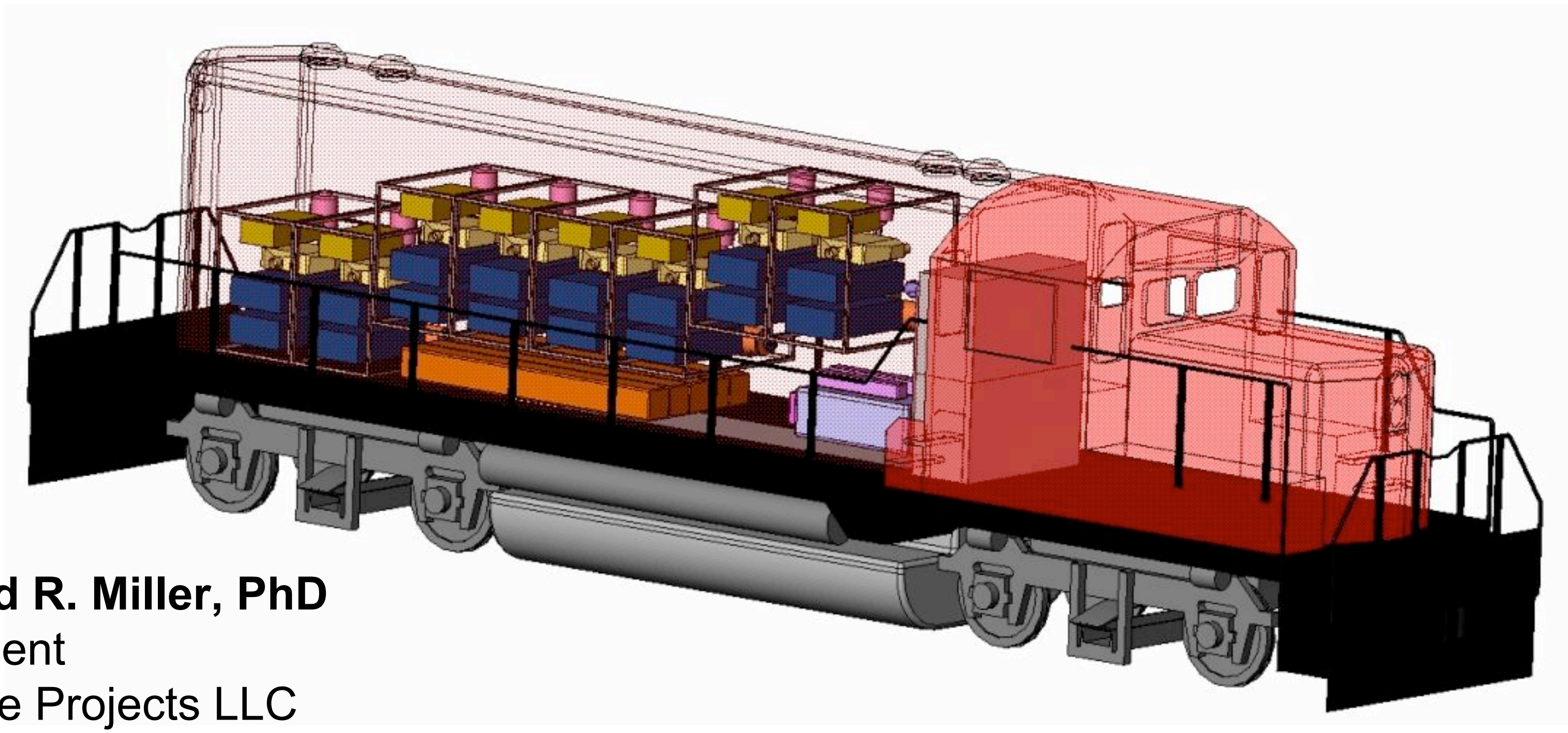
AMMONIA FUEL FOR RAIL TRANSPORTATION



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9 October 2006

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	Port switching applications; switcher integration
Defense NTG & Rail Equipment Center	Power-to-grid applications; road-switcher integration
DOT Volpe Nat'l Transportation Systems Center	Safety and economic analysis
Fuelcell Propulsion Institute	Project advocacy
General Atomics/Power Inverters	Power electronics
MesoFuel/Intelligent Energy	Ammonia fuel analysis
Modine Manufacturing Co	Heat exchangers
New York City Transit	Advisor on subway transit applications
Railway Technical Research Institute, Japan	Advisor on passenger rail; test of prototype PM
Regional Transportation District – Denver	Advisor on Light rail applications
To be determined	Hybrid switcher power modules (PMs)
To be determined	Metal-hydride or compressed-gas storage
Transportation Technology Center Inc	Locomotive performance analysis
University of Nevada – Reno	Refueling system
Union Pacific Railroad	Advisor on freight applications
Vehicle Projects LLC	Prime contractor and consortium manager
Washington Safety Management Solutions LLC	Safety analysis

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.

