CALIFORNIA HYDROGEN BUSINESS COUNCIL

California Hydrogen Business Council

"*Hydrogen and Fuel Cells in On-Road Freight*"

- A CHBC Webinar -

August 1, 2017

www.CaliforniaHydrogen.org

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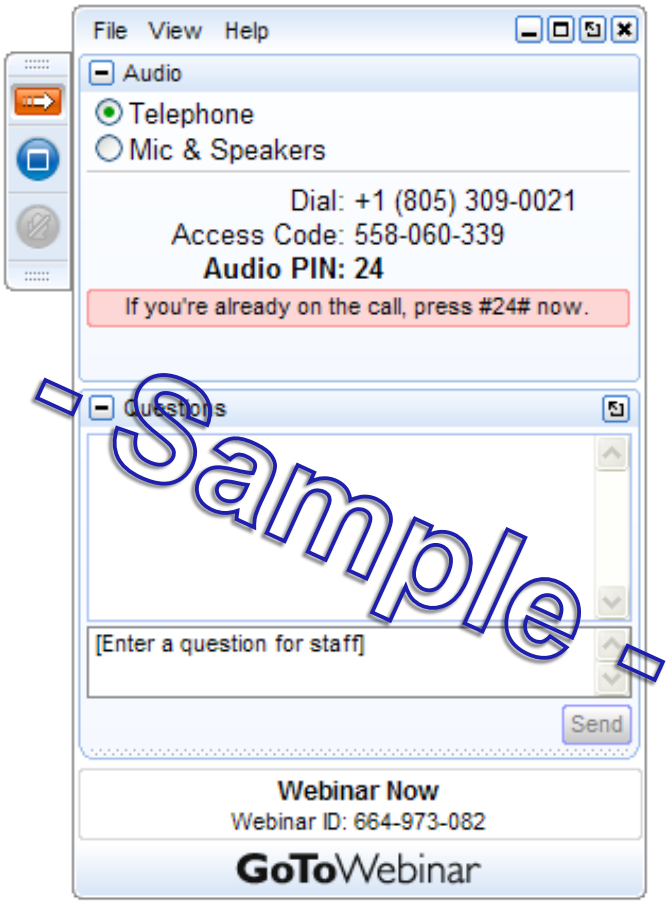
Quick Notes

- Two Audio Options: Streaming Audio and Dial-In.
  - Streaming Audio/Computer Speakers (Default)
  - Dial-In: Use the Audio Panel (right side of screen) to see dial-in instructions. Call-in separately from your telephone.
- **Ask questions using the Questions Panel on the right side of your screen.**
- The recording of the webinar and the slides will be available after the event. Registrants will be notified by email.



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Webinar Speakers & Outline

- Welcome & Overview – Emanuel Wagner
- Freight Workshop Report – Cory Shumaker
- OEM & Customer Perspective – Jim Petrecky
- Funding Opportunities – Naveen Berry
- Discussion/Q&A

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Welcome and Overview

Emanuel Wagner

Assistant Director

California Hydrogen Business Council

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, state and federal agencies
- Component suppliers

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2017 Focus & Events

Overall goal is to grow markets and include hydrogen and fuel cells technology in transportation, energy and clean air decisions made in Sacramento & beyond.

CHBC Market Sector Action Groups (SAGs):

- Hydrogen Energy Storage and Renewable Hydrogen
- Heavy Duty Transportation, Goods Movement, and Clean Ports
- Public Transportation

CHBC Workshops and Summits

- September 10-12 – Las Vegas, NV – Hydrogen and Fuel Cell North America at SPI – CHBC Renewable Hydrogen Session
- September 25-26 – Sacramento, CA – 2017 California Hydrogen and Fuel Cell Summit
- September 27 – Sacramento, CA – Hydrogen Fuel Cell Bus Workshop & Microgrid Tour
- October 3 – Vallejo, CA - CHBC Ports Workshop (at Fleet Week SF October 2-9)
- December 5 – Annual Membership Meeting

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Freight Workshop Report

Cory Shumaker

Project Coordinator

California Hydrogen Business Council

- CHBC May 1 freight workshop attracted over 120 attendees
- Purpose:
  - Build awareness and hear from a diverse group of panelists on the ability of hydrogen and fuel cell technologies to enable commercial customers to meet sustainability and regulatory compliance objectives,
  - Address the technical and non-technical challenges with transitioning hydrogen and fuel cells into fleets, and
  - Understand the substantive economic and operational benefit drivers.

