# Intercity Zero-Emissions Analysis

**Intercity Transit Authority Board and Staff Workshop**

**July 12, 2023**

cte

# Introductions

# Project Team

## CTE

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**Tim Payne,** Senior Principal

## Hatch LTK

**Mihir Bodarya**, Zero Emissions Transportation Consultant

Positive Change for the Next Century

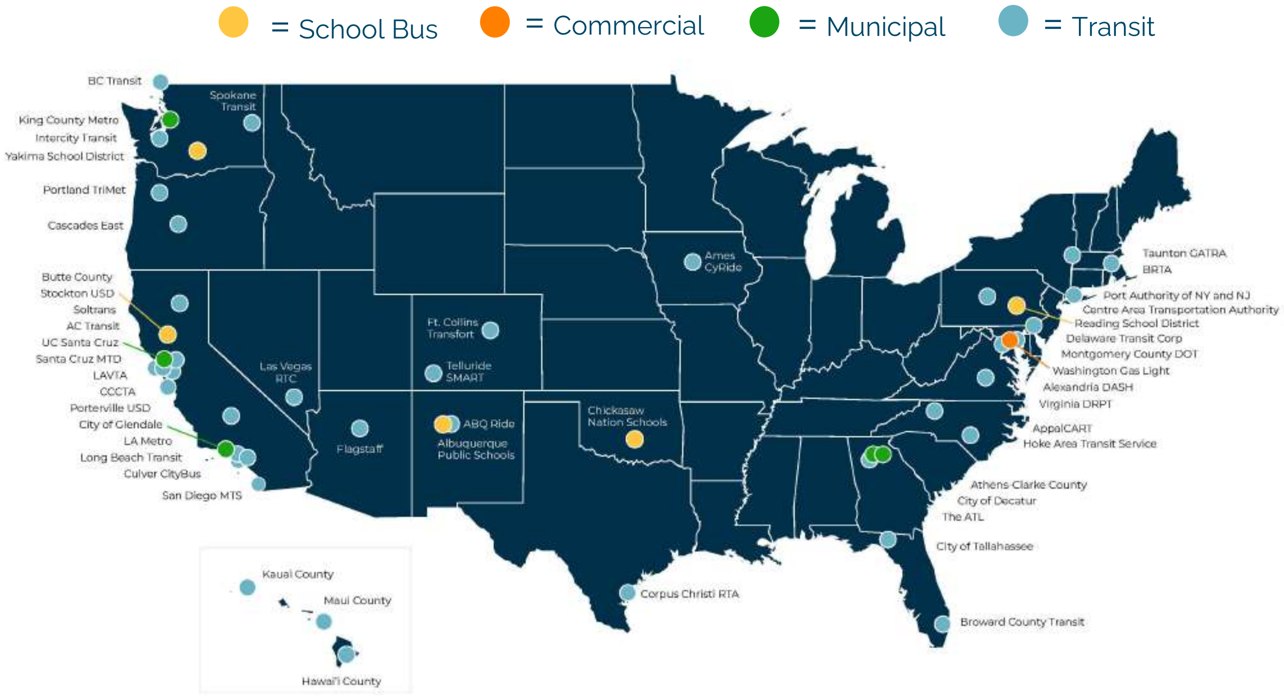
# About CTE

## WHO WE ARE
501(c)(3) nonprofit engineering and planning firm

## OUR MISSION
Improve the health of our climate and communities by bringing people together to develop and commercialize clean, efficient, and sustainable transportation technologies

## PORTFOLIO
$850 million

- *Research, demonstration, deployment*
- *100+ Active Projects totaling over $336 million*




## OUR FOCUS
Zero-Emission Transportation Technologies

## NATIONAL PRESENCE
Atlanta, Berkeley, Los Angeles, St. Paul

**Developing transportation systems to promote broader community goals of mobility, equity, sustainability, health, and economic development**

**We start by putting people first.**

**Transportation is how we change the world—**

from mitigating climate change to improving public health and dismantling historical inequities.

**We partner with clients & communities**

by using data-driven tools to help them align their transportation investments with their values.

**Working together**

we can achieve the broader goals of mobility, equity, economic development, and healthy living.

## We provide a holistic approach to zero emission fleets.

As leaders in transit service and operations planning, we support sustainability goals with data-driven service planning to guide the successful implementation of zero emission vehicles.

# History of success

Over **100 years** in the transit industry

Procurement, overhaul and integration of over **26,000+** Transit Vehicles and associated systems