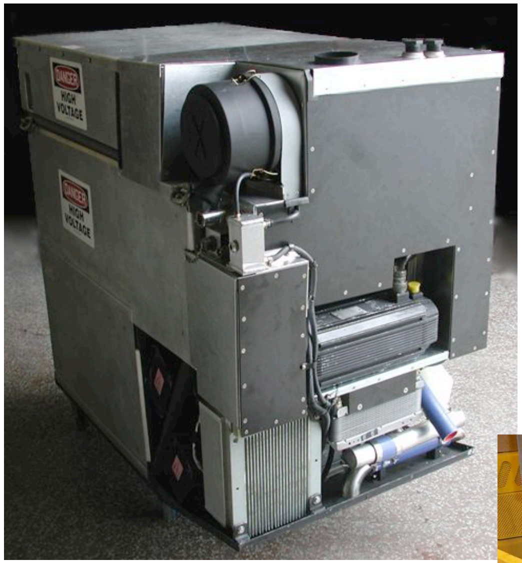
VEHICLE PROJECTS LLC

BACKGROUND – FUELCELL MINE LOADER

Brand new 123-kW diesel loader shown at Caterpillar proving grounds in June 2003, prior to baseline testing and conversion to fuelcell power.

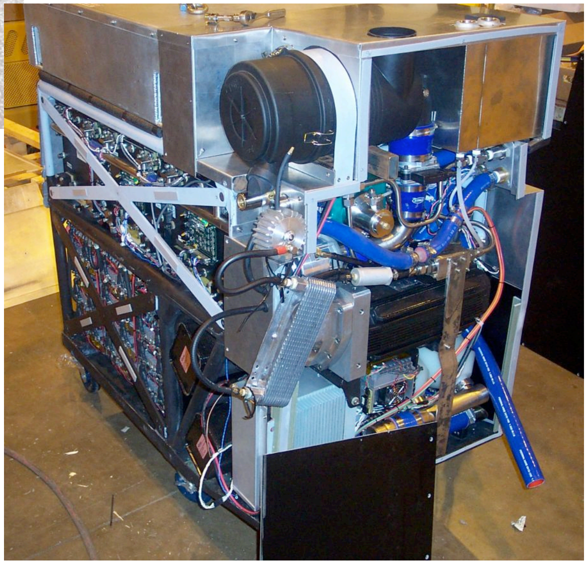
FUELCELL HYBRID POWERPLANT

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.



With covers in place

With covers removed



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.*

FUELCELL HYBRID SWITCHER LOCOMOTIVE

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

HYBRID LOCOMOTIVE CONCEPT

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.

