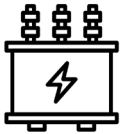
CENTER FOR TRANSPORTATION AND THE ENVIRONMENT

Introduction to FCEV Technology

PJ Callahan
Lead Engineering Consultant
pj@cte.tv

Benefits of H2 for Alaska



Minimal On-Site Electrical Infrastructure Required

- *H2 station requires less power/energy than chargers at a fueling location*

Grid Resilience

- *Liquid hydrogen deliveries can continue in grid-down scenario*

Reduced Impact of Cold Weather on Efficiency

- *Fuel Cell Waste Heat for Cabin Heating*

Improved Range/Payload for Heavy Duty Applications

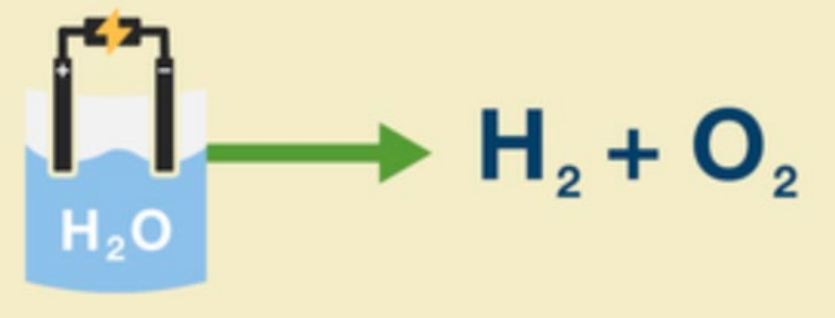
- *Clearer pathway to weight reductions/range improvements*

Hydrogen Overview

H2 is an Energy Carrier

- Odorless
- Colorless
- Non-toxic
- Lighter than air
- Disperses quickly
- Can be transported as a compressed gas or cryogenic liquid

- Most abundant element in the universe
- On Earth, hydrogen is rarely found in its pure form
- Hydrogen is isolated in many different ways

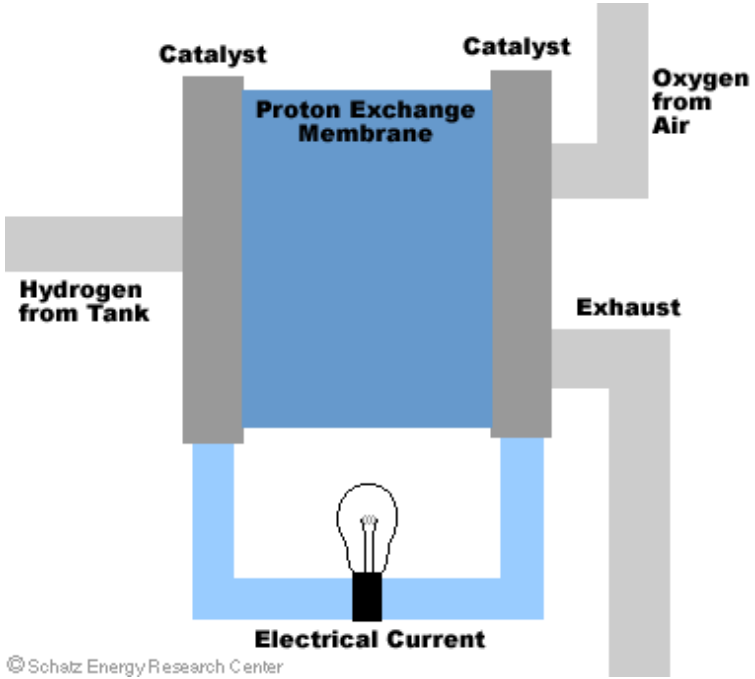


Alberta Energy Regulator. (2021). Hydrogen. Retrieved from https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st98/emerging-resources/hydrogen

