Hydrogen Infrastructure: Scalability and Technical Considerations
(Co-Hosted by California Hydrogen Business Council)

June 20, 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.
Peter Thompson
Project Coordinator
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.

Mission & Sector Action Groups:

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
• Fuel Cell Electric Bus (FCEB) Fact Sheet from CHBC and California Fuel Cell Partnership:
Fuel Cell Electric Bus Technology: Technical Capabilities and Experience

Takeaways

• FCEBs have 300-400 mi range, 6-20 minutes refueling time, and seeing cost reductions.
• Fuel cells and batteries are complementary on all FCEVs (light, medium, heavy duty).
• FCEBs are high performers, exceeding DOE/DOT goals.
• Remaining Challenges: Large fleet deployments, Maintenance Training, and Hydrogen Stations.
• AC Transit and SunLine have proven the capabilities of FCEBs since deploying in the early 2000s.
• If you missed the first two webinars, the recordings are available here: 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 (November 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
Scalable Hydrogen Fueling for Transit Applications

Al Cioffi
Plug Power is the Leader in Hydrogen and Fuel Cell Technology

- 3.5x revenue growth since 2013
- 1st to create a market for HFC technology
- 26K+ units in the field
- 20MM+ Hydrogen fuelings
- 220MM+ operating hours
- 150 HFC patents
- 80% Blue Chip Customer Base
- 70% reduction in cost profile since 2013
- 20MM+ Hydrogen fuelings
Conventional Wisdom of Electrical Infrastructure

- FCEV
- BEV

Effort and Cost vs. Fleet Size
Reality of Hydrogen Infrastructure

1. Initial costs and efforts are much lower than have been portrayed
2. Crossover point occurs at a smaller fleet size
Hydrogen Solutions

- Hydrogen can be delivered
  - Liquid form [LH₂]
  - Gaseous form [GH₂]
- Hydrogen can be generated on-site
  - Steam Methane Reformer
  - Electrolyzer
- Hydrogen can be renewable/de-carbonized
Delivered Gas Solution – A Starter Solution

- Optional Compression
- Optional Storage
- Indoor/Outdoor Dispenser

- As little as $500K investment
- Higher per kG costs
- 1 to 10 buses

All components can be re-used to expand system capacity
Delivered Liquid Solution – Fleet Expansion

- GH2 trailer remains as a back-up
- As little as $1.5M investment
- 5 to 100 buses

Low Capital and per kG costs are realized with Liquid H2 Solution
On-Site Generation Solutions – Fleet Expansion

- Electrolyzer and/or Reformer
- GH2 as back-up
- As little as $1.75M investment
- 1 – 100 buses

Green solutions
Independent of delivered fuel
Hybrid Solutions – Flexible and Forgiving

- Hybrid LH2/Reformer/Electrolyzer
- GH2 and LH2 as back-up
- As little as $2.5M investment
- 25 to 100’s buses

Broad range of customizations to assure the most cost effective solutions
Fleet conversion and expansion plans
  • How many fuel cell vehicles to start at how many locations
  • Current and future locations
  • Ultimate fleet size per location
  • Timing
Access to water, electricity, and gas
  • Rates
  • Renewability
  • Stability of supply
LCFS and Renewable energy credits
Contractor selection
  • H2 experience
  • Turn-key
  • Service Level Agreements
Hydrogen infrastructure expansion can adapt as your plans change (or recover from errors)
Electrolysis for On-Site Hydrogen Generation:
Enabling scalable hydrogen infrastructure for Transit...
Company Overview

Public Company, Pure H₂ Play

• 3 Manufacturing Sites
• 250 Employees
• 3,500+ Electrolyzers Installed
• 40+ H₂ Fueling Stations
• 90+ Years Experience
What we do….

Our technologies produce pure hydrogen from electricity and water. When the electricity is from renewable energy, you have a carbon free source of hydrogen fuel.
Electrolysis is inherently modular: Incremental cost of adding capacity is low

**Example:** M400 electrolyzer being installed at SunLine Transit
- 902 kg/day capacity with 8 modules installed
- Optionally can start with 4 modules and grow from there:
  - *Doubling the capacity is < 50% of initial CAPEX*
HDV’s and buses can help provide scale to hydrogen.

**HDV’s consume much more hydrogen than LDV’s and fleet operation enables high fueling equipment utilization.**

- 25,000 kg/day
- 50MW
- 500 class 8 trucks
- 1,000 transit buses
- 40,000 cars

High fueling equipment utilization (fleet)

Low fueling equipment utilization (network)
Infrastructure cost for H2 decreases with number of buses...

<table>
<thead>
<tr>
<th>Fleet Size</th>
<th>H2 Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 buses</td>
<td>$9.73/kg</td>
</tr>
<tr>
<td>50 buses</td>
<td>$6.86/kg</td>
</tr>
<tr>
<td>150 buses</td>
<td>$5.72/kg</td>
</tr>
</tbody>
</table>
A scalable model for Norway...

Central large scale production, distribution, fueling, services

Efficient Hydrogen distribution:
- 1.500kg pr. truck
- Container swap or dump-off

Produced locally on 100% renewable basis:
- Bus depot capacity can easily be added or expanded
- Fuel with 100% renewable hydrogen at attractive price
Nel Hydrogen® H2 bus refueling station, 700 bar in a 20ft. container

- Arriving (full) swap storage is parked and connected
- Truck driver then leaves with empty trailer
- Scalable and efficient solution, also applicable for other HD segments

Station footprint:
58.5 m²

Fueling capacity per full swap:
1x 70MPa trailer: 25-30 busses*
(780 kg H2 rating per trailer)

Recommended for:
Small to medium fleets.

Single lane design saves space, but imply longer swap-time.