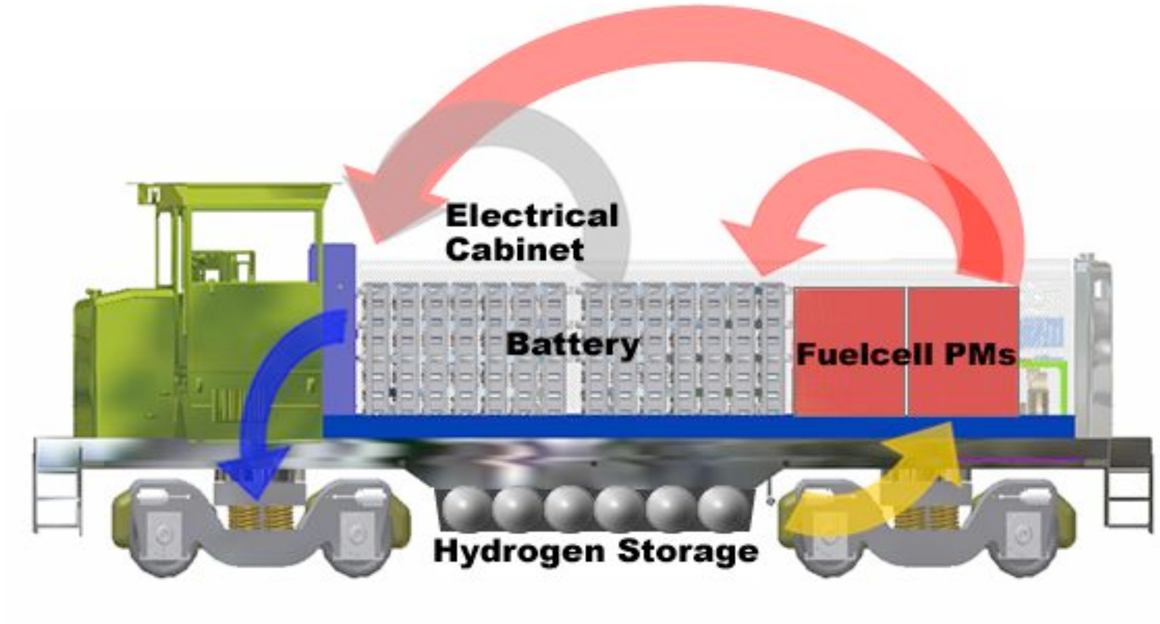
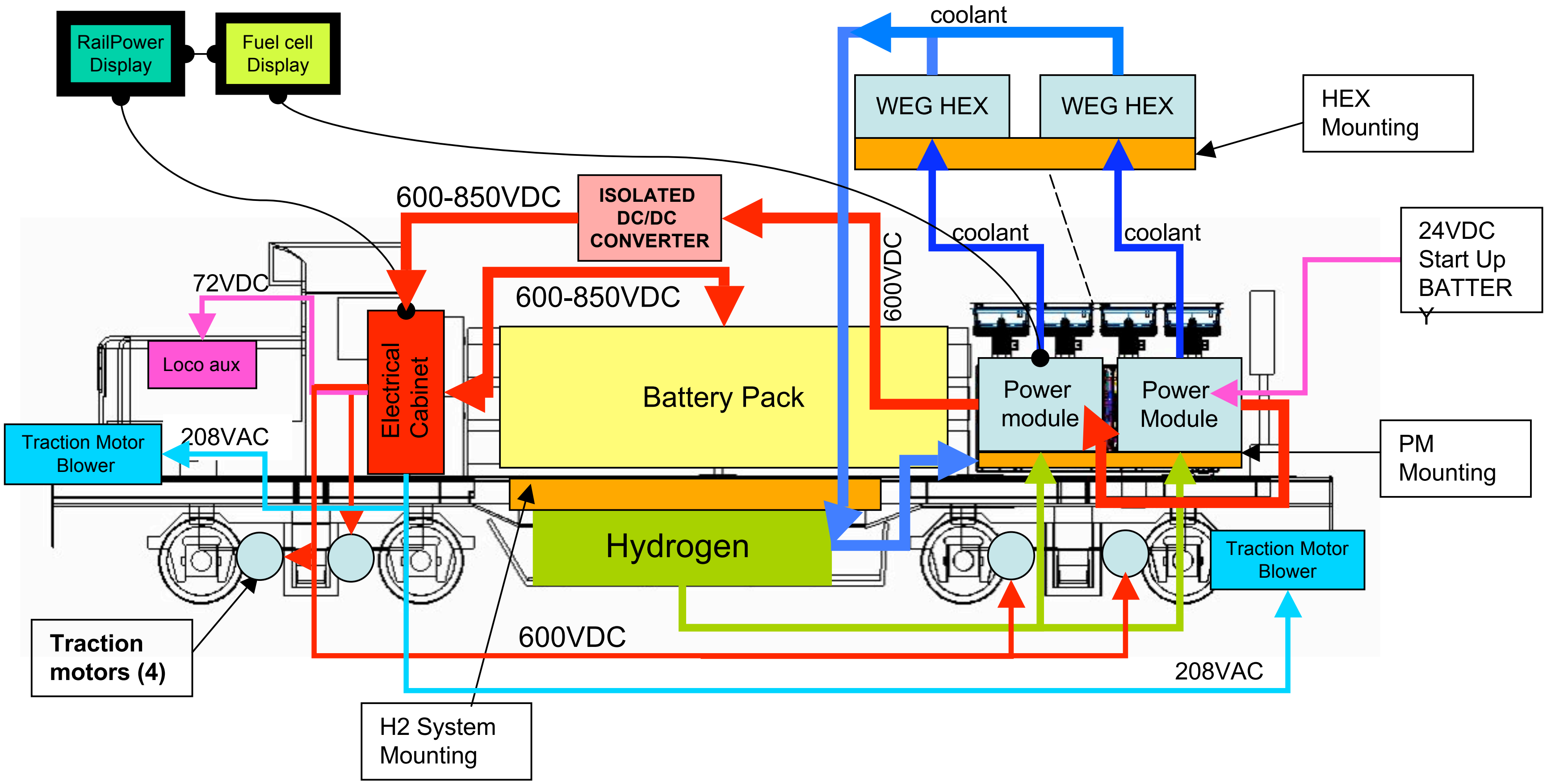