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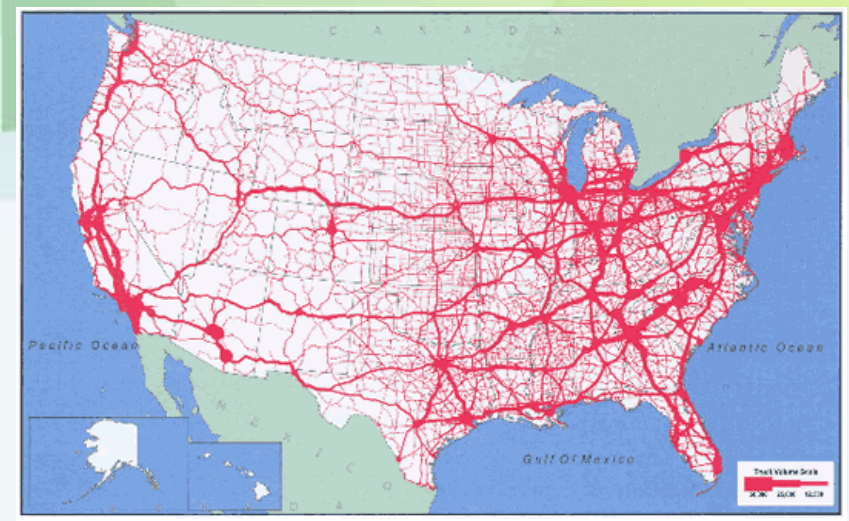
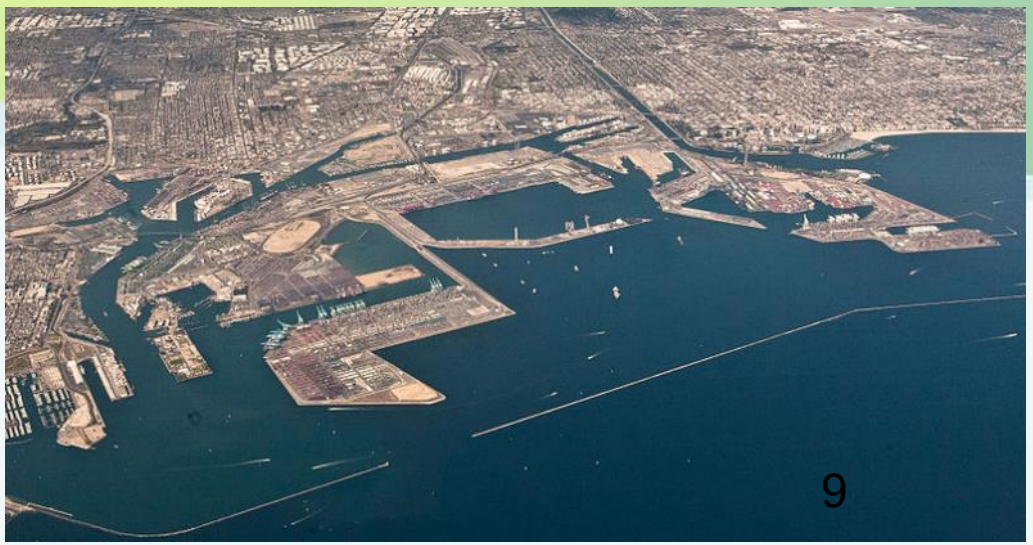
Seaports & Distribution Networks

- Economic drivers for jobs and development
- Entry points for goods used throughout the country
- Significant source of greenhouse gas emissions
- Typically located in areas of heavy auto and truck traffic producing smog and particulate matter





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Zero Emission Fuel Cell Technologies for Freight and Goods Distribution

- Great improvement in reduction of cost for fuel cell membranes: $275/kW(2002) > $53kW(2016)
- Implementing fuel cells into medium & heavy duty fleets are next step to wide commercialization
  - Fuel cell forklifts proven successful, 5 million hours operation
- Hydrogen infrastructure remains a key hurdle
  - National hydrogen station network could be built along major highway corridors with the potential for renewable hydrogen

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

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User and Operator Perspectives

- All operators want better prices for hydrogen and want it to be renewable
- Maintenance training is a major hurdle, even with the reduction from traditional diesel trucks
  - Typical mechanics have no high voltage experience
- Terminal automation will create the case for hydrogen over battery trucks due to quicker turnaround times
  - Union resistance may slow this process

Truck OEM Perspective

- Need to create a sustainable business case for truck manufacturers
  - Total cost of ownership needs to be competitive with diesel and natural gas fuels
  - Government incentives currently required to justify investment in development
- Many challenges with developing fuel cell trucks
  - Cooling, space, cost, excessive wiring, lack of infrastructure
  - Concerned about emissions from hydrogen production
- Kenworth's belief is by 2025 drayage trucks will be required to be zero emission in So Cal Ports

KENWORTH

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Technology Developer Perspectives

- Benefits of using hydrogen are many
  - Range, efficiency, scalability, zero emissions, total life cycle affordability, operation in extreme temperatures
- Limited space on Class 8 truck platform is a challenge
- Success of fuel cell buses can lead fuel cell trucks
- On-site hydrogen production is a solution for freight
- Issues are maintenance training and supply chain
- Loop Energy believes total cost of ownership for HD vehicles can be technology neutral within 10 years

BALLARD PUTTING FUEL CELLS TO WORK

US Hybrid

HYDROGENICS SHIFT POWER | ENERGIZE YOUR WORLD

LOOP

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Heavy-Duty Hydrogen Refueling

