FCEB Webinar Series: Fundamental Components of First-Time FCEB Deployment

February 21, 2023

Webinar Contributors

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Moderator

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Zero-emission adoption, & TCO

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New Flyer FCEB case study

Byron Somerville
Program Manager, Ballard

Service requirements

Fuel Cell Electric Buses Today

Kim Leach

Market Development Manager, Ballard

Ballard by Numbers

44 YEARS

>1,100 employees

PATENTED

1,400 patents & applications

28 years Nasdaq

30 years TSX

publicly listed company

2030 commitment to carbon neutrality

>1,400 transit buses

>2,300 trucks

7 TRAIN projects

8 SHIPS in development

8 MW of stationary power projects

1 GW fuel cell products delivered*

>5.3 MILLION MEAs produced*

>175 MILLION kilometers in operation*

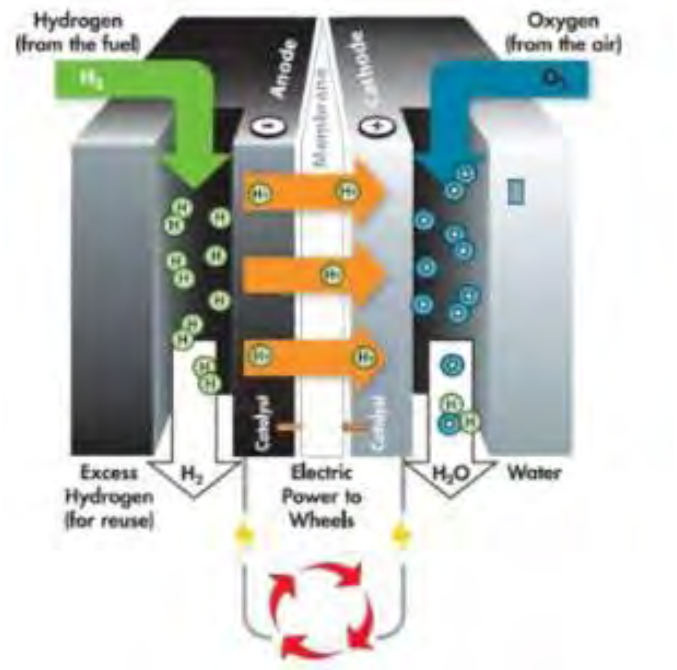
1.6 GW production capacity

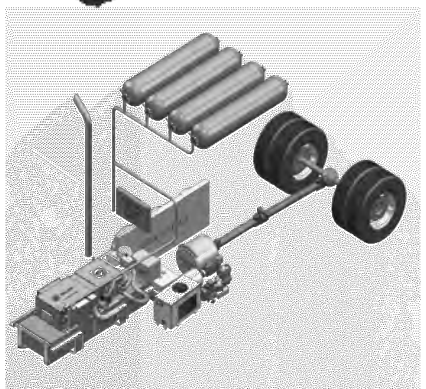
4 PRODUCTION SITE global footprint

*compiled from 2015

Fuel Cell Fundamentals

Unit cells combine to convert hydrogen and oxygen into electricity for power with water and heat as by-products: **ZERO-EMISSION**





UNIT CELL:
Flow Plate / MEA

FUEL CELL STACK

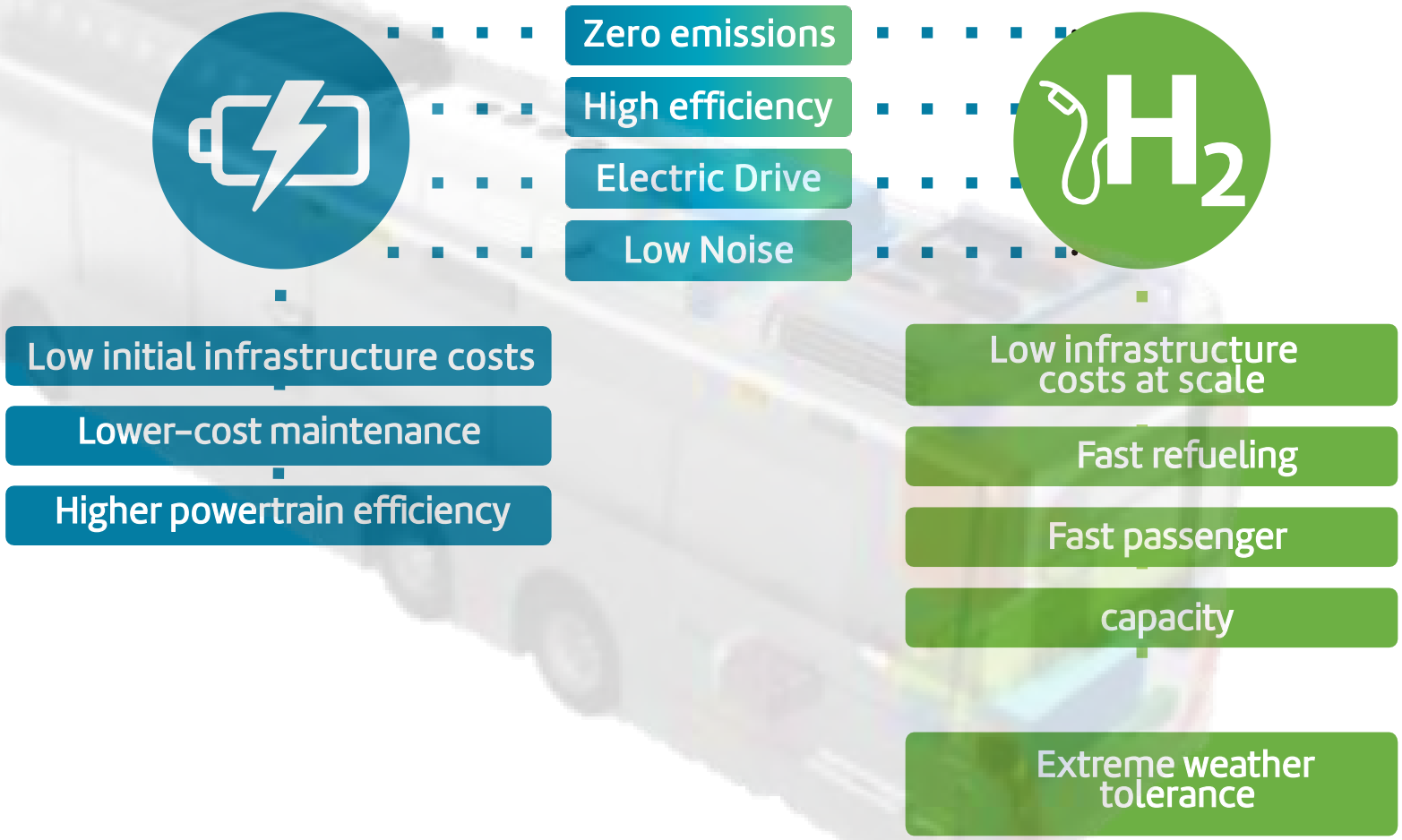
FUEL CELL MODULE / ENGINE

BUS POWERTRAIN

Fuel cell electric buses have evolved over the years

A Hydrogen Bus is an Electric Bus

- Same electric drivetrain as battery electric buses
- Same maintenance and parts – excluding fuel cell power module and gas tanks



Zero-Emission Bus Options

Battery Electric Buses	Fuel Cell Electric Buses
Eco-friendly	Eco-friendly
Robust design	Robust design
200-250 mi range	up to 370 mile range
4–6-hour overnight charge	6-12 minutes fill time
One charger per 2-3 buses	Fill station scalable by fleet size
Diesel auxiliary heater frequently used in cold climates to maintain range	No secondary auxiliary heater required, fuel cell assists cabin heat

Today there are multiple offerings for FCEBs

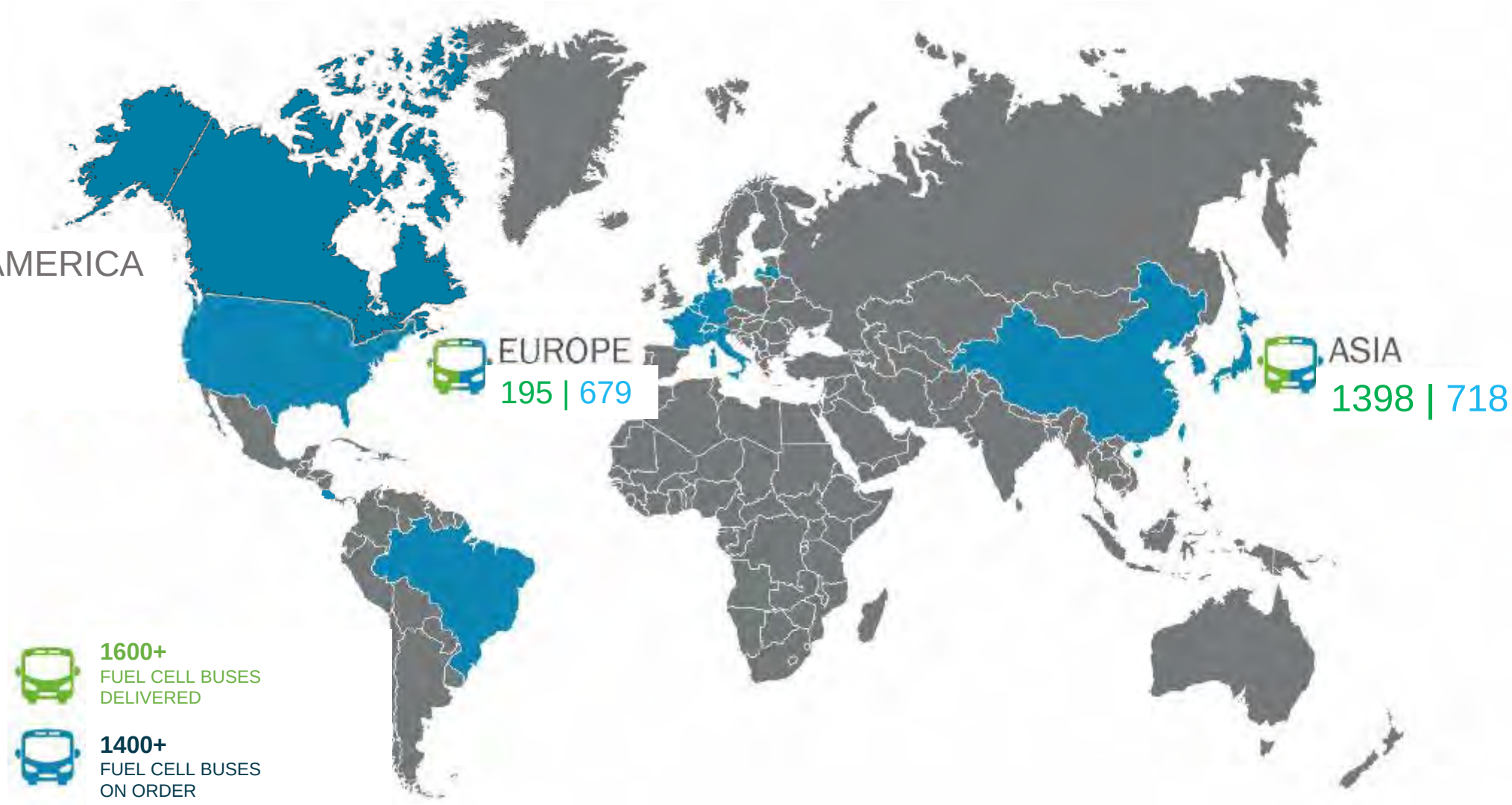
- More than 20 years of road experience
- Fuel cell module availability >97%
- More than 25,000 hours stack durability proven
- Operation in challenging routes and climates
- Buses deployed in over 70 cities worldwide
- 100 million miles on road experience (bus and truck)







Fuel Cell Buses Worldwide



FCmove™ Platform

- Compact innovative design
- Low life cycle cost
- Engine bay and flat configurations for easy integration
- High performance, robust product with wide operating range
- Powerful 100kW power output

Here for Life in the US:
Bend Oregon FCmove™ Manufacturing Facility starting in 2023

U.S. manufacturing of FCmove™HD+ 100kW modules for North American fuel cell bus customers

New Flyer FCEB – the CHARGE FC

Michael McDonald
Operations Manager, New Flyer

Fuel Cell-Electric Propulsion in Xcelsior CHARGE FC™

Facts

370+ miles
on a single refueling with no off-board electric recharging.