with **9,000+** global employees

We **Never** Work for suppliers or bus builders

HATCH LTK

# Project Goals

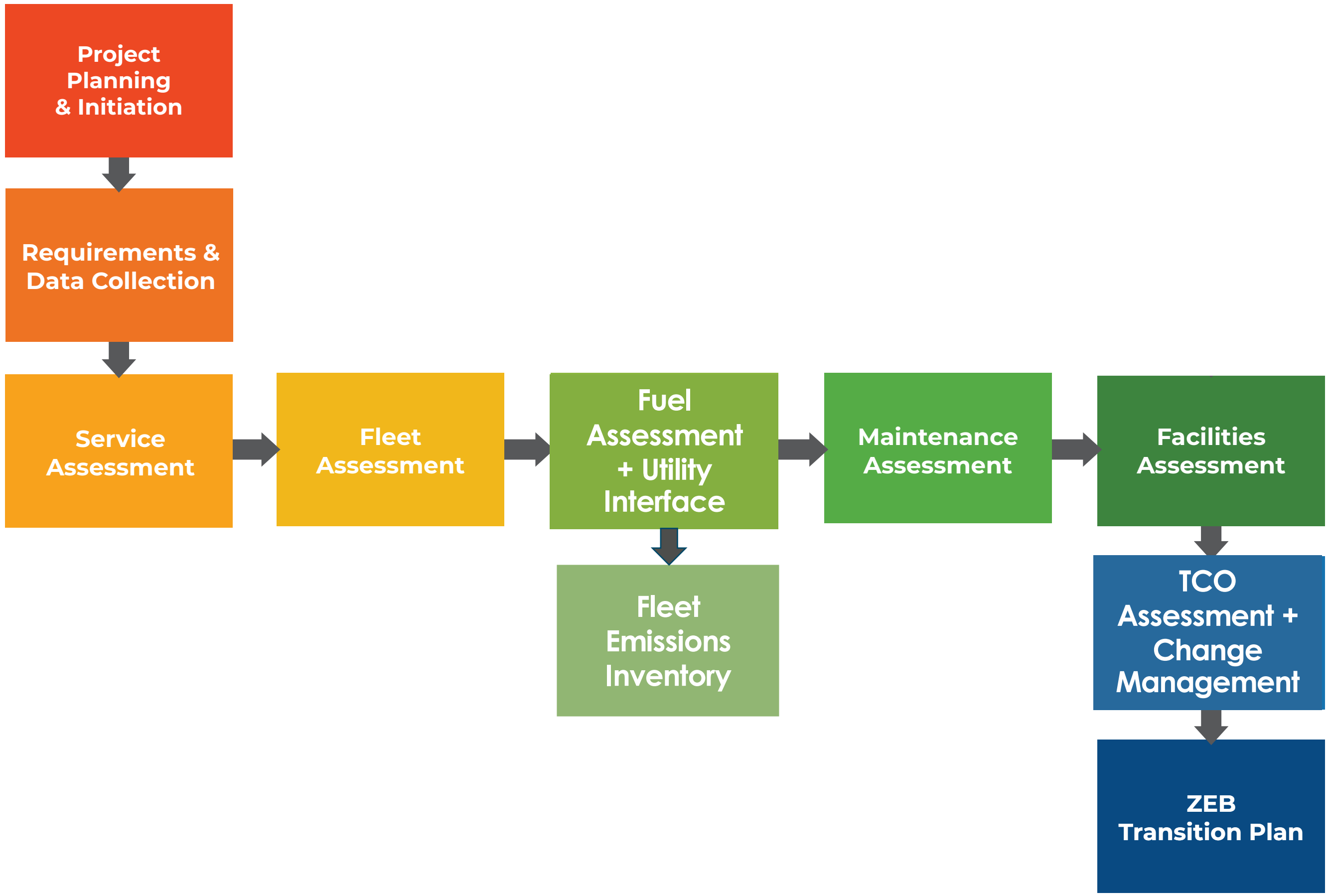
# Intercity Zero Emissions Analysis

## Project Goals

- Perform an analysis of current and emerging zero emission vehicle technology to assist Intercity in preparing for the development of a long-term zero emissions fleet transition plan.
- Understand the barriers, constraints, risks associated with transitioning to zero emission.