Diagram modified from RailPower Technologies

TOTAL VEHICLE SYSTEM DIAGRAM



BNSF TOPEKA RAIL SHOP

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

Fuel Occupying 1 L[a]	Conditions of Storage	H_2 Mass
Gaseous H_2	340 bar (5,000 psi)	25 g
Liquid H_2	ρ = .070 g/mL (P = 1 bar, T = bp)	70 g
Methanol[b]	ρ = .79 g/mL, (T = 25 C)	99 g
Liquid Ammonia	ρ = 0.62 g/mL, (P = 7.2 bar, T = 15 C)	110 g
Metal Hydride (AB_5, $LaNi_5$)	ρ = 8.3 g/mL, wt % = 1.5, 10 bar	125 g

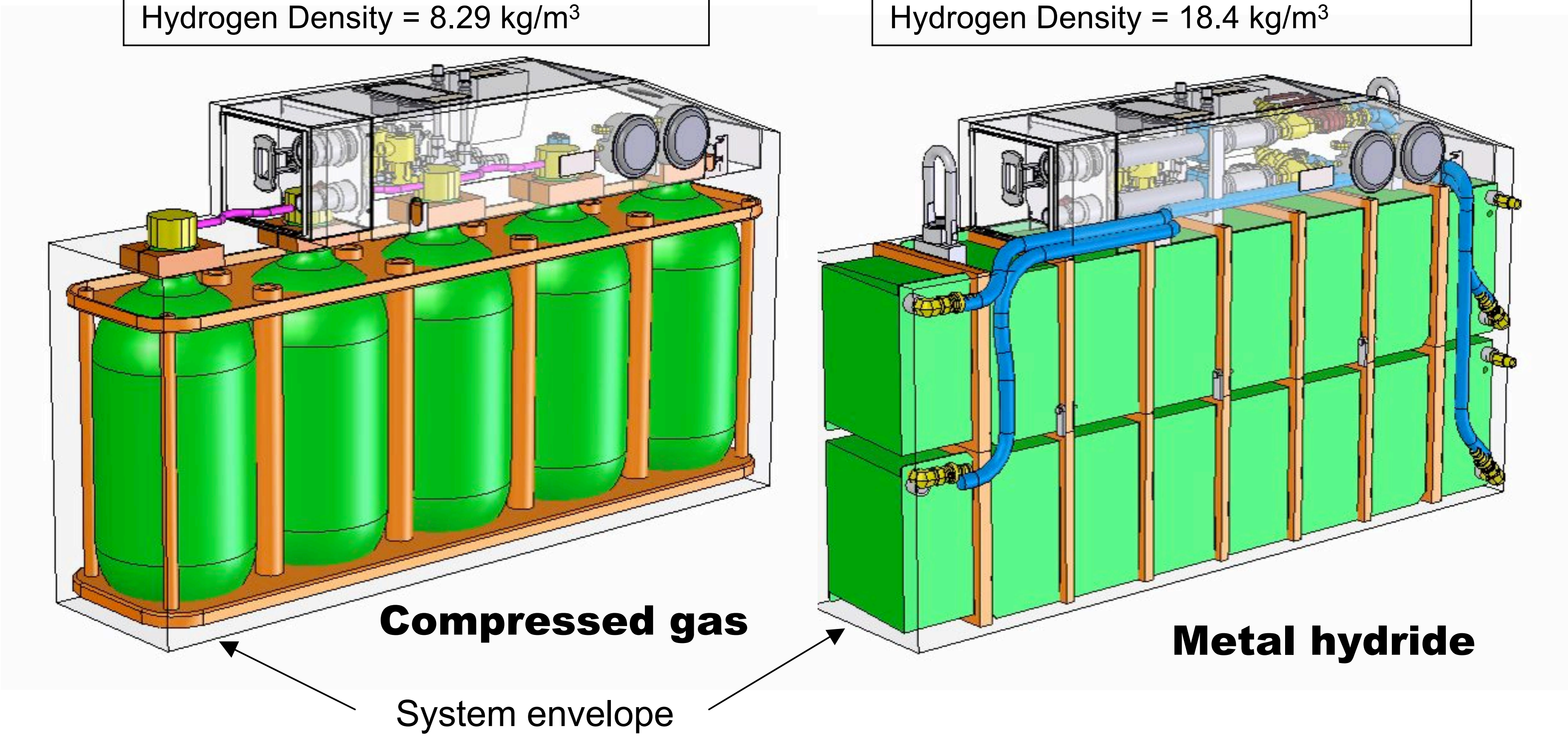
[a] Fuel only – container and processor excluded