20 years
of experience producing fuel cell-electric buses for North American operators.

Avoid 85-175 tons
of greenhouse gas per year from tailpipe emissions compared to a diesel bus.

>85M EV miles
of experience.

WHY CHOOSE A NEW FLYER FUEL CELL-ELECTRIC BUS (FCEB)?

- Zero-emission
- Extended range
- Fast re-fuel
- Quiet in operation
- Robust design & reliability
  - Xcelsior® platform
  - First 60’ fuel cell-electric bus to complete Altoona
  - Only manufacturer to offer both a 40’ and 60’ fuel cell-electric model that qualifies for federal funding

LEADING FCEB EXPERIENCE

1993
Introduced the worlds first FCEB (with technology partners)

2010
20-bus evaluation program for the 2010 Olympics

2018
Delivered first 60' zero-emission fuel cell bus in North America

2019
Reached 350 miles of range in test demonstration

AC Transit	Foothill Transit	GET bus	OCTA	SunLine Transit Agency	MTD	ETS Strathcona County
2017	2017	2020	2020	2022	2022	2022
30	33	5	10	10	2	2

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XCELSIOR CHARGE FC™ TECHNOLOGY

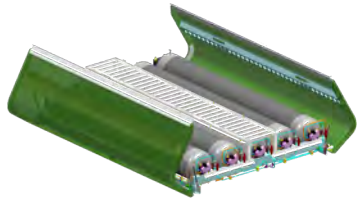
Incorporates four (4) distinct high-performing technologies:

- Ballard Power Systems new high-performing fuel cell power module FCmove™-HD+
- New battery packaging designed and developed by New Flyer
- The newest, high-power, rapid-charge batteries
- Siemens new innovative traction drive system, call “ELFA 3”

ENERGY FLOW IN E-ARCHITECTURE: FCEB







Hydrogen Production → *Electrolysis, SMR* → **Onsite Storage** → *Compressed, LNG + evap* → **Fill Panel** → *350 bar* → **Onboard Fuel**




Traction Motor ← *3-phase AC PEM* ← **Traction Inverter** ← *618 VDC nominal* ← **ESS** ← *100 kW* ← **FC System**

Regenerative braking 20-25%

Brake resistor → *40 kW* → **Heater**

Captured FC waste heat → **Heater**

Lights, Multimedia, Power Steering → **LV Accessory** → *24 VDC* → **Auxiliary Inverters**

HV Accessory → *230 VAC* → **Auxiliary Inverters**

A/C, BTMS, Air Compressor → **HV Accessory**

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FUEL CELL E-DRIVE IN TRANSIT

- It's an electric bus
  - Fuel cell *enables* electric drive
    - Fuel cell creates electricity to provide to ESS, ESS powers electric drivetrain
  - A *'fuel cell range-extended battery-electric bus'*
  - A '*zero-emissions series hybrid*'

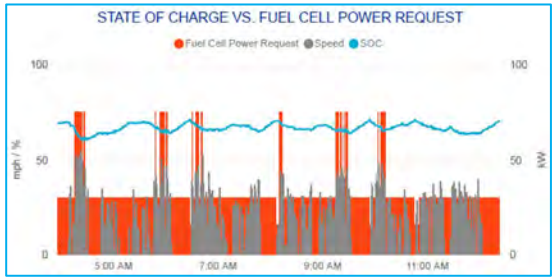
- NFI approaches FCE drive in public transit with a **balance** between the battery system (ESS) and hydrogen fuel cell system
  - 2 ESS strings (140 kWh worth of batteries)
  - 100 kW FC to recharge ESS

ZE TECHNOLOGY: FUEL CELLS

- Hydrogen has high energy density
  - Can store lots of onboard energy
- FCs have poor power density
  - Poor ability to respond with agility to frequent changes in power demand

ZE TECHNOLOGY: BATTERIES

- High power density
  - Good at expending or accepting charge to and from e-drive system
- Modest energy density
  - Unable to make long ranges



The stop-and-go nature of transit = high flux of power demand.

It's a battery application with a need for range boost/recharge.

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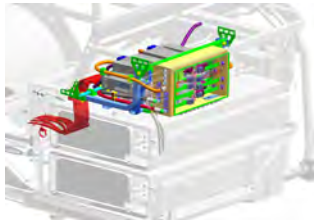
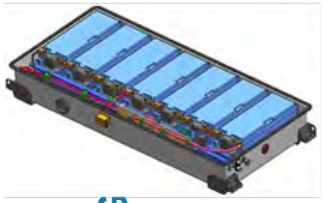
FOUR KEY TECHNOLOGIES



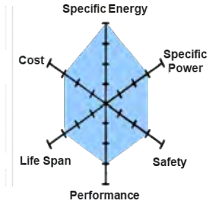
PROPULSION

- More power, torque
- Consolidated packaging
- Weight, space reduction
- Powerful control



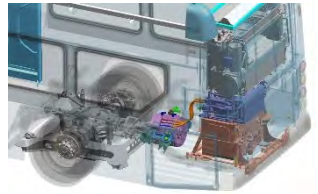
ESS PACKAGING

- Composite
- Lighter weight
- IP67
- Built for serviceability



BATTERY CHEMISTRY

- 13% greater energy density
- Latest NMC technology
- Plug-and-play modules
- Built for HD applications



FUEL CELL

- 85 → 100 kW
- Internal heating
- Smaller, consolidated
- Built for serviceability

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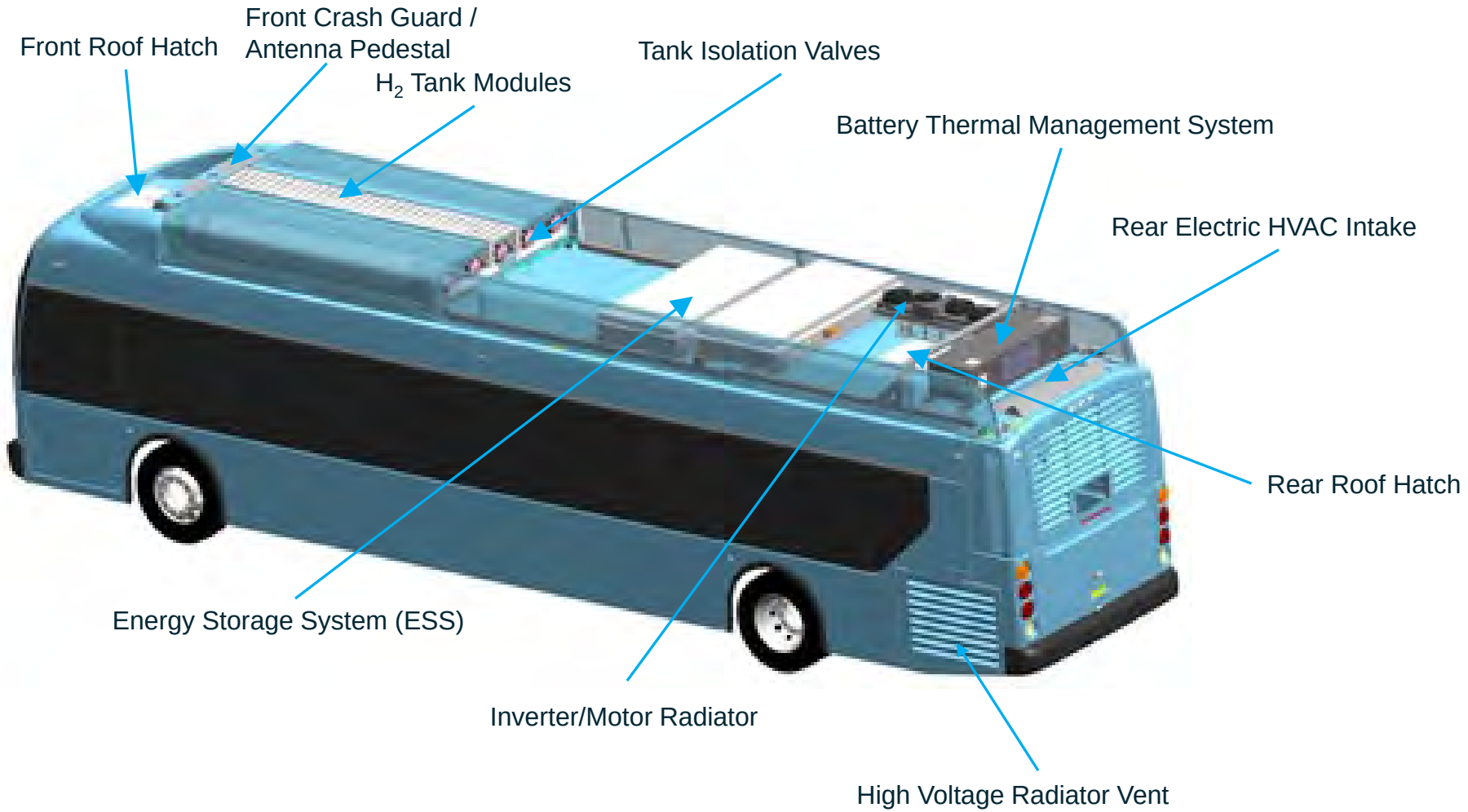
XCELSIOR CHARGE FC™
INTEGRATION & LAYOUT 40-FOOT MODEL



