California Transit Association

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

June 20, 2019

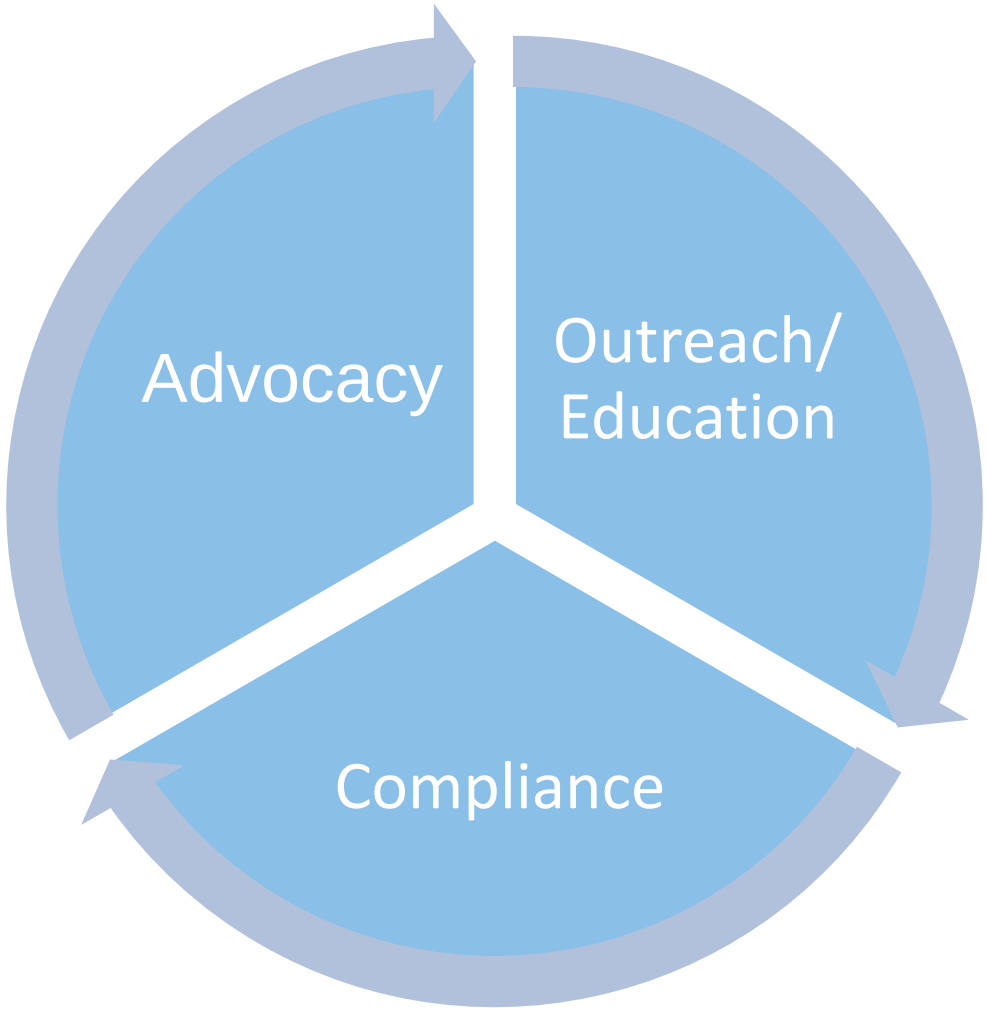
California Transit Association

- 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



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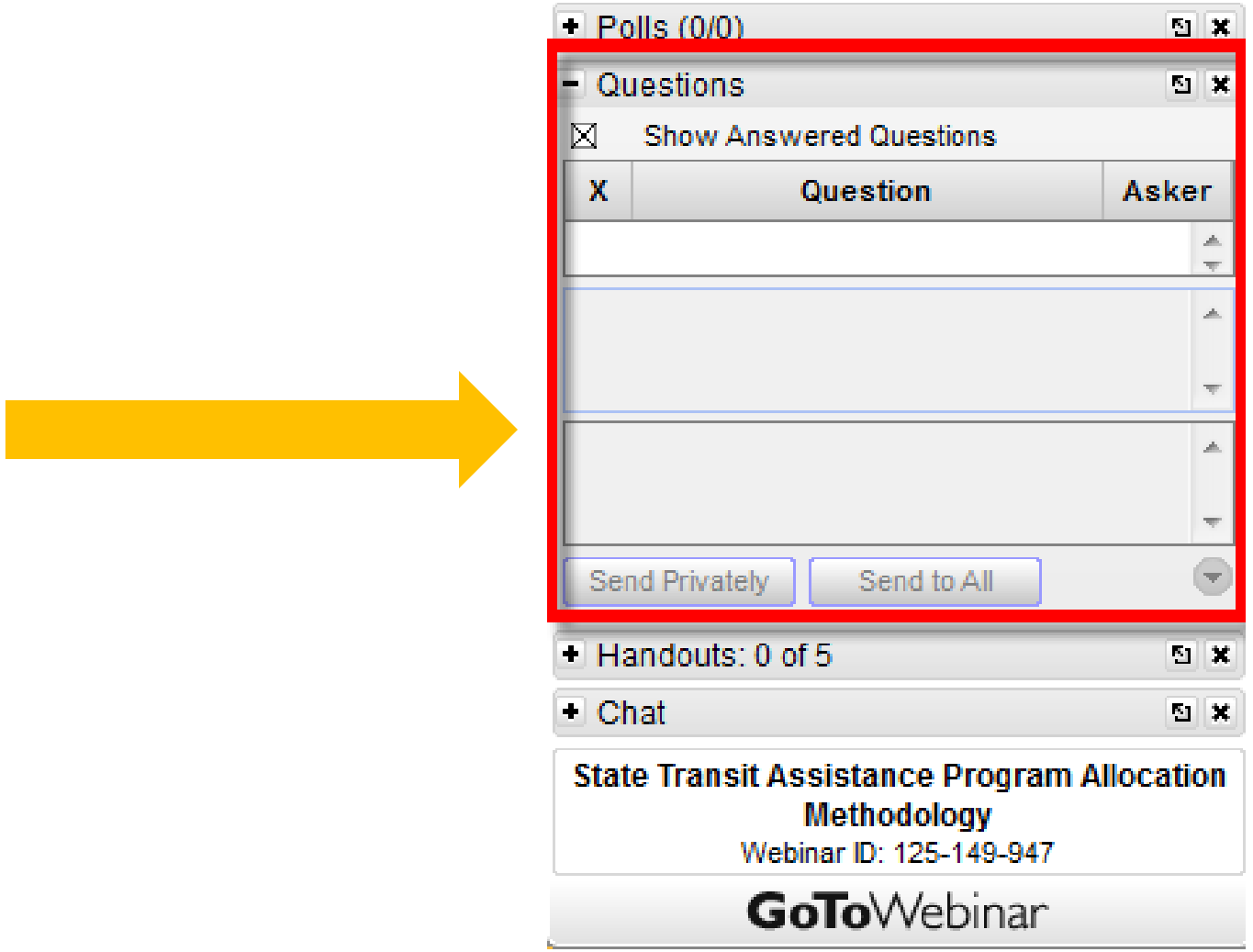

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Peter Thompson

Project Coordinator

California Hydrogen Business Council

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Mission & Sector Action Groups:

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

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Get the Facts!

