Fuel Cell Electric Bus Technology: Technical Capabilities & Experience
(Co-Hosted by California Hydrogen Business Council)

June 13, 2019
California Transit Association

- Represents more than 200 transit-affiliated entities, including more than 80 transit agencies in CA
- Advocates for policies and funding solutions that support and advance public transit
Involvement in Innovative Clean Transit Regulation

• Led negotiation with ARB on behalf of the transit industry
• Focused our advocacy efforts on the following provisions:
  – Benchmarking & Regulatory Assessment
  – ZEB Purchase Mandate Schedule
  – Waiver for Early Compliance
  – Definition of Small vs. Large Agencies
  – Access to Incentive Funding
  – Excluded Buses
Support for ICT Regulation Implementation

Advocacy

Outreach/Education

Compliance
How to Ask Questions

• Submit your questions anytime during the program using the Questions module in your webinar control panel at the right of your screen.

• We will collect all questions and get to as many as time permits during the Q&A portion of the program.
Emanuel Wagner
Deputy Director
California Hydrogen Business Council
The California Hydrogen Business Council (CHBC) is comprised of over 100 companies and agencies involved in the business of hydrogen. Our mission is to advance the commercialization of hydrogen in the energy sector, including transportation, goods movement, and stationary power systems to reduce emissions and dependence on oil in California.

CHBC Activities:

- Advocacy & Initiatives
  - Renewable Hydrogen, Renewable Energy and Climate
  - Hydrogen Blending and Gas System Integration
  - Hydrogen Fueling Station Build-out
  - Stakeholder Advocacy Campaign

- Communications & Business Expansion
- Goods Movement, Heavy-Duty Transportation, and Clean Ports
- Hydrogen Energy Storage and Renewable Hydrogen
- Public Transport
Our Members Include:

- Hydrogen producers and distributors
- Automotive companies
- Public transit systems and suppliers
- Fuel cell, electrolyzer, compressor and storage manufacturers
- Fueling station developers, engineers and consultants
- Municipal and state agencies
- Component suppliers
• Fact Sheet from CHBC and California Fuel Cell Partnership:
Takeaways

- Fuel cells are a mature, commercially available option for public transit.
- Fuel cells electric buses (FCEBs) are one of two available zero emission options to meet the ARB ICT Regulation.
- SunLine Transit has operated FCEBs for more than a decade.
- SunLine is establishing redundancy in its hydrogen fueling infrastructure to have a secure, affordable supply.
- Deployment of FCEBs will increase drastically in the next 3-5 years, with thousands of buses ordered around the world.
- If you missed the first webinar, the recording is available here: [https://caltransit.org/events/webinars/fuel-cell-technology-a-four-part-series/](https://caltransit.org/events/webinars/fuel-cell-technology-a-four-part-series/)
- **Policy Summit** - Sacramento (August)
- The Other Electric Bus: **Meeting California’s Innovative Clean Transit Regulation with Fuel Cell Technology Workshop** (November 2019)
- Hydrogen & Fuel Cell **Ports Briefing** - POLB & POLA (December 2019)
- Stay Informed: [https://www.californiahydrogen.org/chbc-events/](https://www.californiahydrogen.org/chbc-events/)
Thank You!

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Join us!
www.californiahydrogen.org
Capabilities of Fuel Cell Electric Buses (FCEBs)

California Transit Association and the California Hydrogen Business Council Webinar

June 13, 2019
California Fuel Cell Leadership

• Industry collaboration, advocacy, and advancement with cleantech leaders:
  • California Air Resources Board (CARB) / California Climate Investments Program
  • Center for Transportation and the Environment (CTE)
  • CALSTART
  • California Fuel Cell Partnership
  • California Hydrogen Business Council

• Currently supporting OCTA, AC Transit, and Sunline with fuel cell-electric Xcelsior CHARGE H2™ buses.

• To date, New Flyer has sold over 80 electric buses to battery-electric bus programs in California.

• In April 2019, achieved 350 miles of zero-emission range in a fuel cell test demo for OCTA.

• Four California locations: Ontario, Los Alamitos, Fresno, and the Bay Area (Hayward).
Whistler BC Fuel Cell-Electric Bus Project
2009-2014

• BC Transit initiated a project with California Air Resources Board (CARB) and the US National Renewable Energy Laboratory (NREL) to test FCEBs in urban transit operation.

