FUEL CELL ELECTRIC BUSES

Enable 100% Zero Emission Bus Procurement by 2029

California Fuel Cell Partnership

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Contents

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Essential Action Steps

To continue the progress made toward fuel cell electric buses (FCEB) as a full performance and sustainable solution, the following action steps are critical:

1 | **California Air Resources Board** to mandate inclusion of FCEBs in transit agency analyses for rollout plans, especially before granting exemptions.

2 | **Transit agency boards** to include fuel cell buses in zero-emission bus feasibility studies and procurement efforts using current data from FCEB operators and manufacturers.

3 | **Hydrogen infrastructure providers** to promote "starter kits" and make costs known to transit agencies to engage them in fuel cell bus strategy conversations.

4 | **Hydrogen suppliers** to provide transit agencies with an attractive cost trajectory for hydrogen at scale for fleets of 50 or more fuel cell buses. Without an acceptable operating cost for a fleet-wide deployment, investments into pilot fleets will not make financial sense. Improve articulation of the argument of "cost control" advantage offered by hydrogen vs. electric grid.

5 | **State and regional legislators and agencies** to counter-balance the SB350 Transportation Electrification mandate that provides over $600 million CPUC-approved utility investments for medium- and heavy-duty charging infrastructure. Technology neutrality and parity should be extended to state funding and investments.

6 | **Hydrogen producers, fueling infrastructure providers and fuel cell vehicle providers** continue to advance fueling protocols, safety standards and practices to ensure reliable installations and reasonable permitting requirements.

7 | **All stakeholders** to engage the public with a broad and highly visible PR campaign. Key decision makers such as transit boards and legislators need to know they are backed by their constituency in supporting FCEBs.

8 | **Governor** to prioritize funding of heavy-duty hydrogen infrastructure and zero-emission buses, to help fulfill the ***"No diesel by 2030"*** campaign promise.

9 | **Industry** to provide turn-key bus and infrastructure packages for simplicity.

10 | **State agencies** to support ZEB grass roots training programs like those offered by the Centers of Excellence at SunLine and AC Transit. These are key in developing talent and ZEB maintenance staff.

11 | **State of California, academia and/or regional air districts** to evaluate the entire transformation toward zero-emissions transport, the technical and economic impact on the grid and how hydrogen plays a crucial role to facilitate decarbonization to meet SB100 zero-carbon goals.

Transit agencies are resistant to deploying fuel cell electric buses for three reasons:

- The Innovative Clean Transit regulation does not require the use of FCEBs and the assumption is that simply addressing ICT with battery electric buses is sufficient.
- Hydrogen infrastructure capital expenditure is currently high.
- Hydrogen fuel appears too expensive: cost estimates are based on small deployments and cost estimates at scale are unconfirmed.


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Introduction

California has a proud history of leadership in developing and nurturing zero-emission transit options, especially fuel cell electric buses (FCEBs). A short summary of these achievements and milestones gives a snapshot of the activity that has taken place in the Golden State.

- 20 years of demonstrating and operating FCEBs.
- 14 years of federally collected data showing that FCEBs are meeting and exceeding their targets on cost, performance and range.
- More than 4 million miles of operational service.
- FCEB production in Riverside since 2012.
- Two key transit agencies initiated a strong commitment to leadership and early adoption in 2000.

In 2013, the California Fuel Cell Partnership (CaFCP) released *A Road Map for Fuel Cell Electric Buses in California: A zero-emission solution for public transit*. And much has happened since its publication.

At the time, California policy makers were largely focused on light-duty zero-emission vehicles and heavy-duty vehicles were only beginning to be recognized as a significant means of reducing carbon emissions and other pollutants.

The ***Road Map*** counted 15 fuel cell electric buses in operation in California, 13 with Alameda-Contra Costa Transit District (AC Transit) in the San Francisco East Bay and two with SunLine Transit Agency (SunLine) in Southern California's Coachella Valley. Today, 25 buses are on the road with these and other agencies, including the University of Irvine and Orange County Transportation Authority (OCTA), and 21 more buses are expected shortly.

So much more has taken place since 2013.

FCEB Activity in California

- SunLine has expanded its fuel cell bus fleet and is building a 900-kilogram per day hydrogen station, one of the largest stations in the U.S.
- SunLine opened a zero-emission bus Center of Excellence, a concept developed as part of the first bus road map. The Center of Excellence will provide education and training to other transit agency staff, including maintenance staff.
- Nearly all of the fuel cell stacks on AC Transit buses have exceeded 20,000 operational revenue hours, with a few exceeding 25,000 and one exceeding more than 32,000 hours, six times its originally anticipated lifespan. These achievements reflect the durability of the technology.
- An AC Transit bus traveled more than 224 miles from Oakland to Reno without refueling, up a steep grade (Donner Pass) and through rain and snow to participate in the American Public Transportation Association bus & paratransit conference in Reno.
- AC Transit welcomed the first 60-foot, articulated fuel cell bus in North America.
- ElDorado National and New Flyer of America have assumed leadership roles in production, reflecting the maturity of this technology pathway.
- FCEB bus prices have gone down, due in part to larger volumes of production, most notably the recent 25-bus production run by New Flyer for three transit agencies in California.
- A 2019 New Flyer fuel cell bus achieved **350 miles of driving range** on an OCTA route with a payload representing fully-seated passenger capacity.
- CaFCP released its 2030 vision, the *California Fuel Cell Revolution*, detailing policies and market-based mechanisms required to realize a sustainable market without government funding for passenger cars, buses and trucks fueled by renewable and zero-carbon hydrogen.
- In late 2018, the California Air Resources Board approved the Innovative Clean Transit regulation, that mandates that all transit buses be zero-emission by 2040. This is the first vehicle category that is mandated to transition to zero-emission status.