[b] Requires water also: $CH_3OH + H_2O \rightarrow 3H_2 + CO_2$. In principle, water can be obtained from the fuelcell.

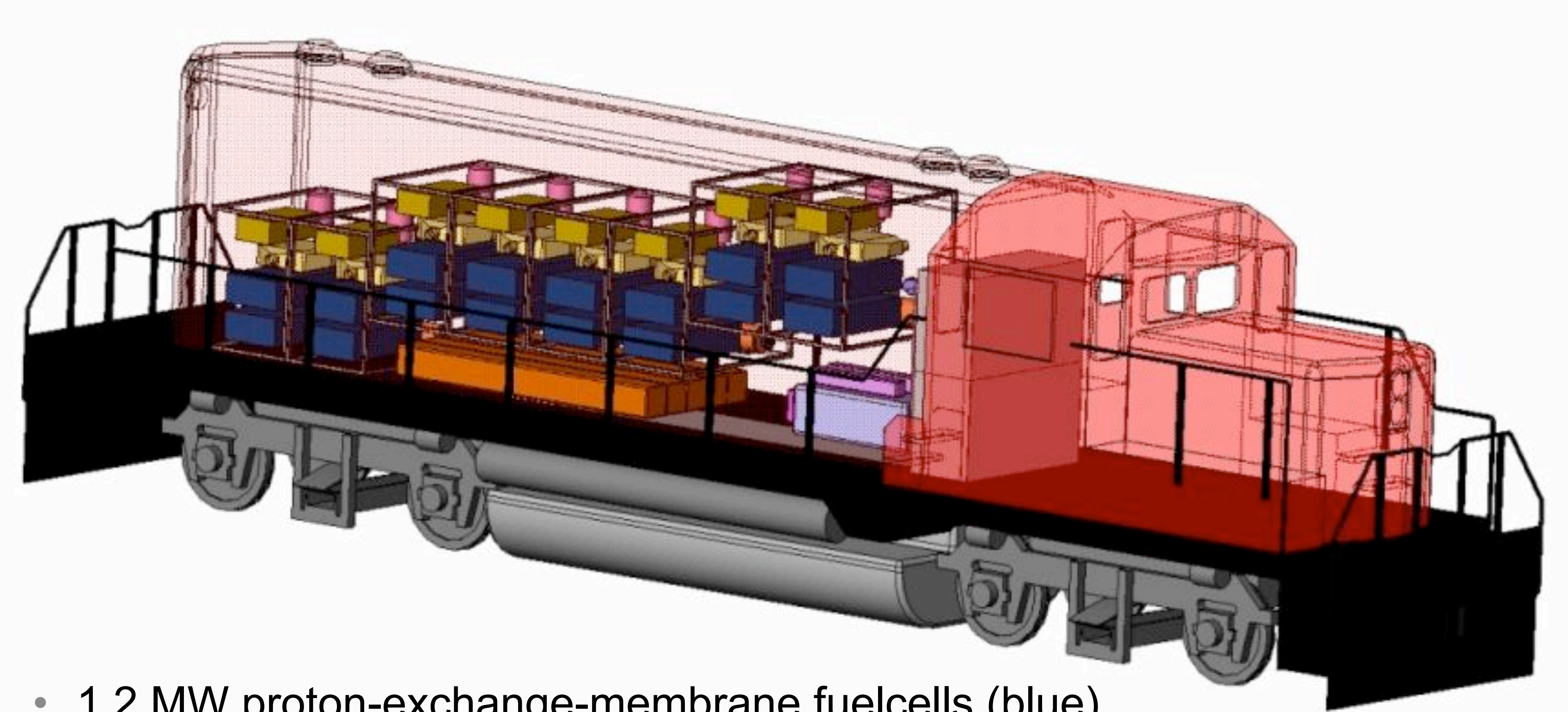
PRACTICAL HYDROGEN VOLUMETRIC DENSITIES

System Envelope Volume = 0.38 m^3
Hydrogen Mass = 3.15 kg (340 bar)
Hydrogen Density = 8.29 kg/m^3