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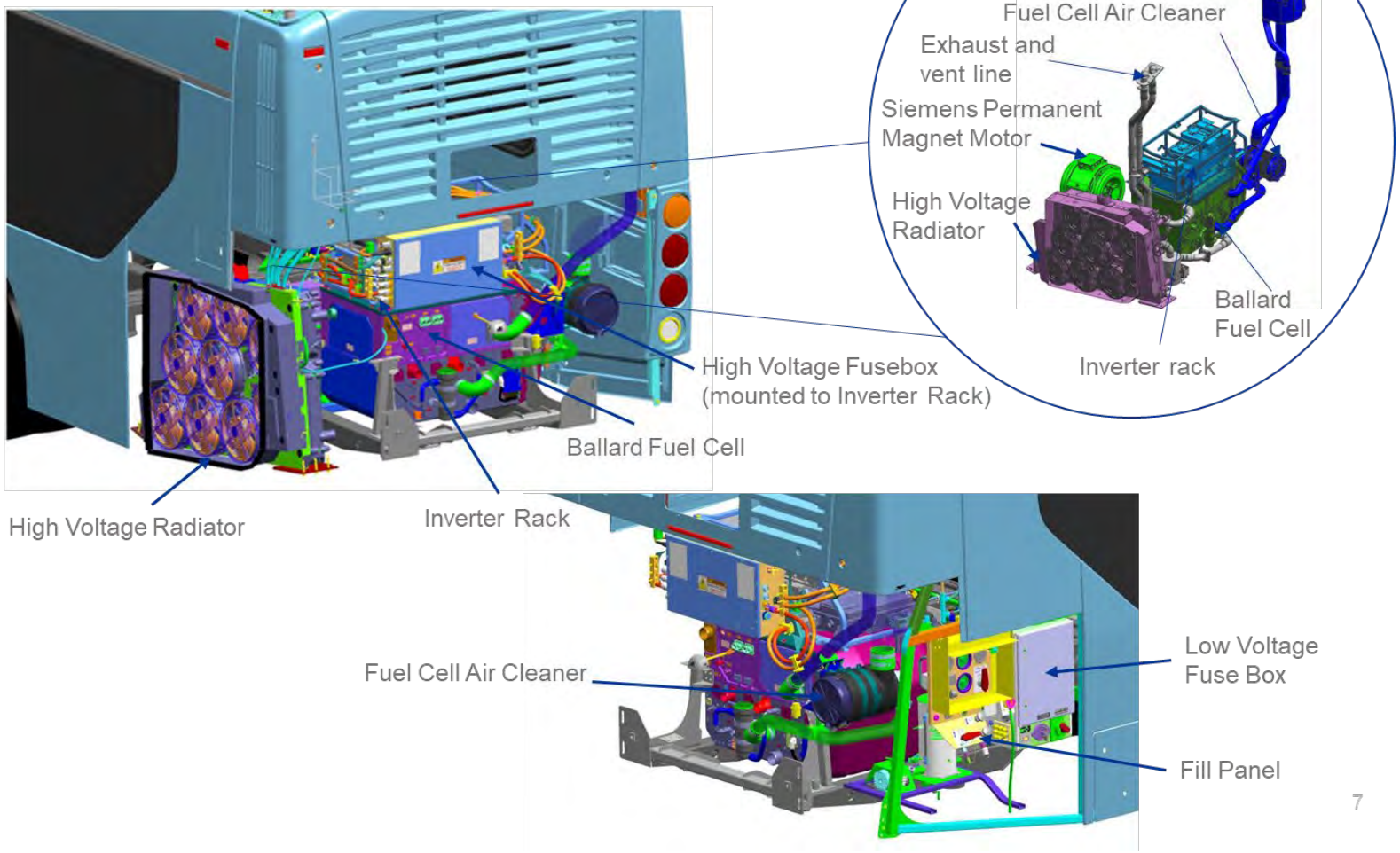
XCELSIOR CHARGE FC™
INTEGRATION & LAYOUT 40-FOOT MODEL



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CHARGE H2™ → CHARGE FC™

Altoona Range @ Seated Load Weight (40’ model)

Std. Duty Cycle	Manhattan	OCBC	UDDS	Average	Xcelsior CHARGE FC™
Power Consumption (kWh/mile)	8.57	1.83	0.94	3.78	3.78
Fuel Consumption (miles/kg)	5.32	6.91	8.33	6.86	6.86
Fuel Cell Range (miles)	192	249	300	247	**256**
Battery Range (Miles)	7	33	64	16	**22**
Total Range (Miles)	199	282	364	263	**278**

Real Life Results (Xcelsior CHARGE H2™):

350 miles (560 km) on a single fill validated during testing in Orange County

- 9.16 miles/kg (14.66 km/kg)
- 330 miles (480 km) fuel only
- 20 miles (32 km) extended battery range

~370 miles for Xcelsior CHARGE FC™

- +3.7% FC efficiency
- +35% ESS capacity (useable)

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DESIGNED FOR OPERATION IN TRANSIT

- Longer **high-speed** capability
  - 18% fuel cell power capability enhancement
  - Larger ESS: longer times at high load
- Improved **range**
  - 3.7% more efficient fuel cell system
  - 35% higher energy density from next-gen HP ESS
  - Numerous weight shedding with next-gen components
- Improved **maintainability**
  - No cabin powertrain components
  - Improved parked cold tolerance - FCmove™-HD+ cold start
  - Next-gen ESS enclosures - rail-mount, touch-safe/quick-connects, etc.
  - Simplified e-powertrain - component reduction, accessibility

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Service and Training

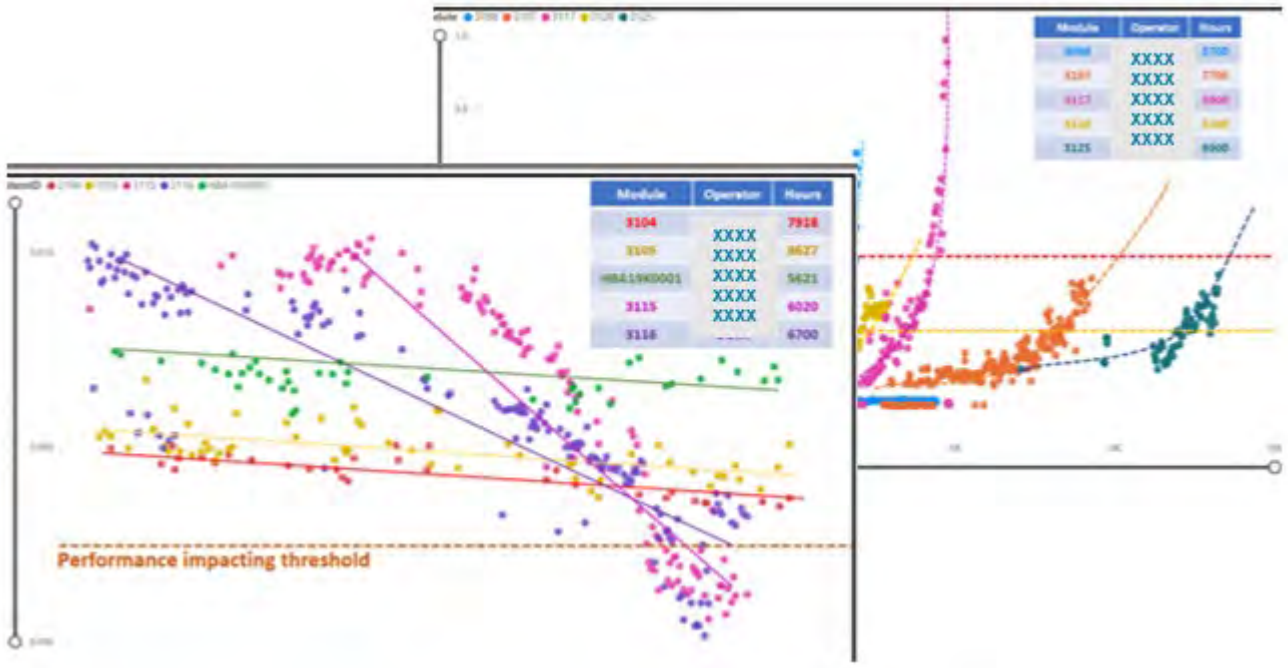
Byron Somerville

Program Manager, Ballard

Service and Support

- **Applications engineers** working side-by-side with our customers to ensure the successful integration and operation of Ballard's products.
- **Simulation and modeling software** ensures the right fuel cell product is selected, based on vehicle drive cycle and operational requirements.
- Insights from our many **years of experience** with fuel cell systems help accelerate and optimize our customers' overall fuel cell vehicle design work and reduce integration risks
- We provide support during **powertrain integration, testing, certification and vehicle commissioning**
- Our after sales team takes over once the bus is on the road with comprehensive customer care packages including **training, onsite assistance, warranty support, diagnostic and spare parts management.**

Voice of the Customer: Predictive Maintenance, Clear and Comprehensive Data Dashboards



Predictive Tools

- State of Health Monitoring of key BOP components
- Key component lifetime metrics identified and tracked
- Automated analytics to tease out key information from the data