Fuel cell electric buses are well beyond showing promise and have demonstrated their value as an option for many transit agencies that require buses that offer longer range, quick fueling times, a business case that matches their current bus and fueling operations, and operate well in extreme cold or heat. Other benefits include:

- High lifetime hours on fuel cell stack
- Positive bus availability data
- Increasing transit agency comfort levels
- Flattening learning curves with fuel cell technology and hydrogen infrastructure
- Established bus manufacturers in leadership roles

Challenges remain and will require continued collaboration among stakeholders, including private industry and government. These challenges include:

- Hydrogen fueling infrastructure for large fleets
- Fueling infrastructure cost for small fleets
- Federal and state funding for fueling infrastructure
- Supply of parts
- Cost of components

This road map—*Fuel Cell Electric Buses Enable 100% Zero Emission Bus Procurement by 2029*—builds on the first and is directed to multiple stakeholders, including transit agencies, policy makers and others who make decisions that affect millions of transit riders. The value proposition for FCEBs is described for the operating environments where they are best applied. Concrete actions are presented for all industry participants and stakeholders toward achieving a self-sustaining industry that enables zero-emissions transit in California.

The focus of this strategy document is the California transit community. However, California's policy and funding leadership, coupled with the size of its vehicle markets, offers opportunities to other U.S. states. Developing complementary policies and funding will enable other states to capitalize on and contribute to the volume of production and lower costs that will result, in part, from the Innovative Clean Transit regulation and other efforts.

The 2029 Vision

Transit Bus Market

CaFCP members envision a minimum growth path from 100 FCEBs ordered in 2020 to over 25% of total zero-emission buses (ZEB) ordered by 2029, including the supporting fueling infrastructure (Table 1).

Over the next decade, fuel cell electric buses will be deployed as the zero-emissions solution for the toughest transit applications in every bus type and for every climate and terrain any day of the year. The smallest paratransit shuttles will extend into long-range rural routes, and the largest over-the-road buses will connect communities across mountain passes and through deserts using FCEBs fueled by carbon-free and renewable hydrogen. Fuel cell electric buses provide solutions for congested bus depots in the most energy-constrained metropolitan areas while maintaining the operational flexibility that is critical to ensuring reliable service and continued public support for mass transit options.

FCEBs will go beyond maintaining the status quo of today's transit operations and help agencies to regain—and even expand—ridership. Full range and performance capability of FCEBs for 1:1 replacement of today's diesel and compressed natural gas (CNG) bus fleet means achieving conventional fleet flexibility. Bus yard operations can maintain the reliable and dynamic route service that transit riders need. The silent, vibration- and smoke-free environment of the electric powertrain offers unparalleled comfort to the rider, and the modular FCEB drivetrain with ever-shrinking component costs will offer bus manufacturers the ability to further tailor their bus design to suit rider needs. Driver experience will continue to be enhanced through these comfort features while still providing drivers with the powertrain performance they need to move nimbly through traffic.

Through these continuing advances in service reliability, rider comfort, bus design, and driver enthusiasm, FCEBs will clean the air for Californians and play a leading role in expanding bus transit into a new era of increased ridership and public enthusiasm.

Envisioned Number of FCEBs

TABLE 1

TARGET YEAR	2020	2025	2029
FCEBs ORDERED	100	300–400	≥ 25% of total ZEBs

Fact-Based Decision Making

Fuel cell electric buses will enable California to fully comply with the ICT regulation. Choosing FCEBs allows transit agencies in California to plan the integration of the Innovative Clean Transit (ICT) regulation[1] into their operations based on rational decisions for their specific needs. Hydrogen electric mobility solutions are similar to natural gas mobility solutions used today and allow the transit agency total ownership of the design, build and operation of fleet and fueling infrastructure without the dependence on

1 *CARB Innovative Clean Transit regulation fact sheet available at: https://ww2.arb.ca.gov/sites/default/files/2019-07/ICTreg_factsheet.pdf*

complex utility programs as well as control of their operating costs. Lengthy, costly grid integration studies, and large-scale public works projects for substation and feeder construction for all grid-charging fleets can take the schedule and cost control for bus infrastructure out of the hands of transit agency planners. Transit agencies can use FCEBs to maximize their facility utilization and control their ICT transition planning (Table 2). A successful rollout of the ICT regulation must enable transit planners to balance their fleets with battery electric options when their operations allow, while utilizing FCEBs to provide full coverage for all circumstances, including harder-to-fulfill longer routes and emergencies.[2]

Zero-Emission Bus Innovative Clean Transit Regulation Transit Agency Purchase Schedule[3]

TABLE 2

DATE	MILESTONES	ZEB PURCHASE SCHEDULE (ZEB percentage of total new bus purchases)	
		Large Transit (LT)	**Small Transit** (ST)
July 1, 2020	LT Board approved Rollout Plan	—	—
Dec 31, 2020	Collective purchase > 850 ZEBs	—	—
Dec 31, 2021	Collective purchase > 1,250 ZEBs	—	—
July 1, 2023	ST Board approved Rollout Plan	—	—
2023	Discharge if > 850 ZEBs 2020	25%	—
2024	Discharge if > 1,250 ZEBs 2021	25%	—
2025		25%	—
2026		50%	25%
2027		50%	25%
2028		50%	25%
2029+		100%	100%

Cost and Incentives

Zero exemptions will require an articulate and transparent description of the value proposition for the complete powertrain, balance of system, operating and maintenance costs, stable long-term fuel cost and supply chain, and fueling system. The hydrogen community needs to focus on total cost of ownership (TCO) analysis, and FCEB cost trajectories—already well known within industry—must be further

2 *Such as resilience in case of natural disaster, FEMA ordered evacuations and FCEBs as back-up of electric grid.*
3 *CARB Innovative Clean Transit rule available at: https://ww2.arb.ca.gov/rulemaking/2018/innovative-clean-transit-2018*

elaborated upon and promoted by bus manufacturers and distributers to transit customers. Maintenance staff and management must be engaged and educated on the continuing reduction of labor requirements and component costs, particularly at the most experienced FCEB fleets.