System Envelope Volume = 0.38 m^3
Hydrogen Mass = 7.0 kg (10 bar)
Hydrogen Density = 18.4 kg/m^3

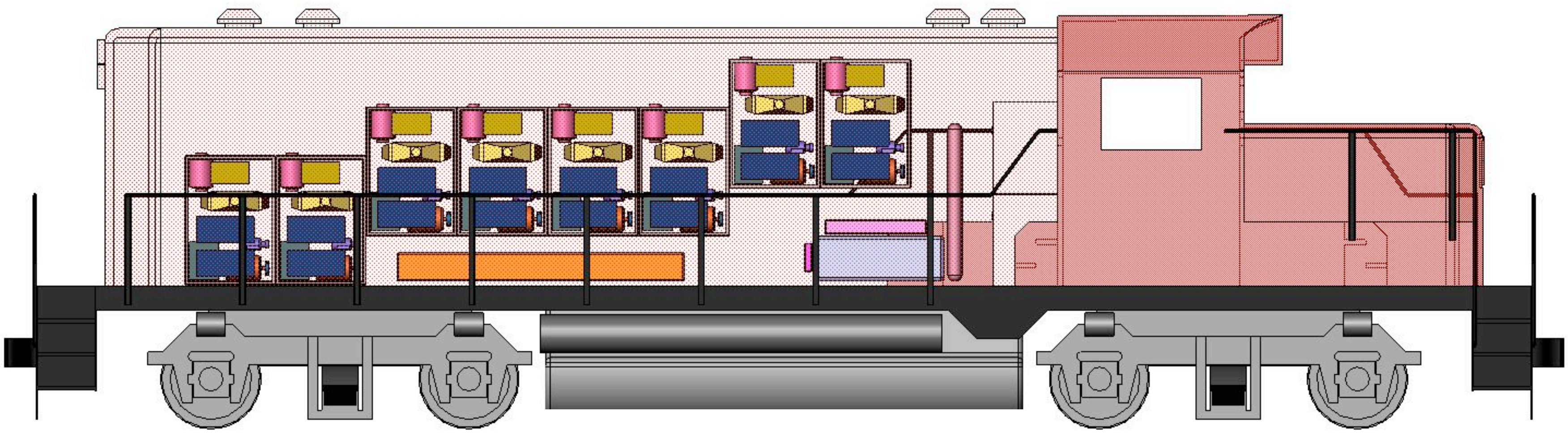


CONCEPTUAL DESIGN OF AMMONIA LOCOMOTIVE



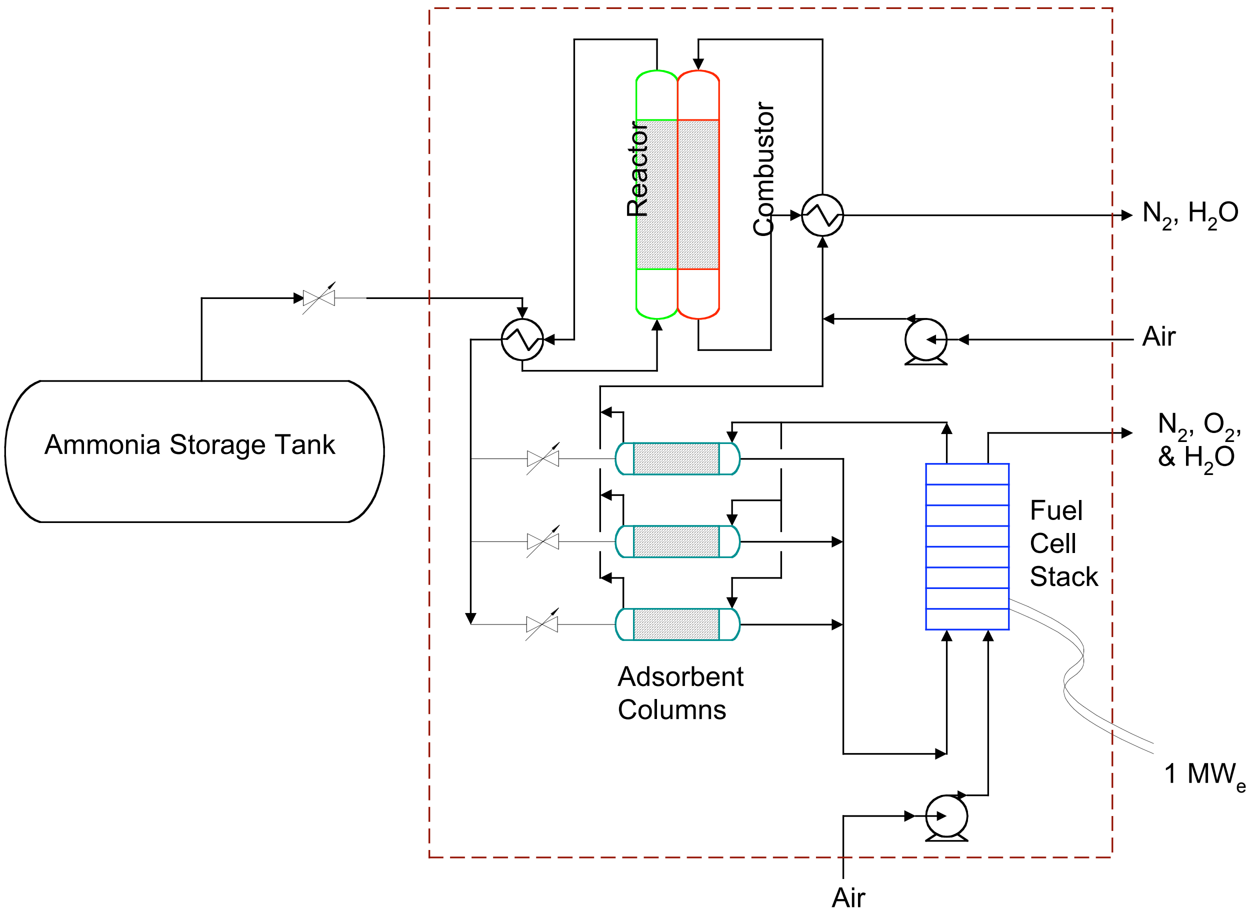
- 1.2 MW proton-exchange-membrane fuelcells (blue)
- 35 kg hydrogen metal-hydride buffer (orange)