Next Generation Technician Training and Communication

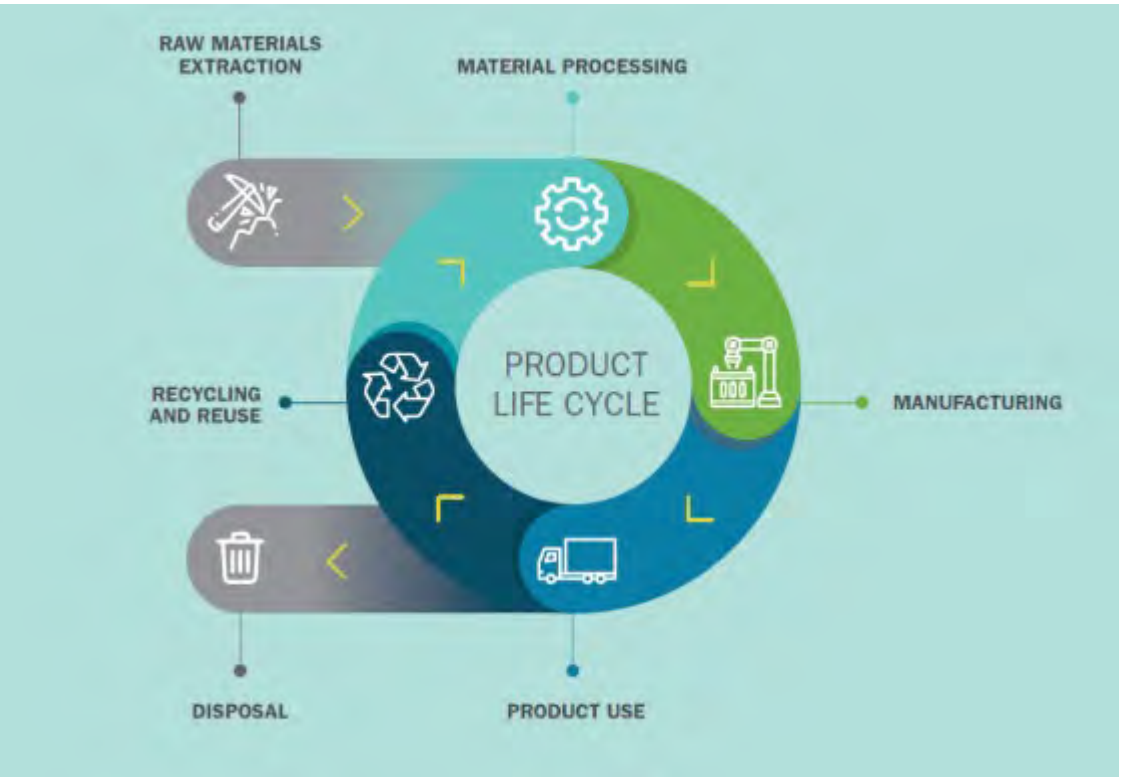
Images courtesy of AC Transit

Fuel Cell Electric Bus Economic Value Proposition

Kim Leach
Market Development Manager, Ballard

Timothy Sasseen
Market Development Director, Ballard

Zero-Emission Transit Should also be Sustainable

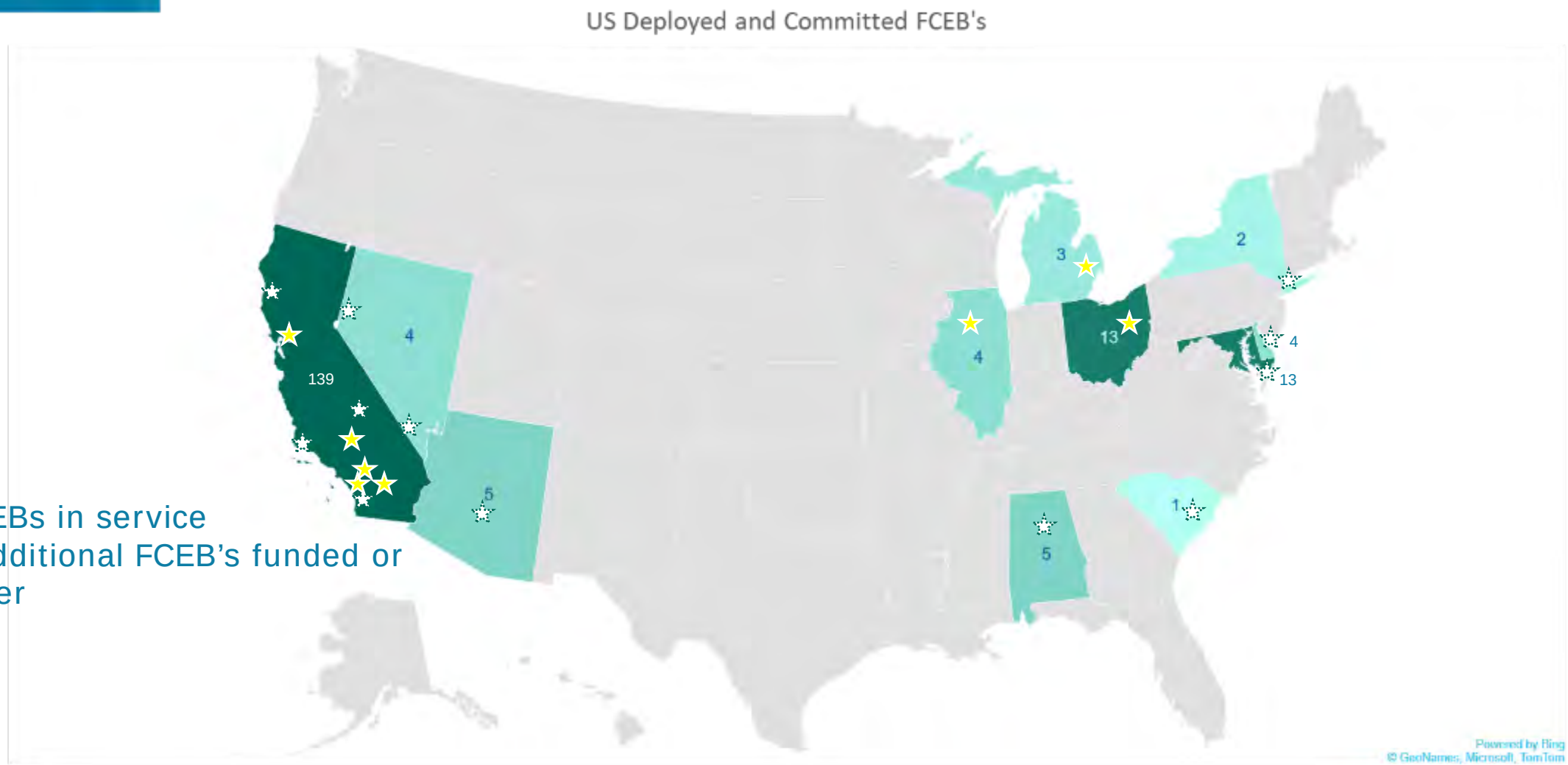


Fuel cells have a lower impact on the environment

At Ballard we:

- Design our product to minimize carbon footprint
- Refurbish fuel cell stacks at the end of life
- Re-use graphite bipolar plates
- Reclaim 95% of the platinum
- We are committed to be carbon neutral by 2030

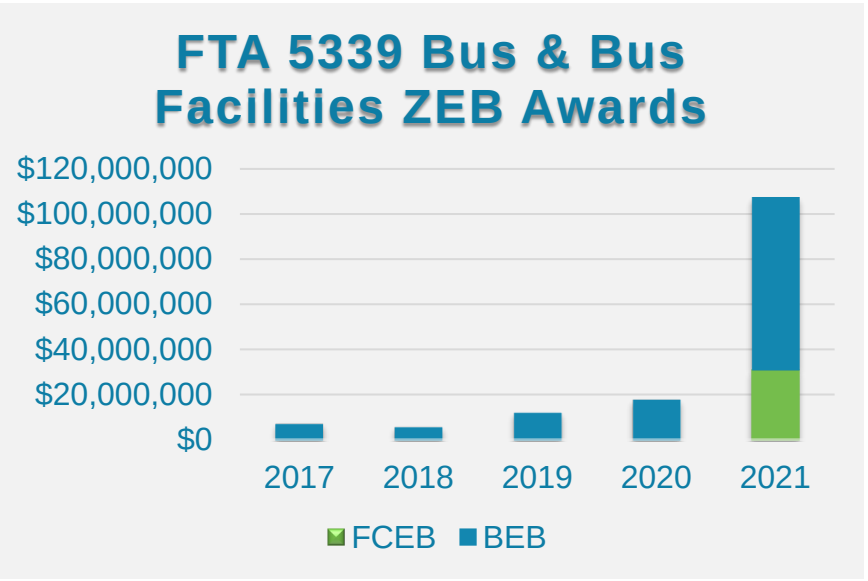
The Demand for FCEBs in North America is Growing - Driven by Zero-Emission Bus Transition