- **Fuel Cell Electric Bus (FCEB) Fact Sheet from CHBC and California Fuel Cell Partnership:** https://www.californiahydrogen.org/wp-content/uploads/2017/10/CHBC-CaFCP-Fuel-Cell-Electric-Bus-Fact-Sheet.pdf

FUEL CELL ELECTRIC BUSES for Zero Emission Public Transit

Emissions and GHG Reductions

Performance

Scalability

Fueling

Cost

CALIFORNIA HYDROGEN BUSINESS COUNCIL

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/

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Events

- **Policy Summit -** Sacramento (August)
- Enabling Deep Decarbonization with **Utility-Scale Hydrogen Energy Storage Workshop** - San Francisco (Sept./Oct 2019)
- 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/

CALIFORNIA HYDROGEN BUSINESS COUNCIL

Thank You!

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Join us!

www.californiahydrogen.org

Scalable Hydrogen Fueling for Transit Applications

Al Cioffi

June, 2019

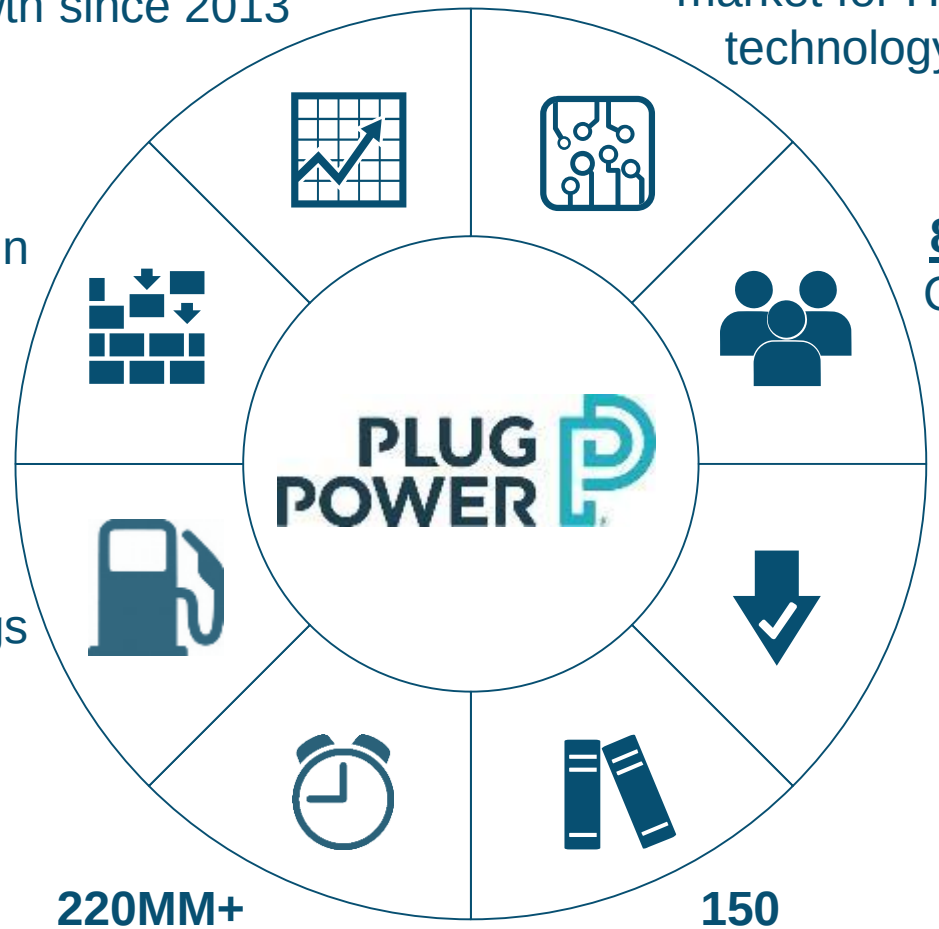
Plug Power is the Leader in Hydrogen and Fuel Cell Technology

