Integrated and Proven Fuel Cell Engines Powering Clean Mobility

Dr. Abas Goodarzi, President, US FuelCell

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www.usfuelcell.com
# US Hybrid Group

<table>
<thead>
<tr>
<th>US Hybrid</th>
<th>US FuelCell</th>
<th>Magmotor Corporation</th>
</tr>
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<tbody>
<tr>
<td><strong>HQ: Torrance, CA</strong></td>
<td><strong>South Windsor, CT</strong></td>
<td><strong>Worcester, MA</strong></td>
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<tr>
<td><strong>Year Established</strong></td>
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<td><strong>Core Competency</strong></td>
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US Hybrid Business Focus is Medium and Heavy Duty Commercial Vehicles
We have been making and operating Fuel Cell Vehicle for decades.

- **2002** 60kW FC Cargo Van
- **2005** FC Transit Bus BOP
- **2007** FC BOP
- **2009** PC40
- **2010** H2 Ride FC Bus
- **2011** FC Refueler
- **2012** FC-Construction
- **2013** FC Tow Tractor
- **2014** FC Cargo Van
- **2015** FC-Construction
- **2016** FC-Construction
- **2017** FC Range Extender
- **2018** FC Drayage Truck

**Acquired UTC PEM Fuel Cell**

**FCe™ 150**

**FCe™ 80**
Fuel Cell Mission Statement

We are committed to the commercialization and manufacture of PEM fuel cell technology in support of zero emission transit and goods movement.

We strive to serve as an exemplary model for the promotion of environmental responsibility and energy efficiency stewardship through an unwavering dedication to the improvement of efficiency, quality, reliability, and life cost of our product.
Fuel Cell is just another Engine delivering electrical energy

Our focus: Integrated Solution for Medium and Heavy Duty Transportation

- Life Cycle Cost
- Power Density
- GHG Footprint

Volume: 0.51 m³  
Weight: 190 kg

Volume: 1.6 m³  
Weight: 1199 kg
Integrated Balance Of Plant, Control and dc-dc

- Automotive Components, Accessible for service and Maintenance
- Integrated Air Processing Unit
- Integrated Fuel Processing unit
- Integrated Thermal Management System
- Integrated Isolated DC-DC Converter Technology
- Freeze Capable
- Integral Safety and Automatic Protection

Ease of Vehicle Integration and Operation
Integrated Robust Automotive (IP67) Controller

J1939 CAN Communications for Command, Control and Engine Diagnostics

In-depth Fuel Cell Diagnostic and Prognostic Monitoring

Common Scalable Functional Controls with over 15 years of refinement

Utilizing existing truck and bus engine diagnostic tools and remote monitoring devices

Continuous Monitoring, reporting and diagnostics of critical Parameters
How did we achieve Reliability;

- PC40 Fuel Cell engine has exceeded 22,000 hours of operation with ZERO failure
- Millions of Miles and hundred thousands of hours with Zero Stack failure and >90% total availability

![Fuel Cell Stack Voltage and Power after 7 hrs. of operation at rated current](image-url)
Early PEM power plant in demonstration bus

**Gen 1 (2000 – 2004)**


- Used as “test bed”
- Introduced:
  - Start/Stop mitigations
  - Enhanced cell performance & durability
  - Refined BOP

**Gen 3 (2009 – 2010)**

- Incorporated improvements from PC40.
- Released design, mfg. process, and supply chain.


- Improved power density
- Integrated BOP Design for Production
- Improved reliability
- Designed for Service & Maintenance

**NEW FREEZE CAPABLE TECHNOLOGY**

- Freeze capable design
- Bus and Truck Market Synergy
- Optimized and Integrated Power Plant (Life cycle cost reduction. Ease of Integration, Operation and Service like conventional engine
- Competitive Life Cycle cost with Zero Emission
Synergetic Bus and Truck market demand to reduce cost

80kW Fuel Cell Power plant can meet Transit bus and Truck power demand, combine market to reduce cost
Transportation Engineering
Why do we do, what we do; Decoupling Traffic

More than 50% of energy is wasted due to traffic

- **GVWR:** 1,800 kg
  - Speed: 32 kph (20 mph), 80 kph (50 mph), 23 kph (14 mph)

- **GVWR:** 20,450 kg
  - Speed: 7 mph

- **GVWR:** 36,300 kg
  - Speed: 9 mph

- **GVWR:** 29,545 kg
  - Speed: 14 mph

**Energy (kWh)**

- **Drive Cycle:** UDDS, US06, J45
- **Ave Speed:** 59%, 47%, 57%

**Energy per unit distance (kWh/mile)**

- **Speed:** 9 mph

**Energy (kWh)**

- **Drive Cycle:** UDDS, US06, J45
- **Ave Speed:** 5 mph, 10 mph, 15 mph
- **GVWR:** 1,800 kg
- **GVWR:** 36,300 kg
- **GVWR:** 29,545 kg

