Xcelsior CHARGE H2™

Michael McDonald, Operations Manager

Vehicle Innovation Center
Highlights

300
Over 300 events and training sessions have been hosted since opening in 2017.

5,000
More than 5,000 industry leaders have visited and learned from our VIC experts.

50 years
50 years of experienced manufacturing zero-emission buses.

50 million
More than 50 million EV miles of experience.

Welcome to the VIC

Our Vision

“To be North America’s leader in the exploration and advancement of bus and coach technology connecting people to places”

• First innovation lab of its kind in North America, opened October 2017
• Lead exploration and innovation technology for bus & coach applications
• EV and AV technologies
• Manufacturing innovation lab
• Interactive exhibits
• Virtual reality learning displays
• Electric bus driving simulator
How To Move a Bus

Internal combustion engine

- Dino juice + O₂ = explosion + CO₂ + H₂O
- Diesel, CNG (NFI: 1990s)

Electric drive

- Electricity → electric motors
- Trolley (NFI: late 1960s)
- Battery-electric (BEB) (NFI: early 2010s)
  - “Plug” → portable
- Hybrid (diesel-electric) (NFI: early 2000s)
  - Acceleration, low speed, regen: e-drive
  - Steady drive: ICE
- Fuel cell-electric (NFI: early 90s)
  - Lessons from BEB + Hybrid + CNG
# EV Propulsion at a Glance

Electric Drive vs. Internal Combustion Engine (ICE)

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Battery-Electric</th>
<th>Fuel Cell-Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Storage</strong></td>
<td>Diesel fuel</td>
<td>Batteries</td>
<td>Hydrogen/Batteries</td>
</tr>
<tr>
<td><strong>Energy Conversion</strong></td>
<td>ICE</td>
<td>Batteries</td>
<td>Fuel Cell</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>Gearbox</td>
<td>Direct Drive</td>
<td>Direct Drive</td>
</tr>
<tr>
<td><strong>Traction</strong></td>
<td>ICE</td>
<td>PEM* A/C Motor</td>
<td>PEM A/C Motor</td>
</tr>
<tr>
<td><strong>Accessories</strong></td>
<td>ICE belt-driven</td>
<td>Electric motor-driven</td>
<td>Electric motor-driven</td>
</tr>
<tr>
<td><strong>Heating</strong></td>
<td>ICE waste</td>
<td>Electric</td>
<td>FC waste/electric</td>
</tr>
</tbody>
</table>

*Permanent Magnet Motor (PEM)
Why Fuel Cell-Electric Bus (FCEB)?

• Zero-emissions*
  *anthropogenic carbonaceous molecules linked to excessive atmospheric solar absorption emissions

• Extended range
  • Far-superior energy density of Hydrogen (H₂) vs. Li-ion batteries
  • Limited by how much H₂ you can carry

• Fast re-fuel
  • No slow charge or specialized infrastructure for fast charging

• Free heat!
  • Capture waste like in ICE vehicles
  • Further enhances range in cold

• Performs like a diesel
  • 1:1 bus substitution ($)
  • Benefits of e-drive
    • Low maintenance ($)
    • Quiet
    • Smooth performance
FCE Drive Summary

• It’s an electric bus
  • Fuel cell enables electric drive
  • An onboard “gas battery”
  • Combines the best of all propulsion systems
• Batteries are power-dense, H₂ is energy-dense
• Drive cycles are erratic:
  • Constantly accelerating & decelerating
  • Batteries can handle that
  • Fuel cells cannot accommodate constantly changing power demand; provide steady power delivery
• Batteries mediate power demand in FCEBs
• Fuel cells are a range extender/onboard ESS charger
Onboard H₂

- Compressed (350 bar/5000 psi) in specialized tanks
- H₂ is the fuel/energy
- Requires conversion
- ICE: ignite fuel $\rightarrow$ heat $\rightarrow$ pressure $\rightarrow$ mechanical
- 25 – 35% efficient
- Increase efficiency by converting to electricity (~50 – 60%)
Chemistry of Hydrogen (H₂) Energy

ICE: 25 – 35% efficient

Convert H₂ to electricity in a **fuel cell**

\[
H_2 + \frac{1}{2}O_2 \rightarrow \text{energy} + H_2O
\]

\[
H_2 \rightarrow 2H^+ + 2e^- \quad \text{oxidation (anodic)}
\]

\[
2e^- + 2H^+ + \frac{1}{2}O_2 \rightarrow H_2O \quad \text{reduction (cathodic)}
\]

- Spatially separate half-reactions
- *Electrochemical conversion*
- “Organized combustion”
- No carbonaceous emissions
- Low mechanical
  - Efficient
  - Low noise
How Do Fuel Cells Work?