3.5x revenue growth since 2013

1st to create a market for HFC technology

26K+ units in the field

80% Blue Chip Customer Base



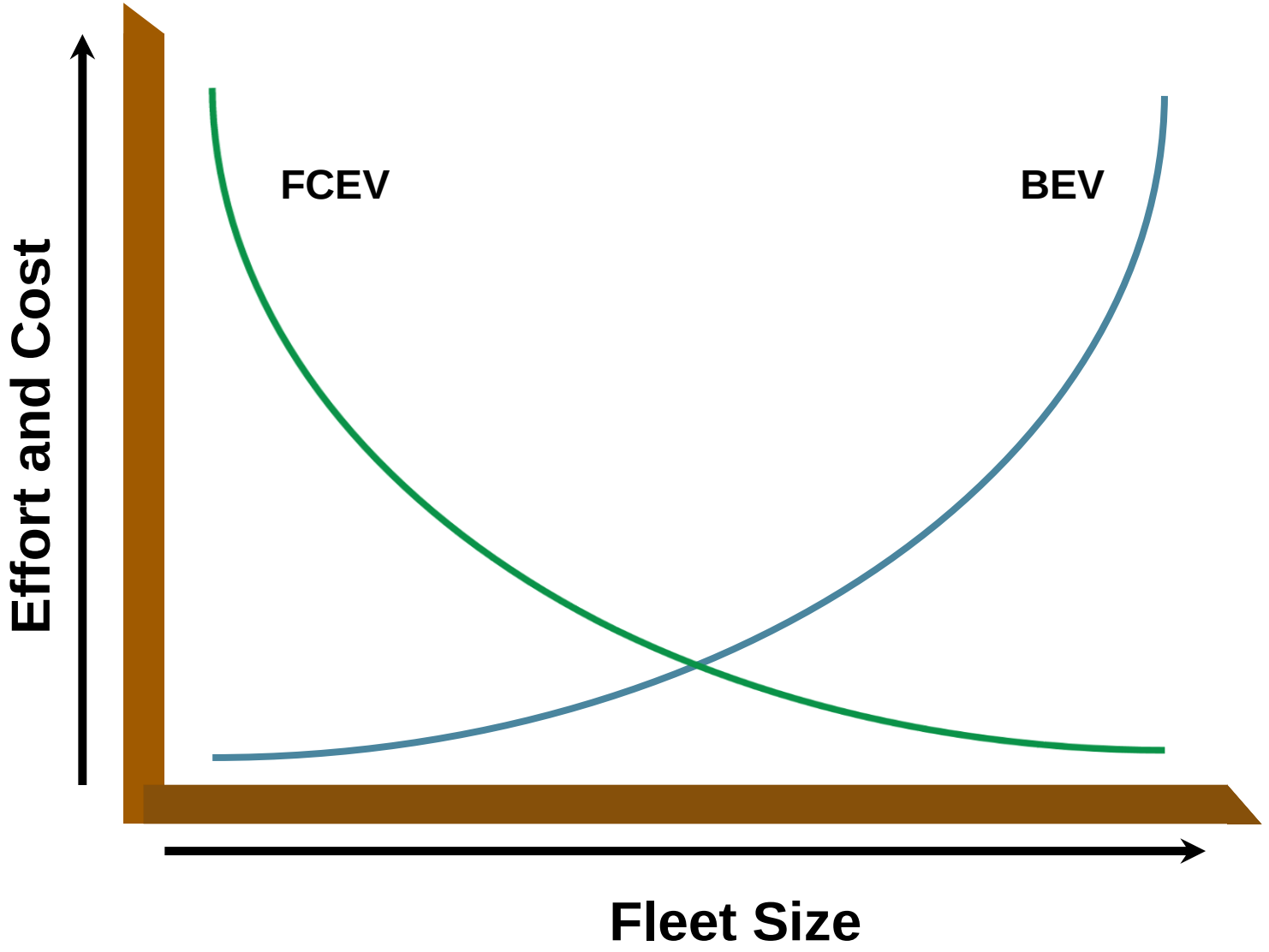
20MM+ Hydrogen fuelings

70% reduction in cost profile since 2013

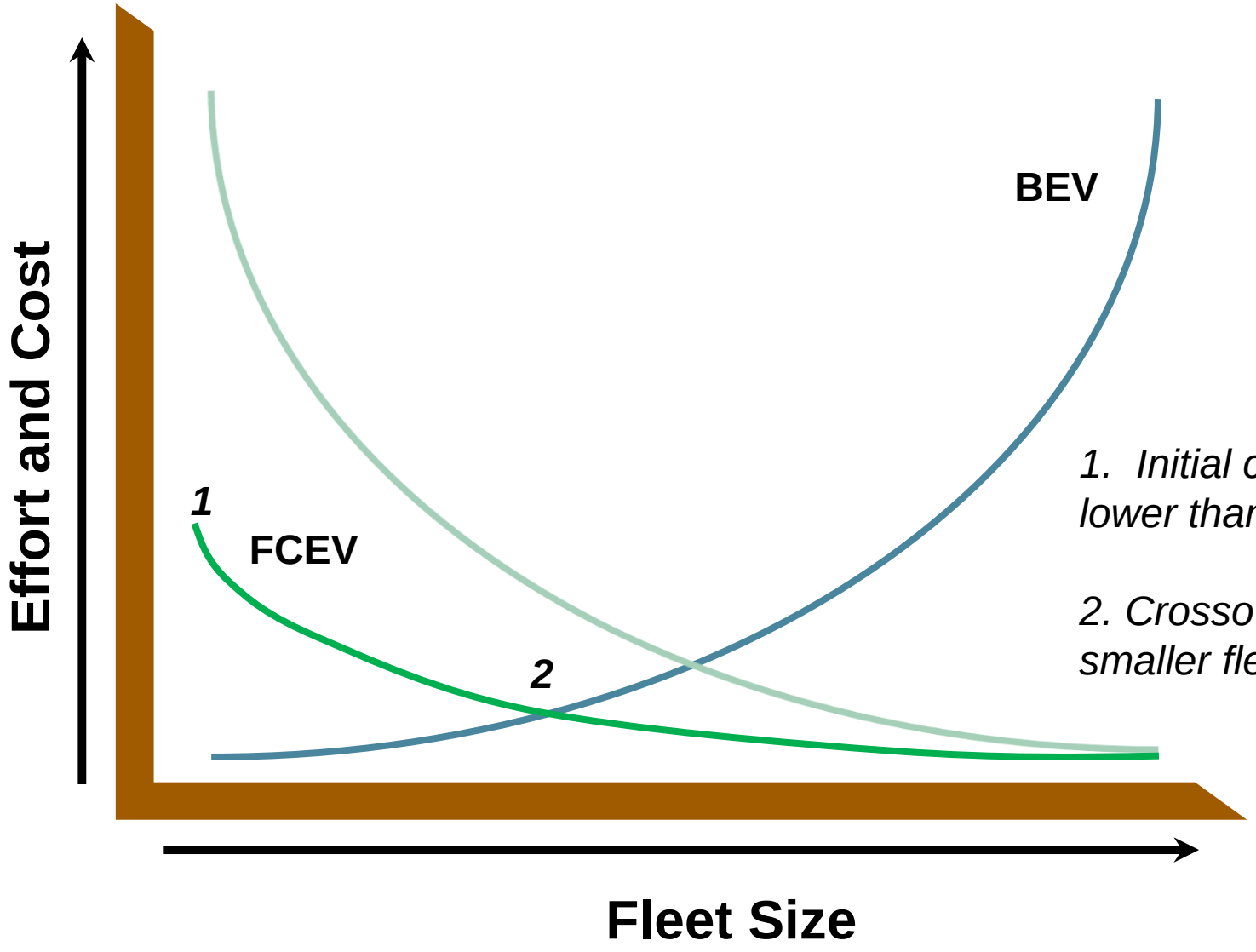
220MM+ operating hours

150 HFC patents

Conventional Wisdom of Electrical Infrastructure



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 [LH_2]
  - Gaseous form [GH_2]
- Hydrogen can be generated on-site
  - Steam Methane Reformer
  - Electrolyzer
- Hydrogen can be renewable/de-carbonized

