Switcher	None	High	Speeds too low to demand high power and store significant brake energy
Light Rail	Low	High	Available space limited for installation of energy storage system
Mass-Transit	Medium	High	Lack of space a major issue
Commuter Rail	Medium	Low	Medium benefits. Space less of an issue (tender car can be used if necessary)
Inter-city Passenger	Medium	Medium	Same as commuter rail but tender car less desirable
High Speed Rail	Low	High	Continuous power rating dominated by high speed drag requirements
Line-haul Freight	Medium	Medium	Duty cycle dominated by long periods spent at full power

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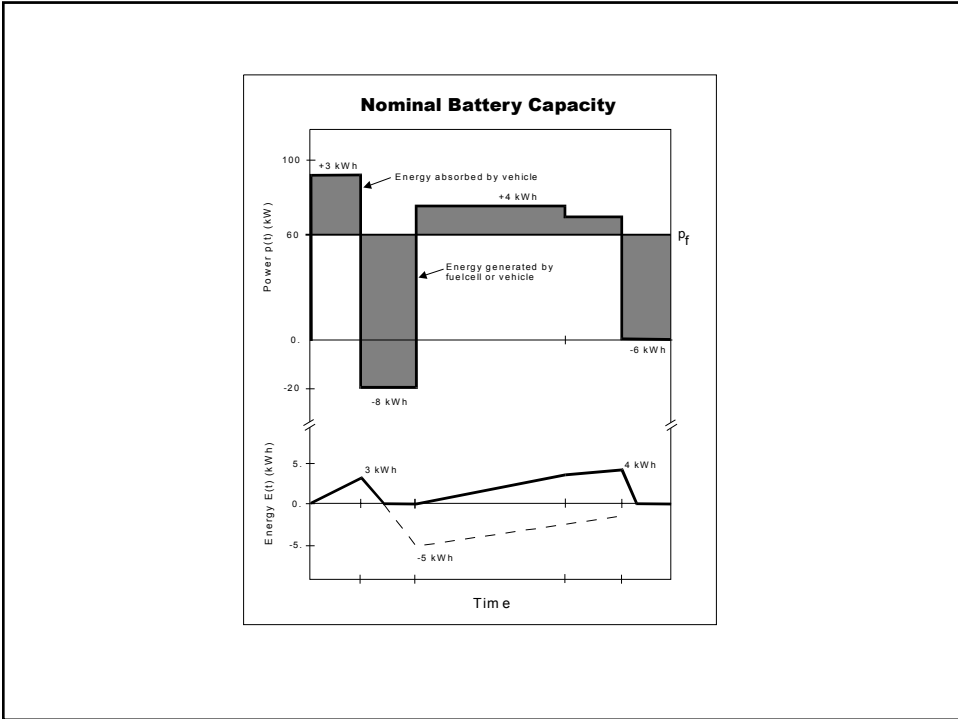
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COST ANALYSIS (1.2-MW Road-Switcher)

Fuelcell Rated Power (kW)	Battery Capacity (kWh)	Battery Weight (Tonne)	Total Cost	Hybrid Fuel Cost	Fuel Cost Penalty	Fuel Capacity Penalty (%)
200	1863	28.7	\$345,001	\$106,829	\$36,904	53
250	1105	17.0	\$276,578	\$102,442	\$32,517	47
300	870	13.4	\$261,006	\$98,091	\$28,166	40
350	824	12.7	\$267,075	\$94,558	\$24,633	35
400	752	11.6	\$260,033	\$90,474	\$20,549	29
450	683	10.5	\$266,299	\$87,753	\$17,828	25
500	624	9.6	\$269,961	\$85,793	\$15,868	23
550	559	8.6	\$281,328	\$83,458	\$13,533	19
600	497	7.6	\$271,644	\$80,826	\$10,901	16
650	372	5.7	\$279,592	\$79,479	\$9,554	14
700	328	5.0	\$286,634	\$78,497	\$8,572	12
750	288	4.4	\$293,836	\$77,246	\$7,321	10
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1200	0	0	\$369,925	\$69,925	0	0

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-	-	-	-	-	-	-
-	-	-	-	-	-	-
1200	0	0	\$369,925	\$69,925	0	0

CONCLUSIONS

- **Tractive effort for switchers is generally limited by wheel adhesion, not power**
- **Regeneration benefits are minimal for all applications**
 - Switchers have little braking energy to absorb and would lose efficiency
 - Others have too much energy to absorb by practical devices
- **Reduced capital cost can be realized for yard switchers**
 - Zero emissions
 - Low noise

PROPOSAL

- **An existing diesel-battery hybrid switcher would be retrofitted with our 165-kW fuelcell power module**
 - Powerplant design and development are complete
 - First unit to be delivered to offshore customer in January 2006
- **The fuelcell-battery hybrid yard switcher would be demonstrated in the LA Basin**
 - Lower capital cost than pure fuelcell locomotive
 - Zero emissions, low noise

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2. **A. R. Miller, et al, Analysis of Fuelcell Hybrid Locomotives.**
Journal of Power Sources, in press, 2006



FINANCIAL SUPPORT

- US Department of Energy, Hydrogen Program
- US Department of Energy, Office of Industrial Technologies
- Government of Canada, Action Plan 2000 on Climate Change
- Natural Resources Canada, Emerging Technologies Program
- US Department of Defense, US Army National Automotive Center (NAC)
- Government of Japan, Railway Technical Research Institute
- Fuelcell Propulsion Institute
- Corporate cost-share contributors