- 67 light duty CA hydrogen stations in various stages
  - 0 heavy duty stations
  - Difficult to co-locate heavy duty and light duty stations
- Number of challenges for heavy duty refueling
  - No current protocol for fueling heavy duty vehicles
  - High throughput is needed for larger vehicles; Class 8 fuel cell truck requires about 20kg/day
  - Pipelines are expensive at around $2 million/mile
  - Every station buildout has different requirements
- SCAQMD interested in collaboration on heavy duty station feasibly study with CaFCP

South Coast AQMD

Linde

cte

Luxfer Gas Cylinders

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Lessons Learned from Fuel Cell Forklifts

- PlugPower has delivered 14,800 fuel cells at 43 sites
  - 130 dispensers totaling 6 million hydrogen fills
- Lessons:
  1. Offer a suite of vehicles
  2. Hydrogen fuel & infrastructure must be part of solution
  3. Being “green” does not sell; economics must make sense
     1. Both CAPEX and OPEX models to be looked at
  4. BEV demand charges need to be explained to customer
  5. The more hydrogen used the cheaper it becomes
  6. Sufficient high voltage training needs to be put in place
  7. Bring hydrogen to customers to fit into their work process
  8. Use customer preferred chassis vendors for familiarity

PLUG POWER

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Open Discussion & Outcomes

- Education is the key issue across the board; there is a need for dedicated technical learning centers
- Truck OEM manufactures do not see necessary market pull from customers to produce fuel cell trucks
  - Needs to be more consumer demand to affect supply chain
- Need to increase public awareness
  - Partner with hospitals and work with first responders
- An increase in fuel cell trucks will drive infrastructure
- Bundled solutions of vehicles and fueling are needed

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Next Steps/Activities

- Workshop Report; available online at http://californiahydrogen.org/sites/default/files/Hydrogen%20and%20Fuel%20Cell%20On-Road%20Freight%20Workshop%20Report_Final.pdf
- Webinar on Workshop Report
- Document to provide guidance for CHBC Advocacy activities
- Hydrogen and Fuel Cells in the Ports Workshop – October 3rd 2017, California Maritime Academy, Vallejo, CA
- Potential follow-up workshop at the Port of LA or LB in November/December

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OEM & Customer Perspective

Jim Petrecky

Vice President - Business Development

Plug Power

CHBC Freight Webinar
Customer & OEM Perspective

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August 1, 2017

Freight Vehicles Need Hydrogen

Customer behavior in commercial applications drives the need to use hydrogen as part of the EV solution

Heavy Utilization - High Energy Intensity - Inability to Pause Operations

1 kg/day

Material Handling Forklifts

- Saves ~13 min. every shift with refueling in work cell
- Enables 24/7 3-shift operation with a single asset

4-8 kg/day

Ground Support Equipment

- Tows 50,000 lbs. in energy-intensive shifts
- No stop during 4 hr. shift

10-12 kg/day

Class 5/6 Delivery Trucks

- Satisfies the need for 150 miles before refueling
- Does not diminish the cargo payload

20 kg/day

Class 8 Trucks

- Extends route capability
- Enables EV for aggressive load profiles

Package delivery trucks are limited to about 60 miles

- Class 5/6 trucks have approximately 80 kW-hr battery bank
- More batteries diminishes payload, increases weight, decreases efficiency
- 70% of batteries is usable → 56 kW-hr usable
- BEV (battery electric vehicle) efficiency is roughly 1 mile per kW-hr

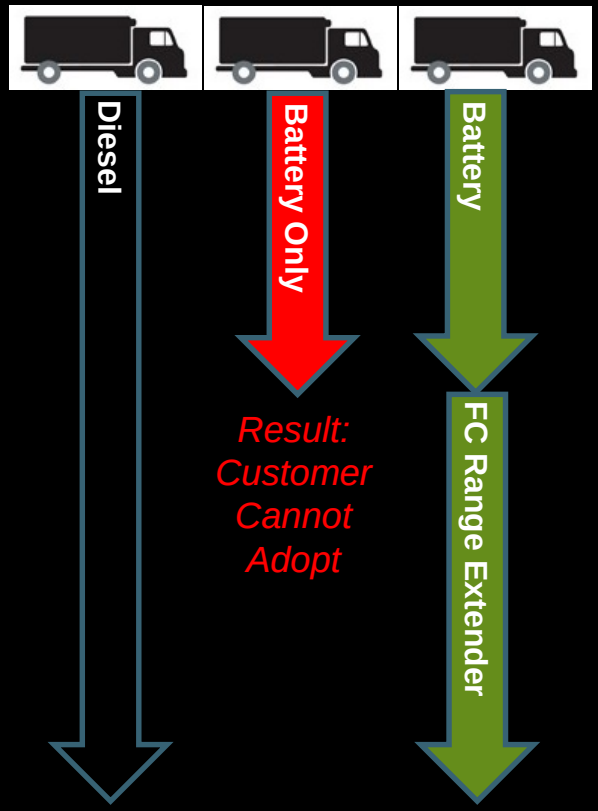
80 kW-hr BEV are currently limited to a fraction of available routes

- Manhattan is a perfect low distance, high frequency route for batteries
- Routes that require a highway drive from the ship center are not possible

Commercial delivery need is 150 miles to handle majority of routes

- Trucks need an additional 90-100 kW-hr of energy
- Hydrogen fuel cells charge the truck throughout route

With hydrogen fuel cells, EV can be used on all commercial routes.