H2 is an Energy Carrier

	Hydrogen	Natural Gas	Gasoline
Color	No	No	Yes
Toxicity	None	Some	High
Odor	Odorless	Mercaptan	Yes
Buoyancy Relative to Air	14X Lighter	2X Lighter	3.75X Heavier
Energy by Weight	2.8X > Gasoline	~1.2X > Gasoline	43 MJ/kg
Energy by Volume	4X < Gasoline	1.5X < Gasoline	120 MJ/Gallon

Fuel Cells



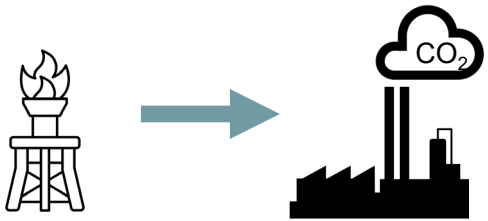
- Uses fuel, but **NO** combustion
- **NOT** a battery
- A chemical reaction between hydrogen and oxygen
- Emits only water vapor and heat

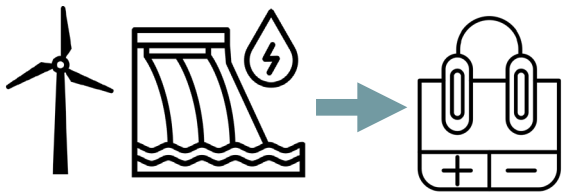
Hydrogen Life Cycle

Energy Source → H_2 Production → Transport → Storage/Fueling → FC Vehicle Layout