# Project Approach

# ZEB Transition Approach and Methodology



# State of the Industry :
## ZEB Overview

# Zero Emission Buses —What's Different?

Propulsion System

- *Traction Motor instead of engine*

Energy Storage System

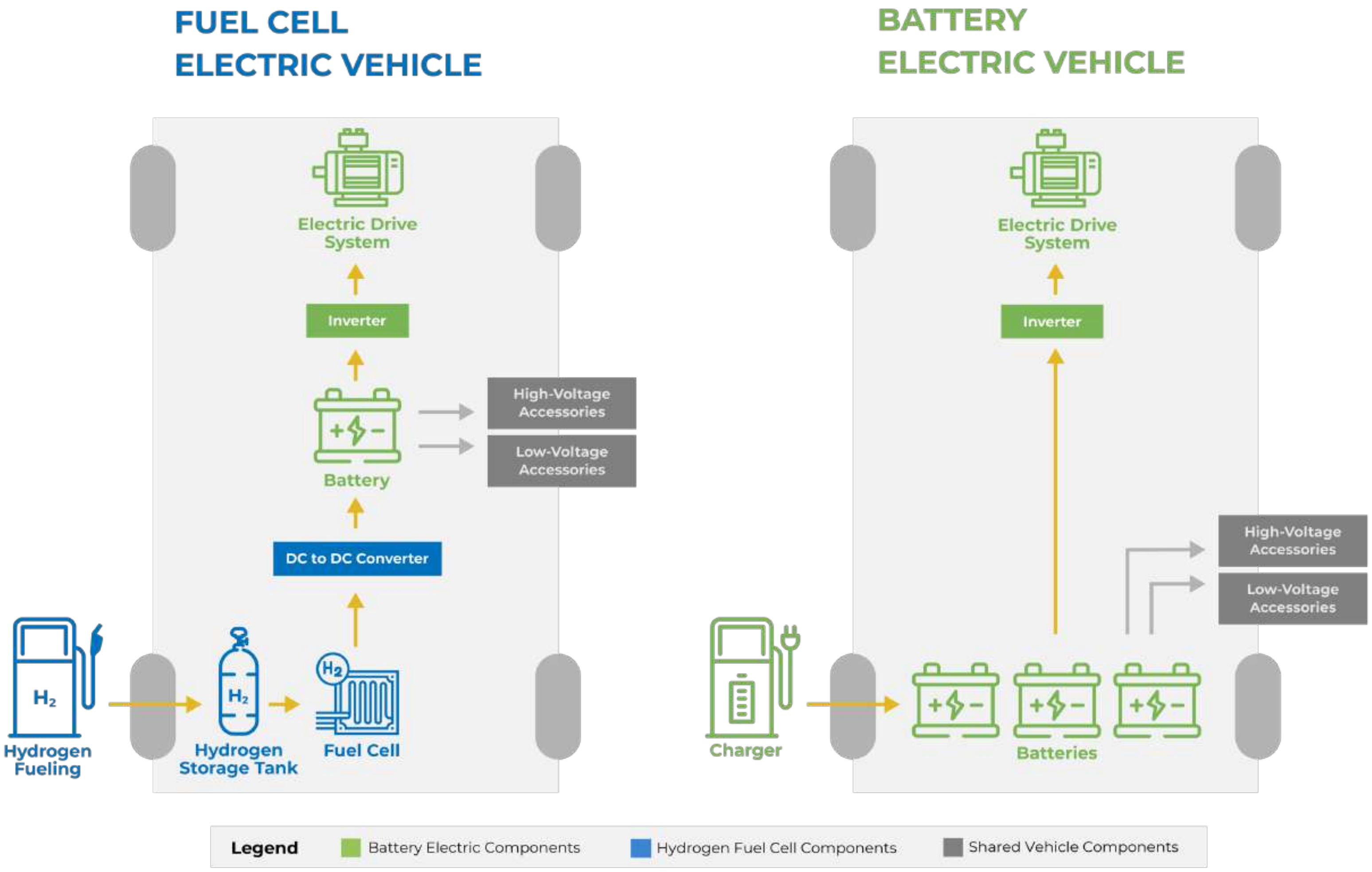
- *Battery instead of fuel tank*

HVAC

- *No "free" heat*
- *Electric heater*

Time to "Re-fuel"

- *FCEB: 10 minutes*
- *BEB: ~3 hours*



# BEB Benefits

- Zero tailpipe emissions; Lower source emissions
- More efficient, lower energy consumption compared to ICE vehicles
- Lower fuel cost in some parts of the country
- US-produced fuel source, predictable fuel cost

# BEB Challenges

Rapidly developing technologies

- Bus: energy storage, vehicle efficiencies
- Charging: new vendors, charge rates, configurations, software

Timeline for improvements in energy density

- Some blocks are too long for 1:1 replacement with current BEB technology
- Weight issue: trade-off between range and passengers

Electricity can cost more than diesel depending on rate structures

Battery degradation impact on range

- Beginning-of-Life vs. End-of-Life batteries

Infrastructure footprint

- Purchase of land and planning and design

Increased fueling time

# FCEB Benefits

Zero tailpipe emissions; Lower source emissions

More efficient, lower energy consumption compared to ICE vehicles

US-produced fuel source

Increased range (300+ miles) compared to BEBs

- 1:1 replacement of conventional vehicles

Rapid refueling speeds (~10-18 minutes)

Significant reduction in vehicle weight compared to BEBs

- Increased passenger capacity

# FCEB Challenges

When will economies-of-scale kick in?

- FCEBs cost more than BEBs
- Hydrogen fuel cost more than electricity

Limited demonstrations

- Easier to deploy BEBs on a limited basis because charging technology can be easily scaled to small fleets

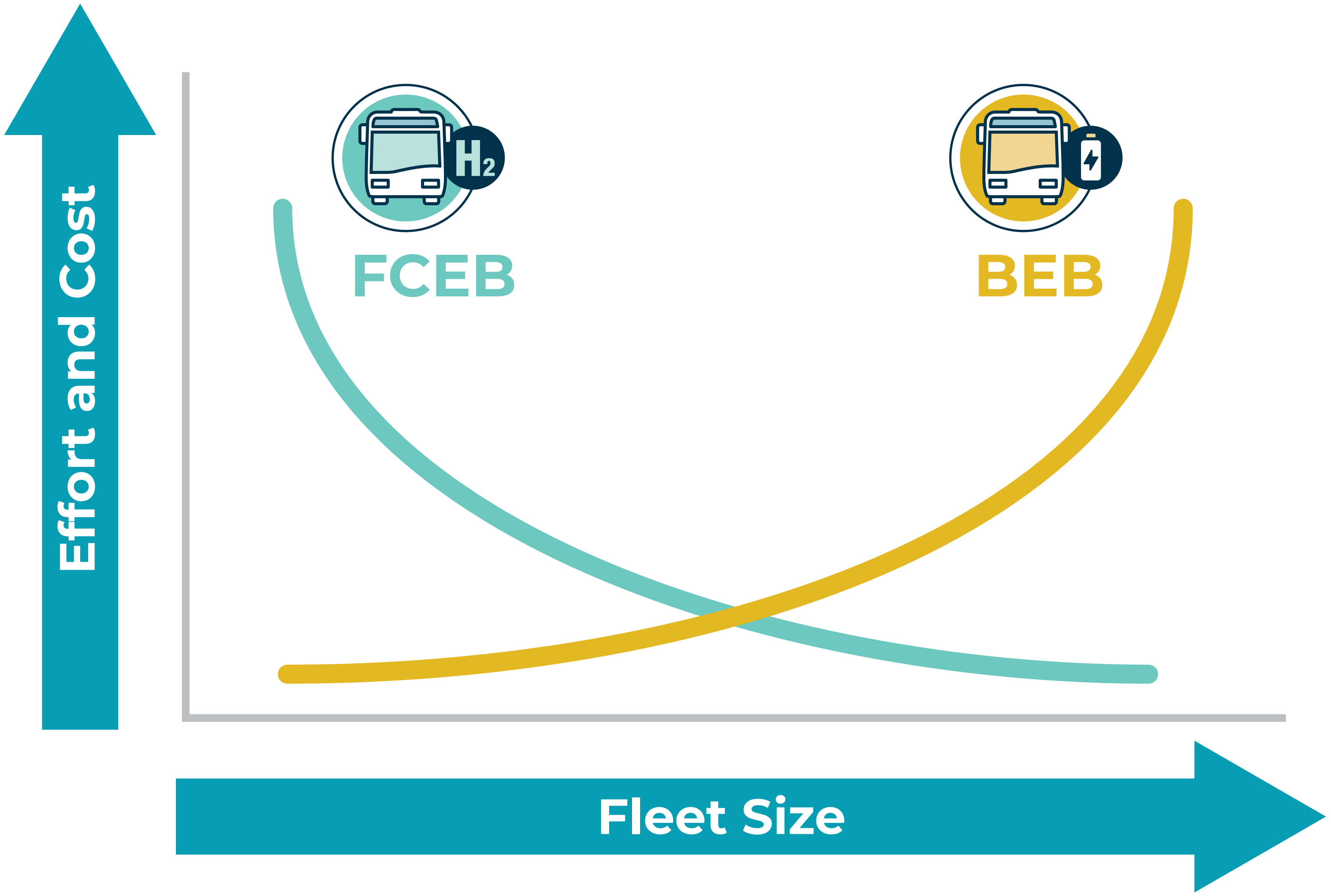
Fuel cell & battery degradation impact on range

