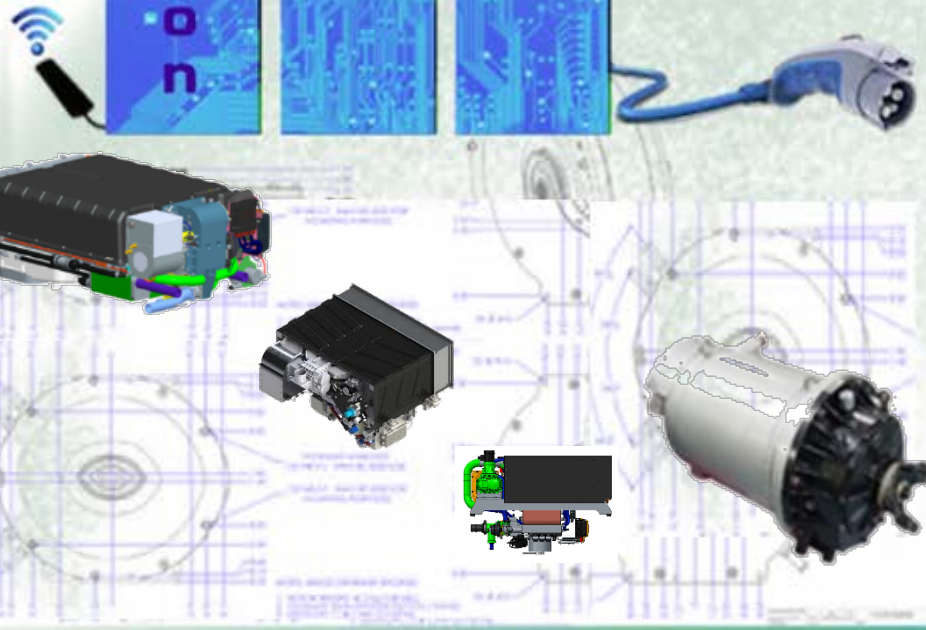
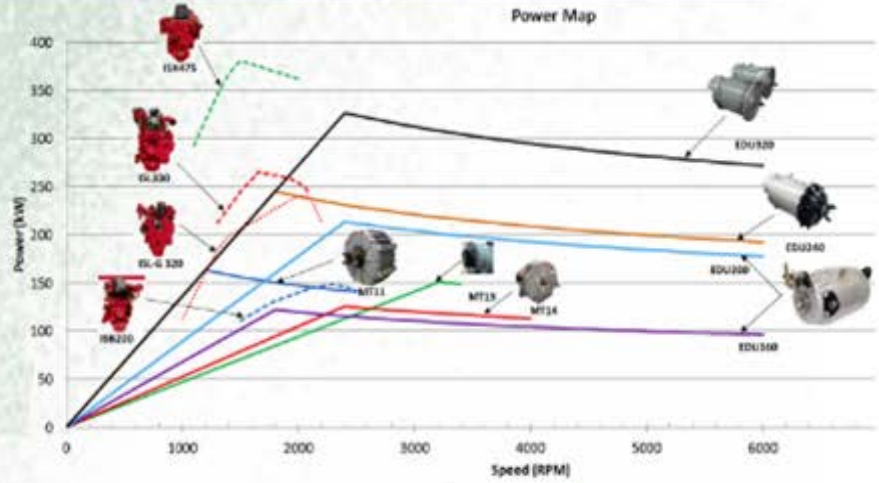
ISO 9001 ISO 14001

# US Hybrid

Innovation Quality Service










EQUIPMENT FLEET MANAGEMENT 2018 NATIONAL CONFERENCE

Michael Harrington

## Integrated Electric, Fuel Cell and Hybrid Powertrain Components Powering Clean Mobility

# US Hybrid Group

| US Hybrid<br>HQ: Torrance, CA | |
|---|---|
| Year Established | 1999 |
| Core Competency | Electric Powertrain for Electric, Hybrid and Fuel Cell Heavy Duty Vehicles |

| FuelCell Engine Div.<br>South Windsor, CT | |
|---|---|
| Year Established | 2013 |
| Core Competency | Fuel Cell Engines |

| Magmotor Corporation<br>Worcester, MA | |
|---|---|
| Year Established | 1876<br>(Acquired by US Hybrid in 2008) |
| Core Competency | Servo Motors and Drives Automation, Robotic and Semiconductor Mfg. |