• At the time, became the world’s largest single location hydrogen fuel cell fleet (20 buses) for the Vancouver 2010 Olympics in British Columbia, Canada.
New Flyer: Integrator to Innovator

• **Knowledge gained through experience**
  • New Flyer needs to take ownership of system controls
  • Serviceable components need to be located in accessible areas
  • Ownership of fuel cell balance of plant needs to be with the manufacturer

• **Development of Electrical Accessories**
  • Component selection needs to align with vehicle performance expectations
  • Select technology with proven performance & reliability
  • Improve energy consumption
**Fuel Cell-Electric Bus Control Strategy**

**THEN**

- Fuel cell-dominant hybrid
- Large fuel cell/small battery
  - Ballard FCveloCity HD6-150 fuel cell (150 kW)
  - Single battery string
    - Ability to take advantage of frequent regen events

**NOW**

- Battery-dominant hybrid
- Small fuel cell/large battery
  - Ballard FCveloCity HD85 fuel cell (85 kW)
    - Sized to meet average Net Power of 30-45 kW
  - Two or Three String A123 ESS (100-150 kWh)
    - Ability to take advantage of frequent regen events
    - Up to 235 kW peak power for acceleration, high-speed operation and hill climbs
    - Extends range when bus is out of fuel
<table>
<thead>
<tr>
<th>Development</th>
<th>Bus Model</th>
<th>Fuel Cell</th>
<th>Readiness</th>
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<tr>
<td></td>
<td>40-Foot</td>
<td>Hydrogenics Celerity(+)</td>
<td>Evaluation</td>
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<tr>
<td>Production Builds</td>
<td>60-foot</td>
<td>Ballard HD85</td>
<td>Commercial Production</td>
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<tr>
<td></td>
<td>40-foot</td>
<td>Ballard HD85</td>
<td>Commercial Production</td>
</tr>
</tbody>
</table>
Zero-Emission Options

**xcelsior CHARGE**
- Eco-friendly
- Robust design
- Up to 220 miles range*
- 4-hour overnight charge
- Range decreases over the life of the batteries*
- One charger per 2-3 buses
- Diesel auxiliary heater recommended for cold climates

**xcelsior CHARGE H2**
- Eco-friendly
- Robust design
- Up to 350 miles range*
- 6-20 minutes fill time
- Range consistent over the life of the batteries & fuel cell*
- Fill station scalable by fleet size
- No secondary auxiliary heater required for cold climates

*40-foot on APTA BAC transit duty cycle
xcelsior CHARGE H2™
40-foot & 60-foot Components, Specs, and Design Layout
### Altoona Range @ SLW

<table>
<thead>
<tr>
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<th>CBD</th>
<th>ART</th>
<th>COM</th>
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<td>Power Consumption [kWh/mile]</td>
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<td>Fuel Consumption [miles/kg]</td>
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<td>Fuel Cell Range [miles]</td>
<td>277.61</td>
<td>227.61</td>
<td>431.96</td>
<td>293.97</td>
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<td>Battery Range [miles]</td>
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<td>19.54</td>
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<tr>
<td>Total Range [miles]</td>
<td>299.77</td>
<td>247.16</td>
<td>466.33</td>
<td>317.90</td>
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### Real Life Results:

**TBD**: Bus recently delivered to AC Transit in Oakland, CA for a 2 year demonstration
## Altoona Range @ SLW

<table>
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<td>Fuel Consumption [miles/kg]</td>
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<td>6.91</td>
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<td>6.86</td>
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<td>Fuel Cell Range [miles]</td>
<td>191.52</td>
<td>248.76</td>
<td>299.88</td>
<td>246.96</td>
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<td>Battery Range [miles]</td>
<td>7.00</td>
<td>32.79</td>
<td>63.83</td>
<td>15.87</td>
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<tr>
<td>Total Range [miles]</td>
<td>198.52</td>
<td>281.55</td>
<td>363.71</td>
<td>262.83</td>
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</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
Fuel Cell-Electric Bus Price Trends

- Decrease in fuel cell cost
- Decrease in battery cost
- Improved design for manufacture and assembly
  - Mass production optimization
  - Standardization between FC electric and battery electric
  - Reduced complexity and highly repeatable assembly
- Expanded supply chain with increased competition
- Manufacturing volume will reduce cost

*Note: Actual bus price will vary based on battery capacity and customer options
Questions?