- 3000 L of liquid ammonia stored under frame
- 30-40 hours of operation between refueling

AMMONIA LOCOMOTIVE – SIDE VIEW



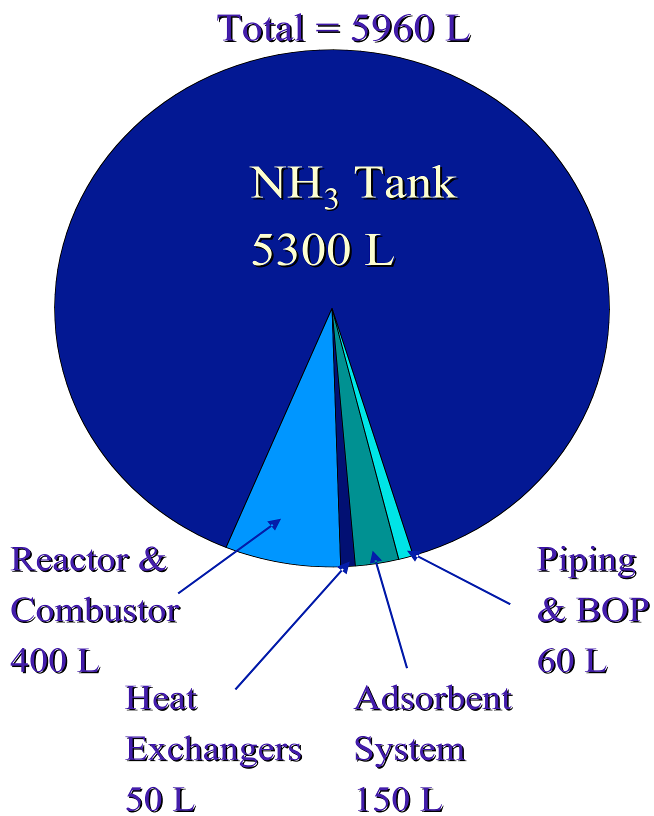
- 1.2 MW proton-exchange membrane fuelcells (blue)
- 35 kg hydrogen metal-hydride buffer (orange)
- Ammonia dissociator (violet/blue)