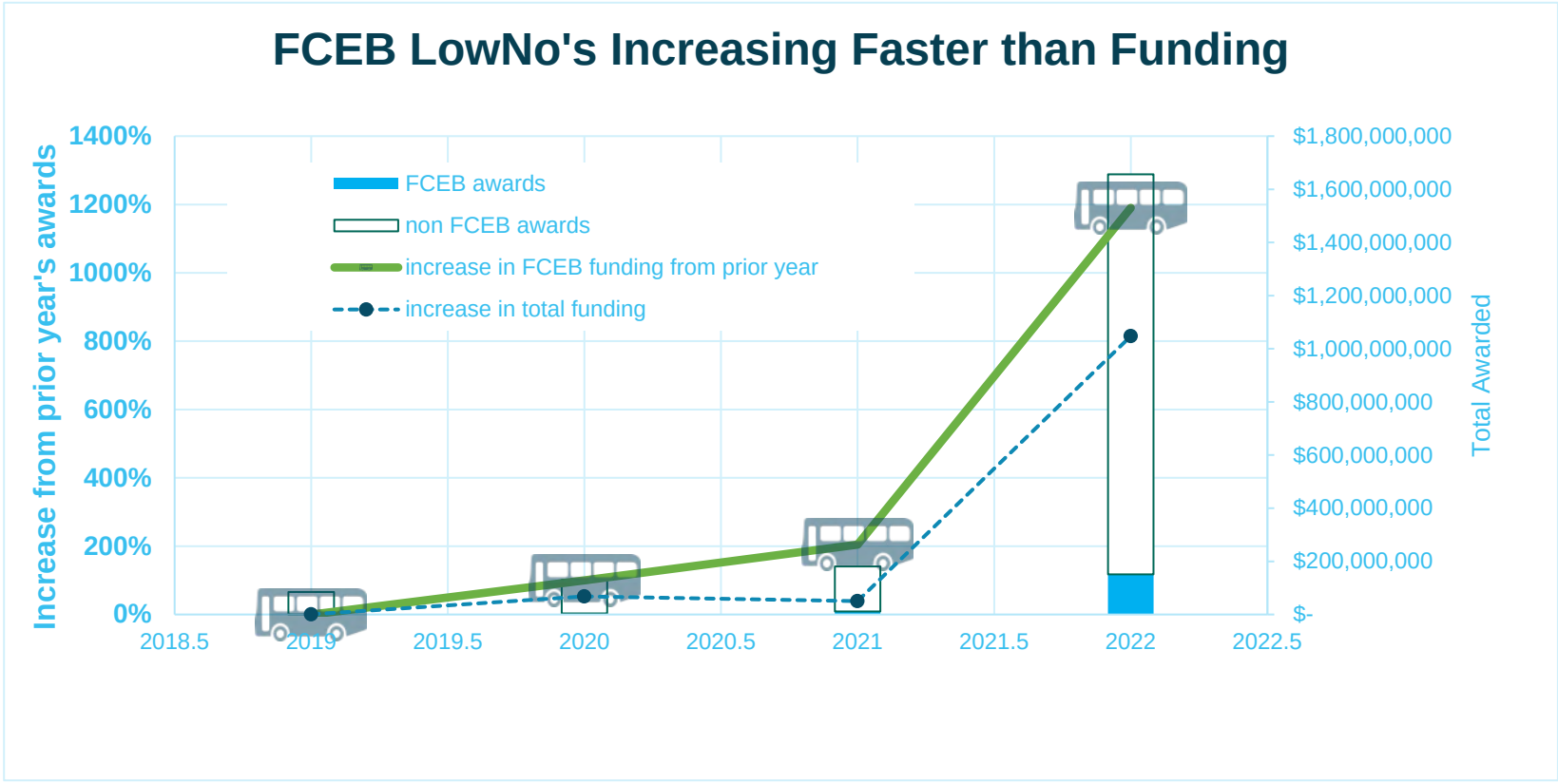


★ **87** FCEBs in service

☆ **106** additional FCEB's funded or on order

FTA 5339 Zero-Emission Bus Awards

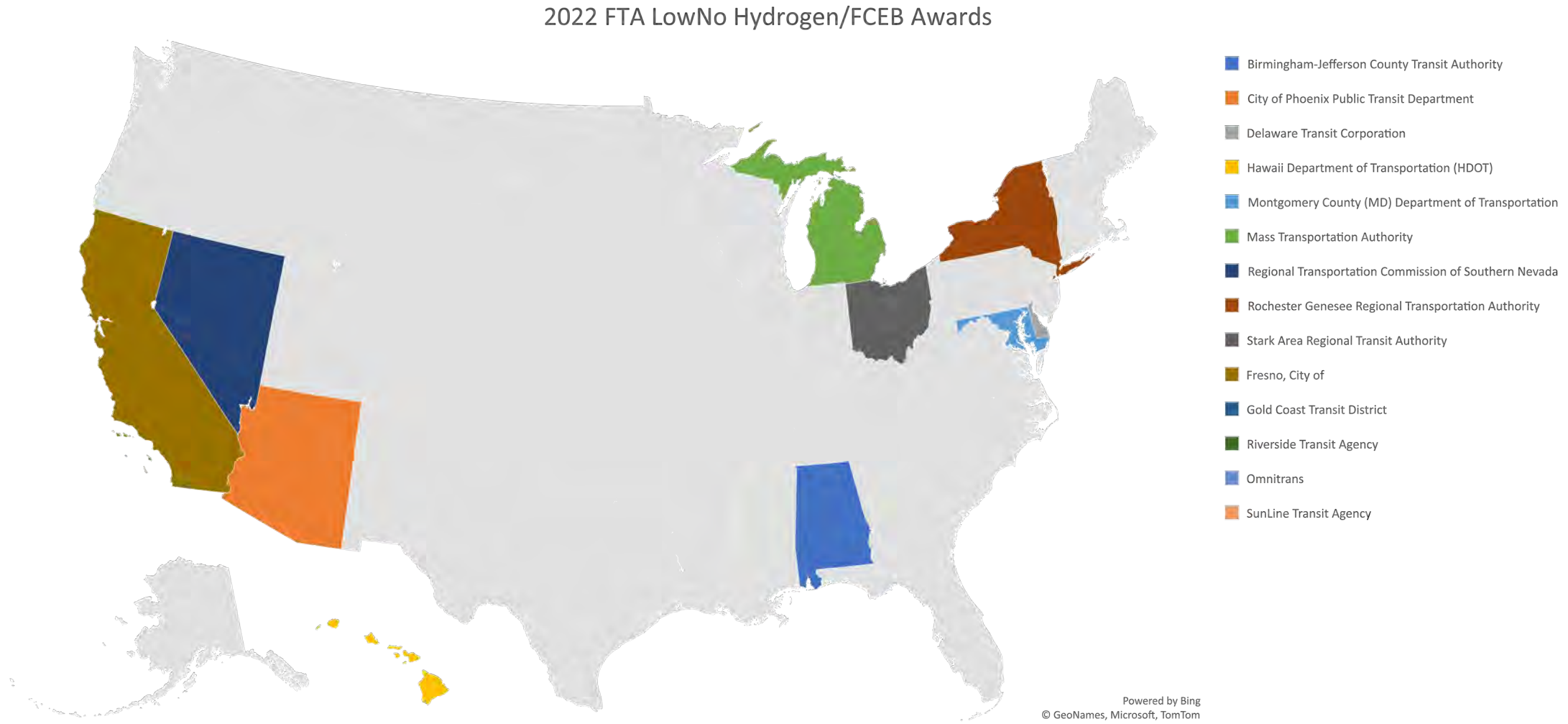




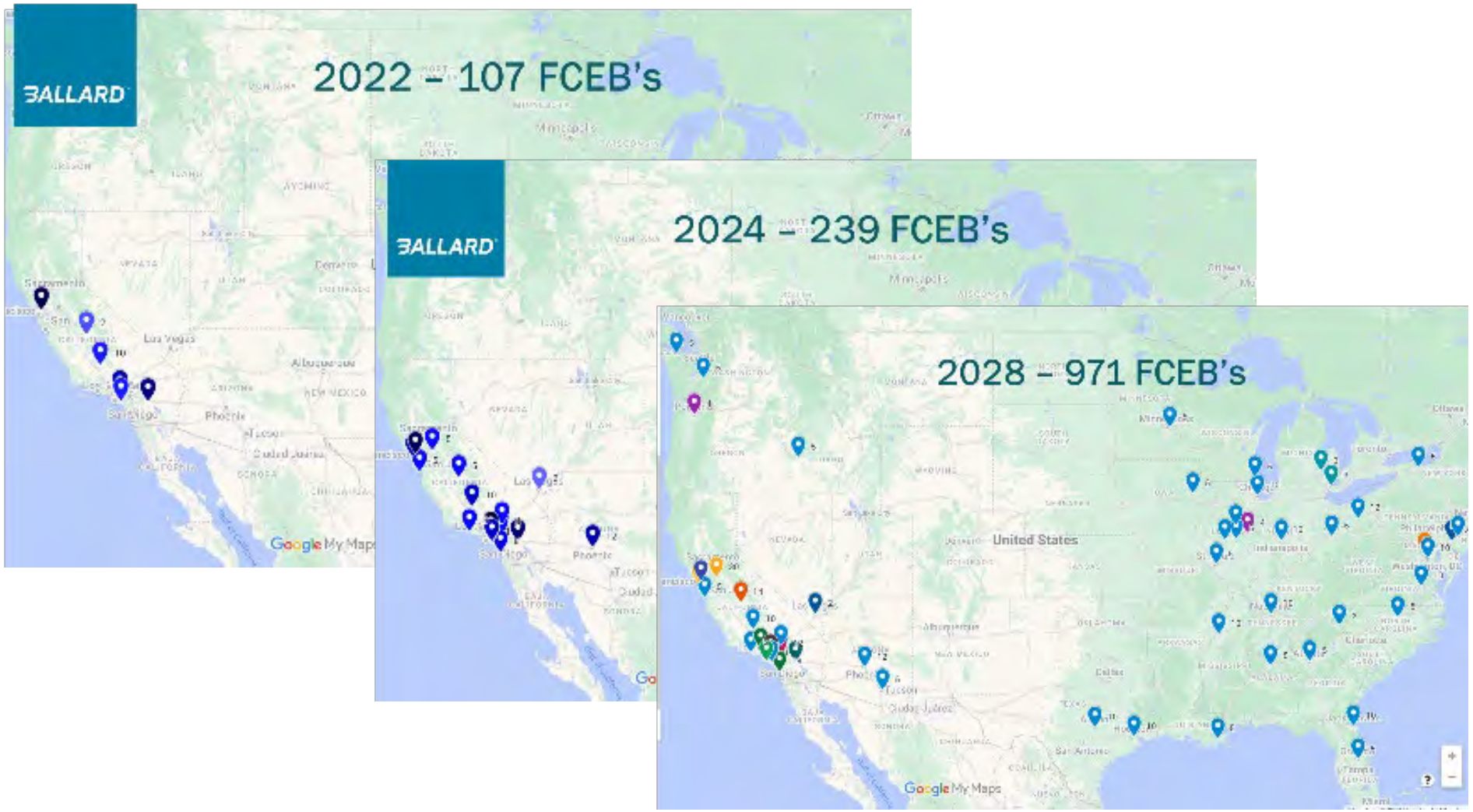
Awards for zero-emission buses **are not only focused in California.**

The FTA is awarding across the country, with awards increasing in dollar amounts.

FTA 5339 Zero-Emission Bus Awards



FCEBs Expanding Across the U.S.



AC Transit 5x5 ZEB Study

https://www.actransit.org/zeb

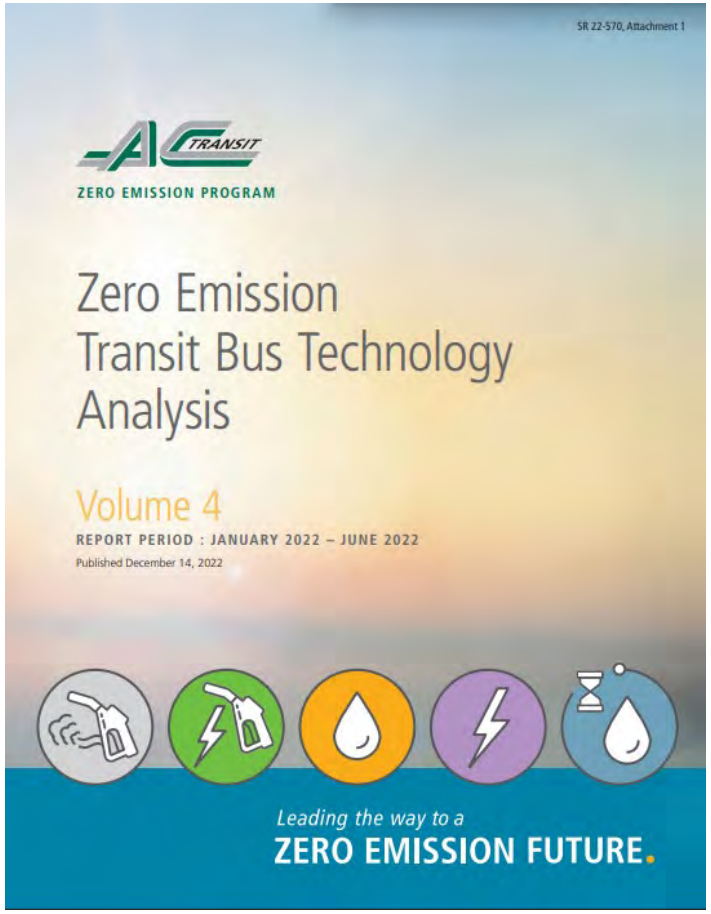


Figure 1: 5x5 Vehicle Matrix

FLEET	DIESEL (BASELINE)	DIESEL HYBRID	FUEL CELL ELECTRIC (FCEB)	BATTERY ELECTRIC (BEB)	LEGACY FUEL CELL
Series Grouping	1600	1550	7000	8000	FC
Technology Type	Diesel	Hybrid	Fuel Cell	Battery	Fuel Cell
Bus Qty	5	5	5	5	5
Manufacturer	Gillig	Gillig	New Flyer	New Flyer	Van Hool
Year	2018	2016	2019	2019	2010
Length	40'	40'	40'	40'	40'
Data Summary (January 2022 – June 2022)					
Fleet Mileage	92,128	54,660	88,188	59,549	34,533
Life-to-Date Mileage	757,363	1,235,654	452,103	272,046	1,423,925
Cost/Mile	$2.29	$3.11	$2.52	$1.61	$4.15
Cost/Mile (w/credits)	$2.25	$3.00	$2.20	$0.53	$4.11
Emissions (CO_2 Metric Tons)	235	106	0	0	0
Fleet Availability	89%	51%	78%	66%	57%
Reliability (MBCRC)	10,236	5,466	6,299	59,549	3,139
MPG (DGE)	4.0	5.3	7.9	17.7	5.5