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256-473-3246 (Mobile)

newflyer.com/chargeH2
Fuel Cell Electric Bus Evaluation Results

Leslie Eudy
National Renewable Energy Laboratory
NREL Role in ZEB Evaluation

- **3rd party evaluation of advanced technology in real-world service**
  - Established evaluation protocol provides consistent data collection and reliable analysis
  - Unbiased results in common format
  - Comparison to baseline conventional technology and technical targets

Transit Agencies

- Share information with the transit industry that will aid in advanced technology purchase decisions & fleet operations

Government

- Provide feedback to federal, state and local government to understand technology status and prioritize funding for necessary R&D

OEMs

- Collaborate with tech providers to understand status and share performance results for ZEB and baseline buses
NREL works closely with the transit agencies and other partners to gather data including:

- Fueling records – cost and efficiency calculations
- Maintenance records – cost per mile by system
- Daily bus use & availability – reliability
- Roadcalls – reliability
- Fleet experience – lessons learned
### Results Summary

#### FCEB fleets included in data summary

<table>
<thead>
<tr>
<th>Transit Agency</th>
<th>Abbreviation</th>
<th>Location</th>
<th>Bus Type</th>
<th># Buses</th>
<th>Data Included</th>
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<tbody>
<tr>
<td>AC Transit</td>
<td>ACT</td>
<td>Oakland, CA</td>
<td>Van Hool</td>
<td>13</td>
<td>Fuel cell hours and fuel cost only</td>
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<tr>
<td>SunLine Transit Agency</td>
<td>SL</td>
<td>Thousand Palms, CA</td>
<td>AFCB</td>
<td>4</td>
<td>All, prototype bus removed</td>
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<tr>
<td>Orange County Transportation Authority</td>
<td>OCTA</td>
<td>Santa Ana, CA</td>
<td>AFCB</td>
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<td>All</td>
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<tr>
<td>Stark Area Regional Transit Authority</td>
<td>SARTA</td>
<td>Canton, OH</td>
<td>AFCB</td>
<td>5</td>
<td>All</td>
</tr>
</tbody>
</table>

AC Transit | SunLine | OCTA | SARTA
Top Fuel Cell Powerplant Exceeds 32,000 Hours

- Top fuel cell powerplant (FCPP) >32,100 hours
- Ten FCPPs have surpassed DOE/DOT ultimate target

FCPP retired (9) and replaced with spare (10)

Total hours accumulated on each FCPP as of 4/30/19
• Data from newer buses (in service from July 2014)
• Fuel cell system roadcalls are caused by balance of plant components, not stack issues
## Hydrogen Cost Data Summary, $/mi

<table>
<thead>
<tr>
<th></th>
<th>AC Transit(^a)</th>
<th>SunLine(^b)</th>
<th>OCTA(^c)</th>
<th>SARTA(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data period</td>
<td>2/13–7/17</td>
<td>3/12–12/18</td>
<td>3/16–12/18</td>
<td>2/18–12/18</td>
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<tr>
<td>Number of months</td>
<td>54</td>
<td>82</td>
<td>34</td>
<td>11</td>
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<tr>
<td>Average H(_2) cost, $/kg</td>
<td>8.39</td>
<td>10.17</td>
<td>13.95</td>
<td>5.14</td>
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<tr>
<td>Maximum H(_2) cost, $/kg</td>
<td>10.26</td>
<td>26.02</td>
<td>16.99</td>
<td>5.88</td>
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<tr>
<td>Minimum H(_2) cost, $/kg</td>
<td>6.49</td>
<td>2.53</td>
<td>12.99</td>
<td>5.00</td>
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<td>Overall FCEB fuel cost, $/mile</td>
<td>1.41</td>
<td>1.83</td>
<td>2.21</td>
<td>1.04</td>
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<td>Baseline technology</td>
<td>Diesel</td>
<td>CNG</td>
<td>CNG</td>
<td>CNG/diesel hybrid</td>
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<tr>
<td>Average fuel cost, $/gal or $/gge</td>
<td>2.43</td>
<td>0.96</td>
<td>1.15</td>
<td>1.89/2.30</td>
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<tr>
<td>Overall baseline fuel cost, $/mile</td>
<td>0.57</td>
<td>0.32</td>
<td>0.32</td>
<td>0.45/0.51</td>
</tr>
</tbody>
</table>