Many transit agencies remain skeptical or are unaware of long-term fuel costs and overall powertrain efficiency. However, lower cost of low carbon intensity hydrogen will be reached when produced at scale from renewables. Amortization of production and dispensing infrastructure from today's hardware costs adds up to a low-cost fuel that is cost-superior to CNG, diesel, and gasoline. Combined with an expected 30% reduction in maintenance costs over the lifetime of the bus enables improved long-term transit planning.

The transition to full TCO parity will require a brief but essential period of incentives to drive production cost down through scaling while maintaining affordability to transit agencies. A few ZEB incentives exist in California programs like the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, Transit and Intercity Rail Capital Program, Carl Moyer Program and Low Carbon Transit Operations Program, and at the national level in the Federal Transit Administration's Low-No program, as well as the VW Mitigation Trust Fund. However, most of these are competitive and vehicle specific, which translates into limited usefulness for hydrogen fueling infrastructure implementation. Hydrogen production can benefit from the Low Carbon Fuel Standard (LCFS) program, particularly when producing hydrogen from renewable and low-carbon sources, and LCFS credits can lower fuel costs for the user, particularly at scale.

Hydrogen Supply

Transit fleets must have reliable, low-cost fuel sources and FCEBs fueled by hydrogen can assure this. Although 9 million metric tonnes of hydrogen are produced each year in the US, the majority of this supply is locked into long-term contracts with electronics companies, refiners, and food processors. Nevertheless, there is an existing and understood hydrogen supply chain with diverse manufacturing sources such as methane reforming, biogas reforming, and electrolysis projects. Some take advantage of power purchase agreement pricing from intermittent solar or wind that reduces costs.

Moving gaseous and liquid hydrogen from source to user also occurs along a variety of vectors, including trucking, pipeline distribution, and local production. This portfolio of supply vectors is absolutely essential for stable energy supply as California transitions to SB100 goals over the next 25 years.[4] As is the case for electricity and natural gas, manufacturing, distribution, and demand can be decoupled to enable optimal location of manufacturing sites (often rural, with limited demand) and efficient distribution to demand centers (often urban, with space constraints).

Decarbonized hydrogen in California is needed to avert further climate change and bolster fundamental resiliency of the energy supply. As California rapidly transitions to a carbon-free grid, industries from agriculture to manufacturing will be electrifying in parallel with all of transportation. This will intensify demands on California's power grid, requiring significant (additional) generation and multiplication of grid capacity at the substation level. Although legislation[5]

4 *Statutes of 2018, Public Utilities Code Sections 399 and 454.*
5 *SB 100 "California Renewables Portfolio Standard Program: emissions of greenhouse gases" (2018). Available at: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100*

has been passed to reach 100% zero-carbon power generation in California by 2045, there are issues with penetration into the grid due to demand/supply mismatches. Increased peak demand on already stressed distribution infrastructure in dense urban areas could necessitate new high-voltage transmission lines across California's fire-prone wilderness areas. Hardening transmission line systems for reliability will require ratepayer- or bond-funded investments in storage, redundancy, and advanced technology, as well as increased private investment in distributed generation.

Achieving a low-cost, resilient energy infrastructure must start by easing end-user adoption. The experience with hydrogen must be leveraged along with education of local permitting and first-responder agencies to streamline permitting time and reduce costs. Simple, turn-key fuel infrastructure packages are needed to provide easy fueling options for typical bus transit trial fleets of 2-to-10 vehicles. Fleets of 50-to-100 vehicles or more are needed to obtain economies of scale in bus and infrastructure manufacturing and supply chains. Such intermediate stages of development in refueling and distribution should be developed in coordination with bus OEMs. Development of new infrastructure business models are needed, as seen for CNG with fuel service providers investing in infrastructure in exchange for long-term service contracts. Coordination is a role that government must play through funding, regulation, and legislation to enable a cross sectoral and segment transition. Examples of coordination among infrastructure providers includes standards and fueling protocol development and the development of novel business models like developing rapidly deployable dispensing, fuel-as-a service models, and partnerships with bus OEMs.

Safety

As hydrogen scales, it is critical that industry is proactive in addressing the changing demands of increased distribution, including bulk storage near residential zones and sensitive environmental areas, assured pipeline safety, and user comfort across a variety of usage cases. The safety of hydrogen as a fuel already meets or exceeds that of natural gas and liquid petroleum fuels, with the added benefits of zero toxicity and natural elimination of lost fuel from leaks or spills due to its rapid transition to a gaseous state and high buoyancy. While hydrogen has these benefits, its wider flammability range requires careful attention to potential ignition sources and careful leakage detection at storage and transfer points.