Industry Roll-Out Plans

GET has selected 100% FCEBs in their ZEB roll-out plan

GET Zero Emission Bus Rollout Plan

OCTA plans to transition 100% of its 500+ buses to fuel cell models

OCTA Zero Emission Bus Rollout Plan

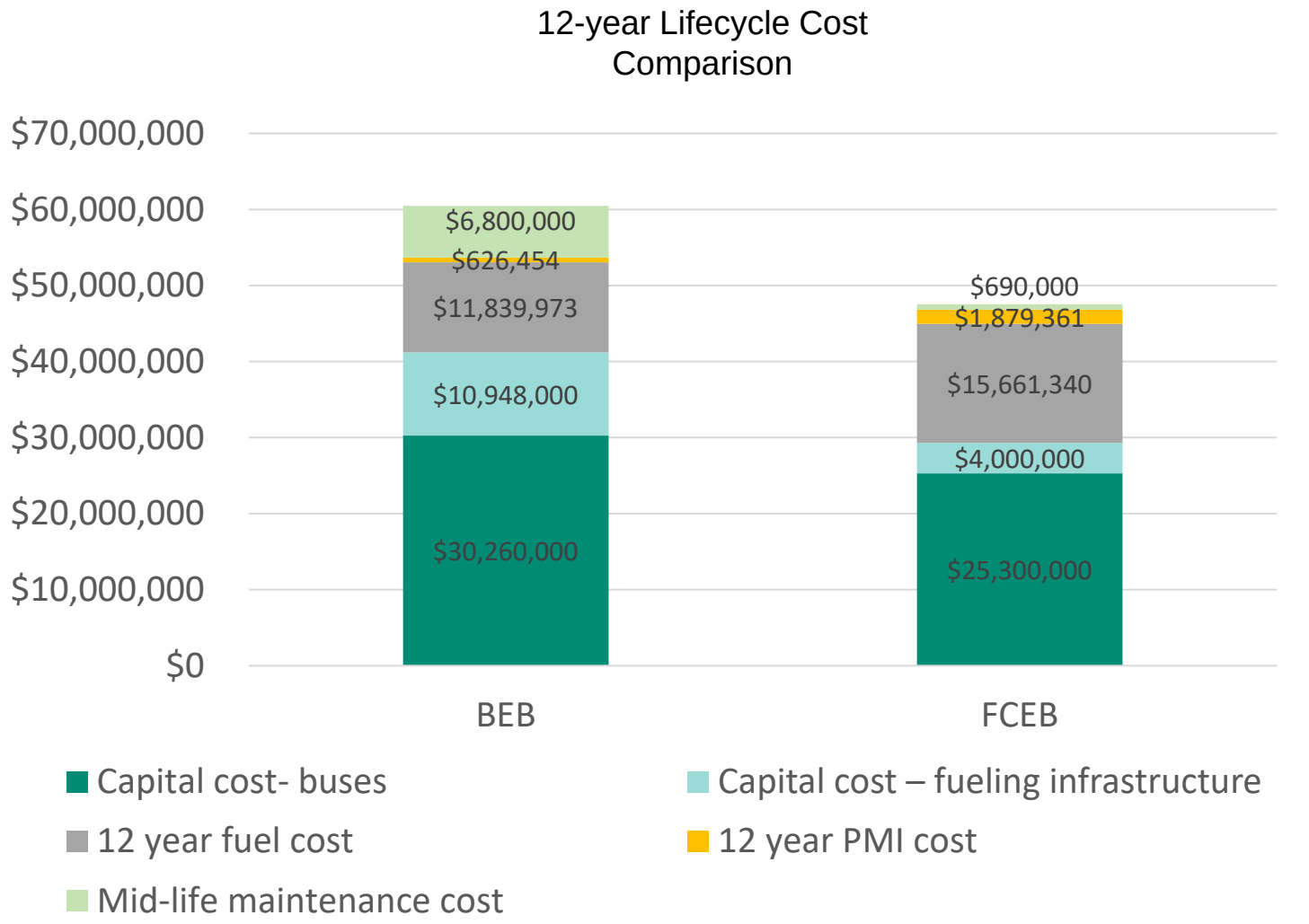
Sunline Transit fleet will be zero-emission by 2035 with 85% FCEBs (67 units)

Sunline ZEB roll out plan 2020

Foothill Transit Study Shows Total Cost of Ownership of FCEBs Lower than BEBs

Foothill Transit's study compares the cost of deploying 20 zero-emission buses on a 42-mile roundtrip route (up to 263 miles per daily block)

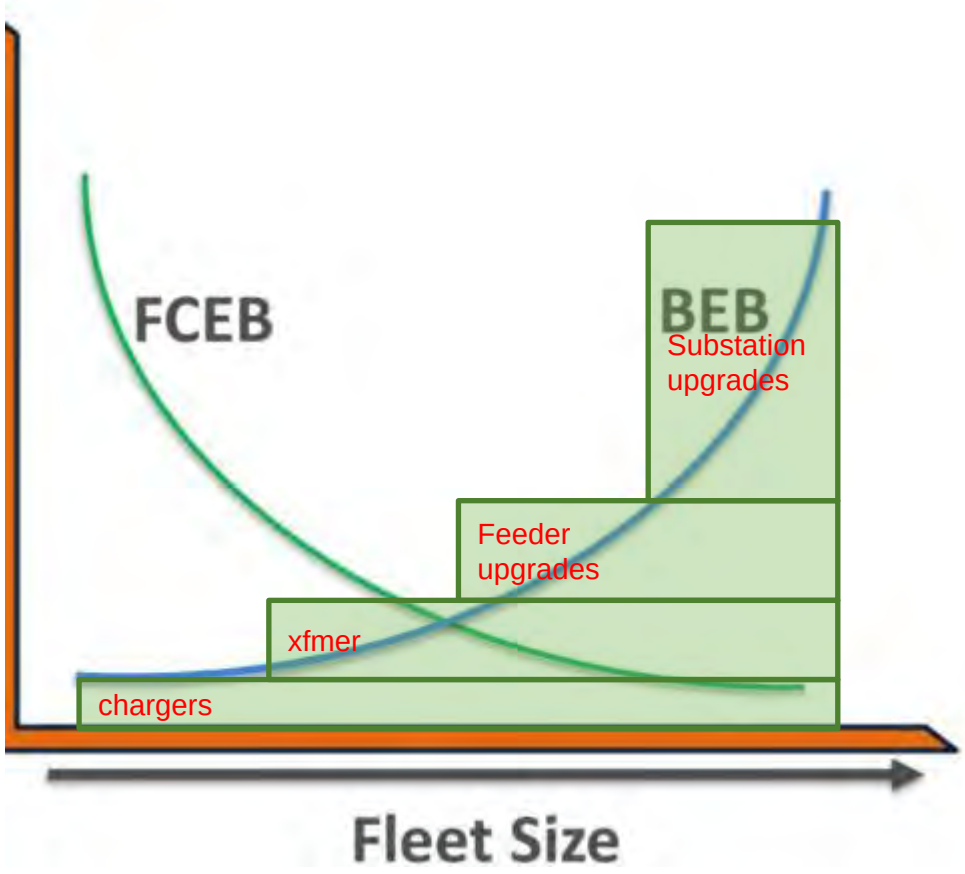
Due to the range limitations of BEBs, it was determined the line will require 34 BEBs vs 23 FCEBs.

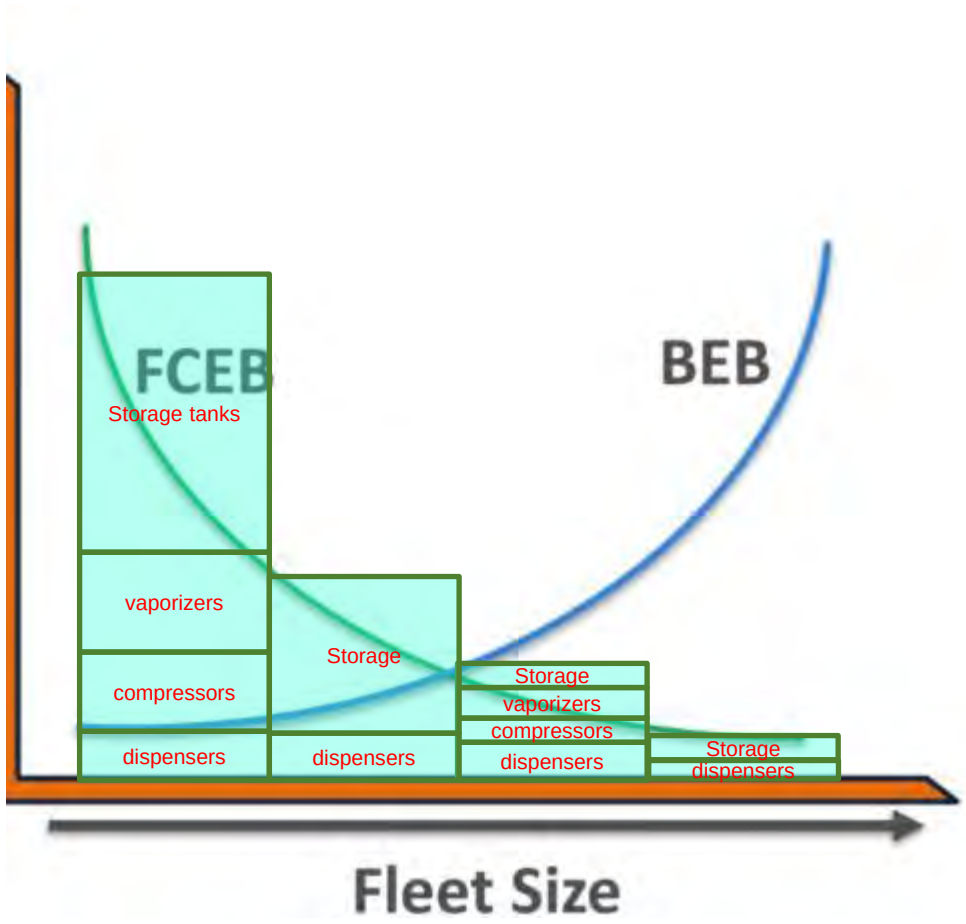


Cost Savings with FCEB: $12,943,726 (20%)

Foothill Transit Executive Board Meeting (July 24, 2020)

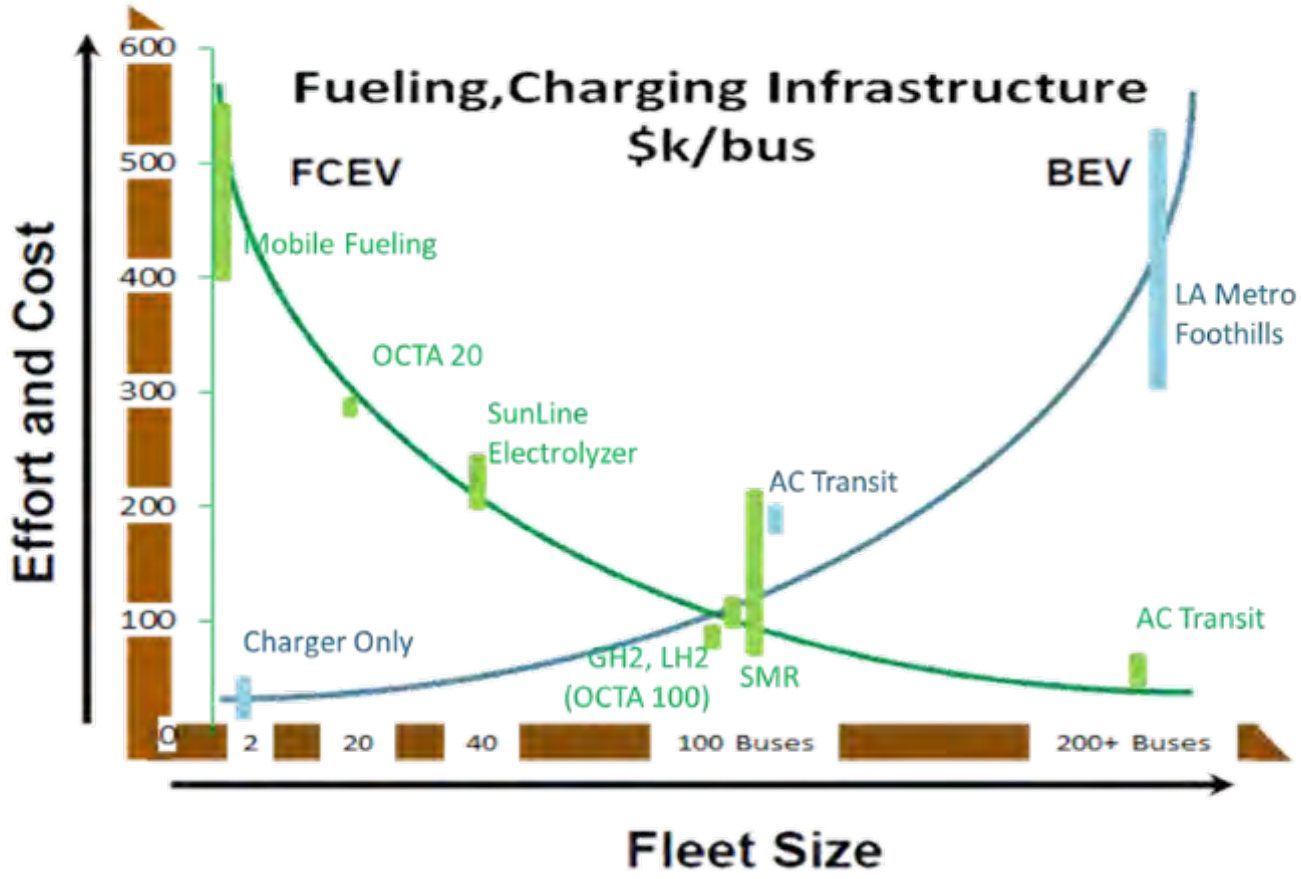
Infrastructure and Scalability





Hydrogen Infrastructure Cost Decreases as Number of Vehicles Increase

Agency	FCEB	BEB
SunLine	$231k/bus, 35 buses	$64k/bus, 14 buses
Foothill Transit	$133k/bus, 30 buses	$322/bus, 30 buses
Long Beach	$108k/bus, 125 buses	$209k/bus, 100 buses
AC Transit	$90k/bus, 200 buses	$560/bus, 530 buses
NCTD	$291/bus, 158 buses	$348k/bus, 158 buses