- Beginning-of-Life vs. End-of-Life

Hydrogen production and fueling Infrastructure

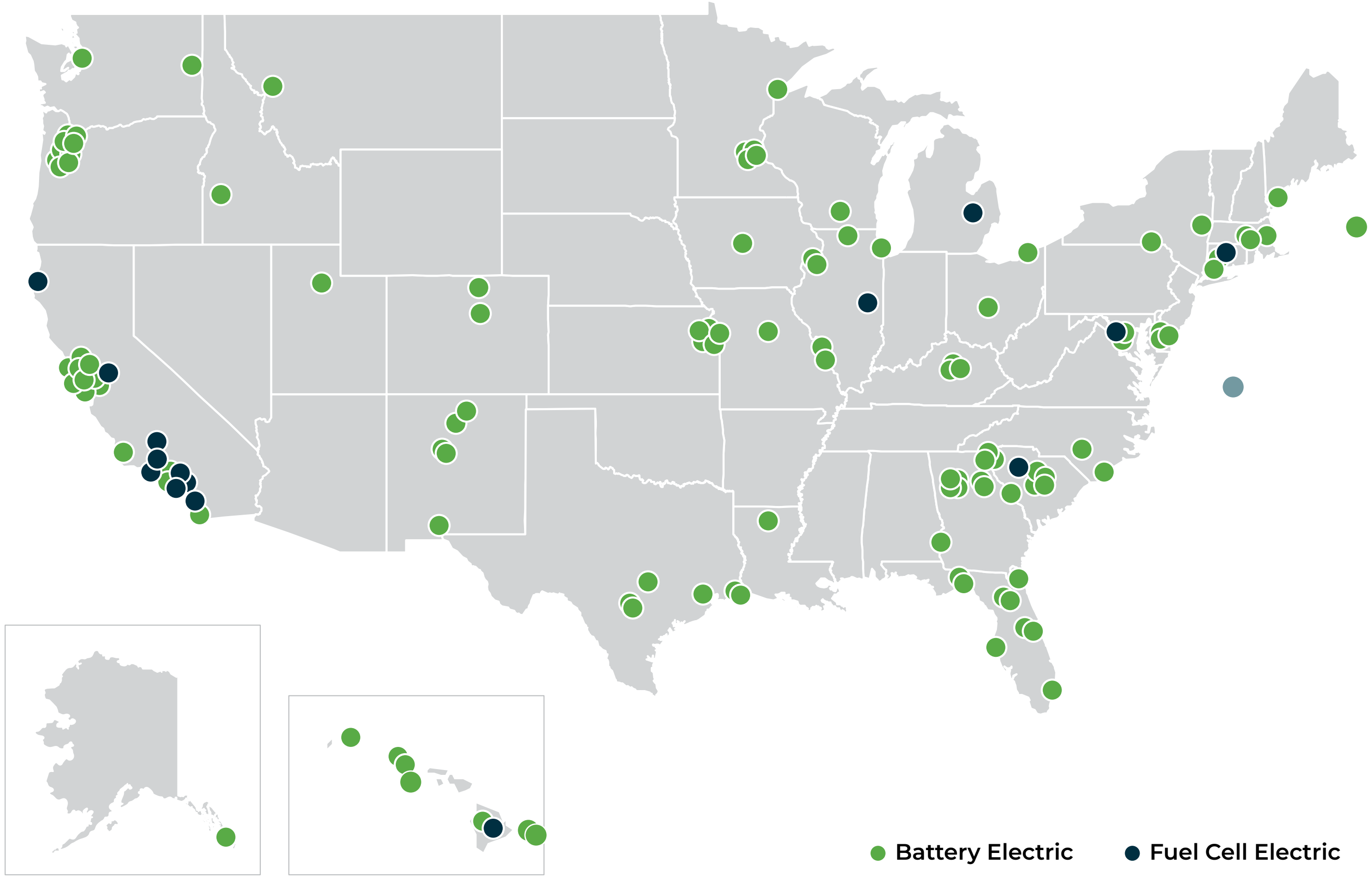
- Infrastructure footprint
  - Purchase of land and planning and design