Accidents with hydrogen are rare but have occurred. Recent incidents were met with immediate and highly cautious responses by the station providers. The high level of transparency and responsiveness shown is critical to mitigate public concerns, alleviate misperceptions, and eliminate unnecessary fears. Safety standards capture the knowledge acquired from these events to ensure responsible adoption of hydrogen in a rapidly evolving energy transition. CaFCP energy members with long histories of managing hydrogen continue to spearhead efforts to bring appropriate standards and protocols to the transportation sector, and much of the work in engaging stakeholders and general public has commenced.

Over the next decade, fuel cell electric buses will be deployed as the zero-emissions solution for the toughest transit applications, in every bus type and for every climate and terrain any day of the year.

Getting Started

Competent and confident service and operations staff make new technologies work at scale. Operations and maintenance training programs that are now underway at transit agencies and demonstration fleets must be translated to widely accessible, standardized curricula that address all aspects and phases of FCEB implementation. Local community and technical colleges are excellent resources for such programs and must be engaged and funded to propagate and advance training for technicians, drivers, fleet managers, and all fleet operations personnel.

The first hydrogen operations of any bus fleet must be user friendly and familiar to those accustomed to working with existing liquid or gaseous fuels. Operators and technicians are starting to become familiar with elevated electrical voltages in powertrains through battery electric bus (BEB) experiences, but technician confidence must be further enhanced as deployments propagate. Gas detection and ventilation systems, already familiar to CNG facilities, require only minor upgrades for hydrogen, but their use and operation must be taught to those new to gaseous fuels. Vehicles and fueling systems are designed to minimize or eliminate exposure to hazards during daily operations and maintenance procedures.

FCEB Road Map

1 ZERO EMISSIONS, ZERO COMPROMISE[6]

The value proposition for fuel cell electric buses must be made simple and clear to all audiences and stakeholders in California.

Correcting the misperception of FCEBs as costly or complex relative to other solutions is paramount. The falling capital cost of today's battery electric bus draws attention away from the total cost of ownership for full fleet integration. FCEBs are following a similar cost reduction path as battery buses with larger fleets of FCEBs being built. Fuel cell technology is used across multiple mobility platforms, such as cars, trucks, and rail vehicles. This drives cost reduction from manufacturing volumes as there still exists a large cost reduction potential within manufacturing, compared to the materials cost component of the total cost.

Large transit agencies are only now starting to understand the true incremental cost difference between a demonstration fleet deployment of a few to a dozen or so buses against the complete fleet replacement demanded by the ICT regulation. Dispensing from liquid hydrogen at a transit depot eliminates the need for infrastructure projects outside of the fence of the transit agency. Grid capacity and stability analyses for multi-megawatt installations can take many months or years before project costs can be assessed and installing new infrastructure through crowded public rights-of-way can be cost prohibitive. Hydrogen infrastructure can minimize real estate impact for space-constrained depot properties. Long, full driving range capabilities mean that the number of buses in the fleet and associated depot area need not be expanded. Furthermore, fueling operations can remain largely unchanged to present operational practices with diesel and CNG with the depot. Outside of the depot, no additional fueling infrastructure is required. Fuel cells also have highly recyclable components—already up to 95% of the fuel cell platinum is recycled at refurbishments and plates are reused—meaning there are no costly disposal concerns.

While zero emissions technology may be new to transit fleet operators, they are keenly aware of the various factors that stack up to affect their total fleet operations cost (Table 3). The value of FCEBs must be clearly directed to the end users who will ultimately enjoy lower costs for FCEB fleets, while acknowledging the value of BEBs where they are appropriate. Smaller fleets, those with consistently shorter routes, and ample real estate and route flexibility may find better value in BEB fleets. Early assessment of these factors is key to ensuring that perception of FCEBs does not result from misapplied deployment. Total cost of ownership illumination must be the focus of fleet technology evaluation.

6 *Fuel Cell and Hydrogen Energy Association*

© HYDROGENICS

TABLE 3

Commercial Sustainability Goals for FCEBs

CATEGORY	GOAL
Performance	Performance and availability comparable or better than conventional buses
Range	Range comparable to conventional buses
Capital cost	Reaching parity with diesel hybrid buses by 2023[7]
Fueling infrastructure	Capital expenditures equal or below $60,000/bus[8] depending on fuel distribution method No need for additional infrastructure outside of bus yard/depot
Fuel	Targeting $5/kg for parity with present diesel costs (per mile)
Maintenance	Comparable to CNG buses[9]
Mid-life	Less than $30,000/bus for fuel cell module refurbishment
Fleet size	No need to increase fleet size to provide same service as current operations

7 *California Air Resources Board Innovative Clean Transit regulation TCO assumptions. Available at: https://www.arb.ca.gov/msprog/bus/tco_assumptions.xlsx*
8 *Below $100k/bus in OCTA project, projected below $60k/bus for successive similar projects.*
9 *For a recent cost comparison, see "American Fuel Cell Bus Project Evaluation: Third Report" L. Eudy, M. Post, and M. Jeffers, NREL (May 2017). Available online at: https://www.nrel.gov/docs/fy17osti/67209.pdf*