Torrance, CA


Torrance, CA


Honolulu, HI

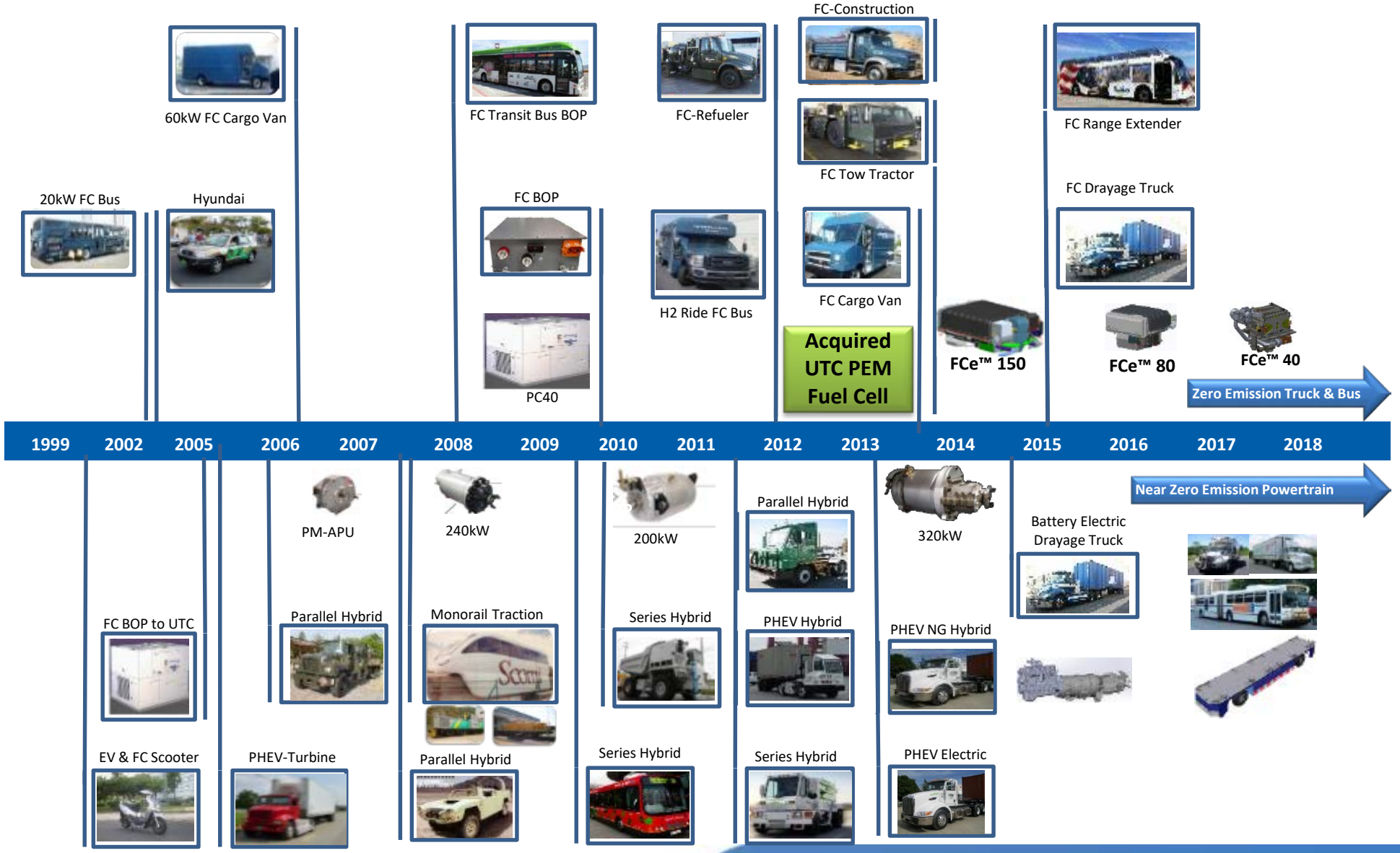

South Windsor, CT


Worcester, MA

**US Hybrid Business Focus is**

**Medium and Heavy Duty Commercial Vehicles**

# Manufacturing & operating BEV & Fuel Cell Vehicle for decades



# 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



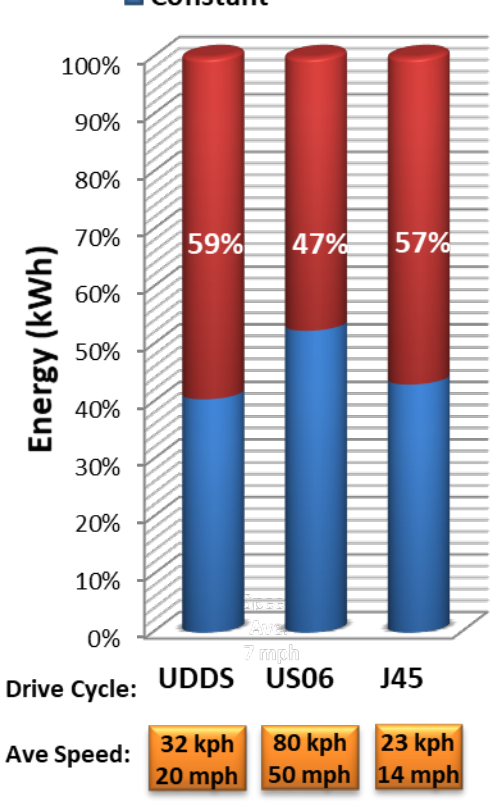
GVWR
20,450 kg
45,000 lbs.

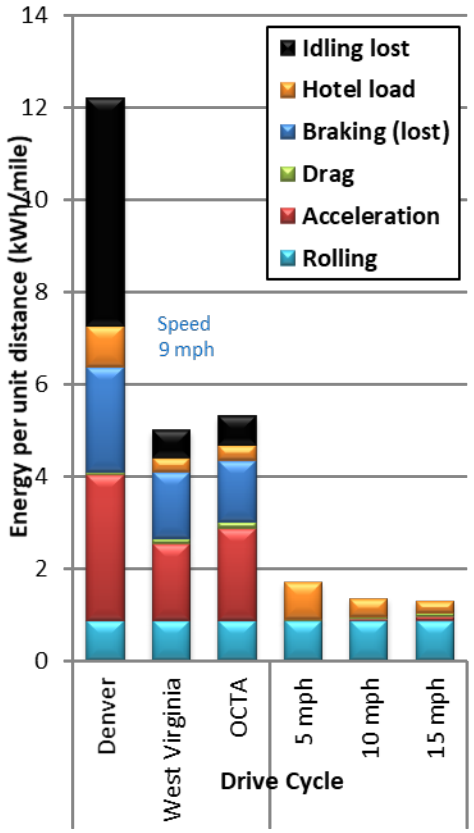


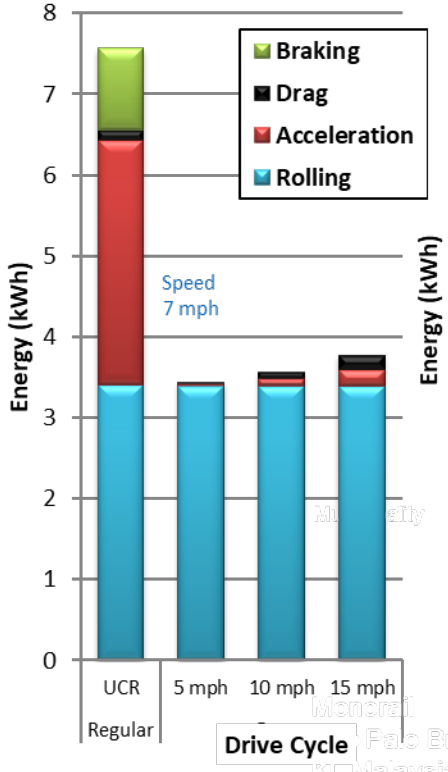
GVWR
36,300 kg
80,000 lbs.

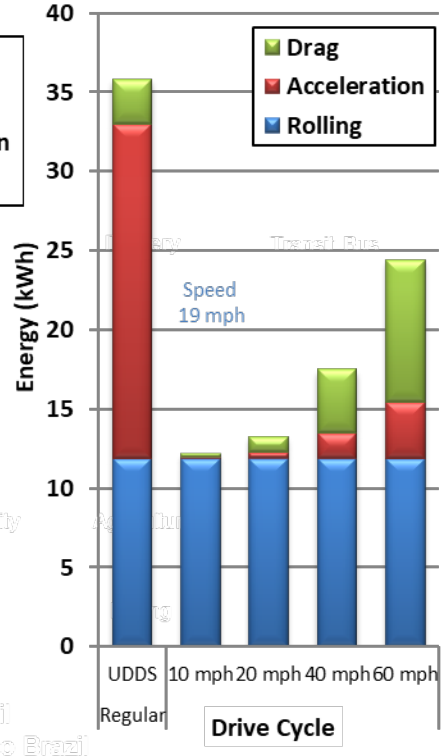


GVWR
29,545 kg
65,000 lbs.