Natural Gas / Biogas

Steam Methane Reformation

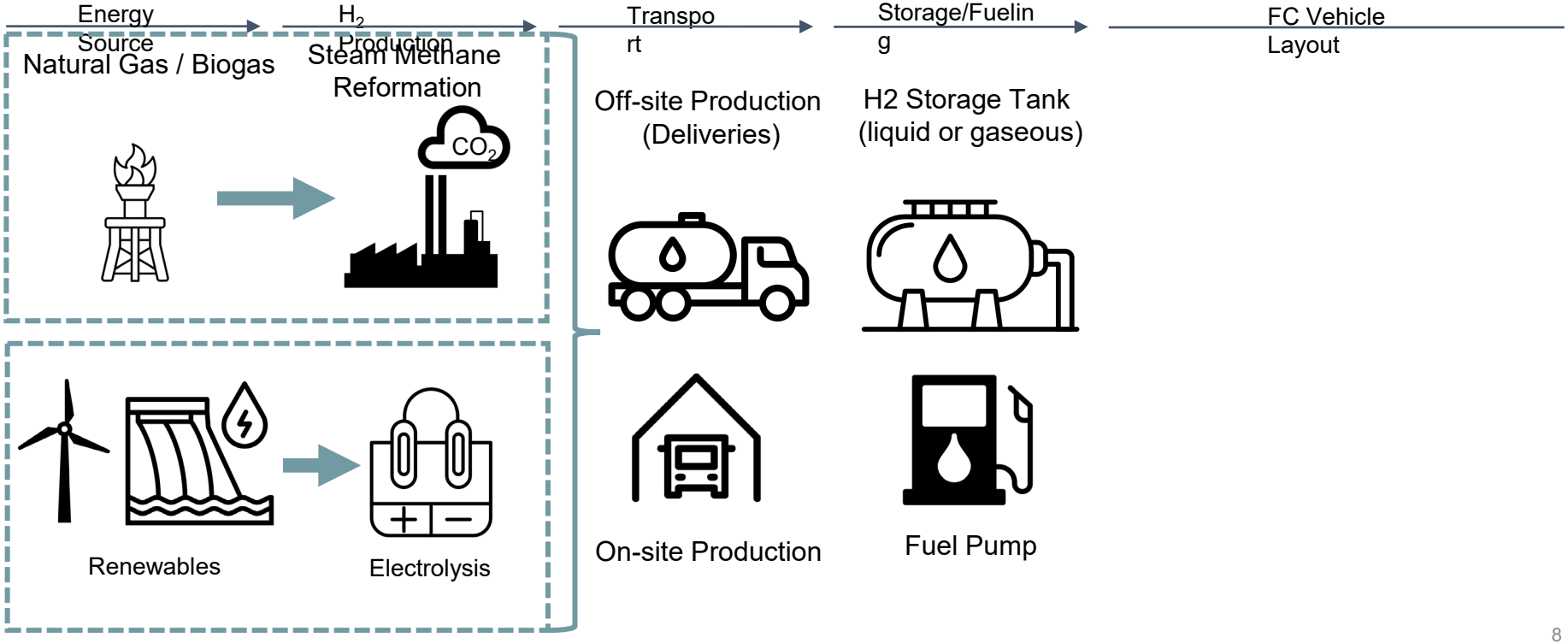




Renewables

Electrolysis

Hydrogen Life Cycle



Hydrogen Life Cycle

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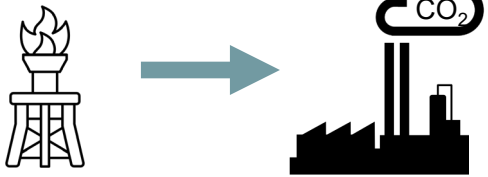

Renewables

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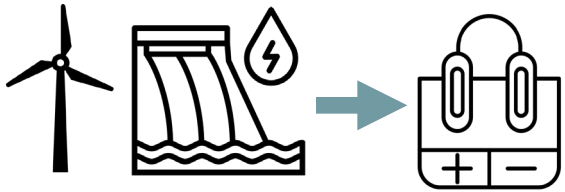
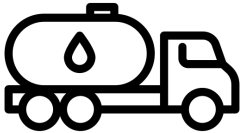
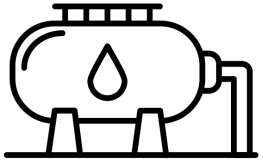


Off-site Production (Deliveries)

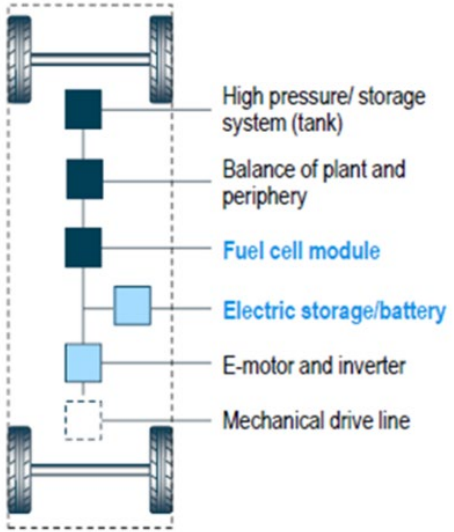


On-site Production

H2 Storage Tank (liquid or gaseous)