# Scalability



# BEB and FCEB Deployments

- Past, current, and future CTE projects featuring deployments of BEBs or FCEBs



# Trends and Future Advancements

## Battery Electric

Increased BEB Range

- Larger battery capacities; weight reduction

Charging Equipment and Strategies

Increased BEB OEMs in the Market

More Turnkey Charging Solutions

Larger Battery Electric Technology Deployments:

- CapMetro (TX)
- Anaheim Regional Transportation (CA)
- Long Beach Transit (CA)
- Broward County Transit (FL)
- Montgomery County Transit (MD)
- Connecticut DOT (CT)

Expected updates to NFPA codes for ZEB storage

# Trends and Future Advancements

## Fuel Cell

Expanded Hydrogen Fuel Supply

Clean Hydrogen Production Incentives Act of 2021

DOE's Regional Clean Hydrogen Hub Program –

- $8 billion in funding

Increased FCEB OEMs in the Market

Increased adoption of FCEB technology

- Over 1,800 FCEB procurements planned across 19 CA transit agencies by 2035
- Rochester-Genesee Regional Transportation Authority (NY)
- Montgomery County Transit (MD)
- County of Hawaii (HI)

Increased FCEB Range

- More hydrogen storage, fuel cell technology improvements, weight reductions

Expected updates to NFPA codes for ZEB storage

# State of the Industry :
## Zero Emission Vehicle Market

# Heavy-Duty Transit Buses

# Zero Emission Transit Bus OEMs

Battery Electric Options

ARBOC SPECIALTY VEHICLES

GP GreenPower Bus
The Future of Public Transportation

ENC
REV GROUP

NEW FLYER

GILLIG

BYD

MCI

WHERE TRANSIT MEETS TOUR HOMETOWN Coach

NOVABUS
bring life to your city

PROTERRA

Fuel Cell Options

ElDorado National - California

NEW FLYER

# BEB Transit Bus Product Offerings

| | | Size | Battery Capacity | OEM Stated Range | Altoona Tested? | Buy America Compliant? |
|---|---|---|---|---|---|---|
| Battery Electric | ARBOC | 30’ | 350 kWh | 210 miles | N | Y |
| | | 35’ | 437 kWh | 230 miles | N | Y |
| | BYD | 30’ | 215, 313 kWh | 158 – 196 miles | Y | Y |
| | | 35’ | 391 kWh | 196 miles | Y | Y |
| | | 40’ | 313, 446 kWh | 157 – 203 miles | Y | Y |
| | | 60’ | 578 kWh | 193 miles | Y | Y |
| | ElDorado (ENC) | 32’ | 492 kWh | N/A | Pending | Y |
| | | 35’ | 492, 615, 738 kWh | N/A | Pending | Y |
| | | 40’ | 492, 615, 738 kWh | N/A | Y | Y |
| | GILLIG | 35’ | 490, 588, 686 kWh | N/A | Y | Y |
| | | 40’ | 490, 588, 686 kWh | N/A | Y | Y |
| | GreenPower | 30’ | 260 kWh | 163 miles | N | N |
| | | 40’ | 400 kWh | 212 miles | N | N |
| | Hometown Coach | 30’ | N/A | 120-200 miles | N | Y |
| | | 35’ | N/A | 120-200 miles | N | Y |
| | | 40’ | N/A | 120-200 miles | N | Y |
| | New Flyer | 35’ | 350, 440 kWh | 179-220 miles | Y | Y |
| | | 40’ | 350, 440, 525 kWh | 174-251 miles | Y | Y |
| | | 60’ | 525 kWh | 153 miles | Y | Y |
| | Nova Bus | 40’ | 376, 564 kWh | N/A | Y | Y |
| | Proterra | 35’ | 492 kWh | 240 miles | Y | Y |
| | | 40’ | 492, 738 kWh | 340 miles | Y | Y |

- Altoona Testing is independent testing performed by The Altoona Bus Research and Testing Center, which is responsible for testing new model buses as required by U.S. federal law to be eligible for U.S. federal funding.
- Buy America Compliant refers to the fact that rolling stock in a transit project must be at least 70% produced domestically in the US in order for federal tax dollars to be used in the purchase.

**Note:** MCI has battery electric coach (45’) buses available.

# FCEB Transit Bus Product Offerings

| | | Size | Battery Capacity | OEM Stated Range | Fuel Tank Size | Altoona Tested? | Buy America Compliant? |
|---|---|---|---|---|---|---|---|
| **Fuel Cell Electric** | ElDorado (ENC) | 40’ | 26, 37 kWh | ~400 miles | 60kg with 8 tanks | Pending | Y |
| | New Flyer | 40’ | 150 kWh | 370+ miles | 37.5kg | Y | Y |
| | | 60’ | 150 kWh | | 56kg | Y | Y |


# Market Conditions

- Availability
  - Current lead times range from 12 to 22 months for transit buses, based on feedback from the bus OEMs.
  - Lead times vary widely for electric cutaways and vans
    - Vans typically available 3-6 months
    - Cutaways typically available 6-12 months
    - Cutaway lead time heavily impacted by supply issues (chassis)
- Prices (Base Bus)
  - BEB
    - 35' : ~$900,000 - $1M
    - 40' : ~$980,000 - $1.1M
  - FCEB
    - 40' : ~$1.2M
  - Different battery configurations impact cost
  - Current state contracts with ZEBs: CA, FL, GA, NM, WA, VA
- Mid-life Maintenance Overhauls
  - Energy storage system replacement and fuel cell rebuilds expected at mid-life (6 years)
  - Other possible mid-life overhauls needed
    - Traction motor, transmission, inverters

# Cutaways

# Challenges with Zero-Emission Cutaways

- **Limited engagement of established vehicle manufacturers**
  - Very few are Altoona tested
- **Battery size and range limitations**
  - Impact of auxiliary equipment (ADA lift, HVAC, etc.)
- **Very limited hydrogen integration**

# Zero Emission Cutaway OEMs

Battery Electric Options

ENDERA

GP GreenPower Bus
The Future of Public Transportation

ZEUS ELECTRIC CHASSIS

PHOENIX MOTORCARS

MOTIV it's inEVitable

OPTIMAL·EV

LIGHTNING eMOTORS

SEA Electric

Fuel Cell Options*

US HYBRiD by Ideanomics

PLUG POWER

*US Hybrid and Plug Power offer fuel cell conversion systems.