**Energy per unit distance (kWh/mile)**

- **Speed:** 7 mph

**Energy (kWh)**

- **Drive Cycle:** UDDS, 10 mph, 20 mph, 40 mph, 60 mph
- **Speed:** 19 mph

**Energy Types:**
- **Idling lost**
- **Hotel load**
- **Braking (lost)**
- **Drag**
- **Acceleration**
- **Rolling**
# Niche Fuel Cell Powered Transportation (on/off-road) Market

<table>
<thead>
<tr>
<th>Public Transit</th>
<th>Special Purpose</th>
<th>Special Applications</th>
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<tbody>
<tr>
<td>People Mover</td>
<td>Military Vehicles</td>
<td>Commercial Trucks</td>
</tr>
</tbody>
</table>

- **Public Transit People Mover**
  - Image of a zero emission bus

- **Special Purpose Military Vehicles**
  - Image of an armored military vehicle
  - Image of a military vehicle

- **Special Applications Commercial Trucks**
  - Image of a commercial truck with a crane
  - Image of a commercial truck
  - Image of a commercial truck with a trailer
## Hydrogen Gas is as Safe as LNG/CNG, if not safer

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen</th>
<th>Natural Gas</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color</strong></td>
<td>None</td>
<td>None</td>
<td>Clear to Amber</td>
</tr>
<tr>
<td><strong>Toxicity</strong></td>
<td>None</td>
<td>Some</td>
<td>High</td>
</tr>
<tr>
<td><strong>Odor</strong></td>
<td>None</td>
<td>None</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Physical state at 25°C and 1atm</strong></td>
<td>Gas</td>
<td>Gas</td>
<td>Liquid</td>
</tr>
<tr>
<td><strong>Buoyancy relative to air</strong></td>
<td>14.4x lighter</td>
<td>1.6x lighter</td>
<td>3.7x heavier</td>
</tr>
<tr>
<td><strong>Diffusion coefficient in air (cm²/sec)</strong></td>
<td>0.61</td>
<td>0.16</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>NPFA 704 Diamond</strong></td>
<td><img src="image" alt="NPFA 704 Diamond" /></td>
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<td><img src="image" alt="NPFA 704 Diamond" /></td>
</tr>
<tr>
<td><strong>Auto-ignition temperature (°C)</strong></td>
<td>585</td>
<td>540</td>
<td>228 - 471</td>
</tr>
<tr>
<td><strong>Flammability range in air [volume %]</strong></td>
<td>4.0 - 75</td>
<td>5.3 - 15</td>
<td>1.0 - 7.6</td>
</tr>
<tr>
<td><strong>Relative thermal radiation</strong></td>
<td>10%</td>
<td>33%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Flame temperature in air (°C)</strong></td>
<td>2045</td>
<td>1875</td>
<td>2197</td>
</tr>
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Summary: Hydrogen characteristics relative to other common fuels are **less hazardous**, such as it generates **less severe radiant energy** (1/10th), and it **disperses rapidly** when not confined and outdoors.

References:
**Performance Characteristics**

### Electrical
- Output Power: 6 - 80 kW
- Output voltage: 375 - 750V DC (integrated dc-dc converter)
- Ramp rate: 50 kW/sec

### Efficiency
- System Efficiency: 56.9% to 46.3% (10% to full power)

### Temperature
- Ambient Operating: -40 to 50°C
- Cooling Inlet (50/50 WEG): 55 to 57°C

### Fuel
- Fuel Flow: 5.2 kg/hr @ full power
- Fuel Pressure: 1200 ±300 kPa
- Fuel Type: SAE J2719 Hydrogen

### Physical Characteristics
- Dimensions (L x W x H): 916 x 879 x 614 mm
- Weight: 248 kg

### Interface
- Vehicle Communications: CAN SAE J1939

### Startup / Shutdown
- Startup Time: 30 seconds
- Startup from Frozen Time: 6 minutes
- Shutdown Time: 10 seconds
**FCE™ 150**  
**Fuel Cell Engine**  
**The World’s Leading Fuel Cell System for Commercial Vehicles**  
**Integrated Fuel Cell Electric Engine for Transportation**

The 150kW system has been designed for heavy duty fuel cell vehicles. The fast power transient capabilities make this electric engine ideal for transit, articulated buses, street cars, light rail, drayage and TRU trucks and off-road applications. The industry leading durability of over 12,000 hours ensures years of clean service.

### Performance Characteristics

#### Electrical
- Idle power: 7.5 to 10 kW
- Continuous Power†: 130 kW
- Peak power: 150 kW

#### Efficiency
- System Efficiency†: 54 to 46% (10% to full power)

#### Temperature
- Operating: -40 to 50°C

#### Fuel
- Fuel Flow: 0.8 to 8.4 kg/hr. (10% to full power)
- Fuel Pressure: 1200 ±300 kPa
- Fuel Type: SAE J2719 Hydrogen

#### Cooling
- Cooling: 59 to 72°C (50/50 WEG)

#### Physical Characteristics
- Dimensions (L x W x H): 1465 x 890 x 506 mm
- Weight: 474 kg

### Interface
- Vehicle Communications
- Startup Time: 30 seconds
- Shutdown Time: 10 seconds

**US FuelCell Hybrid Company**  
**www.usfuelcell.com**  

US FuelCell reserves the right to change the specification without notice. Rev: 160104