Fuel Pump



Cold Weather Efficiency

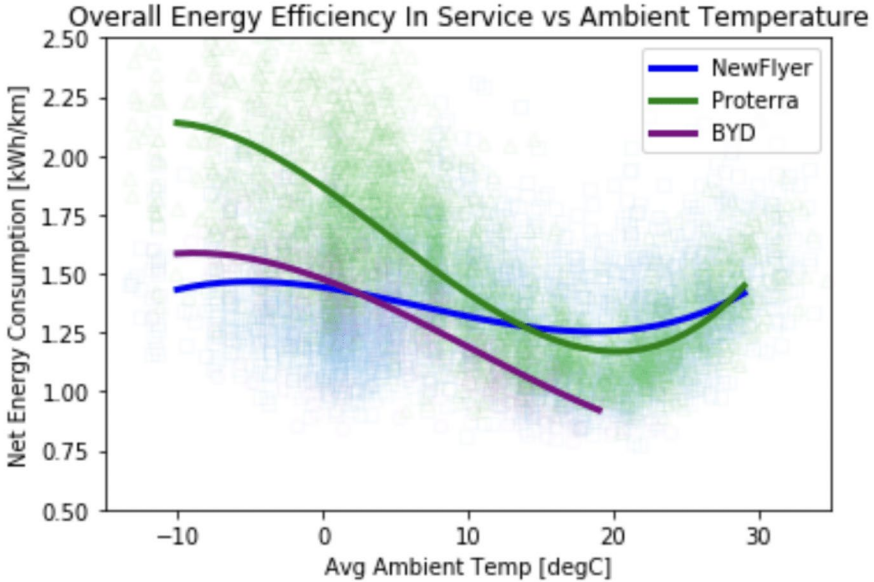
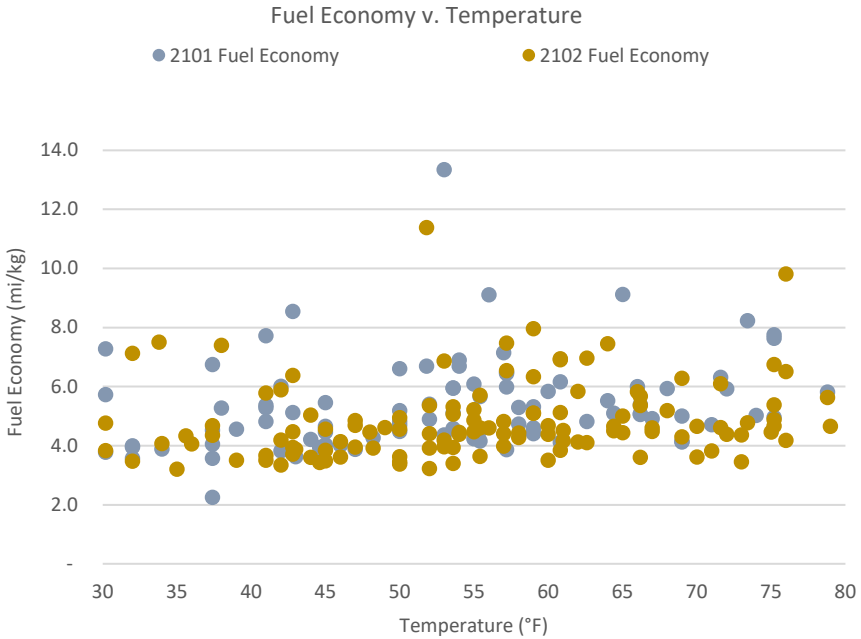


Chart 3: Energy Consumption vs. Ambient Temperature

Source: TTC's Green Bus Program: Preliminary Results of TTC's Head-to-Head eBus Evaluation



Source: Champaign-Urbana MTD, 60-foot FCEB fuel economy report

BEV and FCEV Summary

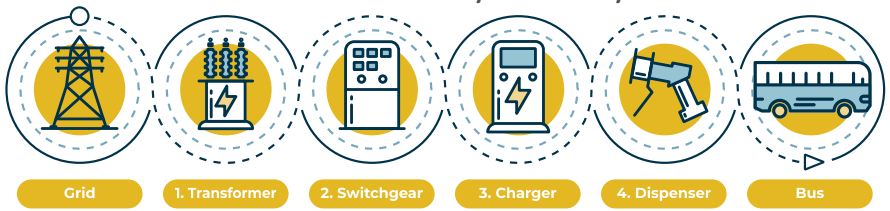
Battery Electric Vehicles (BEVs)

- On-board Energy Storage/Range Limitations
- Fueling time longer than ICE vehicle
- Greater potential for lower cost fuel
- Lower vehicle capital costs than FCEV
- Greater Market Maturity than FCEV