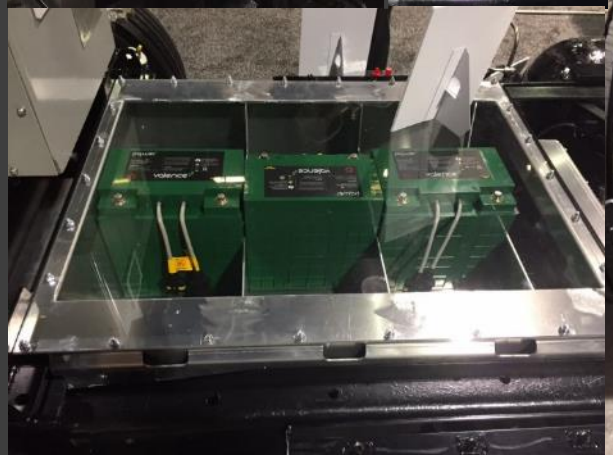
UPS Package Truck

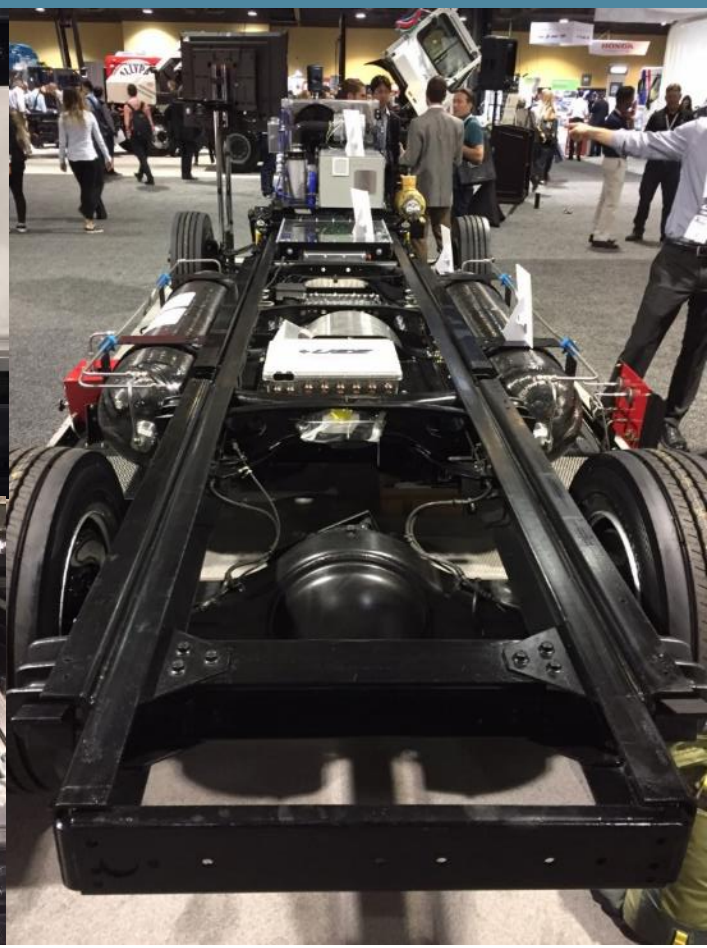
FC / H2 Specifications

- GVW: 19,500 lbs.
- Target Range: 125 miles
- Fuel Cell Power: 32 kW
- Batt Energy Storage: 45 kWh
- H2 Storage: 10 kg
- Hybrid PEM FC / Li-Ion Battery

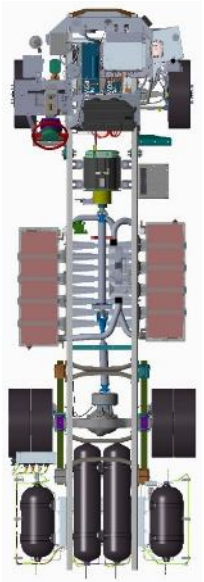
Partners

- CTE
- Hydrogenics
- UES
- UT-CEM
- Valence
- CEC
- SCAQMD





FedEx Express Package Truck



FC / H2 Specifications

- Target Range: 150 miles
- Voltage: 48 VDC
- Fuel Cell Power: 20 kW
- H2 Storage: ~156 kWh (11.6 kg)
- Hybrid PEM FC / Li-Ion Battery
- FC Efficiency: 45% (15 kWh/kg)

Truck Specifications

- GVW: 16,500 lbs.
- Voltage: 430 VDC
- Motor Power: 268 hp
- Motor Torque: 1620 ft-lbs
- Batt Energy Storage: 80 kWh
- Truck Efficiency: 0.9 kWh/mile