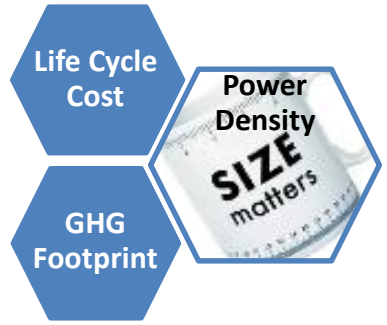



# Long Term Solution;
# FCe™ “Combustion-Less Engine” delivering electric Power

## Electric Propulsion is the future Powertrain

### Our Product: Integrated Fuel Cell Engine

### for Medium and Heavy Duty Transportation






Volume: 0.51 $m^3$
Weight: 292 kg

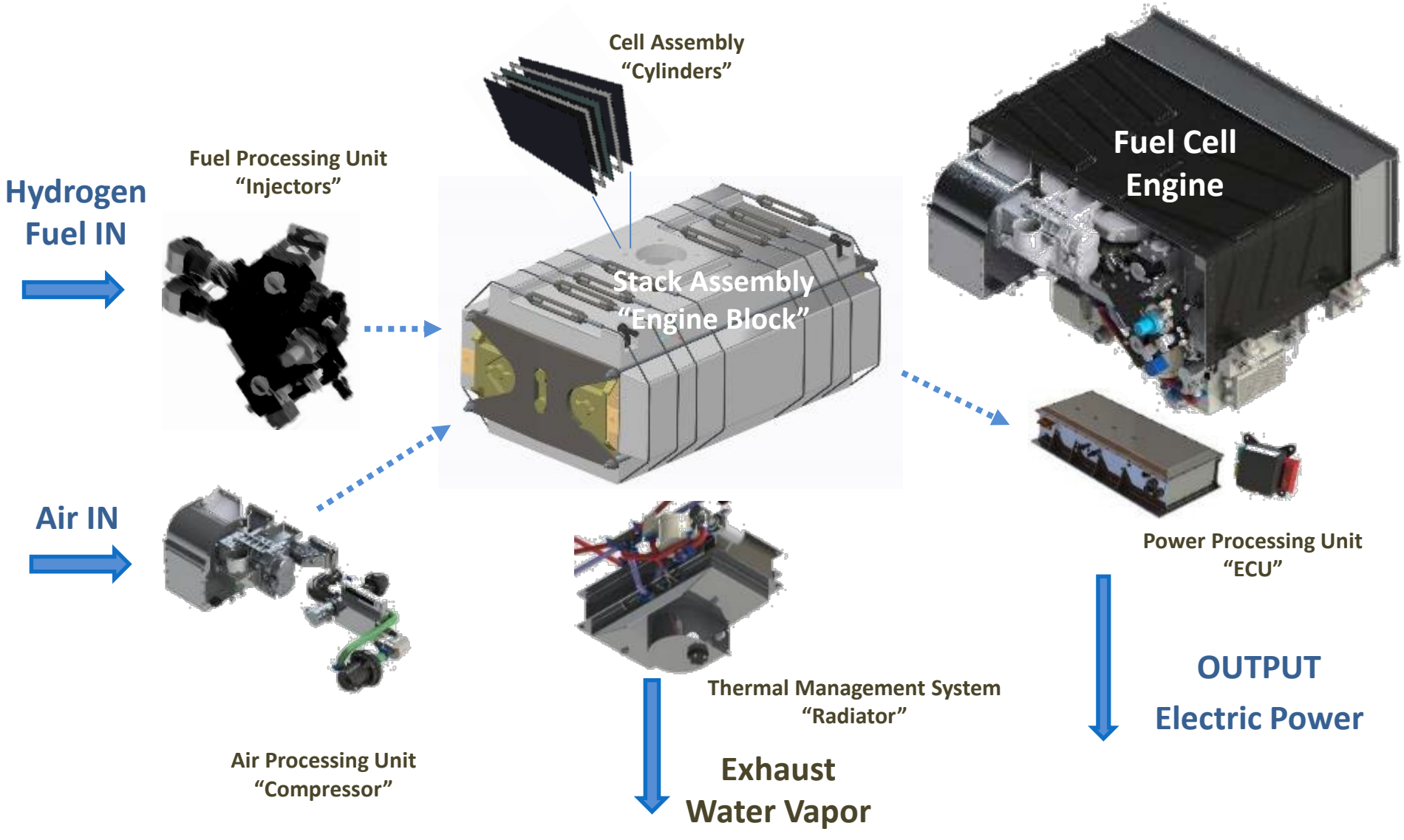


Volume: 1.6 $m^3$
Weight: 996 kg

US Hybrid 2018 ©

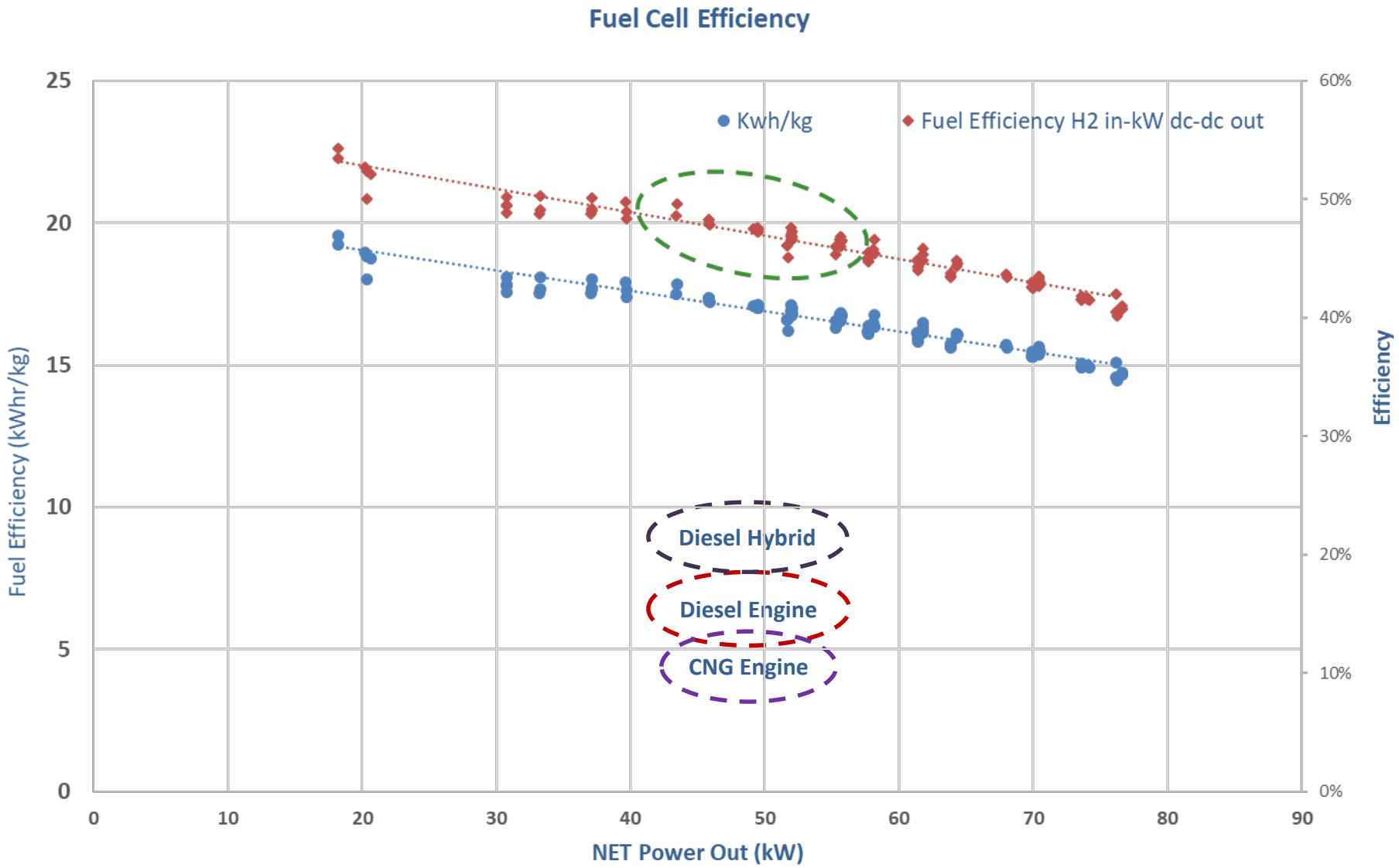
# Fuel Cell Engine

## Designed, installed, controlled, diagnostics and service like an Engine




US Hybrid 2018 ©

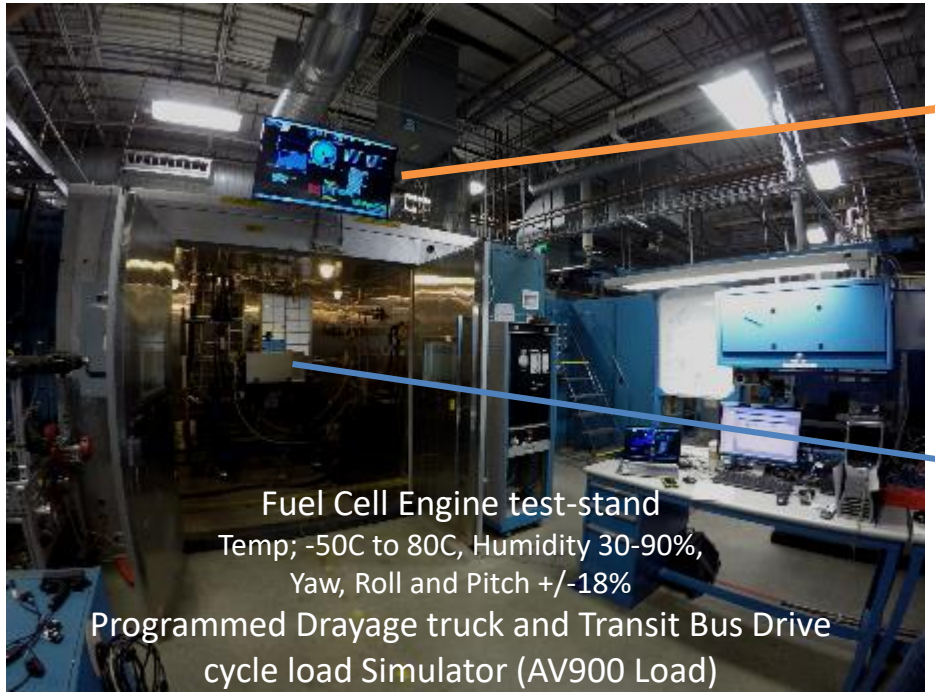
# FCe™ engine is the most efficient Engine delivering electric Power

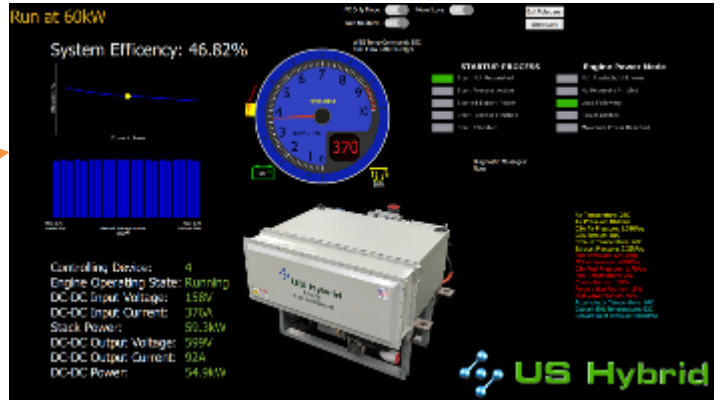


# FCe™ 80, Freeze Capable FC engine under test

FCe™80 FC engine

at the test-stand running Port of Los Angels Drayage Truck Duty cycle.