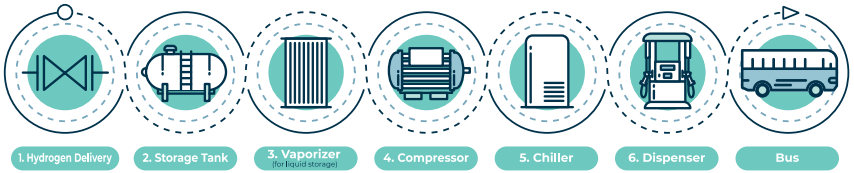
Fuel Cell Electric Vehicles (FCEVs)

- Comparably greater range than BEV
- Fueling time comparable to ICE vehicle
- Fuel cost significantly higher than BEV
- Vehicle cost significantly higher than BEV
- Limited purchasing options (40’ only)

BEB Fuel Delivery Pathway

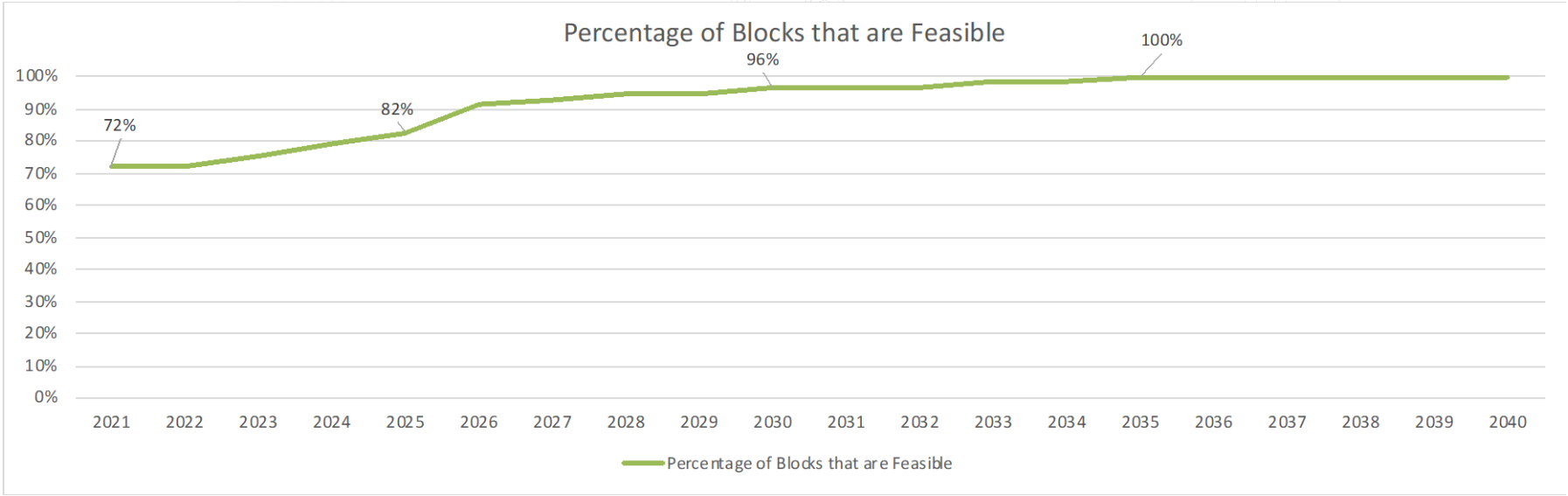


FCEB Fuel Delivery Pathway



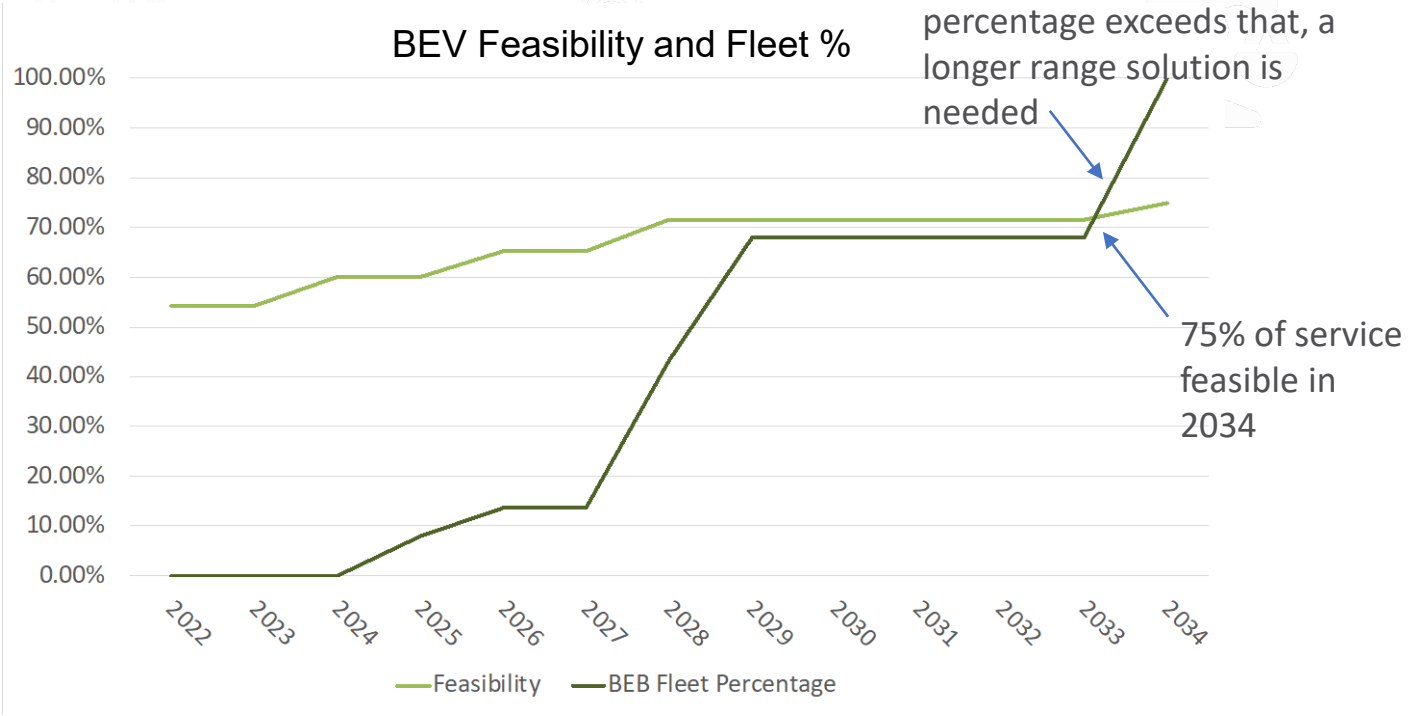