# Battery Electric Cutaway Bus Product Offerings

| | Battery Capacity | Range | Altoona Tested? | Buy America Compliant? |
|---|---|---|---|---|
| Endera (Model B4, B6 & B8) | 150 kWh and 226 kWh | 150 miles | No | Yes |
| Forest River Bus | 90-157 kWh | 95-155 miles | Yes | Yes |
| Lightning eMotors Shuttle Bus | 120 kWh | 130 miles | No | Yes |
| Motiv Power Systems | 127 kWh | 105+ miles | No | Yes |
| Optimal EV (S1 Low-Floor) | 113 kWh | 125+ miles | No | Yes |
| Phoenix Motorcars (Zeus 400) | 90-150 kWh | 100-160 miles | No | Yes |



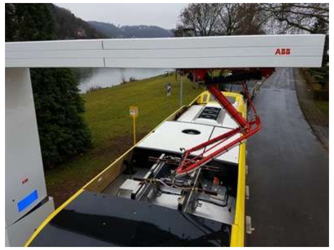
# Vans

# Zero Emission Van Offerings

| | Battery Capacity | OEM Stated Range | Altoona Tested? | Buy America Compliant? |
|---|---|---|---|---|
| GreenPower Motor Company (EV Star) | 118 kWh | 150 miles | Yes | Yes |
| GreenPower Motor Company (EV Star +) | 118 kWh | 150 miles | No | Yes |
| Ford (E-Transit Van) | 68 kWh | 126 miles | No | Yes |
| Forest River Bus (Transit Van EV) | 80 or 120 kWh | 140-170 miles | Yes | Yes |
| Lightning eMotors (ZEV3) | 80 or 120 kWh | 140-200 miles | Yes | Yes |
| Sunset Vans (Low-Floor Minibus) | 50 or 75 kWh | 150-200 miles | No | Yes |

# State of the Industry :
## Zero Emission Fueling Market

# Zero-Emission Bus & Infrastructure



| | Depot Charging | On Route (Conductive) | On Route (Inductive) | Fuel Cell |
|---|---|---|---|---|
| **Charge Interface** | Plug-in, overhead pantograph, or inductive at depot | Overhead pantograph and charger on-route | Overhead or in ground | On board charge via fuel cell |
| **Batteries** | Large battery packs | Smaller battery pack | Large battery packs | Smaller Battery Pack |
| **Range** | 70-200 miles | Virtually Unlimited, pending sufficient charge time on route | Virtually Unlimited, pending sufficient charge time on route | 300+ miles |
| **Charger Power** | 50kW - 1.4MW charger | 300-450 kW charger | Up to 500 kW | No charger needed |
| **Charge Time** | Full charge in ~3-4 hours | ~2.5 miles per charge minute | Range extender | ~10 - 18 minutes to full tank |
| **Limitations** | Charge time; infrastructure footprint | Layover schedules; cost; available location | Layover schedules; cost; limited OEM bus compatibility; no current heavy-duty charging standard | Initial investment; hydrogen storage footprint |

# Charger Market

# Plug-in Charger Styles

Integrated Charger & Dispenser


Electronics Charging cabinet w/ remote dispenser(s)

# Overhead Charger Styles


**Pantograph Up**

- Extendible charging arm mounted on bus
- Stationary charging rail on charger structure


**Pantograph Down**

- Charging arm mounted on charger structure
- Stationary charging rails on bus roof

# Wireless/Inductive Chargers

- In-ground
- No physical connection
- No overhead obstructions
- Alignment is critical

# Scalable Depot Charging

## Overhead Cable

- Reel, boom, or hanging

## Overhead Pantograph

- Automated operation
- Minimizes yard obstructions

# Bus Charger Vendors

chargepoint

ABB

PROTERRA

heliox

BYD

SIEMENS

WAVE Wireless Advanced Vehicle Electrification

efacec

INDUCTEV

(formally Momentum Dynamics)

BTC POWER

TRITIUM

# Charger Offerings

| | Plug-in Chargers | Pantograph Chargers | Inductive Chargers |
|---|---|---|---|
| ABB | ✓ | ✓ | |
| BTC Power | ✓ | | |
| BYD | ✓* | | |
| ChargePoint | ✓ | | |
| efacec | ✓ | | |
| Heliox | ✓ | ✓ | |
| InductEV | | | ✓ |
| Proterra | ✓ | ✓ | |
| Siemens | ✓ | ✓ | |
| Tritium | ✓ | | |
| Wave | | | ✓ |

*AC chargers only


# Charging Standards

General

- Communication should be OCPP 2.0.1 (or newer) compliant
- Charging equipment should be UL classified or field certified for the intended purpose prior to acceptance.