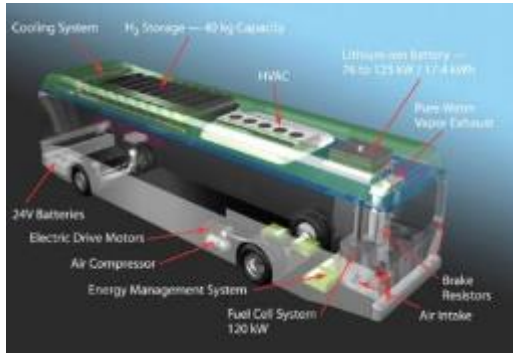


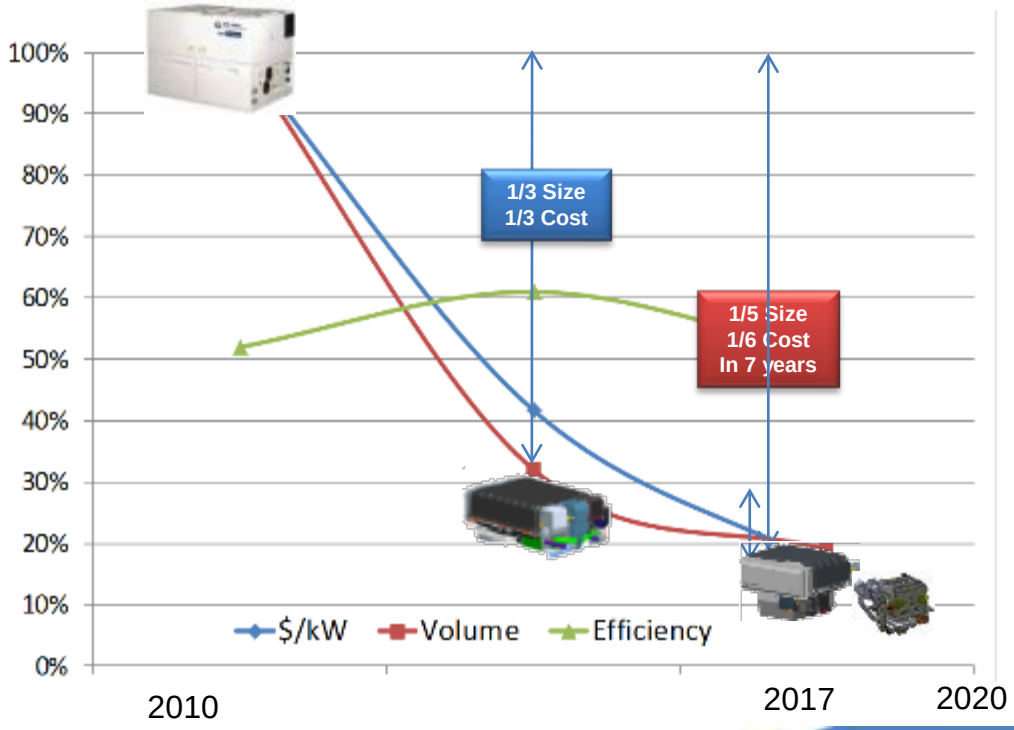


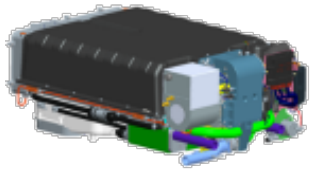

# FC engines are cost competitive with Engine APU & after-treatment

## Rapid Technology and Scale of Economy cost reduction (2008-2017)





FCe™150



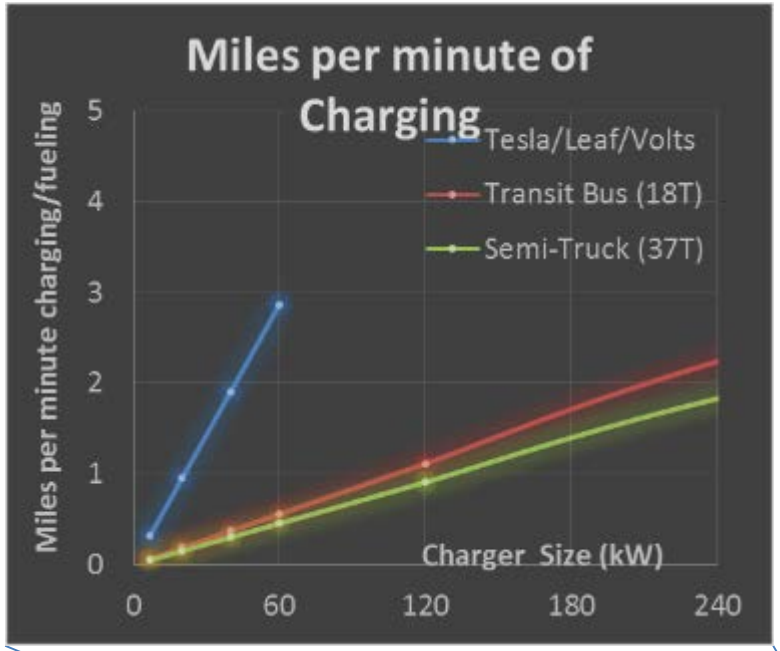
FCe™80



FCe™40

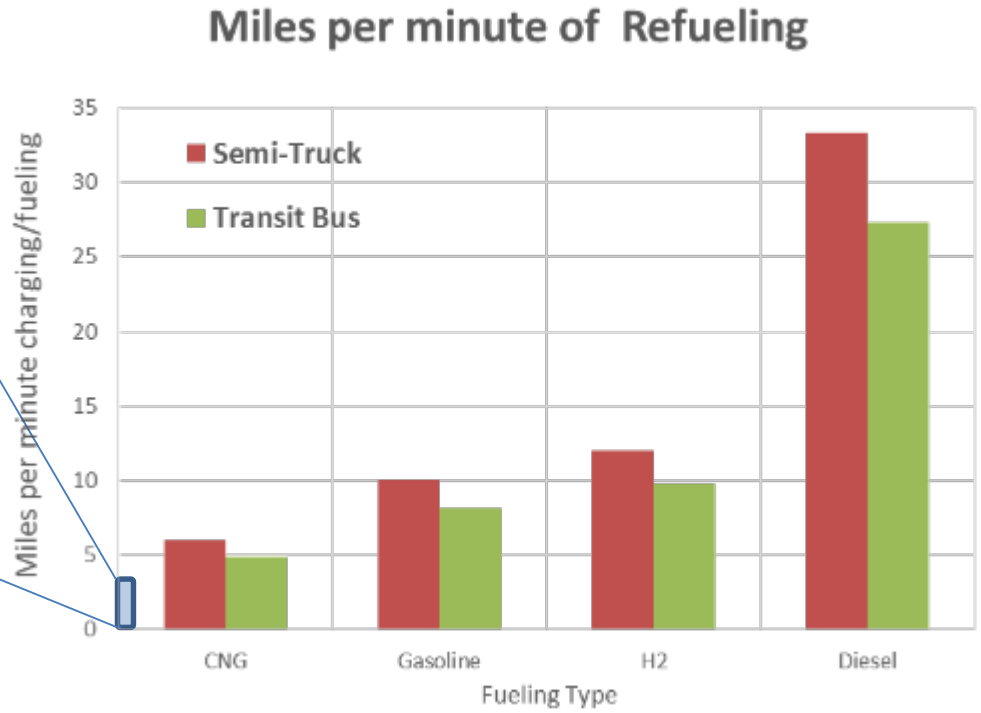


FCe™10



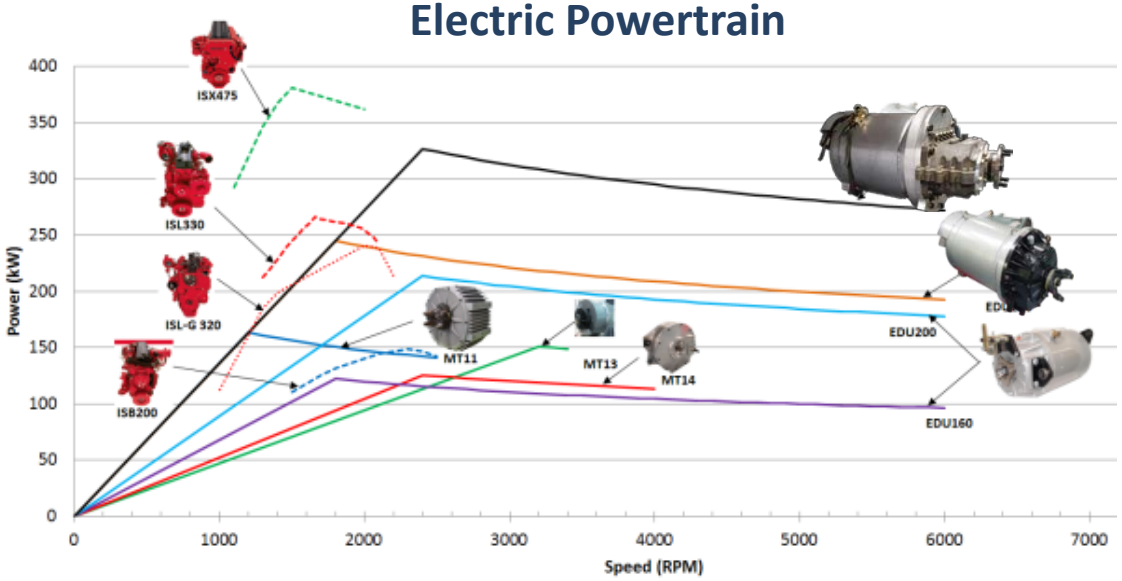

# Fuel Cells enable;

1. Fast Fueling
2. 24/7 operation
3. No range compromise
4. Most Efficient Zero Emission Cargo transportation



# Products: Electric Powertrain Production for MD/HD vehicles

## Electric Powertrain

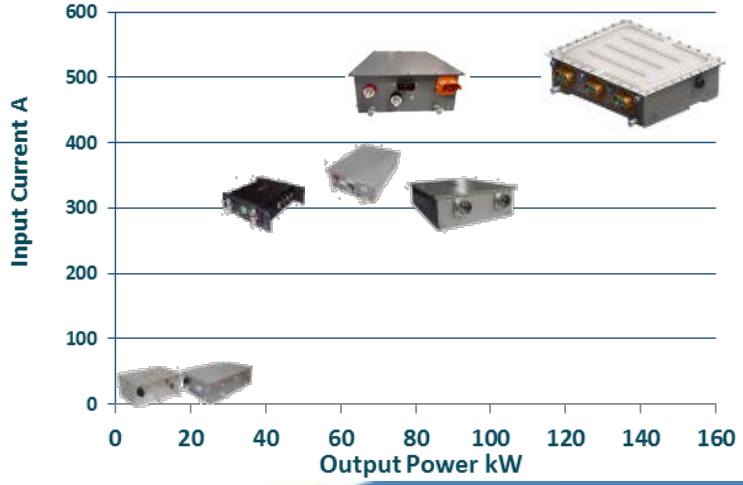



320kW

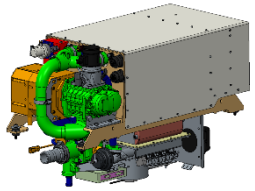
240kW

200kW

## DC-DC & Auxiliary Drives



## Proven Reliability, Performance and Freeze Capability



FCe™40



FCe™10




FCe™80

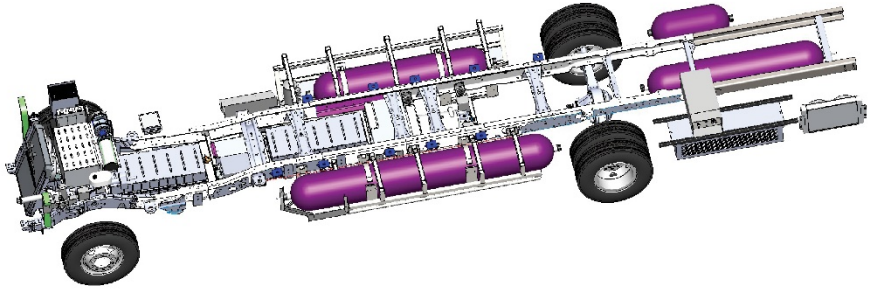
80kW Fuel Cell Engine for Transit Bus and Heavy Duty Logistics Trucks