FCEB Technical and Cost Targets

TABLE 4

TARGETS FOR 40' FUEL CELL ELECTRIC TRANSIT BUS					
Factor	**Units**	**2020**	**2025**	**2029**	**Comments**
Bus lifetime	years/miles	12/500,000	12/550,000	12/600,000	
Power plant lifetime	hours	25,000	27,000	30,000	Expected efficiency improvements
Bus availability	%	≥ BEB	≥ BEB	≥ BEB	
Fuel fills	per day	1 (<10 min)	1 (<7 min)	1 (<5 min)	Specific transit agency requirement may differ
Bus cost	$	$850,000	$725,000	$600,000	Assuming alignment with Table 1 target orders by 2020, 2025 & 2029
Power plant cost	$ Δ	$200,000	<$100,000	$0	Incremental cost versus current conventional buses
Hydrogen storage cost	$	$50,000	$40,000	$30,000	
Road call frequency (bus/fuel cell system)	miles between road calls	>4,000/ >20,000	>5,000/ >20,000	>5,000/ >25,000	
Operation time	hours per day/ days per week	20/7	20/7	20/7	
Scheduled and unscheduled maintenance cost	$/mile	$0.40	$0.28	$0.20	Path to reduce cost must be obvious Unscheduled maintenance cost reduction is key Transit size may influence cost reduction
Range	miles	300	325	400	For all climates, terrains and loading conditions
Fuel economy	MPGDE	8	9	12	Improves with increased scale of production & efficiency improvements
Infrastructure cost	$/kg/day	Decreasing	Decreasing	$1.00	H_2 fueling station equipment & civil construction cost ≤ BEB EVSE
Total Cost of Ownership	Not a common factor/parameter for transit operations, but is informative to decision makers and aligns with other transportation modes				

At a policy level, both staff and decision makers within government must be educated to the cost of ***not*** considering FCEBs as a vital feature in California's ICT ZEB deployment. If transit agencies, particularly larger ones, do not evaluate FCEBs for their most challenging range and infrastructure issues; and excessive cost to transit agencies, electrical ratepayers, and California taxpayers, this will result in numerous agencies citing prohibitive costs to ICT compliance. Exemption options in the ICT regulation can allow major agencies to continue operations without zero-emissions fleets. If this becomes the dominant practice, the validity and practicality of the ICT regulation will be called into question. The impact of this result cannot be overstated; the ICT regulation represents the first major transportation sector decarbonization effort in California and its failure will have a crippling effect on California's SB100 goals and erode public support for decarbonization funding. California cannot deny its role as a leader to the U.S. and the world in averting climate change. A failure on this scale will resonate across our borders and regress decarbonization efforts. We must empower our stakeholders now to make fully informed, comprehensive, and transparent choices for our future. It will make the ICT regulation the success story that inspires California, the U.S. and the world to accelerate the transition to zero-carbon energy.

2 | CLEAN, LOCAL LOW-COST FUEL; SCALE IS KEY

The hydrogen industry is dedicated to achieving carbon-free transportation, as evidenced by the global Hydrogen Council's resolution of zero-carbon transportation fuel by 2030[10] that represent the position of the hydrogen fuel industry. Simultaneously, the transition to zero-emission buses must focus on total cost of ownership and the recognition that all costs, including fuel, must be competitive.

Low carbon intensity hydrogen sources available today include dedicated and curtailed renewable power, biogas steam methane reforming (SMR), SMR of methane with carbon capture and storage (CCS) technologies, and waste gas (or off-gas) capture from fertilizer production and other industrial processes. Even with existing hydrogen production from fossil sources, there is at least a 20-to-30% efficiency gain today compared to diesel and CNG powertrains which lowers relative carbon intensity.

Zero carbon renewable energy from solar and wind sources can be achieved in certain markets at $0.05/kWh or less for megawatt-scale installations, before transmission and distribution costs are added.[11] Electrolyzer cost trajectories drop rapidly due to scale with higher volume equipment manufacturing and development of larger electrolyzing stacks. Zero-carbon renewable hydrogen becomes cost competitive against grid power at scale, even when considering sizing for peak power of intermittent sources. Hydrogen distribution costs also drop rapidly when pipelines or liquefaction are introduced, both of which achieve low cost-per-kilogram when deployed at the scale of many tons per day.

When combined, these factors lead to a dramatic drop in renewable hydrogen cost at the fleet pump to eliminate the need for incentives within a 10-year horizon. All of these approaches lend themselves to large-scale, centralized production near the renewable energy resource location.

This rapid scale-up of zero-carbon hydrogen production requires support to move from its present limited scale to the full incentive-free, self-sustaining commercial phase. The influence and resources of natural

10 Hydrogen Council 2030 goal: http://hydrogencouncil.com/our-2030-goal/
11 Lazard Levelized Cost of Energy and Levelized Cost of Storage 2018 (November 8, 2018): https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

gas utilities will further this effort and leverage the knowledge they have gained in gas transport and distribution. The power of the California Public Utilities Commission (CPUC) to aggregate and deploy capital resources must be enhanced to promote and support renewable hydrogen at equal treatment alongside grid charging infrastructure investments.[12]

Legislative funding support will only be gained through advocacy by the environmental justice community, which means setting aggressive targets for renewable content in transportation hydrogen that meets or exceeds the carbon content of the electrical grid.

Assessing the Cost

The cost advantage of hydrogen as a transportation fuel becomes apparent when considering the cost of converting all of California's transportation to grid-charging, then considering hydrogen approaches for the most expensive components of this transformation. Expanding renewable energy generation capacity to meet these needs means distant large-scale solar and wind farm installations, requiring increases in high-voltage transmission across environmentally sensitive areas. Hydrogen production at these distributed generation facilities can replace high-voltage transmission projects and can use existing roadways, railways and pipelines that are resilient to fire, flood, and natural disasters while intrinsically providing energy storage.[13]

The distribution of power to end users, when considering only grid charging, means installing infrastructure to distribute double or more of the power flowing through California's grid today.[14] The impacts are even greater in areas of higher energy use concentration, such as shipping ports or industrial zones. Addressing these areas with hydrogen-fueled vehicles avoids expensive and time-intensive public works projects on substations, feeders and distribution lines in congested areas.