Plug-in Charging

- SAE J1772 for DC Level 2 plug-in charging

Pantograph Charging

- SAE J3105 for overhead pantograph down charging

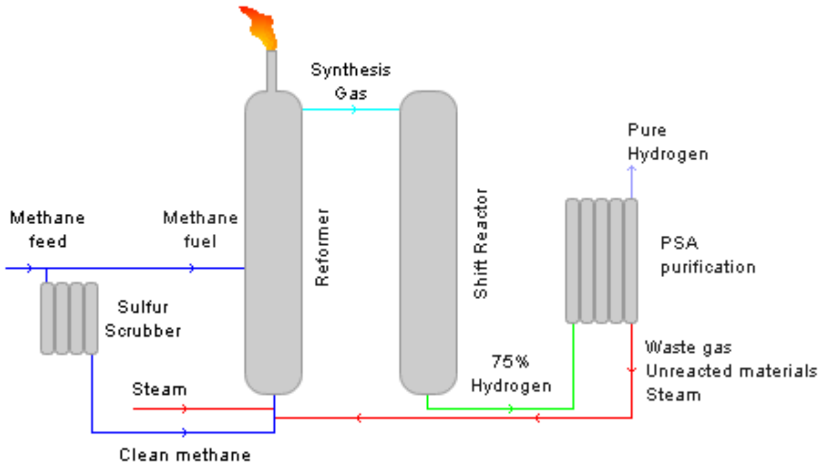
Inductive Charging (light-duty)

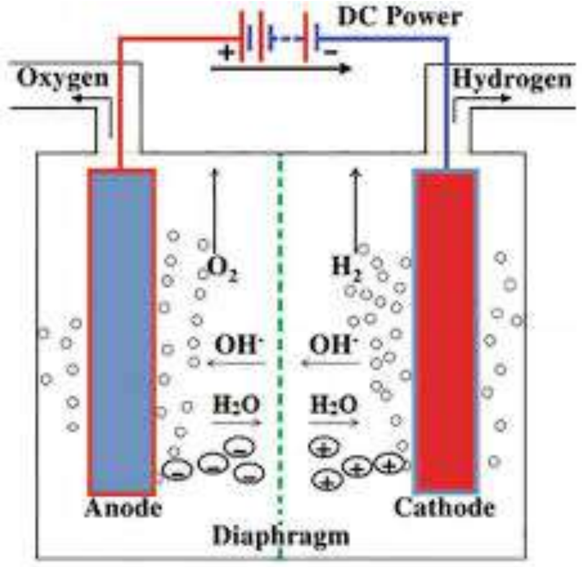
- SAE J2954 for wireless inductive charging for light-duty
- No heavy-duty inductive charging standard currently

# Hydrogen Fueling Market

# Hydrogen Production

- **Steam Methane Reformation (SMR)**
  - Process involving methane, water, and heat
    - Produces CO2 byproduct
    - High carbon intensity
  - Cheapest and most common method for producing hydrogen
    - 95% of U.S. hydrogen
    - Must be purified for fuel cell use
- **Electrolysis**
  - Energy Intensive (electricity)
  - Produces 99.99% pure H2
    - Oxygen is the only byproduct
  - Can be 100% zero-emission if produced using renewable energy



# Hydrogen Station Options

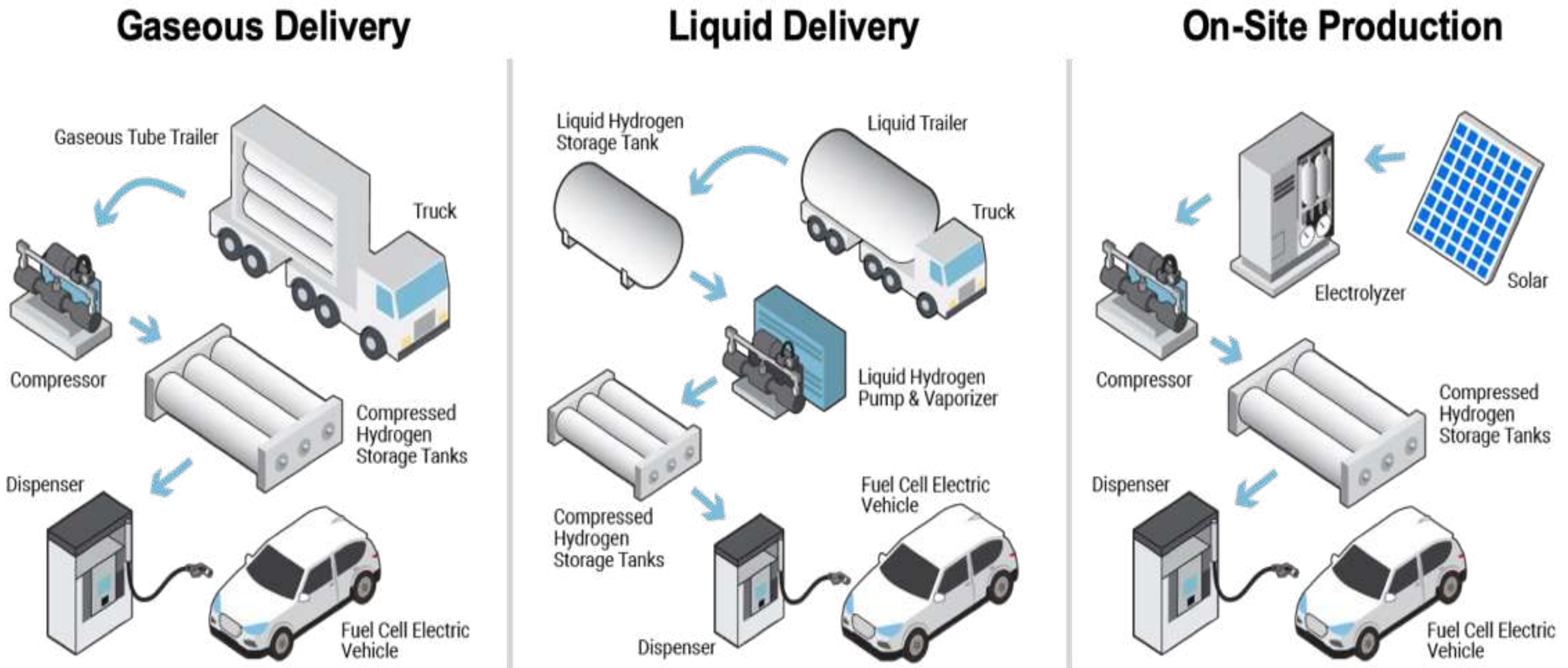



*Figure 5. Summary of hydrogen fueling station delivery options (Image source: California Fuel Cell Partnership)*