FCe™150

150kW Fuel Cell Engine for Articulated Bus and Heavy Duty Trucks

### Turn Key Integrated Transportation System Solutions

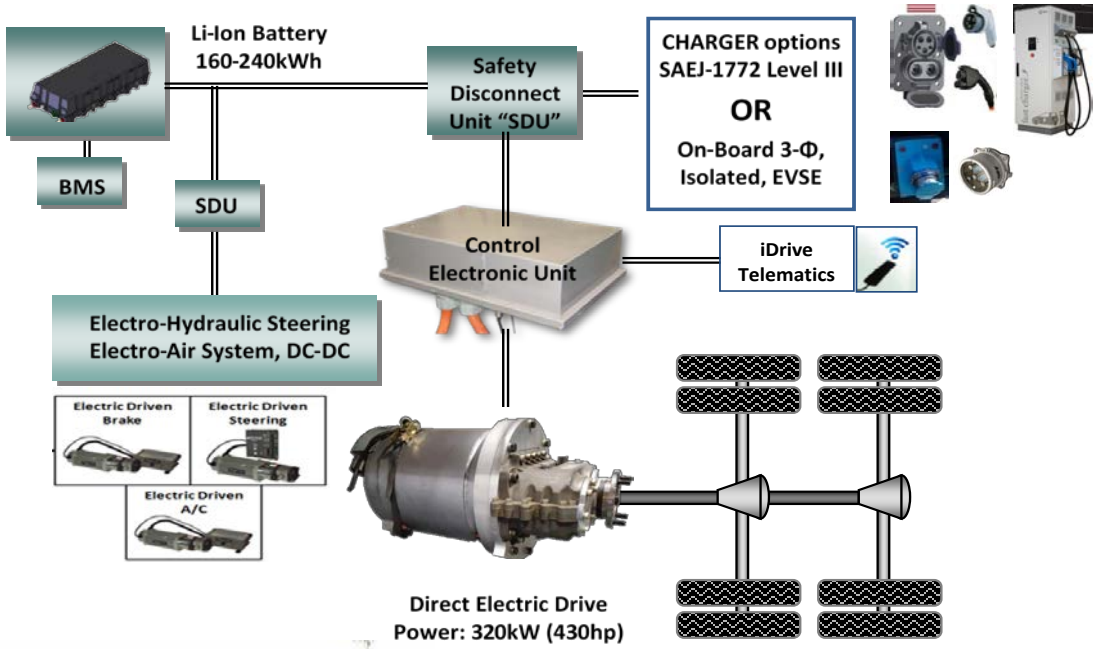




# Battery Electric Zero Emission Class-8 Truck (37T)

- Hybrid Electric
- Plug-in Hybrid
- **Battery Electric**
- Fuel Cell Electric

## eTruck™ Electric Drayage Class-8 Truck



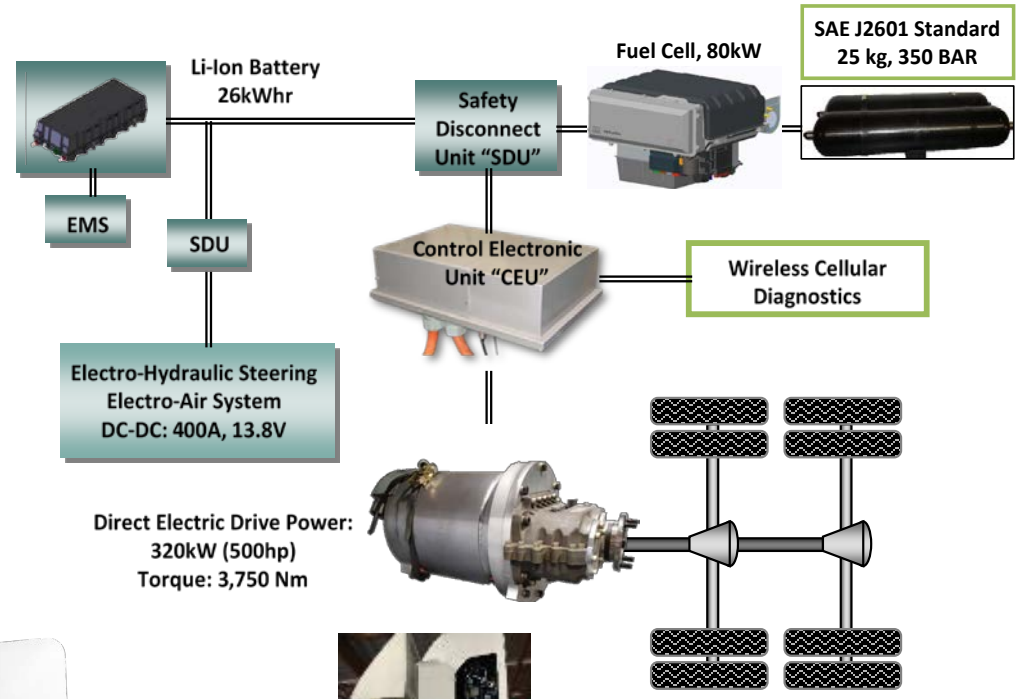






# Fuel Cell ZE Class-8 Truck (meeting 2035-2055 Targets)

- Hybrid Electric
- Plug-in Hybrid
- Battery Electric
- **Fuel Cell Electric**





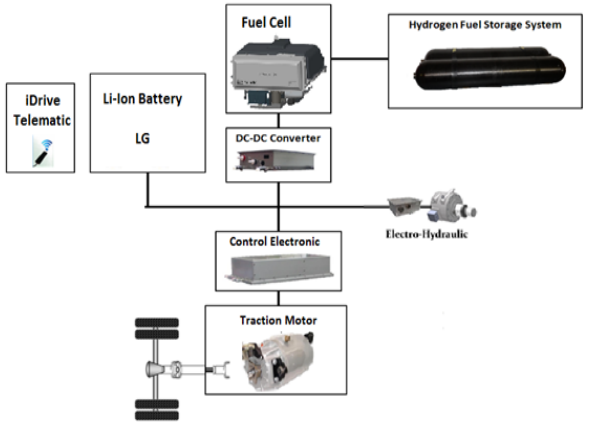






# Fuel Cell Sweeper (Caltrans, CA)
# Battery Sweeper (New York Sanitation)




# Fuel Cell Transit Bus
# Sunline





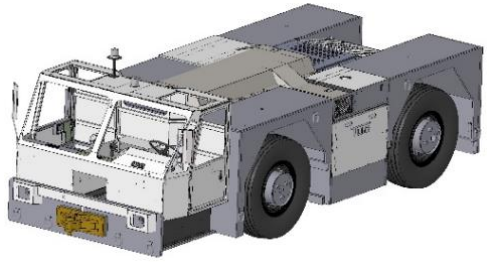



# U30; C-17 Push Back Tractor (GSE)







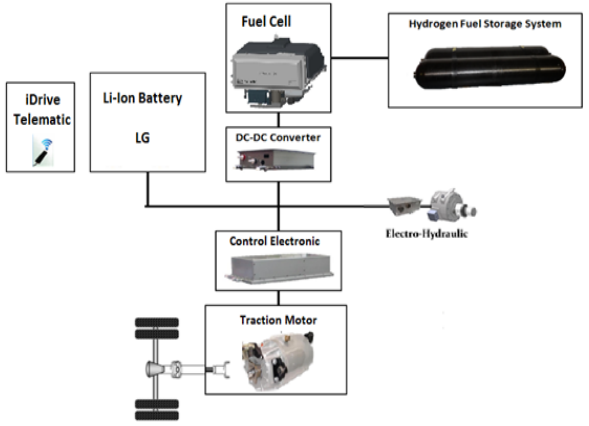




# FC Sweeper Top Level Specification

Comparable CNG Performance with Zero Emission
Proven Technology and Components




| Fuel Cell Zero Emission Sweeper Specifications | |
|---|---|
| GVWR | Up to 33,000 lbs. |
| Wheel Base: Length, Width, Height | 130 in. |
| Dimensions: Length, Width, Height | 142 in. 208 in. 102 in. |
| OEM Manufacturer & Model | Global Environmental Product M4HSD |
| Top Speed (MPH) | 60 -65 MPH |
| Operation Time (Sweep Duty) | 10 Hrs. |
| Battery Only Mode | 30 minutes |
| **Fuel Cell Engine APU Specifications** | |
| Fuel Cell | FCe™80, 80kW (PEM) |
| H2 Tank | ~15kg $H_2$ at 350 BAR |
| Power Plant Control & Diagnostics | SAEJ1939 CAN |
| **Electro-Hydraulic System Specifications** | |
| Motor | 60hp |
| Control | Variable Speed Control |
| Protection | Over Temp, Current, voltage and Power |
| **Energy Storage Specifications** | |
| Battery Technology | Li-Ion |
| Battery Voltage | 380V Nominal |
| Battery Power | 160 kW |
| Battery Energy | 22 kWh |
| **Direct Electric Traction Drive System Specifications** | |
| Propulsion | Direct Electric Drive |
| Motor Type | AC Induction |
| Traction Drive Power | 200 kW |
| Traction Inverter Power | 240 KVA |
| Control | Digital, Torque Vector Control |
| **Auxiliary Systems Specifications** | |
| DC/DC Converter | 13.8 V, 200A, 24V, 100A |
| Data Collection and Reporting | Wireless Telematics |
| Protection | Chassis Isolation Protection |
| Information | Driver Economizer Display |
| Diagnostics | SAEJ1939 CAN |