Fleet Transition Planning

It's important to analyze feasibility and costs of a fleet transition to determine the ***best fit***



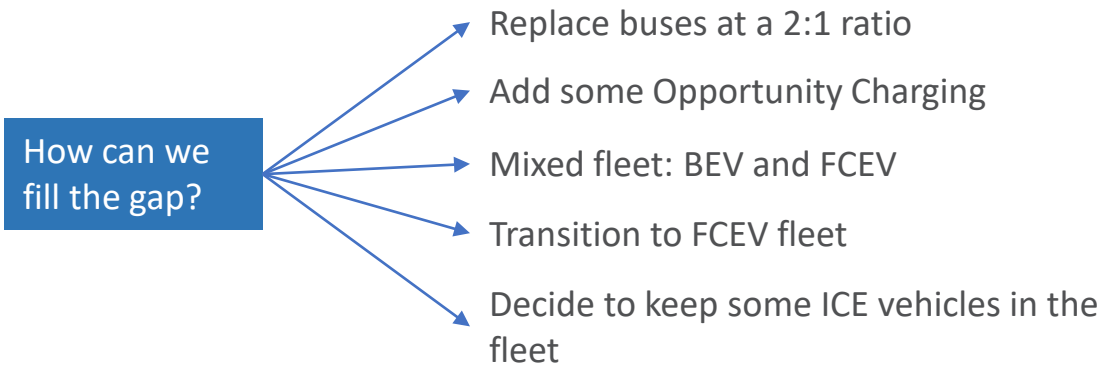
Fleet Transition Planning

When BEV range is insufficient…



Fleet Transition Planning

- How are we going to meet the service demands?
- Some transition scenarios that will help fill that range gap in order to reach 100% ZEV