OEM Perspective

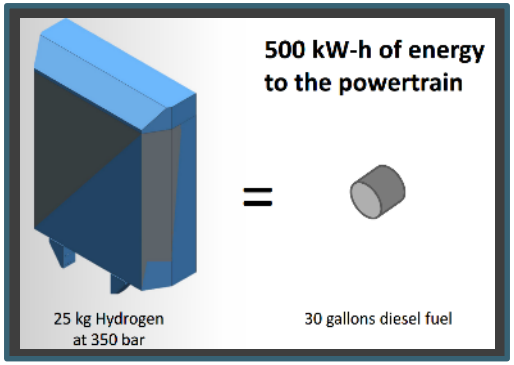
KENWORTH

- **Market**
  - Driver for hydrogen is emissions reduction, not energy efficiency
  - Expect that drayage trucks will be required to be ZEV by 2025
  - Large market opportunity in hybrid systems and zero emission vehicles

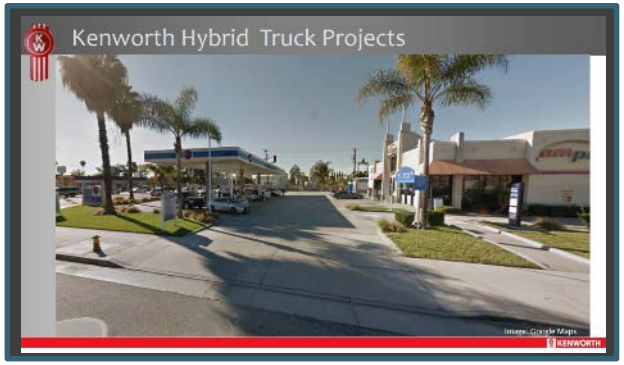
- **Technical**

	Battery-Electric Truck with Hydrogen Fuel Cell Range Extender
Traction Motor Power	420 kW (560 hp)
Battery Capacity	100 kW-h
Range Extender Power Source	Ballard Hydrogen 85 kW Fuel Cell
On-board fuel storage	25 kg Hydrogen
Range (assumes batteries are fully charged)	110-150 miles (depending on load & route)
All-Electric Range (without starting fuel cell)	30 miles (depending on load & route)

- **Challenges**
  - Several different cooling systems with various requirements (fuel cell, power conversion equipment, cab heating/cooling)



- Access to hydrogen infrastructure
  - *"Although there are retail stations, it's not easy for a Class 8 tractor trailer to refuel"*



- H2 storage
  - amount of real estate required
  - 350 bar vs. 700 bar
  - Cost of tanks ($1k/kg)

OEM Perspective

US Hybrid

- **Market**
  - More than 50% of energy is wasted due to urban traffic
  - More than 80% of emissions is due to urban traffic
  - Major contributors being 1) idling, 2) braking, 3) acceleration
  - Market driver: EPA is talking of 2024 national standard for .02 NOx for the majority of trucks service the ports

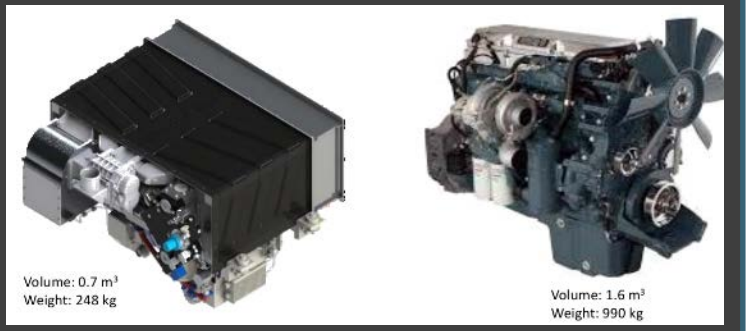
- **Technical**
  - Fuel cell engines can offer great power density
  - FCe fuel cell engine (for POLA drayage) compares favorably
  - 15% efficiency improvement over CNG (37% FC vs. 22% CNG)
  - Class 8, 80kW, 26 kWh, 320 kW (430 hp) drive motor, 3750 Nm torque, 25 kg H2 storage @ 350 bar
  - Compared to BEV drayage at 240 kWh battery bank

- **Benefits**
  - Fast fueling | 24/7 operation | No range limitations
  - H2 safer than gasoline and CNG, disperses much faster ~4x faster than NG, ~12 faster than gasoline
  - HD trucks lower carbon intensity than diesel and CNG

Comparison of Fuel Energy Density

• **Diesel:** 37.1 kwh/gal (Energy content),	Engine Output:	**4.5 kWh/kg**
• **Gasoline:** 32.9 kWh/gal, (Energy content),	Engine Output:	**2.8 kWh/kg**
• **Hydrogen:** 39.7 kWh/kg, (Energy content), (1kg H2 =11 gal @5000 psi, same as 2 gal of diesel fuel)	FC Engine Output:	**15 kWh/kg**
• **Energy Storage Density:** Li-Ion Battery		**0.11 kWh/Kg**

Comparison of Engine Weight & Volume



OEM Perspective – Loop Energy

- **Market**
  - **Believe California HVIP incentives can be used to offer a yard dog / Class 8 drayage payback period of < 4 years**
    - **Assumes $9/kg H2 and $4/gal diesel**

- **Benefits**
  - **Power density | Less weight**
  - **Zero tailpipe emissions | Less noise pollution | Regulator compliance**
  - **3x range of batteries**
  - **Quick refueling**