| AC Export Power (Option) | AC, 110/220V, 60 Hz, 10kVA |

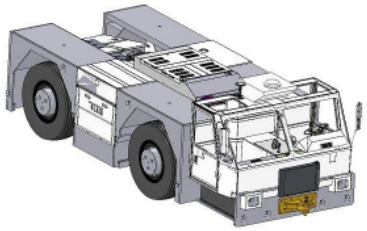
US Hybrid 2018 ©

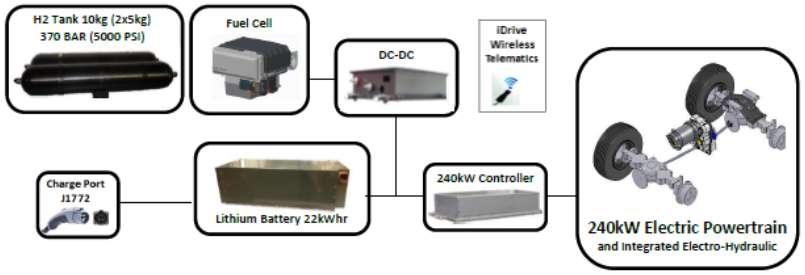
In Development

US Hybrid

## Fuel Cell Plug-In Hybrid Electric C-17 Tow Tractor








**Fuel Cell Plug-in Tow Tractor Powertrain System Block Diagram**

The C-17 Tow Tractor can be used in a variety of military and airport ground support (Boing 747) applications. It is currently being deployed at US Air Force Joint Base Pearl Harbor- Hickam in Honolulu, Hawaii.

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US Hybrid

### Fuel Cell Plug-In Electric C-17 Tow Tractor

| | |
|---|---|
| **Overall Vehicle Specifications** | |
| Gross Vehicle Weight | 100,00lbs |
| Max Drawbar Pull | 72,000lbs |
| OEM Manufacturer & Model | TUG Technologies Model U30 |
| **Vehicle Performance Specifications** | |
| Range from H2 and Battery | 12 hours |
| Forward/Reverse Max Speed | 15/4MPH max |
| Turning Radius | 260" Outside Diameter, Coordinated Steering |
| Steering | 3-Modes Steering (Coordinated, Track, Carb) |
| Ground Clearance | 10" |
| Max Grade | 7" Approach, 12" Breakover, 17" Departure |
| Overall dimensions | L=258", Width=110", Height=68" |
| Wheel Base | 124" |
| **Fuel Cell System Specifications** | |
| Fuel Cell | 30kW |
| Fuel Cell Technology | PEM |
| Fuel Cell Voltage, Current, and Power | 60V-120V, 500A, 30kW |
| **Hydrogen Storage System Specifications** | |
| Storage Capacity | 10kg of H2 (2 x 5kg tanks) |
| Max Pressure- Min Pressure | 350 BAR/5076 PSI - 13.8 BAR/200 PSI |
| **Energy Storage Specifications** | |
| Battery Cells Type | Li-Ion |
| Battery Voltage | 390V Nominal |
| Battery Max Power | 240kW |
| Battery Energy | 22kWhr |
| Battery Management | Integrated BMS |
| **Direct Electric Traction Drive System Specifications** | |
| Traction Motor Type | AC Induction |
| Electro-hydraulic Pump | AC Induction, Integrated |
| Traction Drive Power | 240kW |
| Hydraulic Drive Power | Integrated Electro-hydraulic PTO |
| Traction Inverter | IGBT, Digital Vector Drive |
| Charger Interface | SAE 1772- Level II |
| Charger- On-board | 6.6kW |
| **Auxiliary Systems Specifications** | |
| DC/DC Converter | 13.8V, 200A |
| Telematics | iDrive; Wi-Fi & Cell |
| Driver Display | Analog Gauges |
| Information Center Display | Digital with Fault Code Display |

