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**LOCOMOTIVE PROGRAM OBJECTIVES**

Develop and demonstrate prototype fuelcell-powered locomotives leading to commercial locomotives that will:

- Reduce air pollution in urban rail yards, in particular, yards associated with seaports
- Increase energy security of the rail transportation system by using a fuel independent of imported oil
- Reduce atmospheric greenhouse-gas emissions
- Serve as a mobile backup power source (“power-to-grid”) for military bases and civilian disaster relief efforts
**FUELCELL LOCOMOTIVE PROGRAM**

**Project 1: Develop and Demonstrate Pure Fuelcell (Non-hybrid) Road-Switcher**
- Feasibility Analysis (completed one year from June 2003, funding from DOD)
- Conceptual Design (completed one year from June 2004, funding from DOD)
- Development of eight PM, 1.2-MW Road Locomotive
- Demonstration of Locomotive in Line-Haul and Military Power-to-Grid Applications

**Project 2: Develop and Test Prototype Power Module (PM)**
- Funding from Government of Japan and US Department of Energy
- PM delivered to Japan on 28 February 2006
- Presently undergoing shakedown tests in rail vehicle in Japan

**Project 3: Develop and Demonstrate Fuelcell-Battery Hybrid Switcher**
- Project commenced 14 July 2006
- Initial funding by BNSF and DOD
- To be demonstrated in Los Angeles basin
FUELCELL LOCOMOTIVE PROGRAM CONSORTIUM

BNSF Railway Company
Defense NTG & Rail Equipment Center
DOT Volpe Nat’l Transportation Systems Center
Fuelcell Propulsion Institute
General Atomics/Power Inverters
MesoFuel/Intelligent Energy
Modine Manufacturing Co
New York City Transit
Railway Technical Research Institute, Japan
Regional Transportation District – Denver
To be determined
To be determined
Transportation Technology Center Inc
University of Nevada – Reno
Union Pacific Railroad
Vehicle Projects LLC
Washington Safety Management Solutions LLC

Port switching applications; switcher integration
Power-to-grid applications; road-switcher integration
Safety and economic analysis
Project advocacy
Power electronics
Ammonia fuel analysis
Heat exchangers
Advisor on subway transit applications
Advisor on passenger rail; test of prototype PM
Advisor on Light rail applications
Hybrid switcher power modules (PMs)
Metal-hydride or compressed-gas storage
Locomotive performance analysis
Refueling system
Advisor on freight applications
Prime contractor and consortium manager
Safety analysis

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BACKGROUND – FUELCELL MINE LOCOMOTIVE

This 3.6-tonne fuelcell mine locomotive was developed and demonstrated by Vehicle Projects LLC during 1999-2002. Fuelcells provide 17 kW of continuous power and a reversible metal hydride stores 3 kg of hydrogen. The locomotive is not a hybrid.
Brand new 123-kW diesel loader shown at Caterpillar proving grounds in June 2003, prior to baseline testing and conversion to fuelcell power.
160-kW fuelcell-battery hybrid powerplant: Three fuelcell stacks provide nominally 90 kW of continuous power; a 12-kWh nickel metal-hydride battery provides additional 70 kW of transient power and absorbs energy during regenerative braking.
METAL-HYDRIDE STORAGE

Hydrogen fuel is stored as a reversible metal hydride, a safe and compact method of storing hydrogen as a solid. Photo shows half of the hydride storage system, the vehicle’s fuel tank, being lowered into the loader. The vehicle can be refueled in 10-15 minutes.
ASSEMBLY OF LOADER

The left half of the hydride-storage unit sits in front of the powerplant (labeled “High Voltage”). The storage units may be refueled in situ or after removal from the vehicle.
Led by Vehicle Projects LLC, a government-industry consortium is developing a 127-tonne fuelcell-battery hybrid switcher locomotive with 250 kW of prime-mover power. The vehicle will look virtually identical to the diesel-battery hybrid switcher at right, one of four Green Goats™ owned by the US Army.