Hydrogen – *THE* Grid Alternative

Gridlock is on the horizon

- 95% of the renewables needed in 2035 are backlogged today for transmission
- 20% of planned capacity for utility-scale solar projects was delayed in the first half of 2022
- U.S. transmission's 1% annual growth must **more than double** to an average of about 2.3% to meet federal climate goals

An **alternative** is needed to **capture and distribute** renewable energy which:

- Allows **storage for indefinite periods**
- Can be **readily redirected** to new places at arbitrary times
- Creates **no GHG's** or criterion pollutants
- Captures **remote, intermittent renewable electricity**
- **Nontoxic**

"Two infrastructures are cheaper that one…"

US Federal Hydrogen Cost Reduction Programs

Bipartisan Infrastructure Law - Hydrogen Highlights

U.S. DEPARTMENT OF ENERGY

- **Covers $9.5B** for clean hydrogen:
  - $8B for at least four regional clean hydrogen hubs
  - $1B for electrolysis research, development and demonstration
  - $500M for clean hydrogen technology manufacturing and recycling R&D

President Biden Signs the Bipartisan Infrastructure Bill on November 15, 2021.
Photo Credit: Kenny Holston/Getty Images

- **Aligns with Hydrogen Shot priorities by directing work to reduce the cost of clean hydrogen to $2 per kilogram by 2026**
- **Requires developing a National Hydrogen Strategy and Roadmap**

THE IRA, A US DECISIVE BILL

U.S. green H2 will become competitive

Hydrogen TCO with $3/kg PTC

Electrolyser load (%) \ Electricity price ($/MWh)	25	35	45	55	65
15%	5.1	5.6	6.2	6.7	7.3
25%	2.4	2.9	3.5	4.0	4.6
35%	1.3	1.8	2.4	2.9	3.5
45%	0.6	1.2	1.7	2.3	2.8
55%	0.2	0.8	1.3	1.9	2.4
65%	(0.1)	0.5	1.0	1.6	2.1
75%	(0.3)	0.3	0.8	1.4	1.9
85%	(0.4)	0.1	0.7	1.2	1.8

$ 1.80 /kg for green H2 net of PTC vs. **$1.5-2.5/kg** for grey H2

Why fuel cell buses

- FCEBs are commercially available today with competitive TCO to other clean transit alternatives
- FCEB can meet winter and hot summer operating conditions on most challenging routes
- FCEBs complement battery electric buses to enable 100% ZEB fleets
- Low-carbon hydrogen can be produced using local resources at same or better GHG impact as electricity
- Hydrogen refueling infrastructure offers a scalable solution compatible with transit operation today.

Q&A

Timothy Sasseen
Market Development Director, Ballard

Kim Leach
Market Development Manager, Ballard

Michael McDonald
Operations Manager, New Flyer

Byron Somerville
Program Manager, Ballard

Sydney Krueger
Sales Representative for Ballard Power Systems, & President of Krueger Transit Consulting (KTC)

Thank you

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Here for life™

ballard.com

Appendix

BALLARD™

1991 - 1995
proof of concept
Phase 1 and Phase 2 buses, the first powered by Ballard fuel cells, are demonstrated in Vancouver, Canada

1996 - 1999
phase 3
Chicago Transit Authority and BC Transit (Vancouver) each deploy three Ballard-powered fuel cell buses in revenue service for a demonstration and testing program.

1999 - 2002
phase 4
ZEbus was operated by SunLine Transit Agency, a leader in the deployment of fuel cell electric buses. SunLine now operates 13 buses powered by Ballard.

2002 - 2009
phase 5
Deployment of 30 fuel cell buses in revenue service operating in ten European cities. In addition, three fuel cell buses are deployed in Perth, Australia and three in Beijing, China.

2009 - 2014
phase 6
hybridized fleets
Deployment of 20 Ballard-powered fuel cell buses in Whistler, BC in conjunction with the 2010 Winter Olympics and Paralympic Games. The fleet surpassed one million kilometers in operation in 2011.

2010 – 2020+
European rollout
Europe has led the rollout of FCEBs, with FCH JU support for six major projects. Combined, the JIVE projects will deploy nearly 300 fuel cell buses in 22 cities across Europe by the early 2020s.

2016
rapid market adoption
First 22 of 300 fuel cell buses planned for deployment in the cities of Foshan and Yunfu, China begin operation, marking the beginning of rapid market adoption in China.

Over 10 million kilometers

2017
industry milestone
Ballard becomes the first fuel cell company to power buses for more than 10 million cumulative kilometers of revenue service. Ballard-powered fuel cell buses have now traveled more than 15 million kilometers

TODAY
commercialization
Buses have passed FTA Altoona testing in US

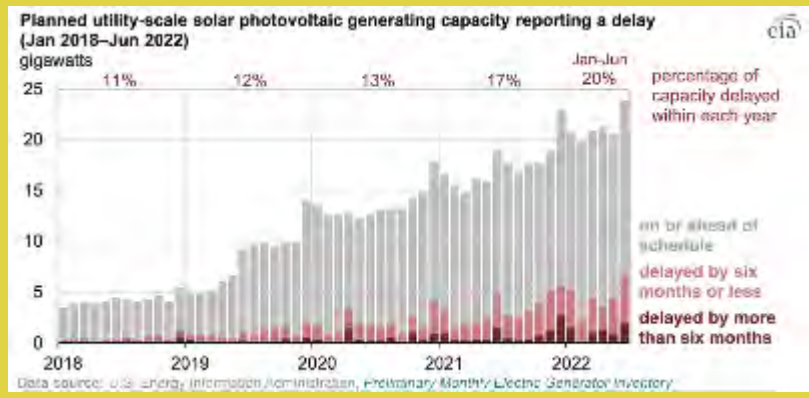
More than 130 fuel cell electric buses powered by Ballard are in operation, with an additional 2,400 planned.

Maybe a

Gridlock is on the Horizon

Renewables Installations Struggle Today, Yet Expansion Is Needed to Serve New Decarbonized Loads

- **95% of the renewables needed in 2035** are backlogged today for transmission
- 20% of planned capacity for utility-scale solar projects was delayed in the first half of 2022
- Less than a quarter of the projects that enter interconnection queues around the U.S. will make it through to completion.



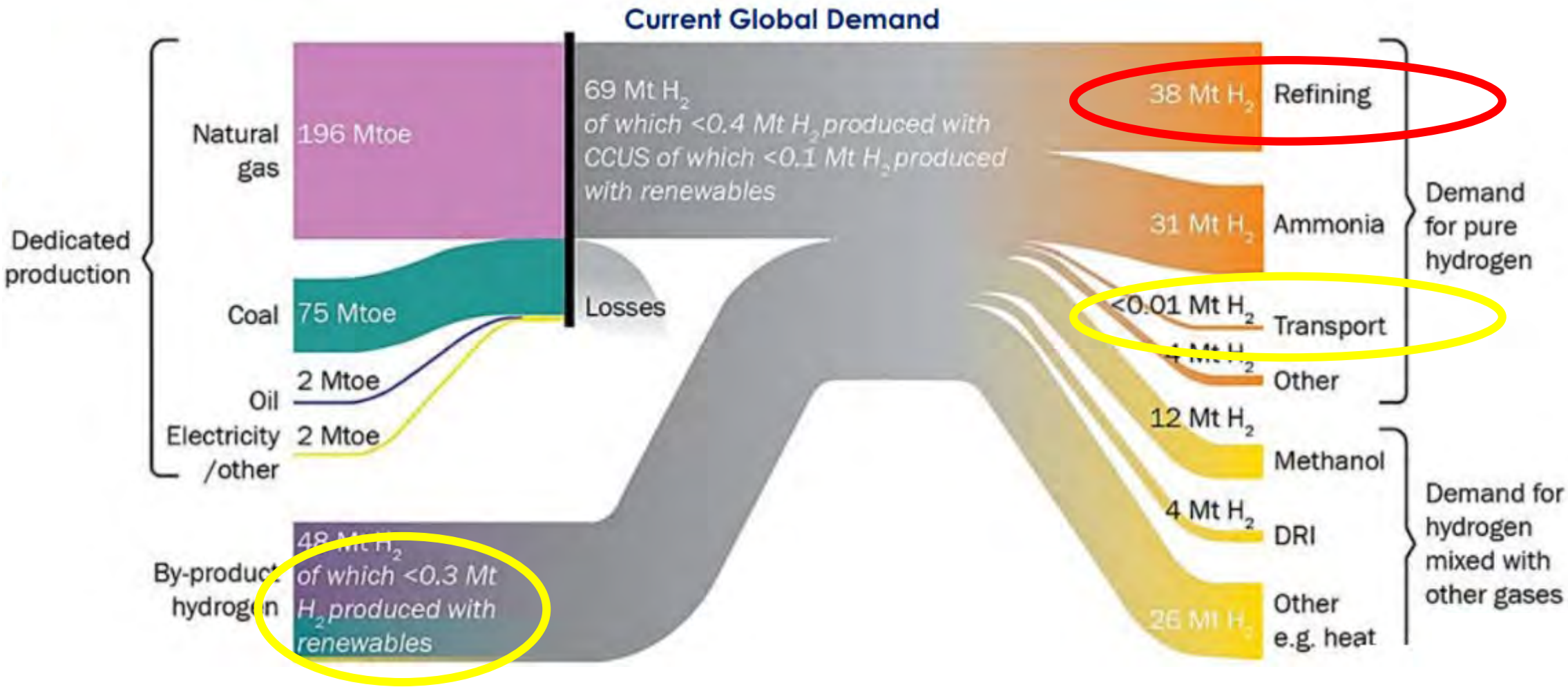
U.S. transmission's 1% **annual growth** must **more than double** to an average of about 2.3% to meet federal climate goals

- EV's from passenger cars, commercial freight
- Decarbonization of heating and industrial processes

- recent analysis from the U.S. Energy Information Administration, Utility-scale solar capacity delays hit 20% in first 6 months of 2022: EIA | Utility Dive
- Princeton University's September report, Electricity Transmission is Key to Unlock the Full Potential of the Inflation Reduction Act.