GH2 Delivery

Electrolyzer

LH2 Delivery

Reformer

Delivered Gas Solution – A Starter Solution

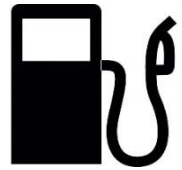
GENFUEL

GH2 Trailer

Optional Intelligent Manifold

Optional Compression

Optional Storage

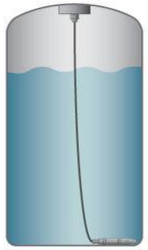


Indoor/Outdoor Dispenser

- 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



LH2 Tank

Evaporator

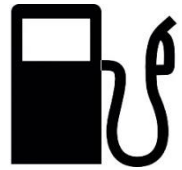
GH2 Trailer

GENFUEL

Intelligent Manifold

Compression

Storage



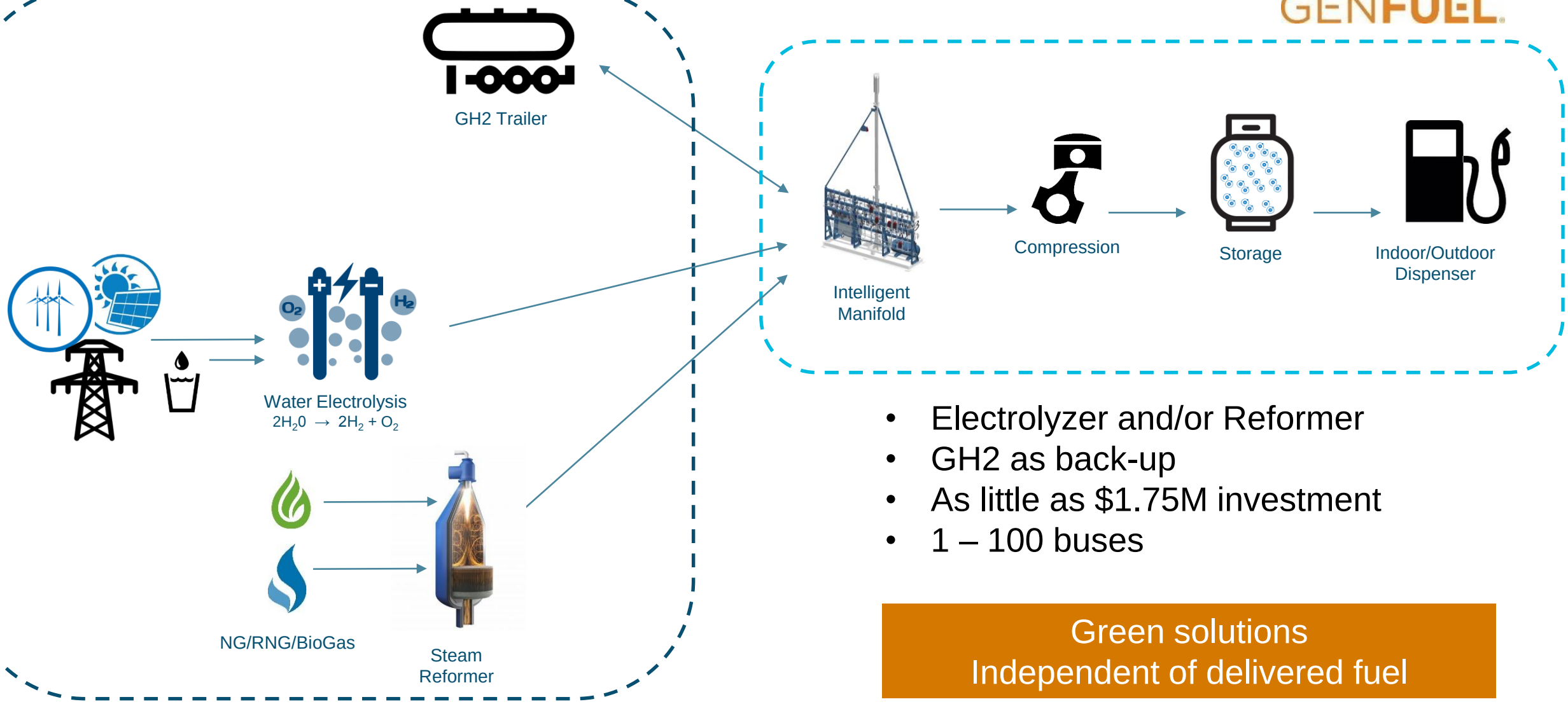
Indoor/Outdoor Dispenser

- 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

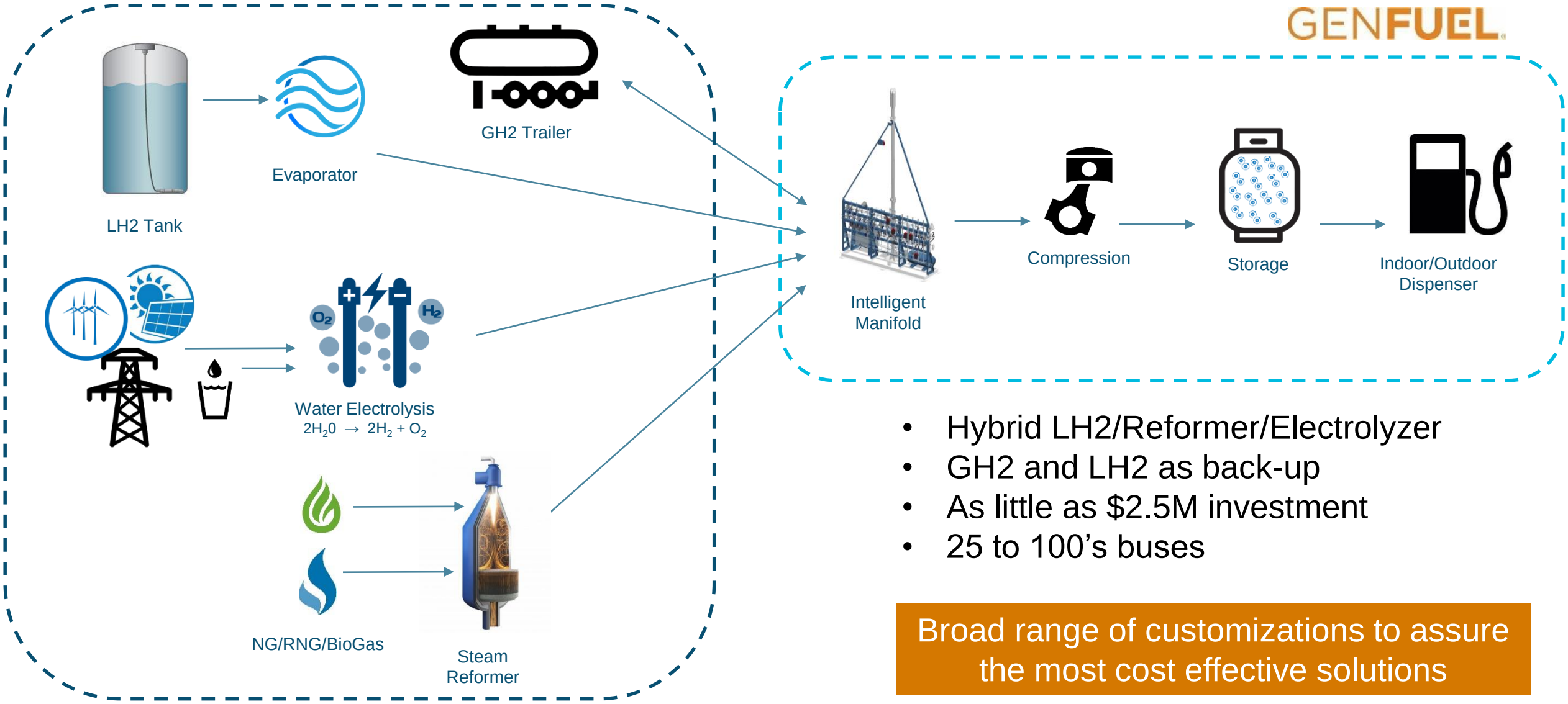
GENFUEL



- 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

Hydrogen Infrastructure Planning Considerations

- 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)