* avg. at 20kg per bus fueling
# swap/s per day to be specified
Large bus depot solution: 150 buses, 2150 SF area

Station footprint: 200 m²

Fueling capacity per full swap:
1x70MPa trailer: 100-150 busses*
(1.560kg H₂ rating per trailer)

Recommended for:
Large fleets.

H₂ parked via free drive-thru, before attaching empty trailer. Two trailers parked at all time.

* avg. at 20kg per bus fueling # swap's per day to be specified
Installation Example: Rosenholm Oslo
10X the capacity at half the cost

Existing solution from 2012:
- Existing H2 Refueling
- Onsite production
- Up to 250 kg/day, ~10-12 FC buses
- Footprint: ~350m²
- H2 Price: $12.59/kg

New proposed solution:
- New H2Station®
- Central production – trucked-in
- Up to 3,000 kg/day, ~150 FC buses
- Footprint: ~200m²
- H2 Price: $5.72/kg
- Supports fossil parity

Enabled by drop and swap hydrogen supply and centralized production
Hydrogen fuel cost parity with diesel/CNG for buses: within reach today...

Achieving hydrogen price parity with diesel/hybrid and CNG will be important for the TCO experienced by Transit Agencies.

FCEB consumption ranging from 0.13 – 0.16 kg/mile results in the following fossil parity price with Diesel/Hybrid and CNG:

- **Diesel**: $4.5 - $5.6 per kg hydrogen
- **Diesel hybrid**: $3.6 - $4.5 per kg hydrogen
- **CNG**: $3.5 - $4.3 per kg hydrogen

Price parity with diesel is within reach today.

Diesel hybrid and CNG price parity requires scale.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Diesel</th>
<th>Unit</th>
<th>Diesel Hybrid</th>
<th>Unit</th>
<th>CNG</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel consumption</td>
<td>3.87</td>
<td>miles/DGE</td>
<td>4.84</td>
<td>miles/DGE</td>
<td>2.91</td>
<td>miles/DGE</td>
</tr>
<tr>
<td>Fuel price (incl. O&amp;M)</td>
<td>$2.79</td>
<td>/DGE</td>
<td>$2.79</td>
<td>/DGE</td>
<td>$1.62</td>
<td>/DGE</td>
</tr>
<tr>
<td>Fuel cost per distance</td>
<td>$0.7</td>
<td>/mile</td>
<td>$0.6</td>
<td>/mile</td>
<td>$0.6</td>
<td>/mile</td>
</tr>
<tr>
<td>H2 parity price - 1</td>
<td>$5.6</td>
<td>/kg</td>
<td>$4.5</td>
<td>/kg</td>
<td>$4.3</td>
<td>/kg</td>
</tr>
<tr>
<td>H2 parity price - 2</td>
<td>$4.5</td>
<td>/kg</td>
<td>$3.6</td>
<td>/kg</td>
<td>$3.5</td>
<td>/kg</td>
</tr>
</tbody>
</table>

Data based on ARB: "Innovative Clean Transit - Cost Data and Sources - Update on 6/26/2017"
Thank you!

www.nelhydrogen.com
Fuel Cell Electric Bus Infrastructure Considerations
• Introduction

• Joe Callaway
  AC Transit Director of Capital Projects

• AC Transit Infrastructure History
  
  • Gen 1 (2003 - 2006) – Electrolyzer (25 kg / day)
  
  • Gen 2 (2006 - 2010) – Dual SMRs (50 kg / day)
    Partnered with Chevron
  
  • Gen 3A (2010 - Present) – LH2 (360 KG / day)
    Solar Powered Electrolyzer (65 kg / day)
  
  • Gen 3B (2014 – Present) – LH2 (360 KG / day)
    SOFC Powered Electrolyzer (65 kg / day)
  
  • Gen 3A - Equipment Upgrade Pending
D2 Hydrogen Station:
- 9,000 Gal LH2
- Vaporizer
- Compressor
- 360 kg of High Pressure Storage

External Access Auto Fueling Facility

Stand-alone Bus Fueling Island
Oakland Hydrogen Station

- H2 Dispensing in the Fuel Island
- 360 kg of High Pressure Storage (7,777 psi)
- 9,000 gal LH2 Tank
- Buffer Storage for Electrolyzer
- IC-50 Compressor
- Vaporizer
Other Hydrogen Program Assets

Power Sources that Support On-site Hydrogen Production by Electrolyzer

- Rooftop Solar at CMF
- Trellis Solar at D6 (Hayward) Division
- SOFC at D4 (Oakland) Division
PLANNING CONSIDERATIONS

- Plan with Operational Integration in Mind
- Be Mindful of Bus Fleet Transformation
- Consider Utility Constraints
- Evaluate Supply Options
  - On-site Generation v. Delivery
- Respect the Learning Curve
DEVELOPMENT CONSIDERATIONS

• Partner Wisely
• Engage your AHJ
• Training
• Permitting
• Consider Maintenance Facilities
OPERATIONAL CONSIDERATIONS

• Integration into Normal Operations
• Training
• Station Maintenance
  • Preventative Maintenance
  • Corrective Maintenance
• Fuel Issues
  • Hydrogen Costs / Hydrogen Supply
FUNDING SUPPORT FOR AC TRANSIT H2

- Complex Matrix of Funding Sources
- Emeryville Hydrogen Station
  - California Air Resources Board
- Oakland Hydrogen Station
  - California Energy Commission
- Oakland Electrolyzer and Solid Oxide Fuel Cell
  - FTA TIGGER Grant with PG&E SGIP Rebate as Matching Funds
Thank You!

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Remember to Register!

• Fund the Fleet: Funding Mechanisms to Assist and Accelerate ZEB Deployment (6/27)

caltransit.org
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