Out of POLA/POLB emissions, changing yard dogs and Class 8 drayage to ZEV represents a reduction of:

Emissions Inventory	PM10	PM2.5	DPM	NOX	SOX	CO	HC	CO2e
Total POLA/POLB Emissions	411	377	360	14388	1281	3897	863	1625230
% of emissions avoided								
Yard Trucks	4%	3%	4%	3%	0%	17%	3%	8%
Drayage Trucks	8%	8%	8%	16%	1%	18%	14%	42%
Clean Freight Emission Reduction Opportunity	12%	11%	12%	20%	1%	35%	17%	50%

Customer Perspective

Takeaways from Panel "User and Operator Perspectives"

Fleet operators and trucking companies provide their insights, identifying their concerns and needs:

- **Moderator: Jim Petrecky, Vice President of Business Development, Plug Power**
- **Mike Britt, Maintenance & Engineering International Operations, Ground Fleet, UPS**
- **Vic LaRosa, CEO, Total Transportation Services, Inc.**
- **Fred Johring, President, Golden State Express**

1. UPS is "drinking the hydrogen cocktail"

- **Deploying a total of 17 Class 6 delivery trucks between two integrators**
- **Benefits detailed:**
  - **Ability to handle hills and large grades (ex. Napa Valley, CA)**
  - **Up to 250 stops and launches, which allows for energy recovery via regenerative braking**
  - **Need 125 miles – marrying fuel cells with EV makes a lot of sense**
  - **1 kWh is about 10 kg, so they can't just keep adding batteries until they get the energy they need**

2. TTSI knows EV trucks are reliable from their work with Vision Motors

- **There is already a familiarity with EV trucks at the ports.**
- **They are interested in gaining experience with fuel cells in the demonstration of Class 8 trucks to be deployed in 2017 and 2018.**

Customer Perspective

3. **Fred Johring (Golden State Express) recommends to make sure that the technology is ready before deploying because port operators are very skeptical and already have a negative view of alternative energy technology that is being pushed onto terminal operators.**
   - **Black eye for alt fuel vehicles resulted from a deployment of underpowered natural gas-powered yard dogs.**
   - **“Alternative fuel OEMs are fishing in a pond where the fishing isn’t too good right now.”**

4. **Primary concern for the panelists is reliability and service.**
   - **Many drayage firms are not large enough to own their own service.**
   - **They outsource non-standard work to dealers when more intensive service is needed.**
   - **It would be a major drag on their operations if service was constantly being escalated.**

5. **Electrical safety is also a concern.**
   - **MD and HD electric vehicles are 400V.**
   - **“Technicians have to be electricians.” – Mike Britt**
   - **Many service do not have experience with this level of voltage.**
   - **Panelists believe that in order for the industry to incorporate more EV, high voltage training needs to be incorporated into the curriculum of maintenance schools.**

Customer Perspective

6. **Maintenance is expected to be a major improvement.**
   - Diesel trucks have about 2200 moving parts. Electric trucks have about 200.
   - Removing diesel trucks eliminates oil changes and DPF
   - The interval for brake work will be extended due to regenerative braking.

7. **Locating hydrogen storage on MD/HD trucks is a concern.**
   - It's all about real estate. There are major differences between Class 6 and Class 8.
   - "A class 6 truck has all sorts of locations to hang things off of the truck. A Class 8 truck does not."
   - For the Class 8 truck, everything needs to be in the engine compartment or right behind the cab.
   - The space behind the cab is also limited so the Class 8 truck can make tight turns.

8. **Automation is the future.**
   - Automated ports have a must faster turnaround time – about half as long.
   - There are currently 2 automated ports. However there is great opposition by the labor unions.

9. **What do alt fuel vehicles have to offer to adopt?**
   - 2x to 3x reduction in OpEx (fuel and maintenance) to overcome the CapEx premium
   - Some terminal operators at ports are progressive and are creating their own fuel.
     - Ex. TTSI is work on a new 100 acre facility which has 88 acres allocated to solar to generate 12.5 MW of electricity
     - Interest in generating its own hydrogen or RNG (renewable natural gas)