PLUG POWER

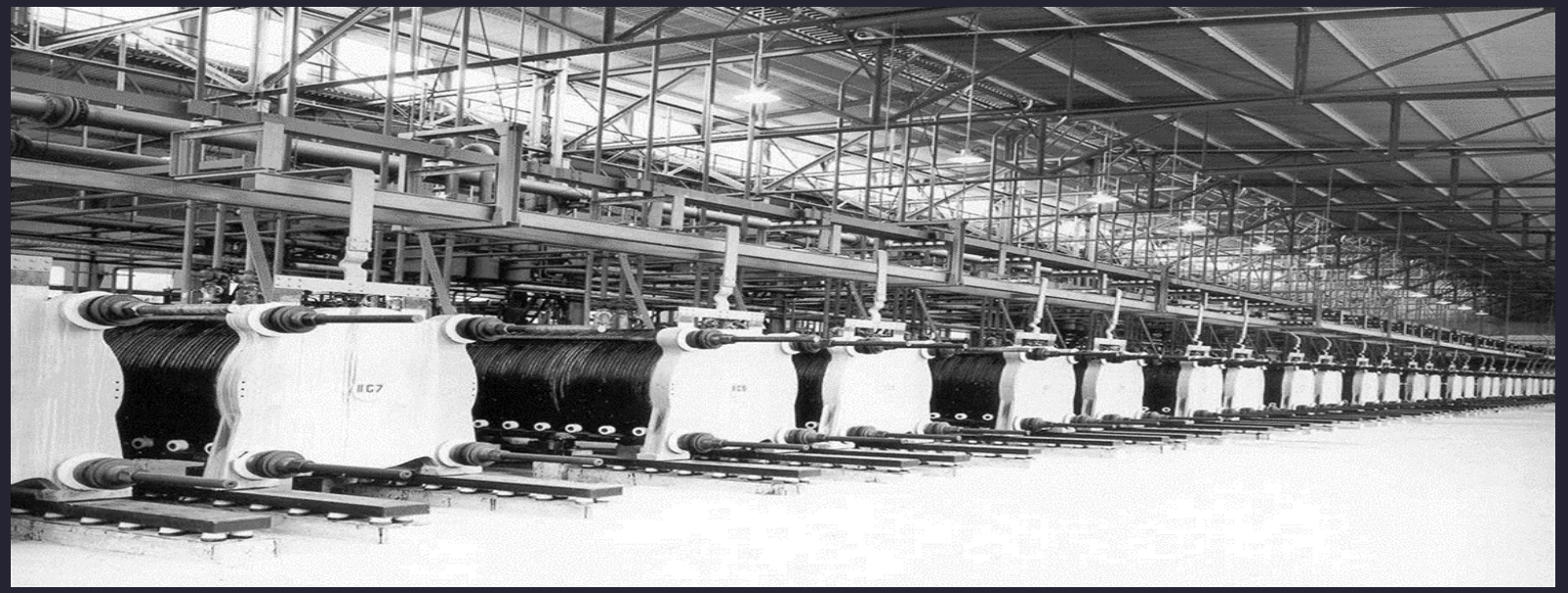
Corporate Headquarters
968 Albany Shaker Road, Latham, NY 12110

West Coast
15913 E. Euclid Avenue, Spokane, WA 99216

plugpower.com

Electrolysis for On-Site Hydrogen Generation:

Enabling scalable hydrogen infrastructure for Transit...



Stephen Szymanski, Director of Business Development, Nel Hydrogen
+1.203.678.2338 • sszymanski@nelhydrogen.com
January 17, 2019

nel
number one by nature™

Company Overview

Public Company, Pure H_2 Play

- **3** Manufacturing Sites
- **250** Employees
- **3,500+** Electrolyzers Installed
- **40+** H_2 Fueling Stations
- **90+** Years Experience

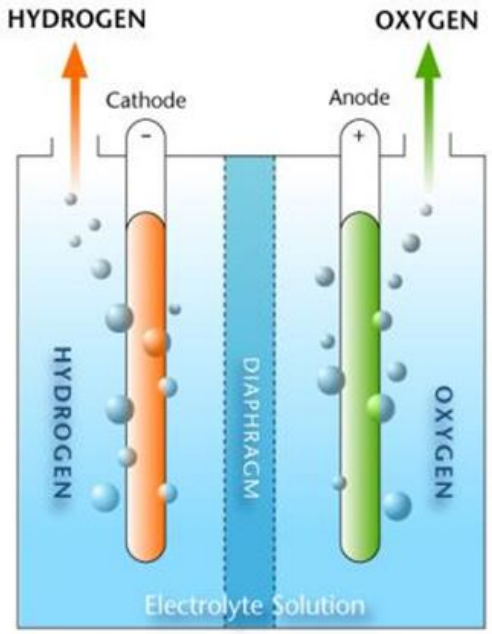
USA (Wallingford, CT)
PEM Electrolyzers

Denmark (Herning)
H_2 Fueling Stations

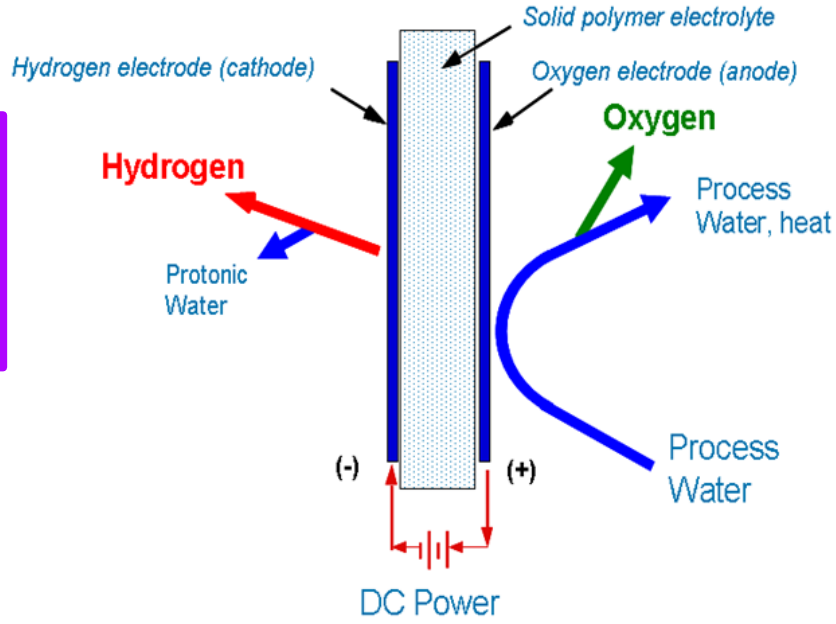
Norway (Notodden)
Alkaline Electrolyzers

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.



Liquid alkaline electrolyzer



PEM electrolyzer

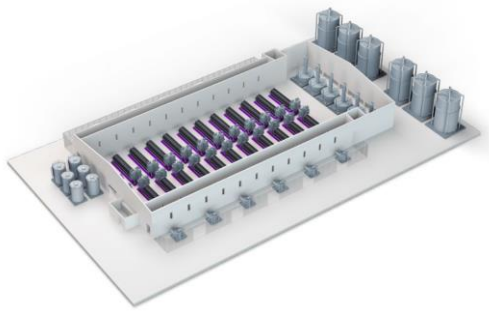
Electrolysis is inherently modular:
Incremental cost of adding capacity is low

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.