It is, therefore, critical to illuminate these costs to policy makers before investments are made to initiate sweeping grid infrastructure changes. This can be accomplished with a comprehensive, comparative study of 2045 zero-carbon transportation scenarios for SB100 goals that assesses an all-grid-charging approach, contrasted with hydrogen and fuel cells used in areas most challenged by grid charging.

With this information, California's legislature can assess the funding needed to scale renewable hydrogen production to commercially self-sustaining levels. California's state funding agencies must also be persuaded to effectively distribute funding for renewable hydrogen production and fast-track large-scale centralized electrolysis and renewable natural gas reformation facilities. This will allow commercial producers to establish firm, long-term fuel contracts, with cost solidified by zero-cost energy input (sun and wind), assured against stricter environmental standards by low or zero-carbon content.

At a policy level, both staff and decision makers within government must be educated to the cost of ***not*** *considering FCEBs as a vital feature in California's ICT deployment.*

12 See CPUC Action "Examine utility electric rate designs to ensure access to affordable electric vehicle charging and hydrogen fuel" in "2018 ZEV Action Plan Priorities Update" September 2018. Available at: http://www.business.ca.gov/Portals/0/ZEV/2018-ZEV-Action-Plan-Priorities-Update.pdf

13 Energy Futures Initiative, "Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California." (May 2019). Available at: https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5ced6fc515fcc0b190b60cd2/1559064542876/EFI_CA_Decarbonization_Full.pdf

14 Sasseen, Tim: A Resilient and Scalable Decarbonization Strategy for California Transport, September 14, 2018. Available at: https://blog.ballard.com/decarbonisation-strategy-for-transportation-in-california

3 OPTIMIZING FUNDING SOURCES

State-managed funding must be programmatically dedicated to stimulate large-scale (50-to-100 vehicles) heavy-duty deployments. Hydrogen funding to date has focused primarily on light-duty passenger cars. Creating a sufficiently dispersed network of retail fueling stations for a decentralized and independent fleet is in many ways a more formidable challenge than is required for fuel cell electric buses and other heavy-duty fleets. The fleet application of hydrogen fueling ensures high, consistent utilization of infrastructure investments. Operations and maintenance can be monitored or assumed by the agency utilizing the fuel. One of the benefits of higher utilization of fuel means a greater and more immediate impact on greenhouse gas emissions, removing criteria pollutant and air contaminant emissions from the communities that transit buses serve.

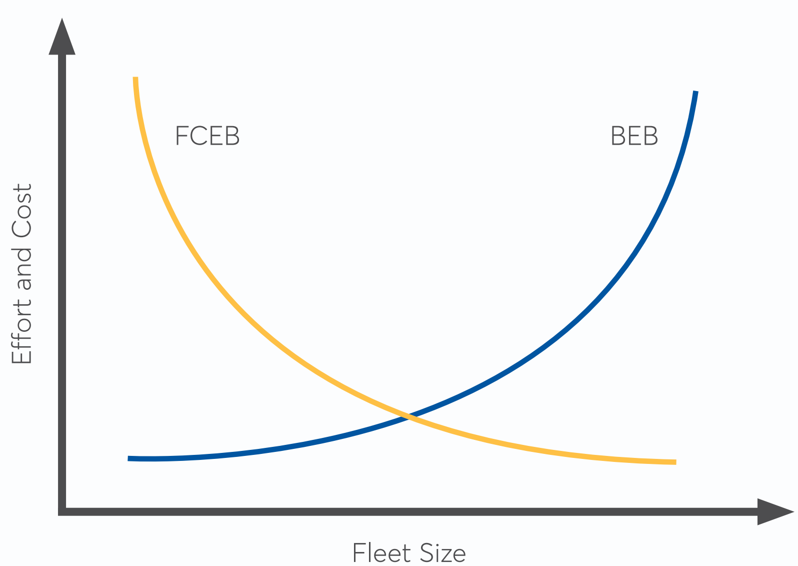
To motivate private infrastructure providers to commit capital, state funding must be secured and allocated in the near term, with particular emphasis on the 2020 to 2025 timeframe. Transit agencies must be assured of funding support as they create their rollout plans in time for the mid-2020 deadline set by the ICT and begin limited pilot fleet deployments of FCEBs as soon as possible with a glide path to scale. Per-vehicle costs for hydrogen infrastructure is intrinsically high for small deployments of 2-to-10 buses, which is the quantity that transit agencies will require before dedicating their procurements to a new technology. However, depot fueling infrastructure costs rapidly diminish per vehicle as fleet sizes increase, dropping below that of grid-charging for fleets as small as 50-to-100 buses (Graph 1). This makes funding support of fueling infrastructure most crucial in the near-term, with high environmental dividends on this investment as fleets expand in size.

Fleet Scaling Assumptions for Available Zero Emission Bus Options

GRAPH 1

The Challenge for 100% ZEB Deployment

Infrastructure and Scalability



Source: Center for Transportation and the Environment

4 PLANNING FOR SCALE AT THE STATION

Funding programs can be structured to incentivize thoughtful planning and scaling of infrastructure. At the demonstration and pilot level, funding of a rapidly deployable fueling system reduces the cost of entry for a transit agency to investigate integration of FCEBs into their fleets, while minimizing their operational risks. Alternatively, a shared-use station for a joint group of transit operators operating 100 FCEBs may offer a similar avenue, while providing the benefit of learning about high throughput infrastructure. This allows for an economic, phased deployment with an offramp for funding support.