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plugpower.com

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Funding Opportunities

Naveen Berry

Technology Demonstration Manager

South Coast Air Quality Management District

Hydrogen Refueling Stations Medium & Heavy-Duty Vehicles

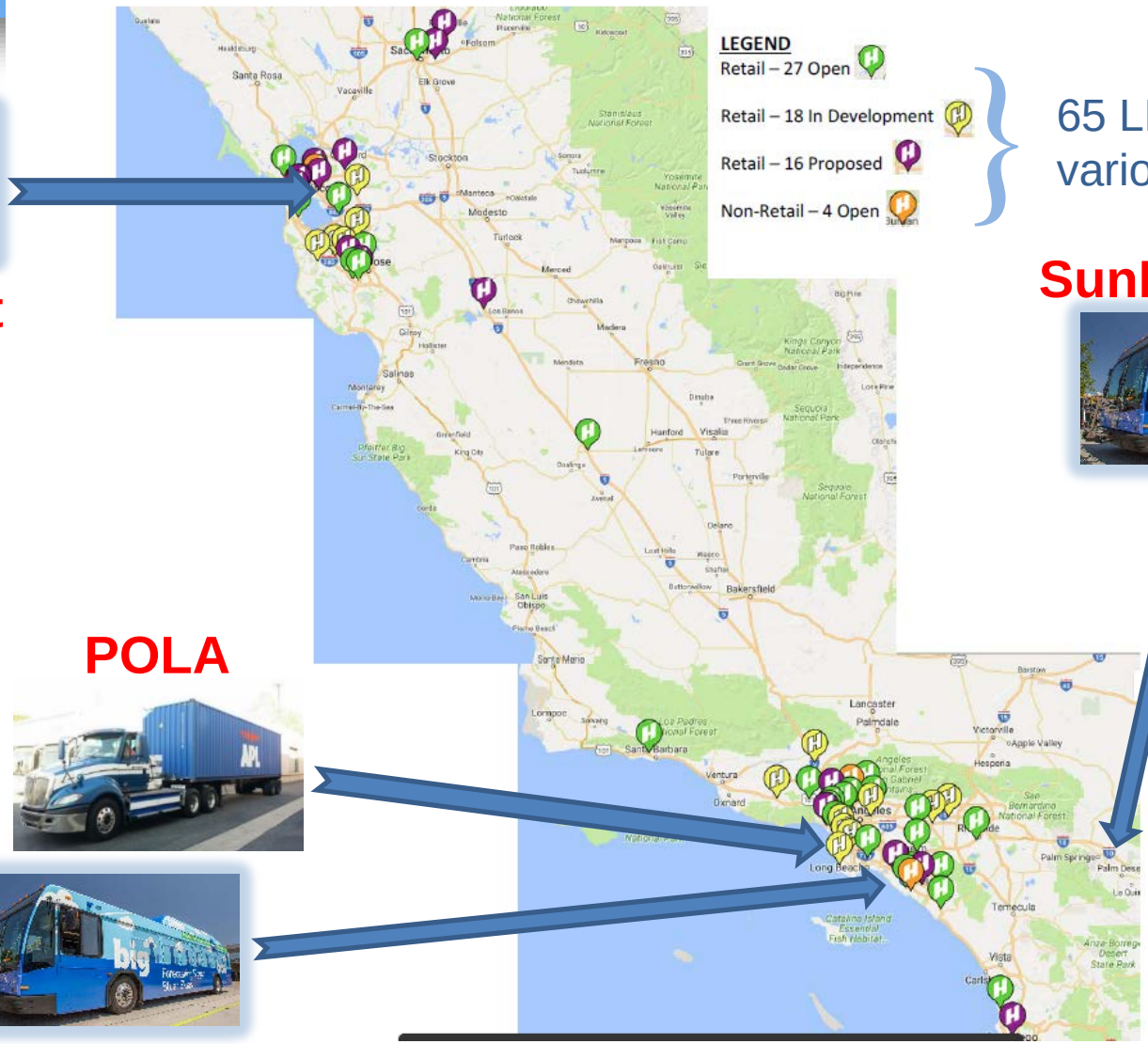
Potential Funding Opportunities

Naveen Berry, Technology Demonstration Manager
Science and Technology Advancement
South Coast Air Quality Management District