Photo courtesy of RailPower Technologies
The locomotive’s prime mover will consist of two 125-kW power modules (PMs), each with complete balance of plant, for a total of 250-kW continuous net power. Because the powertrain is a parallel hybrid, the fuelcell power and traction-battery power are additive. Together, they provide a peak power of at least 1.2 MW.
Vehicle integration will take place at the BNSF Topeka Rail Shop. The completed chassis is being loaded onto a flatcar for transfer to RailPower Technologies for addition of the body shell, traction battery, and vehicle controls.
# Limits of Hydrogen Volumetric Densities

<table>
<thead>
<tr>
<th>Fuel Occupying 1 L&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Conditions of Storage</th>
<th>H&lt;sub&gt;2&lt;/sub&gt; Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaseous H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>340 bar (5,000 psi)</td>
<td>25 g</td>
</tr>
<tr>
<td>Liquid H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>ρ = .070 g/mL (P = 1 bar, T = bp)</td>
<td>70 g</td>
</tr>
<tr>
<td>Methanol&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ρ = .79 g/mL, (T = 25 C)</td>
<td>99 g</td>
</tr>
<tr>
<td>Liquid Ammonia</td>
<td>ρ = 0.62 g/mL, (P = 7.2 bar, T = 15 C)</td>
<td>110 g</td>
</tr>
<tr>
<td>Metal Hydride (AB&lt;sub&gt;5&lt;/sub&gt;, LaNi&lt;sub&gt;5&lt;/sub&gt;)</td>
<td>ρ = 8.3 g/mL, wt % = 1.5, 10 bar</td>
<td>125 g</td>
</tr>
</tbody>
</table>

<sup>a</sup> Fuel only – container and processor excluded

<sup>b</sup> Requires water also: CH<sub>3</sub>OH + H<sub>2</sub>O → 3H<sub>2</sub> + CO<sub>2</sub>. In principle, water can be obtained from the fuelcell.
PRACTICAL HYDROGEN VOLUMETRIC DENSITIES

System Envelope Volume = 0.38 m³
Hydrogen Mass = 3.15 kg (340 bar)
Hydrogen Density = 8.29 kg/m³

System Envelope Volume = 0.38 m³
Hydrogen Mass = 7.0 kg (10 bar)
Hydrogen Density = 18.4 kg/m³

Compressed gas
System envelope

Metal hydride
CONCEPTUAL DESIGN OF AMMONIA LOCOMOTIVE

- 1.2 MW proton-exchange-membrane fuelcells (blue)
- 35 kg hydrogen metal-hydride buffer (orange)
- 3000 L of liquid ammonia stored under frame
- 30-40 hours of operation between refueling
• 1.2 MW proton-exchange membrane fuelcells (blue)
• 35 kg hydrogen metal-hydride buffer (orange)
• Ammonia dissociator (violet/blue)
PROCESS DIAGRAM FOR AMMONIA FUELCELL LOCOMOTIVE*

Ammonia Storage Tank  \rightarrow  Reactor  \rightarrow  Combustor  \rightarrow  \text{N}_2, \text{H}_2\text{O}  \\
\text{Air}  \rightarrow  \text{F}  \rightarrow  \text{N}_2, \text{O}_2, \& \text{H}_2\text{O}  \\
\text{Fuel Cell Stack}  \rightarrow  \text{Adsorbent Columns}  \rightarrow  \text{Air}  \rightarrow  1 \text{ MW}_e


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VOLUME OF SYSTEM COMPONENTS

Total = 5960 L

NH₃ Tank
5300 L

Reactor & Combustor
400 L

Heat Exchangers
50 L

Adsorbent System
150 L

Piping & BOP
60 L

Total = 5960 L
PROCESS FLOW DIAGRAM FOR AMMONIA DECOMPOSITION

(100-W scaled unit)

25C  Temperature  600C

Counterflow HX

Reactor/Combustor

365 SCCM
Anhydrous NH₃

75% H₂
25% N₂
1000 ppm NH₃

7 W
8 W

14 W

Combustion Gas

Fuel/Air Mixture

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AMMONIA AS FUEL

- Produced on a massive scale (> 140 million tons/y)
- Mainly transported by rail car
- Pressure-temperature characteristics similar to propane
- Classified as nonflammable but strong tissue irritant
- Detectable by odor at safe concentrations
- 17% hydrogen by weight and cleanly cracked
- Economical source of hydrogen ($1.70/kg H₂)
BENEFITS OF AMMONIA FUEL

• Renewable fuel – produced from hydrogen and atmospheric nitrogen

• Zero emissions – water and nitrogen

• Energy-dense liquid capable of fueling line-haul freight trains and high-speed rail
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
Government of Japan, Railway Technical Research Institute
Fuelcell Propulsion Institute
BNSF Railway Company
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