The value of the Low Carbon Fuel Standard is significant, with hydrogen electrolyzed directly from solar power receiving as much as $5.25/kg at current credit values.[15,16] Novel fleet-specific business models can also activate the market in the early stage, as has been done for the light-duty market through the Hydrogen Refueling Infrastructure (HRI) capacity credits through LCFS.[17] This HRI credit provides funding from the LCFS market for fueling infrastructure based on projected demand at the station. In hydrogen demand projection models modified for fleets, such as transit fleets, fuel demand is more certain as the fleets scale up, which can reduce investment risk. The coordination of infrastructure providers, transit agencies and bus OEMs could lead to concepts such as shared fuel storage resources between agencies to increase utilization at early deployment stages.

5 A PRACTICAL ELECTRIC SOLUTION

The value proposition of FCEBs must be clearly understood by all of transit's stakeholders, including bus riders, environmental justice community, transit CEOs, transit boards and legislators. This requires a highly impactful messaging campaign that condenses all of the attributes of a fuel cell bus into a message that is inspirational, cross-cultural, far reaching and persistent.

Hydrogen technology has limited public awareness. FCEBs and fuel cell electric cars remain the only hydrogen-powered devices in view of a small segment of the public. Even those exposed to hydrogen buses and cars are rarely aware of them, because they are indistinguishable from other vehicles.

A public awareness and marketing campaign, consistent with product development and deployment with an appropriate communication road map, style and channel entry is necessary. Some stakeholders are becoming aware of industry developments, with manufacturers such as Air Liquide, Ballard, BAE, NEL and Nikola starting effective social media campaigns and other marketing efforts. The story of hydrogen must leave the garage and proliferate to such an extent that no conversation of renewable energy can be completed without its inclusion.

A well executed public awareness and campaign will encourage legislators to engage in meaningful dialogue on hydrogen energy solutions. Real field data is key and must be brought to policy conversations. The goal is to ensure that state senators and assembly members know they will be supported in their advocacy by the voting public. The same will follow for transit agency boards of directors who remain highly attuned to public perception.

Vehicle OEMs, technology suppliers, fuel providers, and experienced end users must collaborate and dedicate real resources to paint a consistent and compelling story and give confidence to key decision makers.

15 *Time stamped credit value (as of March 2019): $180*
16 *CARB online LCFS Data Dashboard: https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm*
17 *See CARB 2018 Action "Recommend ways to expand ZEV infrastructure through Low Carbon Fuel Standard (LCFS)" in "2018 ZEV Action Plan Priorities Update" September 2018. Available at: http://www.business.ca.gov/Portals/0/ZEV/2018-ZEV-Action-Plan-Priorities-Update.pdf*

6 STANDARDIZE AND SIMPLIFY

By following this road map over the next decade, the fuel cell electric bus industry will mature as it expands. This maturation can be nurtured through continued involvement with industry standards groups such as SAE, NFPA and others. All members of industry must be actively involved in advocacy groups such as the California Hydrogen Business Council, CaFCP and FCHEA to share best practices and lessons learned, to arrive at the standardization and industry stability that customers need to fully adopt FCEBs as a transport technology. Only by first working together through a strong spirit of collaboration will the industry create a healthy, competitive and self-sustaining FCEB marketplace that will result in low costs and high operational capability for the transit operators, bus riders and public transit advocates of California.

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7 EASING THE TRANSITION TO ZERO EMISSION

At a practical level, the barrier to entry remains the cost and accessibility of fueling for small deployments. To overcome this barrier, an FCEB "starter-kit," inclusive of buses and fueling infrastructure, is essential. Transit agencies that are new to FCEBs need a low-cost, turn-key solution, with simplicity of operation married with strong vendor support. Funding from state agencies and air pollution control districts can be implemented as demonstration projects and aggregated by geography to share fuel supply and service support. To entice transit agencies to learn and build confidence in the technology, instituting a "borrow-a-bus" program,[18] like the one initiated by Stark Area Regional Transit Authority in Ohio, will allow transit agencies to use FCEBs on their routes and participate in fueling and servicing vehicles with their own personnel. "Borrow-a-bus" would require funding for portable refuelers, personnel and fuel, not to mention the transport and use of an FCEB from an agency that operates it for revenue service.

8 MODERN MARKET BUSINESS PRACTICES

Cost reductions in hardware and fuel can be further leveraged through modern business models that reduce up-front capital costs and minimize customer risk. Financial mechanisms such as sub-component or bus leasing programs offer alternatives to purchases from debt or cash reserves. Devising fuel-as-a-service models can reduce customer infrastructure investment risk and provide scheduling flexibility for fueling resources serving multiple customers. Programs like these can be backed and even subsidized by the financial power of the major corporate players now participating in growing the hydrogen industry.