50MW

25,000 kg/day

500
class 8 trucks

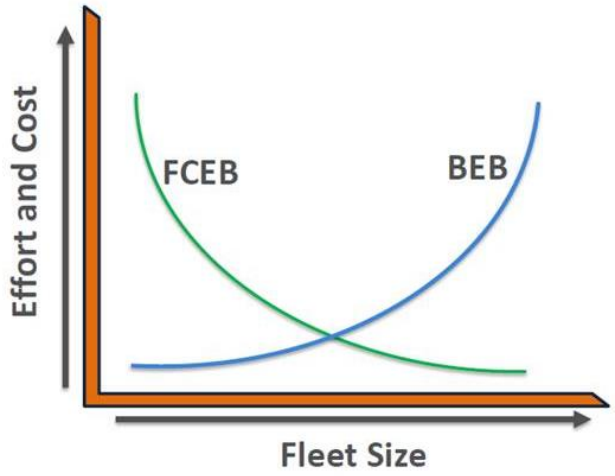
1,000
transit buses

40,000
cars

High fueling equipment utilization (fleet)

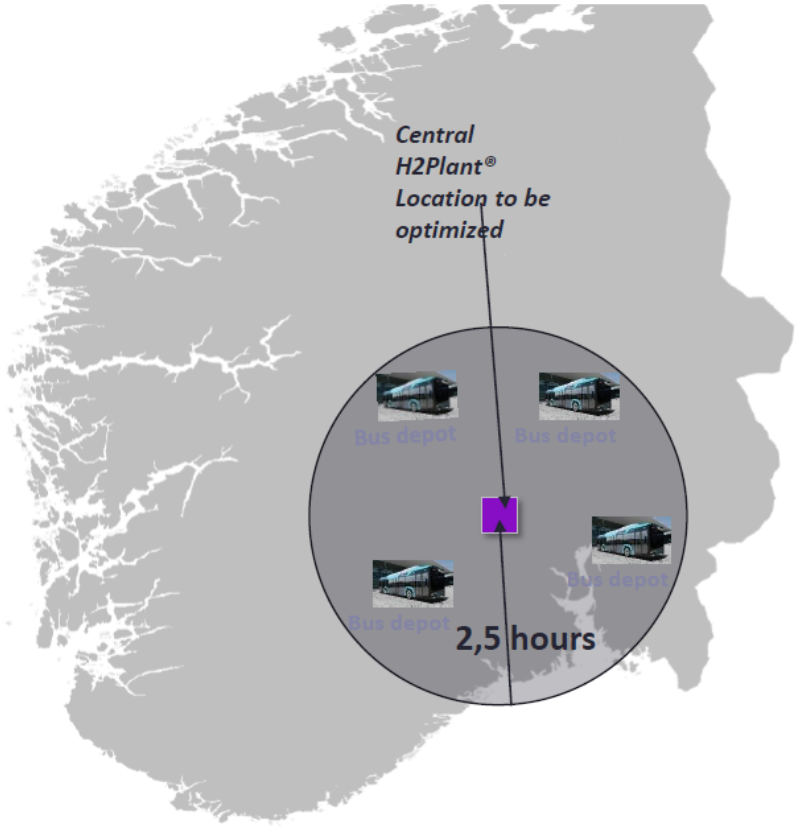
Low fueling equipment utilization (network)

Infrastructure cost for H2 decreases with number of buses…



10 busses	50 busses	150 busses
H2 price: $9.73/kg	H2 price: $6.86/kg	H2 price: $5.72/kg

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

Small bus depot solution: 30 buses, 650 SF area

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

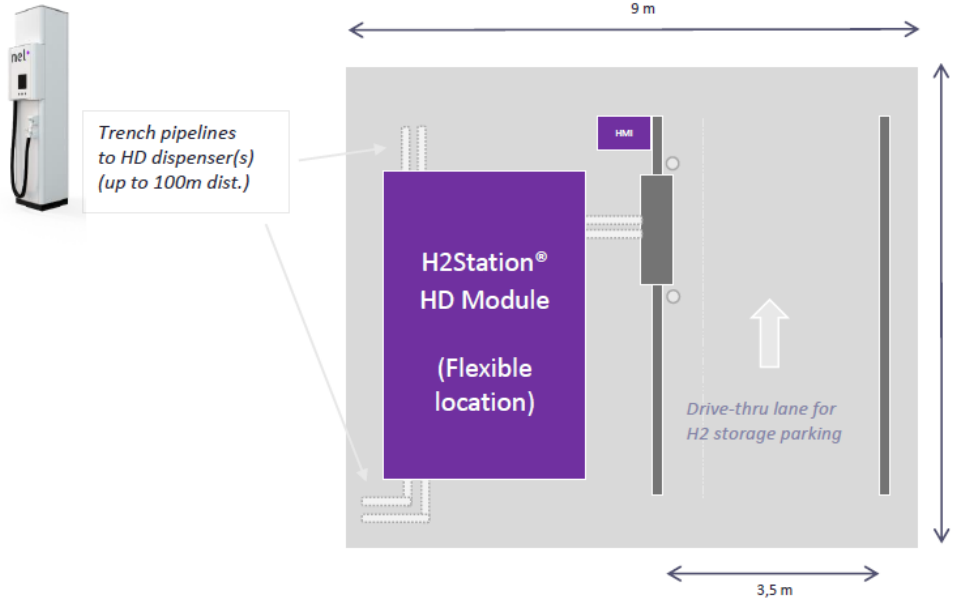
Station footprint:
58,5 m2

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

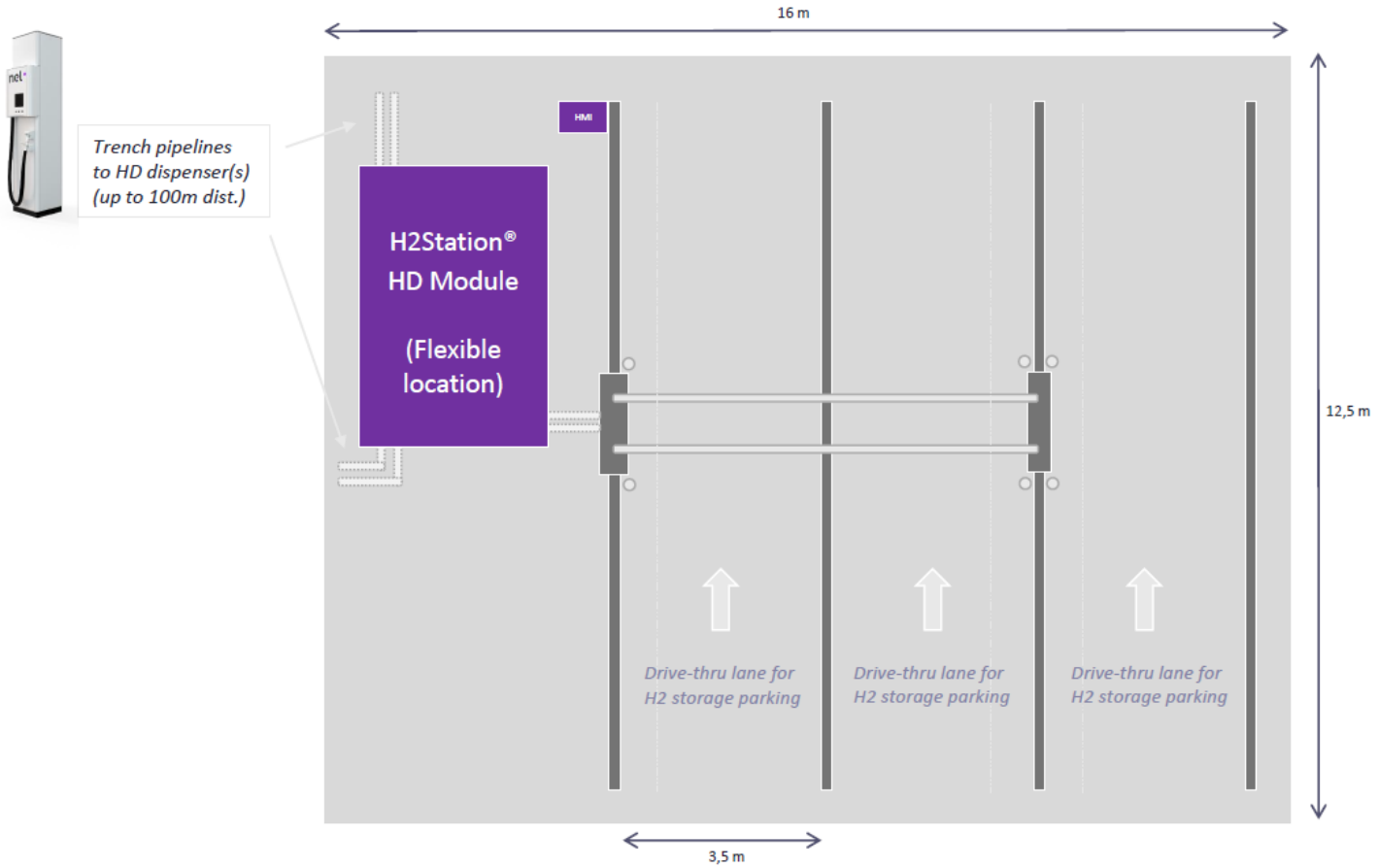
Recommended for:
Small to medium fleets.