Graphite flow plates
- Current collectors
- Bipolar

Electrons from $H_2$ are captured as electric current.

Membrane-electrode assembly (MEA)
- Catalytic: Platinum (Pt)
- Solid electrolyte/separator: Nafion
Commercial Fuel Cells for NFI

- Produce 0.6 – 0.8 V per cell (v 1.23 V thermodynamic potential)
- Electrodes convert and are not “consumed”
  - Available energy external and “unlimited”
- Balance-of-plant subsystems
  - Air intake (compressor)
  - Air scrubbing
  - Thermal management
  - Pressure regulation
  - Exhaust system
Tank Modules & Fill Panel

Tank Modules
- All-composite (Hexagon)
- 7.5 kg H₂
- **350 bar** (15 °C)
- 98 kg empty (excluding valve & mounting)
- Ø16.3” x 125” long
- HGV2 / EC79 certified
- 20-year service life

Fill Panel
- Dual H35 fill receptacles
  - WEH TN1 HF (1) & WEH TN5 (2)
  - Inline Check Valves (3)
- Prepared for IrDA communication w/ fill station
- Lower service panel
  - HP Defuel Port (4)
  - LP Sample Port (5)
  - LP Vent to Roof Stack (6)
- HP & LP Analog Gauges (7) & HP Digital Gauge (8)
H₂ Safety

Kidde dual spectrum sensors provide:

- Hydrogen fire detection
- Hydrogen leak detection

Future Development
Test port to verify Tank Pressure without isolating all other tanks

Impact Sensor
SS Remote TPRD’s plumbed to atmosphere
Tank Isolation Valves
Xcelsior CHARGE NG™ Battery Systems are designed for a wide variety of routes and demanding environmental conditions.

**Battery Supplier**

<table>
<thead>
<tr>
<th>Cell</th>
<th>Sub-Pack</th>
<th>Controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cells designed for long life under tough conditions.</td>
<td>Cells and liquid cooling fins are stacked and retained within the sub-pack, along with temperature and voltage monitoring circuits.</td>
<td>The BMS (Battery Management System) monitors every cell and provides real-time state-of-charge, power, and safety protection.</td>
</tr>
</tbody>
</table>

**New Flyer**

<table>
<thead>
<tr>
<th>Strings</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>The sub-packs are grouped in high-voltage “strings” and housed in environmentally sealed enclosures. Multiple strings are connected in parallel, providing the necessary power and energy.</td>
<td>Depending on the size and expected routes of the bus, the required number of strings are installed and connected to the propulsion system’s power and control electronics, as well as the battery cooling system.</td>
</tr>
</tbody>
</table>
Energy Storage System (ESS) Subpacks

Subpack Level
- Balance-of-plant integration
- Battery management system (BMS)
- Modular, plug-and-play
Current ELFA 2 motor, uses an encoder sensor to verify motor rotation

Propulsion System
Drive Motor

Advantages:

• No additional gearbox necessary
• No noise, no maintenance
• Conventional drive technology integration
• Higher power density than ASM
• Higher efficiency and lower energy consumption than ASM
• Good scalability of power by adaptation of motor length
• Low need of current compared to ASM
• Significantly lower life cycle costs by investment and fuel efficiency

• The Permanent Magnet Motor (PEM) is a twelve-pole excited three phase permanent synchronous motor.
• The motor is cooled by means of a water cooling circuits.
# Propulsion System Power Management