9 DEVELOP CUSTOMERS

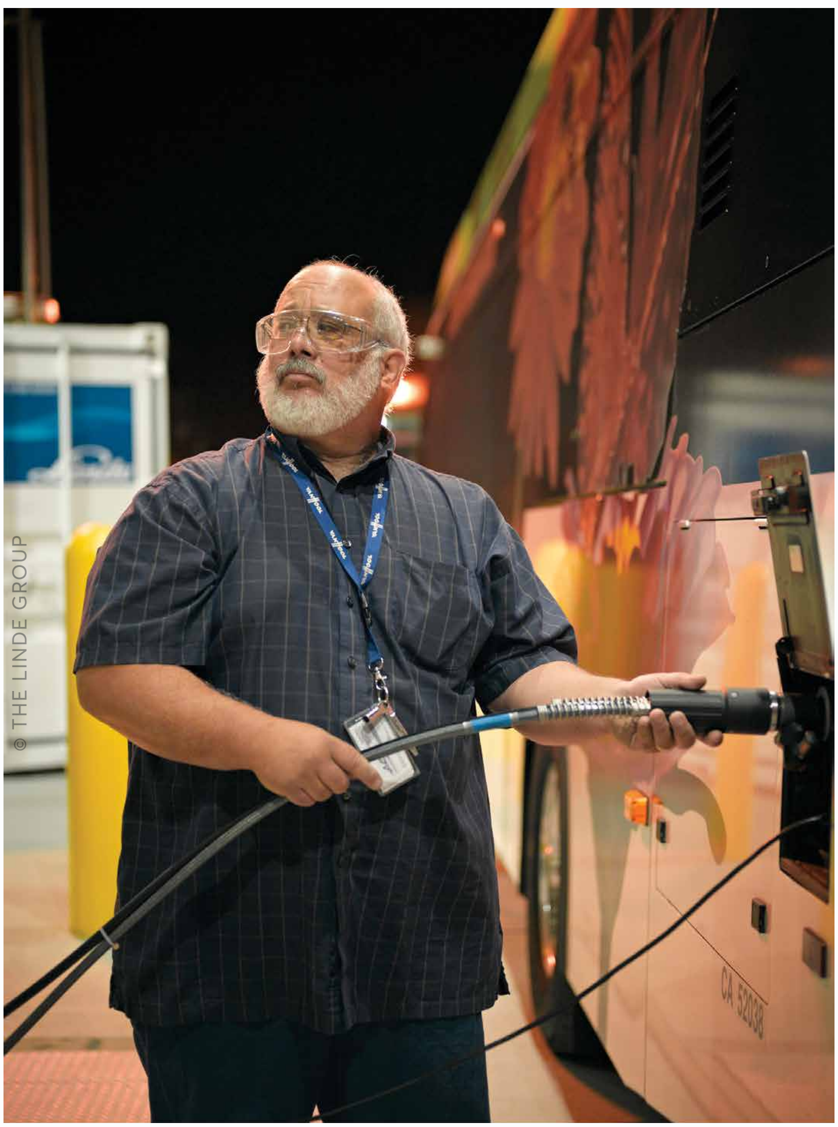
The persistent efforts of long-time FCEB users such as SunLine and AC Transit have carried the industry to the commercial-ready state it has achieved today. However, other transit agencies look towards their colleagues for assurance of new approaches, particularly to see more are becoming convinced, and so FCEB efforts must work not only to insure the success of established fleets, but to win new advocates. SunLine's West Coast Center of Excellence in Zero Emission Technology[19] is a remarkable example of a cross-functional effort that aims to engage every functional group within a transit agency, from purchasing to policy to operations, in redefining themselves as a zero-emissions operation. Bulk procurement can also stimulate collaborate while driving down cost. Key to this is engagement with the California Department of General Services and other purchasing consortia within California and North America.

18 SARTA's Borrow-A-Bus Program: https://www.sartaonline.com/sartas-borrow-a-bus-program
19 SunLine Transit Agency West Coast Center of Excellence in Zero Emission Technology website: https://www.sunline.org/alternative-fuels/west-coast-center-of-excellence-in-zero-emission-technology

10 WORKFORCE DEVELOPMENT

FCEB deployment and service offers an appealing career path to a changing workforce, evolving jobs from trades that have suffered dwindling participation such as diesel mechanic into high technology appeal. FCEB technicians integrate skills in software, systems and power electronics with their mechanical aptitude to create a challenging and rewarding career. Community and technical colleges are perfect resources for fostering these new highly-skilled trades. Rio Hondo College's accredited Electric Vehicle and Fuel Cell Technology Technician degree program is an excellent example of this.[20] Bus OEMs and component suppliers must collaborate with these institutions to transfer the bespoke training programs they have developed into standardized curricula that assures students and potential employers of the value of such degrees or certificates, and the capabilities that graduates will bring. Programs must integrate with similar training programs for heavy and light-duty vehicles, and with those for electric powertrains powered by batteries and fuel cells.

20 Rio Hondo College Alternative Fuel Program & Advanced Transportation Technology: https://www.riohondo.edu/career-and-technical-education/automotive-tech/alternative-fuels/



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The California Fuel Cell Partnership is a unique collaboration of organizations, including auto & truck manufacturers, energy providers, government agencies, fuel cell technology companies, and others that work together to promote the commercialization of hydrogen and fuel cell vehicles. Together, we help ensure that vehicles, stations, regulations and people are in step with each other as the technology reaches its full market potential.

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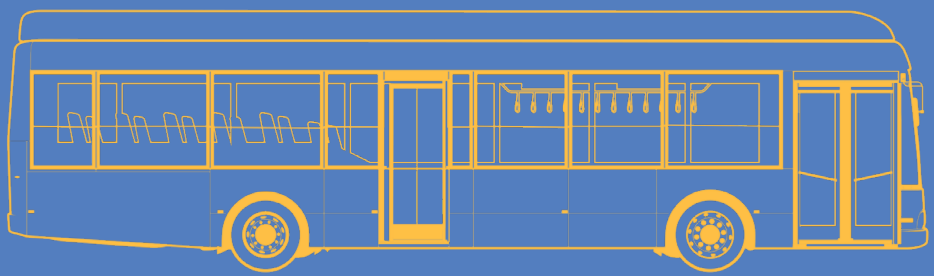
Copies of this document are available upon request or can be downloaded from our website at ***www.cafcp.org***

The "Zero Emissions, Zero Compromise" tagline is courtesy of the Fuel Cell & Hydrogen Energy Association.



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