Fuel cost is based on data provided by agencies; not all are equal comparisons

\(^a\) Delivered cost  
\(^b\) Includes station operating and maintenance (O&M) costs  
\(^c\) Retail cost from local public stations  
\(^d\) Delivered cost
Fueling Cost Data Summary, $/mi

AC Transit
- FCEB: 1.41
- Diesel: 0.57

SunLine
- FCEB: 1.83
- CNG: 0.32

OCTA
- FCEB: 2.21
- CNG: 0.32

SARTA
- FCEB: 1.04
- CNG: 0.45
- Hybrid: 0.51

Delivered cost
Includes station O&M
Retail cost from local public stations
Maintenance Cost by System

- Cost for propulsion system repairs highest for AFCBs
- Propulsion issues include:
  - Cooling system leaks
  - Low-voltage batteries
  - Fuel cell BOP
- Other issues:
  - Air compressor
  - Suspension

- Cumulative cost from in-service date
- Labor @ $50/h

BEB = battery electric bus
BOP = balance of plant
PMI = preventive maintenance inspection
HVAC = heating, ventilation, and air conditioning
Maintenance Cost Trends

Cumulative maintenance cost from start of service

1. Low miles and introduction of new technology leads to higher cost in early stage of FCEB introduction
2. Cost drops and stabilizes as miles increase—most repairs handled under warranty
3. Cost trends up with learning curve for troubleshooting and repair as agency staff take on more maintenance work
4. BEB maintenance work handled by on-site OEM staff
5. BEB costs increase as agency takes over and warranty period ends
Technical Issues Affecting Cost

• Fuel cell system issues—majority due to balance of plant
  – Air handling—blowers, compressors, controller
  – Cooling—pumps, plumbing
• Electrical system: low-voltage batteries
  – Electric accessories can cause a continual drain that shortens battery life (includes IT equipment such as cameras and fareboxes)
    – Issue also affects BEBs
• Cooling system leaks
  – Significant labor to locate
• Bus air compressor
• Added labor hours for troubleshooting problems
Remaining Challenges and Barriers

For industry to fully commercialize FCEBs:

– Deploy larger fleets
  • Lower per-bus price: OEMs estimate ~$1M/bus for higher volumes
  • Accelerate learning curve for staff
  • Combine orders for multiple agencies

– Incorporate training for FCEBs into standard maintenance training

– Install hydrogen stations
  • High capital cost to install, but easier to scale up compared to battery fleet
  • Turn-key stations where fuel provider owns, operates, and maintains station can help with stabilizing cost for long-term budget planning
  • Long-term fuel contracts can lock in lower cost
  • Station utilization—higher volumes can mean lower per-unit cost
Questions?

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Alameda-Contra Costa Transit District
Fuel Cell Bus Program

Fuel Cell Electric Bus Technology:
Technical Capabilities and Experience

June 13, 2019

actransit.org
• 7 member, publicly elected Board of Directors
• Michael Hursh, General Manager
• Serving 1.5 million people
• 364 square mile service area
• 152 lines (31 Transbay)
• 20.4 million annual service miles
• 637 buses (14 – ZEB)
• 6 facilities in the East Bay
• 2,243 employees
Zero-Emission Bay Area (ZEBA) Advance Demonstration Program

- CARB Fuel Path Mandate
  - Three bus demonstration program
  - Twelve bus advanced demonstration program
- Consortium Agencies in ZEBA Program
  - Funding support for AC Transit program
  - Requirement to operate buses in revenue service
Program Advancement

2003-2006
- 1 FC Buses
- 30”Thor
- 60kW UTC PEM
- 48, 12v Panasonic batteries
- 25kg H2 storage
- 175-200 mile range

2006-2010
- 3 FC Buses
- 40’ VanHool A330
- 120kW UTC PEM
- Zebra 90 kWh battery system
- 50kg H2 storage
- 250-300 mile range