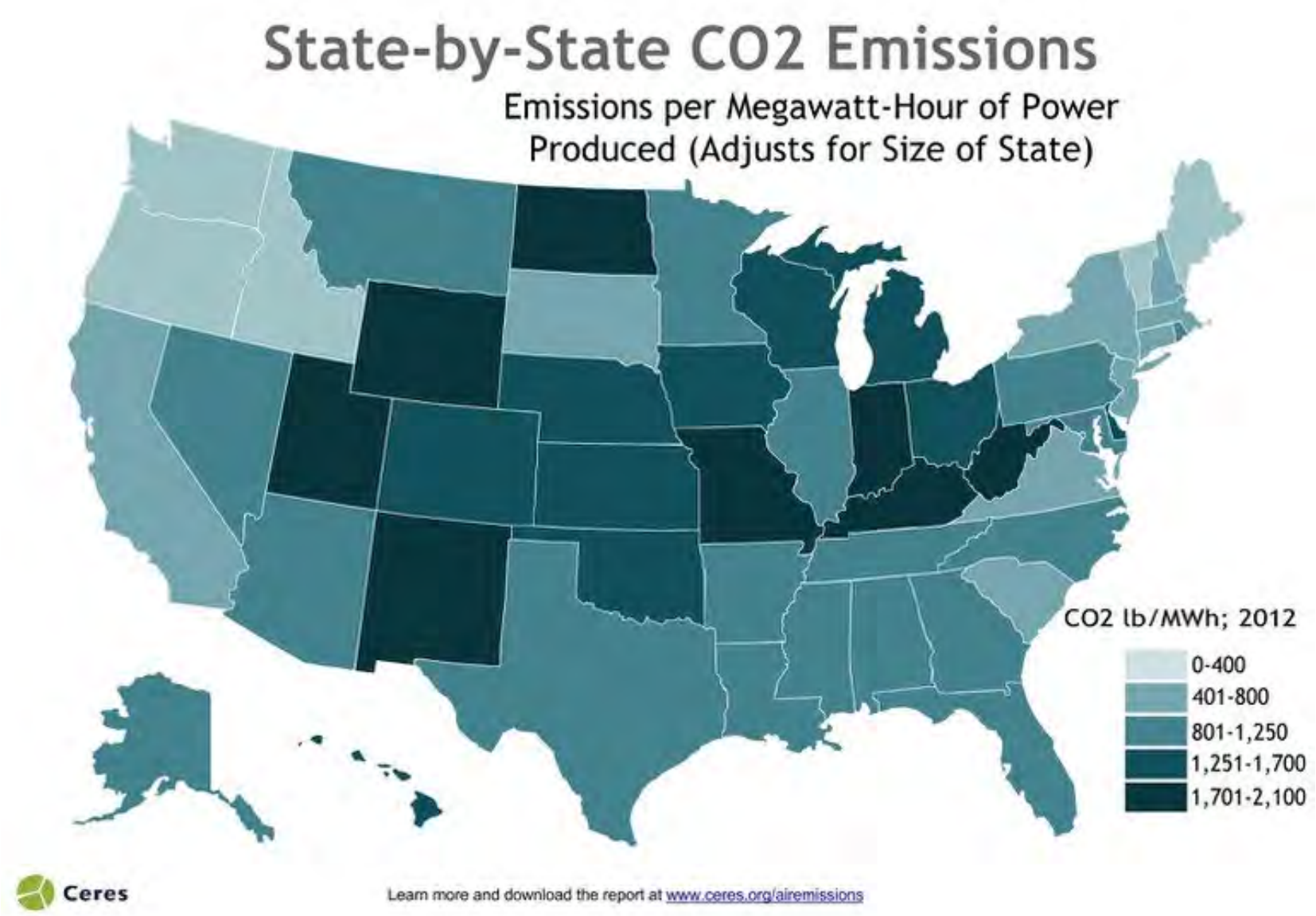
But Doesn't Most Hydrogen Come from Fossil?

Yes, but is that a problem, or a decarb opportunity?



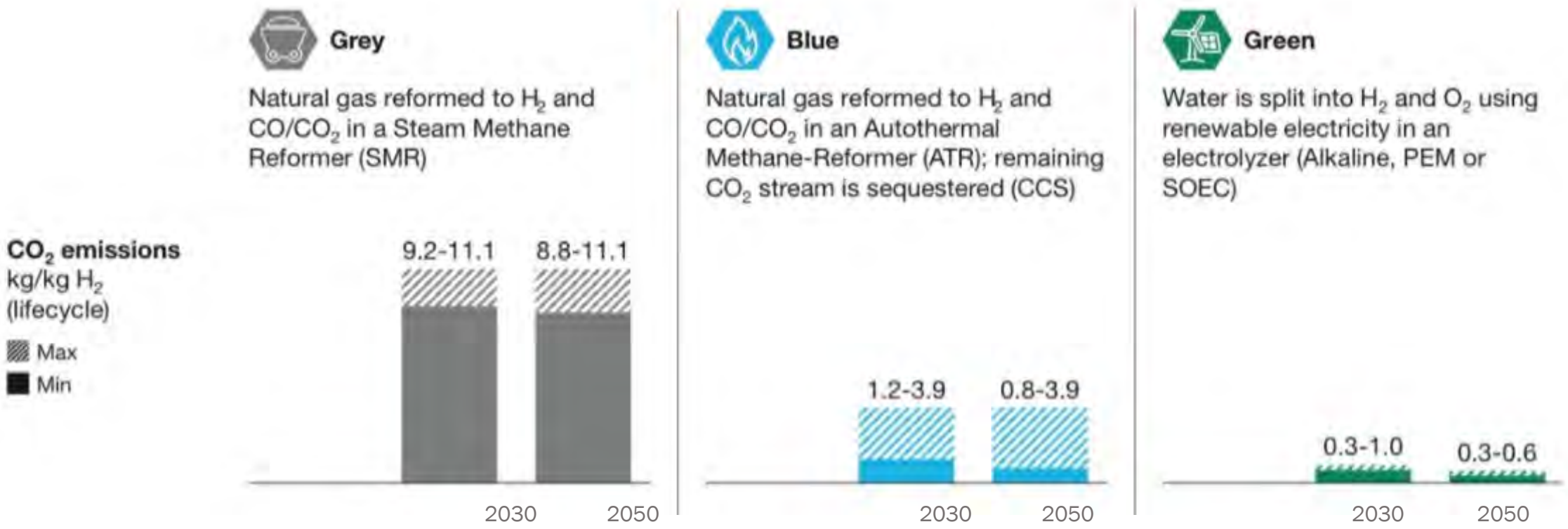
US DOE

Not All Electricity Sources Are Equal



State-by-state power production CO2 emissions – *source Ceres*

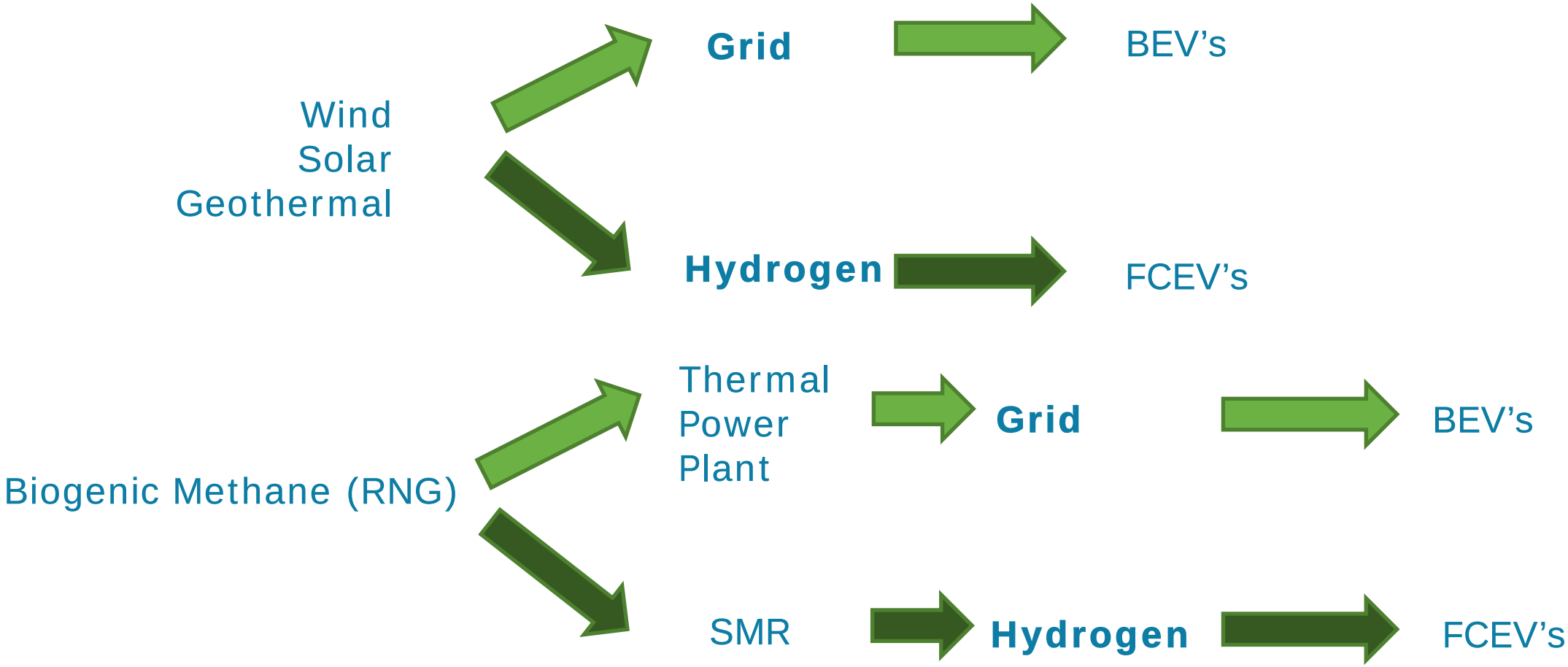
Not all hydrogen fuels are equal



Source: Hydrogen Council 2021

Carbon-Free Renewable Power Depends on the Source

Carbon content is decided before the electron hits the grid, or hydrogen enters the pipe



Options for Hydrogen Supply

Hydrogen can be delivered:

Compressed gas trailer

Liquid hydrogen delivery

Hydrogen can be generated on-site:

Steam methane reformer

Electrolyzer

What is the best option for the fleet-scale deployment of fuel cell electric buses in California?

OCTA Liquid System

Comparing GHG Impact of a Fuel Cell System with Batteries in Typical Transit Bus

GHG Emissions Required to Produce Fuel Cell and Battery System for a Transit Bus

Based on average of 150kg of CO_2e per kWh for batteries[2] and 70kg of CO_2 per kW for FC system

13.5 tons of CO_2 GHG emissions to produce 50kWh battery with 85kW Fuel Cell system

52.2 tonnes of CO_2 GHG emissions to produce a 350kWh battery

In summary: there are 75% less emissions generated in the production of a fuel cell power train.

[2] *International Council of Clean Transportation 2018*