California H2 Refueling Stations

Snapshot

A.C. Transit



65 LDV stations in various stages

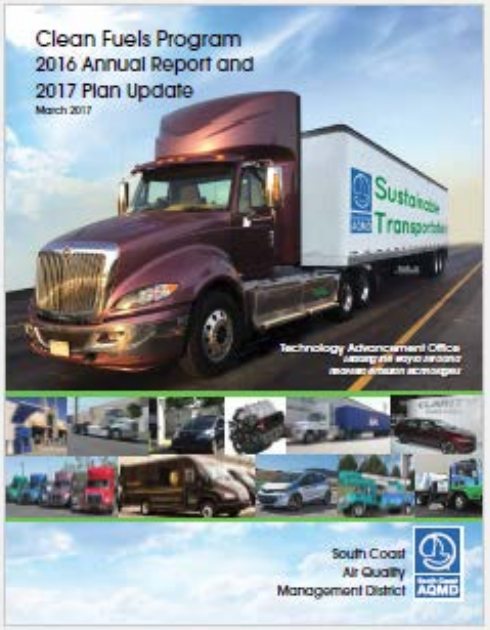
SunLine Transit

POLA

OCTA

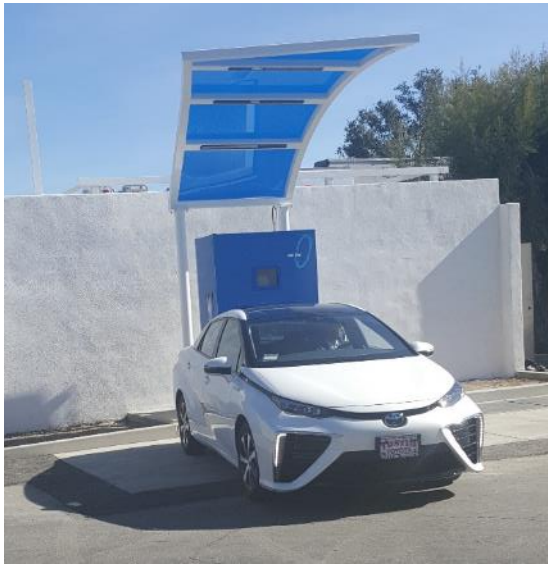
Current Drivers
Medium & Heavy-Duty

- ***2016 CA Sustainable Freight Action Plan***
- ***San Pedro Bay Ports – Clean Air Action Plan - Draft***
- ***SCAQMD***
  - 2016 Air Quality Management Plan
  - Clean Fuels Program - Demonstration Role
    - ZECT project; Class 8 Drayage truck demo
    - UPS project; Class 4 urban delivery demo
- ***CARB***
  - Mobile Source Plan
  - Low Carbon Transportation (LCT) Programs
- ***CEC – Alternative & Renewable Fuel & Vehicle Technology Program (ARFVTP)***



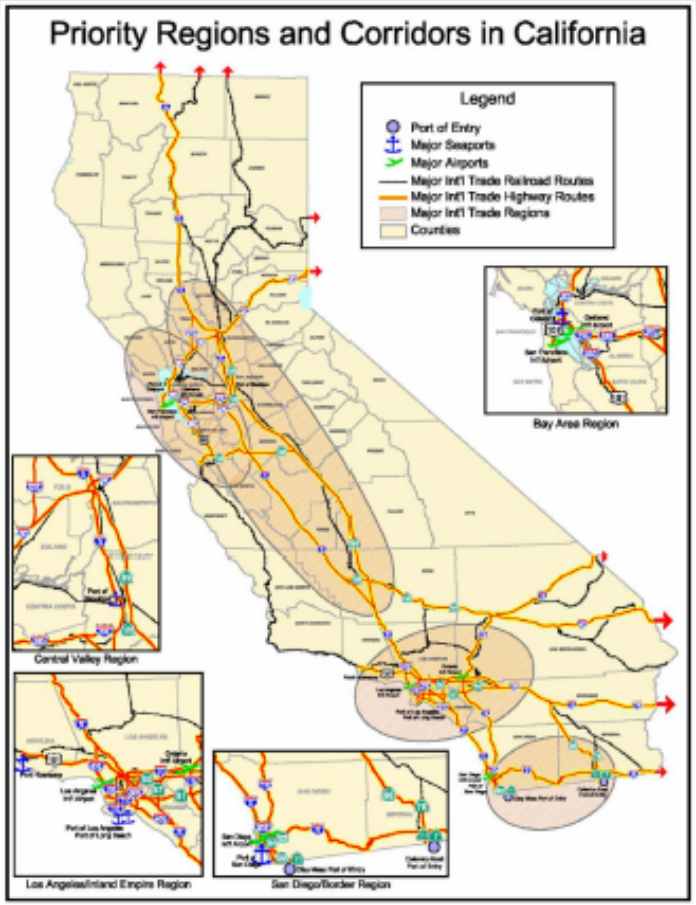
Infrastructure Technical Challenges

- Difficult to collocate with light duty stations or transit stations (e.g. U.C., Irvine)
- Refueling protocol for heavy duty vehicles not yet developed
- Regulatory approval for sale of hydrogen



Medium & Heavy-Duty Station Parameters

- Optimized for truck application
- Location(s)
  - POLA/POLB
  - Inland Empire - Warehousing
  - Goods movement corridors
- Technology options
  - On-site Renewable production: SMR or Electrolysis
  - LH2 delivery
  - Combined w/ Heat & Power – enhanced efficiency
  - Pipeline connected plus on-site purification w/PSA



Potential Funding Sources

- CA Solicitations
  - CARB
    - LCT - Previous Award – Fuel Cell Buses & Station; OCTA/CTE call for proposals – Due 8/25/17
    - On-Road Advanced Technology Demonstration Projects - $10 Million for Fuel Cell Trucks and Infrastructure – Due 8/16/17
    - Off-Road Advanced Technology Demonstrations - Due 9/7/17
  - CEC
    - ARFVTP – Renewable Hydrogen Transportation Fuel Production Facilities & Systems
      - Draft Solicitation Concepts; Comments due 8/15/17
        - $2 Million
        - 100% Renewable H2 – Centralized or Onsite Production
        - Current focus – LDVs
        - Can include Medium & Heavy-Duty vehicle fueling if > 1,000 kg/day
- SCAQMD – Clean Fuels Program – 2017 Plan
  - H2 Infrastructure & Vehicle – Governing Board allocated up to $5.45 Million – to be leveraged with Gov't/Private Funds
  - Unsolicited proposal accepted

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Question and Answer Session

Ask questions using the **Questions Panel** on the right side of your screen.

The webinar slides and recording will be made available after today. Please fill out survey upon leaving.

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Thank you!

Thank you for attending today's webinar and remember to fill out attendee survey. Slides and Recording will be made available within one week.

For more information, contact:

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