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.

Hydrogen price parity with diesel/CNG for busses in California

Fuel	Diesel	Unit	Diesel Hybrid	Unit	CNG	Unit
Fuel consumption	3.87	miles/DGE	4.84	miles/DGE	2.91	miles/DGE
Fuel price (incl. O&M)	$2.79	/DGE	$2.79	/DGE	$1.62	/DGE
Fuel cost per distance	$0.7	/mile	$0.6	/mile	$0.6	/mile
H2 parity price - 1	**$5.6**	**/kg**	**$4.5**	**/kg**	**$4.3**	**/kg**
H2 pariy price - 2	**$4.5**	**/kg**	**$3.6**	**/kg**	**$3.5**	**/kg**

Hydrogen	1	2	Unit
Fuel consumption	8.00	9.85	kg/100km
	0.08	0.10	kg/1km
	0.13	0.16	kg/mile
	7.77	6.308	mile/kg

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

Thank you!

www.nelhydrogen.com

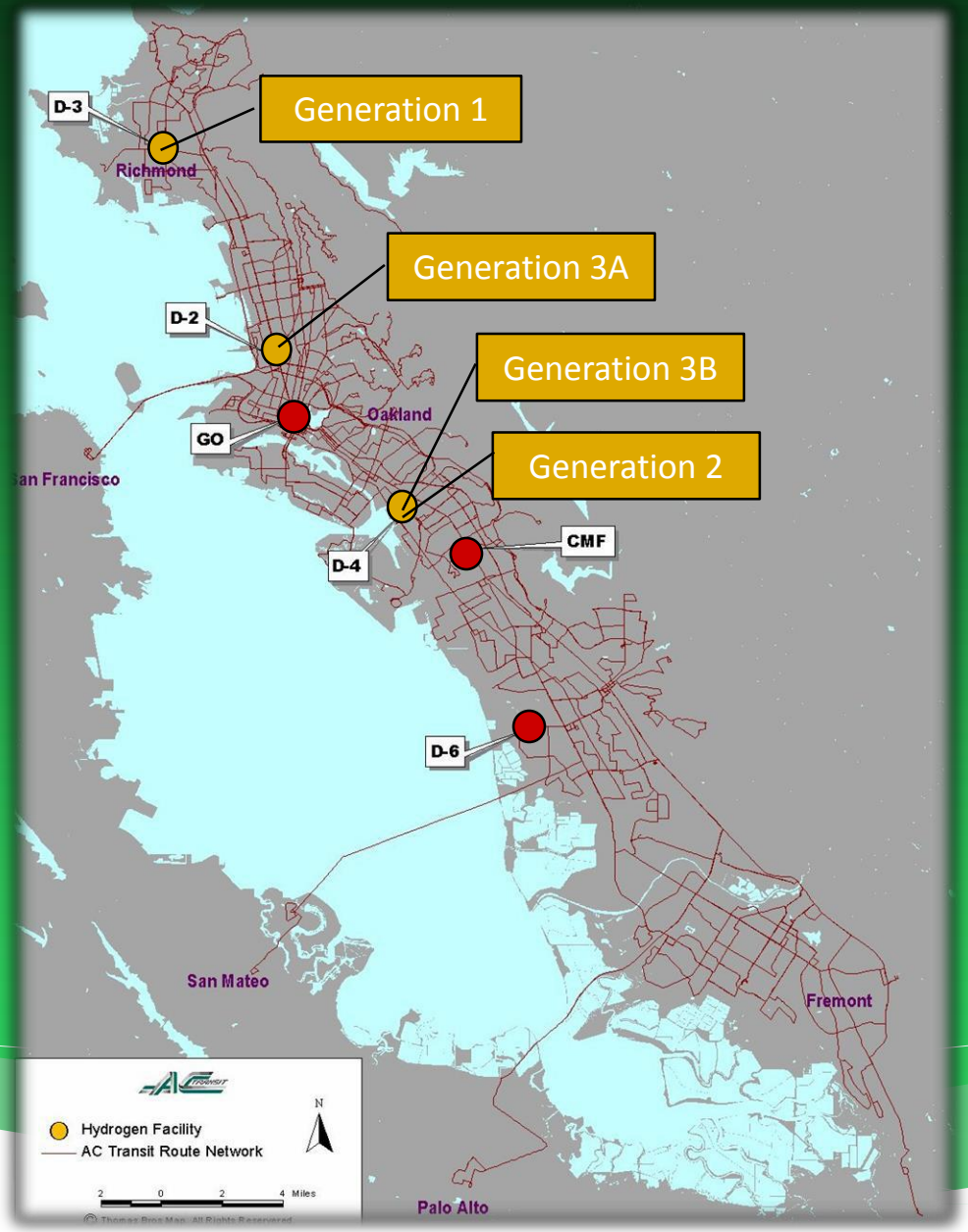
number one by nature™

Alameda-Contra Costa Transit District
Fuel Cell Bus Program

Fuel Cell Electric Bus Infrastructure Considerations

June 20, 2019

- **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



Emeryville Hydrogen Station

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!