www.ushybrid.com US Hybrid© Vehicle Specifications Subject to Change, Rev: 1401

# R12 FC Refueler

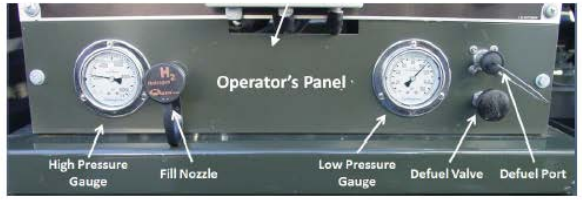
In Deployment

US Hybrid

## Fuel Cell Plug-In Hybrid Electric Re-Fueler (R12)



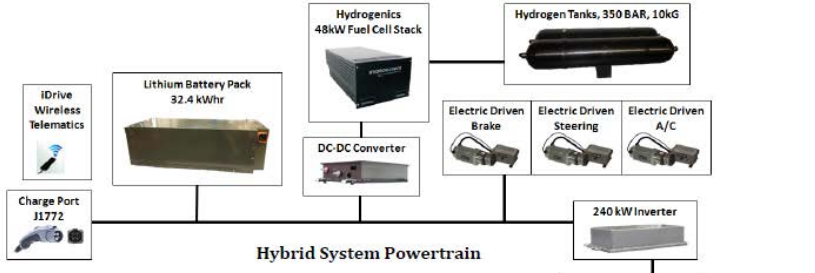








**Hydrogen Fueling and Defueling, Diagnostics, and Telematics Interface**




**Hybrid System Powertrain**

The R12 can be used in a variety of military and airport ground support applications. It is currently being deployed at US Air Force Joint Base Pearl Harbor- Hickam in Honolulu, Hawaii.

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US Hybrid

## Fuel Cell Plug-In Hybrid Electric Re-Fueler (R12) Specification

| | |
|---|---|
| **Overall Vehicle Specifications** | |
| GVWR | 11,340kg/25,500lbs |
| Wheel Base, Length, Width | 187", 301.9", 96" |
| OEM Manufacturer & Model | International® 4300 |
| **Vehicle Performance Specifications** | |
| Range from H2 and Battery | 180km/112 miles |
| Top Speed | 88.5 KPH/55 MPH |
| Acceleration 0-25 MPH | 5.5sec |
| **Fuel Cell System Specifications** | |
| Fuel Cell Supplier | Hydrogenics |
| Fuel Cell Voltage, Current, and Power | 40-80V, 380A, (3x16kW) |
| **Hydrogen Storage System Specifications** | |
| Weight of Storage Tanks | 190kg/418lbs |
| Storage Capacity | 9.78kg of H2 |
| Max Pressure- Min Pressure | 350 BAR/5076 PSI - 13.8 BAR/200 PSI |
| **Energy Storage Specifications** | |
| Battery Cells Type | Li-Ion (NCA) |
| Battery Pack Weight | 300kg/661lbs |
| Battery Voltage | 360V Nominal |
| Battery Max Power | 280kW |
| Battery Energy | 32.4kWhr |
| **Direct Electric Traction Drive System Specifications** | |
| Motor Type | AC Induction |
| Traction Drive Power | 200kW |
| Motor with Integrated Gear Unit Weight | 218kg/480lbs |
| Traction Inverter Power | 240kW |
| Inverter Weight | 27kg/60lbs |
| Charger- Integrated | J1772-Level II, 6.6kW |
| **Auxiliary Systems Specifications** | |
| DC/DC Converter | 13.8V, 400A |
| Air Conditioning Inverter | 5kW |
| Air Compressor Inverter | 5kW |
| Power Steering Inverter | 9kW |
| **Fuel Service End Leading Particulars** | |
| Split Shaft Pump/PTO | Mfr: Hale<br>Model: 501-4200-20-0<br>Pump Type: 4" Single Stage Centrifugal<br>Capacity: 300GPM<br>PTO Type: Split Shaft Driven |

US Hybrid© Vehicle Specifications Subject to Change, Rev: 1401

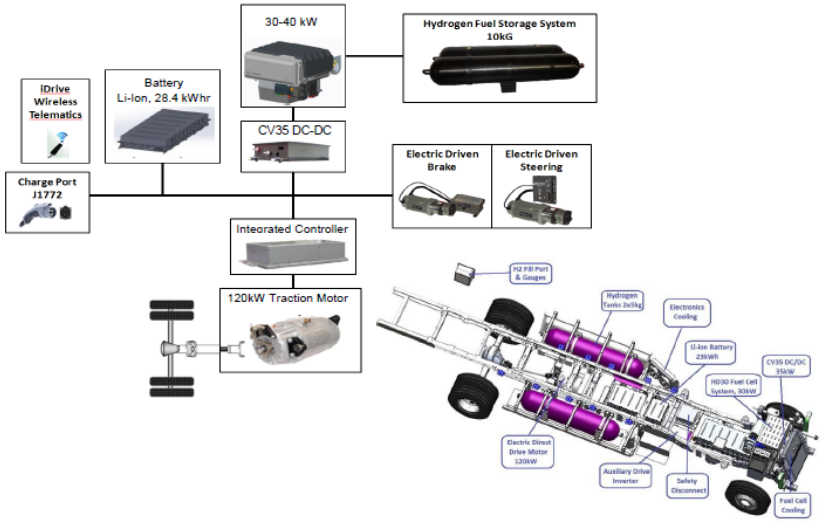
In Production

US Hybrid

## H2Cargo™ Fuel Cell Plug-In Step Van






**Fuel Cell Powertrain Diagram**

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US Hybrid

## H2Cargo™ Fuel Cell Plug-In Step Van Specification

| | |
|---|---|
| **Overall Vehicle Specifications** | |
| GVWR | 6,395kg/14,100lbs |
| Wheel Base | 178" |
| Interior and Seating | 2 Cab Seats With 16' Walk-in Cargo Body |
| OEM Manufacturer and Model | Workhorse or FCCC MT-45 |
| Body | Aeromaster 16' Walk-in, Aluminum |
| Chassis | Workhorse P42 or FCCC MT-45 |
| **Vehicle Performance Specifications** | |
| Range H2 and Battery | 200km/125 miles |
| Range Battery Electric | 31km/19 miles |
| Top Speed | 97 KPH/60 MPH |
| Acceleration 0-40 MPH | 7sec |
| **Fuel Cell System Specifications** | |
| Fuel Cell Supplier | Hydrogenics |
| Model and Type | HD30, PEM |
| Fuel Cell Voltage, Current, and Power | 60-120VDC, 500A, 30kW |
| DC-DC Converter | 35kW rated, CV35 |
| **Hydrogen Storage System Specifications** | |
| Weight of Storage Tanks | 190kg/418lbs |
| Storage Capacity | 9.78kg of H2 |
| Max Pressure- Min Pressure | 350 BAR/5076 PSI - 13.8 BAR/200 PSI |
| Fueling Time | < 5 minutes, Communication Port (90% capacity) |
| **Energy Storage Specifications** | |
| Battery Cells Type | Li-Ion |
| Battery Pack Weight | 300kg/661lbs |
| Battery Voltage | 360V Nominal |
| Battery Max Power | 140 kW |
| Battery Energy | 28kWhr |
| **Direct Electric Traction Drive System Specifications** | |
| Motor Type | AC Induction with Integrated Gear Reduction |
| Traction Drive Power | 120kW |
| Motor with Integrated Gear Unit Weight | 218kg/480lbs |
| Integrated Traction Inverter Power | 200kW |
| Integrated Traction Inverter Weight | 27kg/60lbs |
| Charger- Integrated | J1772-Level II, 6.6kW |
| Control, Communication and Diagnostics | J1939, CAN |
| **Auxiliary Systems Specifications** | |
| DC/DC Converter | 14.2V, 540A |
| Air Conditioning | Electric driven Scroll Compressor |
| Electro-hydraulic Power Steering | Integrated |