PROCESS DIAGRAM FOR AMMONIA FUELCELL LOCOMOTIVE*



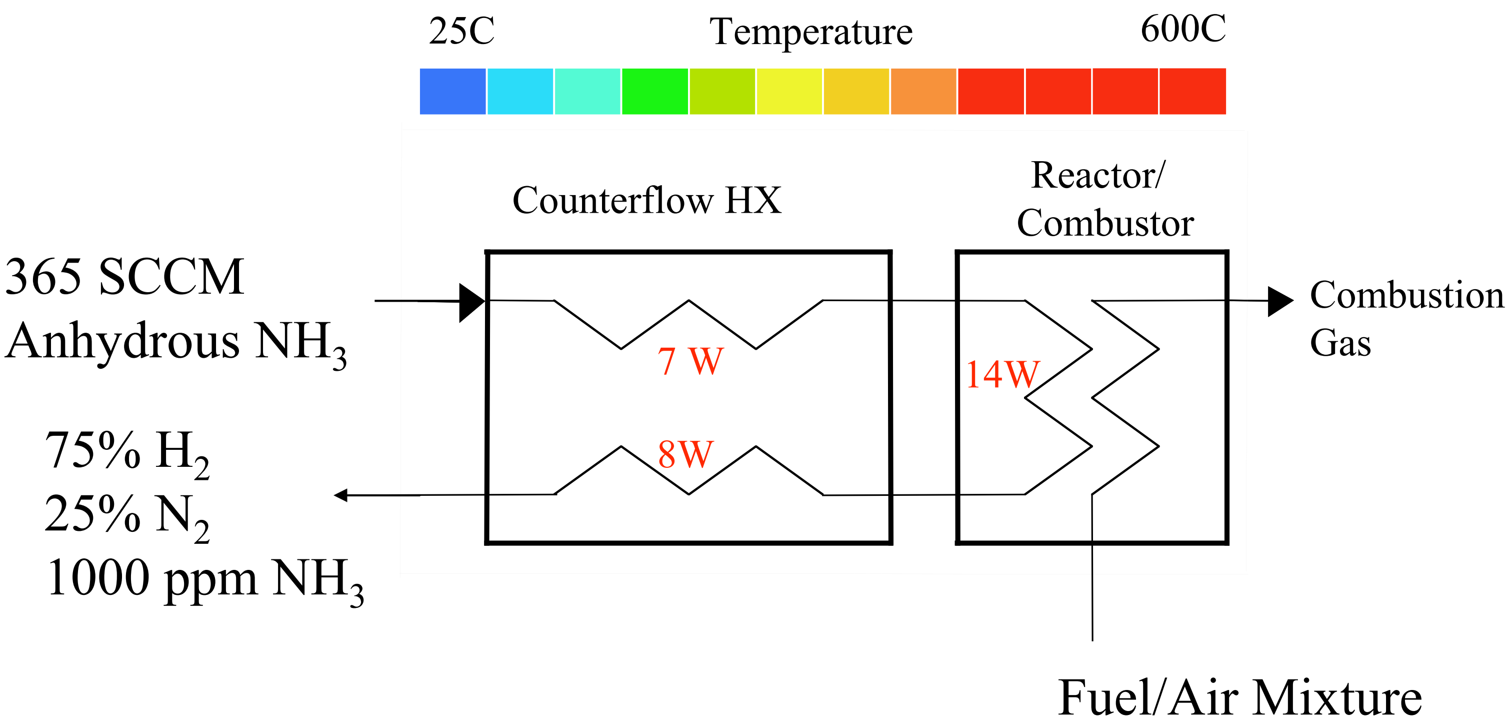
* From "Ammonia-Based Hydrogen Production for the Proposed Fuel-Cell Locomotive," MesoFuel Inc, Albuquerque, NM, study commissioned by Vehicle Projects LLC, Denver, CO, December 2003

VOLUME OF SYSTEM COMPONENTS



PROCESS FLOW DIAGRAM FOR AMMONIA DECOMPOSITION

(100-W scaled unit)



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**
- **Detectible by odor at safe concentrations**
- **17% hydrogen by weight and cleanly cracked**
- **Economical source of hydrogen ($1.70/kg H_2)**

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

Corporate cost-share contributors