For further Information:

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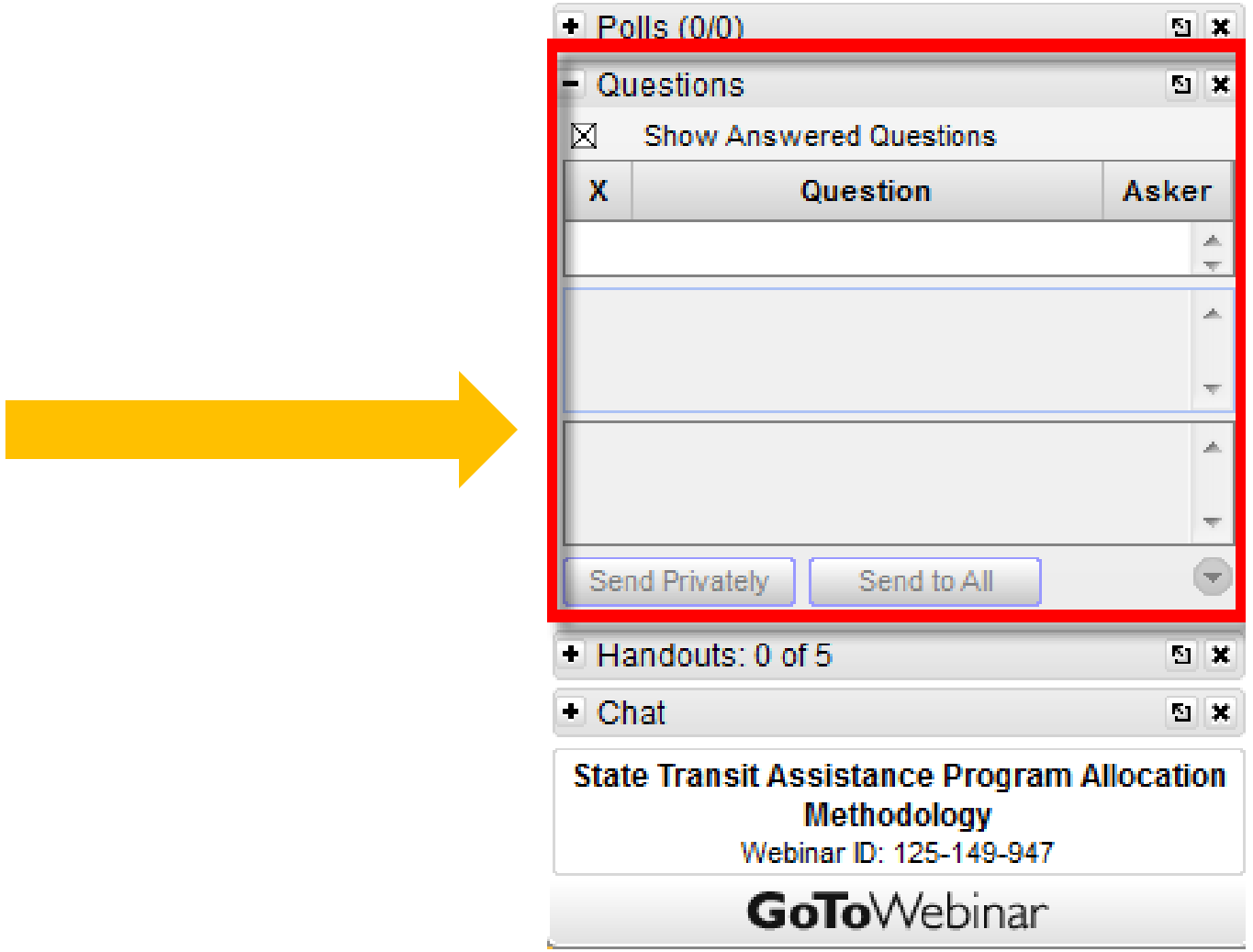
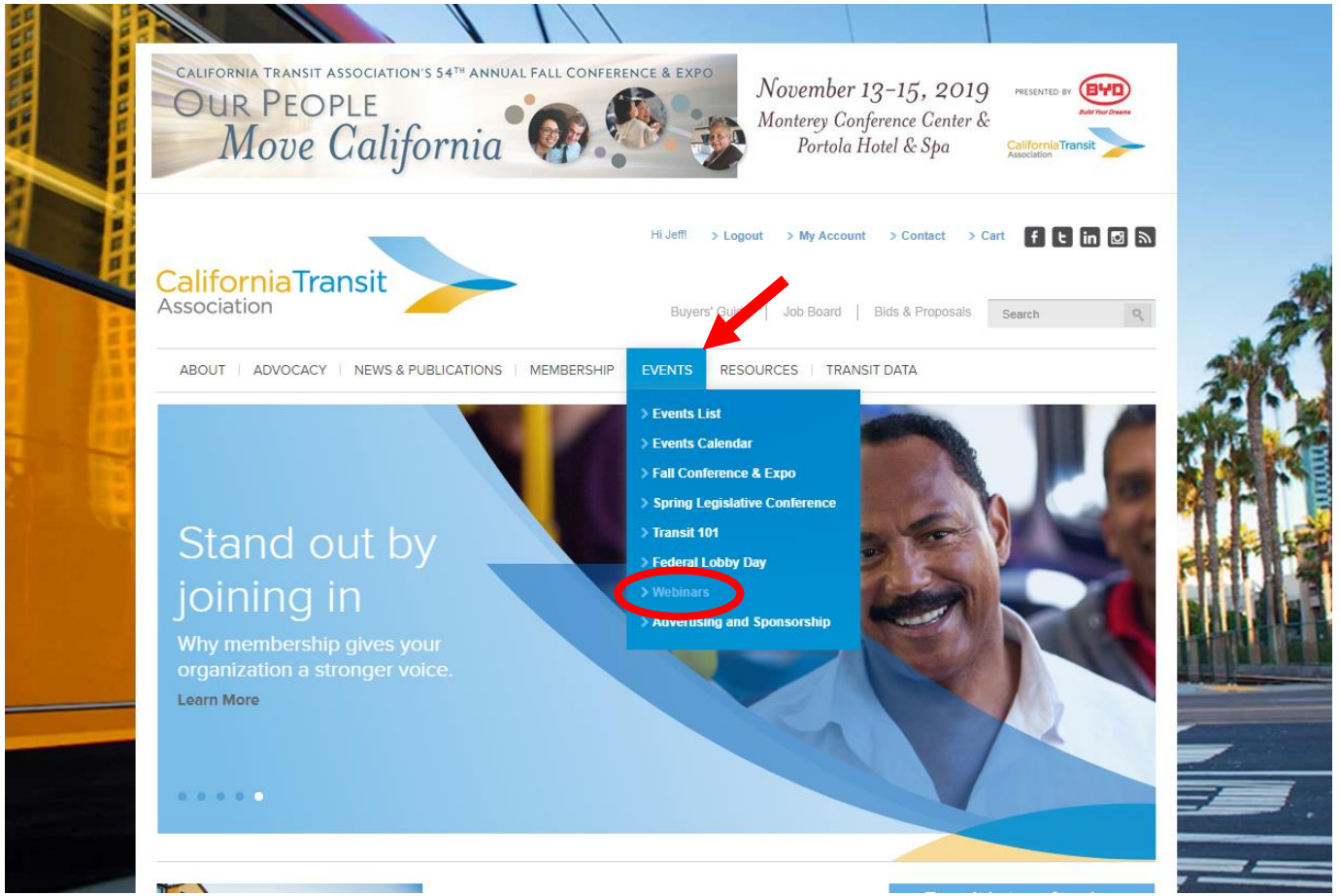


Remember to Register!

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

caltransit.org



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