US Hybrid© Vehicle Specifications Subject to Change, Rev: 1401

# FC Weapon Loader

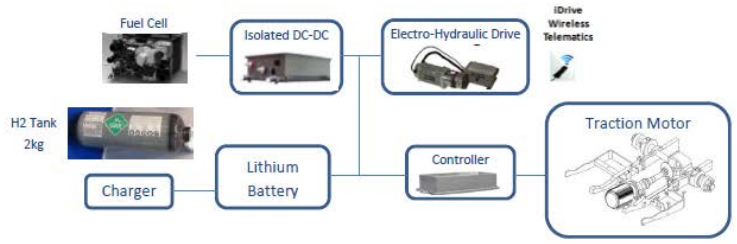
US Hybrid

## Fuel Cell Hybrid Electric Weapon Loader






Hydrogen Fueling and Defueling, Diagnostics and Telematics Interface




Fuel Cell Hybrid Electric Weapon Loader Power Train System Block Diagram

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US Hybrid PROPRIETARY ©

US Hybrid

## Fuel Cell Hybrid Electric Weapon Loader Specification

| | |
|---|---|
| **Overall Vehicle Specifications** | |
| Tare Weight | 3,950 lbs. |
| Lift Capacity On Table<br>Lift Capacity On Fork | 3000 lbs.<br>2250 Lbs. |
| OEM Manufacturer & Model | Hydraulic International MJ-1E |
| **Vehicle Performance Specifications** | |
| Range from H2 and Battery (hr.) | 16 hours |
| Forward Speed<br>Reverse Speed | 8 MPH<br>3 MPH |
| Turning Radius | 15 ft. |
| Ground Clearance | 4.5 in. |
| Max Grade | 10 Deg, loaded, 20 deg, unloaded |
| Hydraulic Fluid | MIL-H-83232 (6-Gal capacity) |
| Mobility | MIL-M-8090 |
| **Fuel Cell System Specifications** | |
| Fuel Cell Supplier and Model | Hydrogenics HD4 |
| Fuel Cell Technology | PEM |
| Fuel Cell Voltage, Current and Power | 20Vdc-40 Vdc, 200A, (4kW) |
| **Hydrogen Storage System Specifications** | |
| Storage Capacity | 2 kG of H2 |
| Max Pressure- Min Pressure | 350 BAR/5076 PSI - 13.8 BAR/200 PSI |
| **Energy Storage Specifications** | |
| Battery Cells Type | Li-Ion |
| Battery Voltage | 240V Nominal |
| Battery Power | 20 kW |
| Battery Energy | 10kWh |
| Battery Management | Integrated BMS. |
| **Direct Electric Traction Drive System Specifications** | |
| Traction Motor Type | AC Induction |
| Electro-hydraulic Pump | AC Induction |
| Traction Drive Power | 10 kW |
| Hydraulic Drive Power | 10 kW |
| Traction Inverter | IGBT, Vector Drive |
| Hydraulic Inverter | IGBT, Vector Drive |
| Charger- On-board | 3.3 kW |
| **Auxiliary Systems Specifications** | |
| DC/DC Converter | 13.8 V, 40 A |
| Telematics | iDrive, Wi-Fi & Cell |
| Driver Display | Analog Gauges |
| Information Center Display | Digital |

US Hybrid PROPRIETARY ©

# Battery Dominant Fuel Cell Bus






| Electrical | |
|---|---|
| Output Power‡ | 6 - 80kW |
| Output voltage | 500 - 750$V_{DC}$ (Integrated dc-dc converter) |
| Ramp rate | 50 kW/sec |
| **Efficiency** | |
| System Efficiency† | 56.9 to 46.3% (10% to full power) |
| **Temperature** | |
| Ambient Operating | -30 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 $kPa_g$ |
| 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 | 15 seconds |
| Startup from Frozen | 6 minutes |
| Shutdown | 10 seconds |

# Electric Powertrain, Enabling Zero and Near Zero Mobility

Optimize Cargo Handling cost $/Ton/km pay load



**Common Electric Powertrain**

Battery Electric
Fuel Cell Electric
Hybrid Electric

HD Truck
Transit Bus
Mining
Military
Monorail
Shunt-train

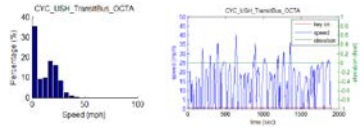
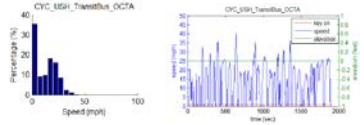
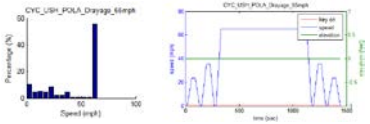
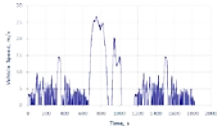
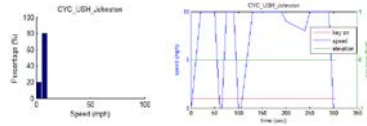
**320kW (500 hp)**



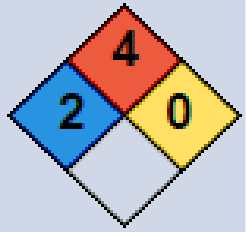
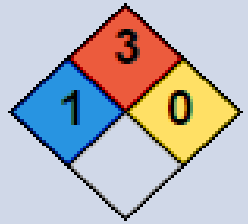
**240kW (320 hp)**



# Well to Wheel Fuel Economy for Commercial Vehicles
# FC is Most Efficient Engine with Zero tail pipe Emission

| Vehicle Type | Driveline Config. | Energy Efficiency % Well to wheel | Fuel Saving | Annual Emissions and GHG NOx kg/Year | CO kg/Year | GHG ton/year | Drive Cycle |
|---|---|---|---|---|---|---|---|
| Transit Bus  | Diesel | 27% | | 174 | 7,909 | 103 |  |
| | Hybrid | 32% | | 140 | 6,358 | 83 | |
| | CNG | 25% | | 6 | 400 | 80 | |
| | Electric | 30% | | - | - | - | |
| | Fuel Cell | 34% | 9% | - | - | - | |
| Shuttle Bus  | Diesel | 27% | | 134 | 6,118 | 80 |  |
| | Hybrid | 32% | | 115 | 5,230 | 68 | |
| | CNG | 26% | | 5 | 326 | 73 | |
| | Electric | 30% | | - | - | - | |
| | Fuel Cell | 38% | 12% | - | - | - | |
| Drayage Truck  | Diesel | 22% | | 264 | 12,010 | 156 |  |
| | Hybrid | 27% | | 237 | 10,809 | 141 | |
| | CNG | 22% | | 8 | 510 | 80 | |
| | Electric | 27% | | - | - | - | |
| | Fuel Cell | 37% | 15% | - | - | - | |
| Refuse Truck  | Diesel | 23% | | 153 | 6,989 | 91 |  |
| | Hybrid | 28% | | 139 | 6,334 | 83 | |
| | CNG | 23% | | 5 | 250 | 48 | |
| | Electric | 27% | | - | - | - | |
| | Fuel Cell | 34% | 11% | - | - | - | |
| Street Sweeper  | Diesel | 25% | | 120 | 5,478 | 71 |  |
| | Hybrid | 29% | | 103 | 4,713 | 61 | |
| | CNG | 24% | | 3 | 218 | 46 | |
| | Electric | 28% | | - | - | - | |
| | Fuel Cell | 36% | 12% | - | - | - | |

# Hydrogen Gas is as Safe as Gasoline/CNG, if not safer

| | Hydrogen | Natural Gas | Gasoline |
|---|---|---|---|
| **Color** | None | None | Clear to Amber |
| **Toxicity** | None | Some | High |
| **Odor** | None | None | Yes |
| **Physical state at 25°C and 1atm** | Gas | Gas | Liquid |
| **Buoyancy relative to air** | 14.4x lighter | 1.6x lighter | 3.7x heavier |
| **Diffusion coefficient in air ($cm^2/sec$)** | 0.61 | 0.16 | 0.05 |
| **NPFA 704 Diamond**<br>**0=none, 4=Severe**<br>**Red: Flammability**<br>**Blue: Health**<br>**Yellow: Reactivity** |  |  |  |
| **Auto-ignition temperature (°C)** | 585 | 540 | 228 - 471 |
| **Flammability range in air [volume %]** | 4.0 - 75 | 5.3 - 15 | 1.0 - 7.6 |
| **Relative thermal radiation** | 10% | 33% | 50% |
| **Flame temperature in air (°C)** | 2045 | 1875 | 2197 |




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:
1. http://cameochemicals.noaa.gov/
2. NREL. US DOE. *Reaching the U.S. Fire Service with Hydrogen Safety Information: A Roadmap*. By Casey Grant. 2009.