Real World Applications

DOE National Blueprint

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Technology solutions for travel modes to reach a net-zero economy in 2050

1 icon represents limited long-term opportunity 2 icons represents large long-term opportunity 3 icons represents greatest long-term opportunity	BATTERY/ELECTRIC	HYDROGEN	SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*	●●●	—	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)	●●	●	●
Long-Haul Heavy Trucks (~7%)	●	●●●	●●
Off-road (10%)	●●	●	●
Rail (2%)	●●	●●	●●
Maritime (3%)	●	●†	●●●
Aviation (11%)	●	●	●●●
Pipelines (4%)	●●	TBD	TBD
Additional Opportunities	• Stationary battery use • Grid support (managed EV charging)	• Heavy industries • Grid support • Feedstock for chemicals and fuels	• Decarbonize plastics/chemicals • Bio-products
RD&D Priorities	• National battery strategy • Charging infrastructure • Grid integration • Battery recycling	• Electrolyzer costs • Fuel cell durability and cost • Clean hydrogen infrastructure	• Multiple cost-effective drop-in sustainable fuels • Reduce ethanol carbon intensity • Bioenergy scale-up

* All emissions shares are for 2019

† Includes hydrogen for ammonia and methanol

Source: The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation

Real World Applications

- Class 6 UPS Trucks
- Class 8 Drayage Trucks
- Cargo Top Loader
- 40’ and 60’ Transit Buses
- HD and LD H_2 Stations

Delivery Vans

To achieve ~97% of delivery routes, UPS needs its vehicles to operate for 125 miles. To meet that requirement, two different project teams took two different approaches:

Fuel Cell Hybrid Electric Delivery Van

- 15 vehicle deployment in Ontario, CA
- Retrofitted 2006 Navistar chassis
- 10kg at 350bar storage
- 32 kW fuel cell engine
- Optimized weight reductions and power delivery controls based on prototype vehicle deployed in real service

Next Generation Delivery Van

- 4 vehicle deployment in West Sacramento, CA
- Upfitted 2019 F-59 chassis
- 15kg at 700bar storage
- 85 kW fuel cell engine
- Sized based on operational profile data across US

NorCal ZERO

Zero-Emission Regional and Drayage Operations with Fuel Cell Electric Trucks

- **Project Location:** Port of Oakland
- 30 Hyundai XCIENT FCETs
- 6 Year Operational Period
- **Largest deployment of FCETs in North America**
- **Fueling Station Location:** 2450 Engineer Rd., Oakland, California
- **Fueling Station Capabilities:** Up to 200 trucks per day

NorCal ZERO Project Goals

- **Eliminate Tailpipe Emissions**
- **Demonstrate Commercial Viability to Fleet Operators:** Range up to 500 miles
- **Expand Hydrogen Refueling Network:** 10- to 20-minute 60 kg fills; Up to 200 trucks with collocated light-duty fueling
- **Provide Local Workforce Benefits:** Service and Repair Facility in San Leandro

California Fuel Cell Partnership. (2021, April 6). California Fuel Cell Partnership Envisions 70,000 Heavy Duty Fuel Cell Electric Trucks Supported by 200 Hydrogen Stations. Retrieved from https://h2fcp.org/blog/california-fuel-cell-partnership-envisions-70000-heavy-duty-fuel-cell-electric-trucks-supported

NorCal ZERO Project Team