<table>
<thead>
<tr>
<th>Type</th>
<th>Inverter 3 Phases &amp; 1 Phase for Chopper or DC/DC converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Media</td>
<td>Water-Glycol</td>
</tr>
<tr>
<td>Rated Voltage DC</td>
<td>650 V</td>
</tr>
<tr>
<td>Operating Voltage DC</td>
<td>300 V - 750 V</td>
</tr>
<tr>
<td>Rated Current Inverter</td>
<td>250 A</td>
</tr>
<tr>
<td>Rated Power Inverter (460V AC)</td>
<td>200 KVA</td>
</tr>
<tr>
<td>Max. Current Inverter (10 s)</td>
<td>350 A</td>
</tr>
<tr>
<td>Max. Power (500V AC)</td>
<td>320 KVA</td>
</tr>
<tr>
<td>Switching Frequency Inverter</td>
<td>2 - 6 KHz</td>
</tr>
<tr>
<td>Rated Current Chopper or DCDC</td>
<td>1 x 150A (@ 6 kHz)</td>
</tr>
<tr>
<td></td>
<td>1 x 300A (@ 0 kHz)</td>
</tr>
<tr>
<td>Switching Frequency Chopper &amp; DCDC</td>
<td>2 - 6 KHz</td>
</tr>
<tr>
<td>Weight</td>
<td>30 kg</td>
</tr>
<tr>
<td>Dim. (wxl)xh) without Connectors</td>
<td>411 x 454 x 183 mm</td>
</tr>
<tr>
<td>Degree of Protection</td>
<td>IP 6K9K</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>-25 °C to 50 °C (for rated values)</td>
</tr>
</tbody>
</table>
Electric Drive Accessories

Electric

- A/C compressor
- Heater
- Power steering pump
- Air compressor
- Thermal management
  - Radiator fans, coolant pumps
Xcelsior® Heavy-Duty Transit Buses

Transforming your community with sustainable, clean transit technology.

- Proven Heavy-Duty Bus Platform
- Introduced in 2010
- Over 1 billion miles of revenue service
- Superior performance at Altoona
- Quietest ride
- Built for accessibility
- Designed for maintainability
- BRT styling and optional features
- Over 14,000 Xcelsior® buses currently on the road
New Flyer Xcelsior CHARGE H2™
Integration & Layout
**Technical Summary**

<table>
<thead>
<tr>
<th></th>
<th>40’</th>
<th>60’</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Cell</strong></td>
<td>Ballard FCvelocity-HD85</td>
<td></td>
</tr>
<tr>
<td><strong>Equivalent Battery Energy</strong></td>
<td>700 kWh</td>
<td>1100 kWh</td>
</tr>
<tr>
<td><strong>Hydrogen Storage Volume</strong></td>
<td>37.5 kg</td>
<td>60 kg</td>
</tr>
<tr>
<td><strong>Net Power</strong></td>
<td></td>
<td>85 kW</td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td>Siemens ELFA 2 Electric Drive System</td>
<td></td>
</tr>
<tr>
<td><strong>Rated Power</strong></td>
<td>160 kW</td>
<td>320 kW</td>
</tr>
<tr>
<td><strong>Rated Torque</strong></td>
<td>1,033 ft-lb</td>
<td>2,066 ft-lb</td>
</tr>
</tbody>
</table>
Performance

Altoona Range @ Seated Load Weight (40’ model)

<table>
<thead>
<tr>
<th></th>
<th>Manhattan</th>
<th>OCBC</th>
<th>UDDS</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption (kWh/mile)</td>
<td>8.57</td>
<td>1.83</td>
<td>0.94</td>
<td>3.78</td>
</tr>
<tr>
<td>Fuel Consumption (Miles/kg)</td>
<td>5.32</td>
<td>6.91</td>
<td>8.33</td>
<td>6.86</td>
</tr>
<tr>
<td>Fuel Cell Range (Miles)</td>
<td>192</td>
<td>249</td>
<td>300</td>
<td>247</td>
</tr>
<tr>
<td>Battery Range (Miles)</td>
<td>7</td>
<td>33</td>
<td>64</td>
<td>16</td>
</tr>
<tr>
<td>Total Range (Miles)</td>
<td>199</td>
<td>282</td>
<td>364</td>
<td>263</td>
</tr>
</tbody>
</table>

Real Life Results

350 miles (560 km) on a single fill validated during testing in Orange County

- 9.16 miles/kg (14.66 km/kg)
- 330 miles (480 km) fuel only
- 20 miles (32 km) extended battery range
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