2010-Present
- 13 FC Buses
- 40’ VanHool A300
- 120kW UTC PEM
- EnerDel 21kWh battery system
- 40kg H2 storage
- 200-220 mile range

2019
- 10 FC Buses
- 40’ New Flyer
- 85kW Ballard
- A123 100kWh battery system
- 37.5 kg H2 storage
- 300 mile range
Future ZEB Programs

New Flyer Xcelsior XHE60
• 60-foot fuel cell transit bus
• Target range of 250 miles

(10) Xcelsior XHE40 (FCEB)
(5) Xcelsior XE40 (BEB)
True side-by-side comparison
• Same Agency
• Same Service Environment
• Same OEM
• CTE – Performance Report
<table>
<thead>
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<th></th>
<th>Units</th>
<th>This Reporta</th>
<th>2016 Target</th>
<th>Ultimate Target</th>
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<tbody>
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<td>Bus lifetime</td>
<td>years/miles</td>
<td>5.3/8,300–131,900b</td>
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<td>12/500,000</td>
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<td>Power plant lifetimec</td>
<td>hours</td>
<td>4,000–21,400d</td>
<td>18,000</td>
<td>25,000</td>
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<td>%</td>
<td>74</td>
<td>85</td>
<td>90</td>
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<td>Fuel fillsb</td>
<td>per day</td>
<td>1</td>
<td>1 (&lt;10 min)</td>
<td>1 (&lt;10 min)</td>
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<td>Hydrogen storage cost</td>
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<td>Roadcall frequency</td>
<td>miles between roadcalls</td>
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<td>3,500/15,000</td>
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<td>Operation time</td>
<td>hours per day/days per week</td>
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<td>20/7</td>
<td>20/7</td>
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<td>$/mile</td>
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<td>Range</td>
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<td>300</td>
<td>300</td>
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<tr>
<td>Fuel economy</td>
<td>miles per diesel gallon equivalent</td>
<td>6.18</td>
<td>8</td>
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</table>

Fuel Cell Fleet Advancements

- 5 fuel cells met the 2016 target in Oct 2016, 11 by 2017
- FC7 achieved “Ultimate Target” of 25K hrs in June 2017 & reached over 32K hrs
- 10 fuel cells have met the “Ultimate Target”
- Over 356,490 combined hours!
- More than 3.2 million clean zero emissions miles!
ZEB Study Results

Beginning-of-Life (BOL) & End-of-Life (EOL) batteries by bus length & route

<table>
<thead>
<tr>
<th>Bus Length (feet)</th>
<th>Energy Storage (kWh)</th>
<th>BoL Service Energy (kWh)</th>
<th>EoL Service Energy (kWh)</th>
<th>Route Category</th>
<th>Nominal Range BOL (miles)</th>
<th>Nominal Range EoL (miles)</th>
<th>Strenuous Range BOL (miles)</th>
<th>Strenuous Range EoL (miles)</th>
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<td>70</td>
<td>46</td>
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<td>110</td>
<td>130</td>
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</tbody>
</table>

Route, charge, and rate modeling to assess energy efficiency and energy consumption.

20% of AC Transit blocks could be replaced with BEBs on a 1:1 basis with a single overnight charge.

95% of all blocks can be served by FCEBs on a 1:1 replacement basis.
ZEB Training Initiatives

- H2 Fuel Cell Safety & Familiarization
- Lithium Ion Battery Safety
- Fuel Cell Power Plant
- Siemens Drive System
Hands-on Technical Experience

5 week program
• Basic P.M.I.
• Basic Diagnostics & Repair
• Advanced Diagnostics & Repair

Training Provided:
• 343 Mechanics
• 16,560 Hours
• Every Bus Operator
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Thank You!
How to Ask Questions

• Submit your questions anytime during the program using the Questions module in your webinar control panel at the right of your screen.

• We will collect all questions and get to as many as time permits during the Q&A portion of the program.
Remember to Register!

- Hydrogen Infrastructure: Scalability and Technical Considerations (6/20)
- Fund the Fleet: Funding Mechanisms to Assist and Accelerate ZEB Deployment (6/27)
Contact Us

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Fuel Cell Electric Bus Technology: Technical Capabilities & Experience
(Co-Hosted by California Hydrogen Business Council)

June 13, 2019