# Hydrogen Transport Considerations

- **Hydrogen can be delivered by trailer, either as a gas or liquid**
  - Liquid H2 is much more energy dense
  - Liquid H2 production is very energy intensive
  - Gaseous supply has greater availability today
- **Pipeline delivery is only economical with large quantities of H2 and short distances**
  - Requires pipeline infrastructure; generally not feasible yet
- **No delivery necessary with onsite generation**
  - Onsite SMR and electrolysis are energy intensive and exhibit low efficiency compared to large-scale production

# Hydrogen Infrastructure Standards

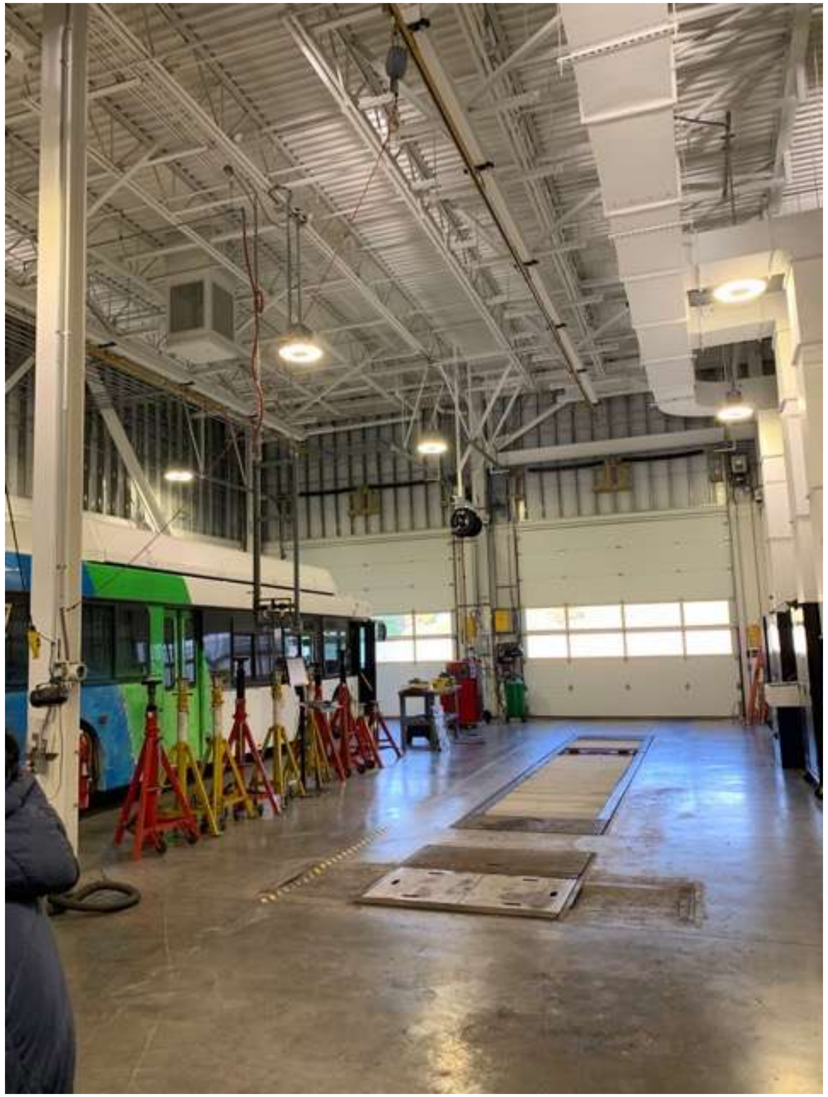
- **NFPA 2 - Hydrogen Technologies Code**
  - Fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (GH2) form or cryogenic liquid (LH2) form.
  - Chapters 7, 8, and 10 discuss required standard setbacks
- **State and Local Codes and Standards**
- **Consider a ‘Performance Based’ design approach, as necessary**

# Two Grades of Hydrogen Fuel

- **H35 (350 bar)**
  - Currently available for HD, applications including buses.
- **H70 (700 bar)**
  - Currently available for light-duty retail applications
  - HD dispensing & vehicles currently under development

# Facility Modifications

- Definitions as a “major” and “minor” repair garage.
- Gas Detection, ventilation, and consideration for electrical hazard areas.
- Similar in scope to CNG facility modifications.



# Transit H2 Stations


Approximately 36’ x 85’ footprint

# PSE Engagement/Discussion

# PSE Engagement

- Building Partnerships
- Energy Portfolio
- Zero Emission Fleet Transition Support

# Fixed Route Fleet Analysis Results

# Fixed Route

## Future ZEB Technology Scenarios

- 100% ZEB Procurement Fleet Transition
    - Replaces 35' and 40' diesel buses with ZEBs, starting in **2026** based on block feasibility.
    - If Intercity Transit were to procure 100% ZEBs moving forward, **100%** of the procurements in 2026 would be ZEBs, outside of planned procurements.
        - Bus purchases made before 2026 are not assumed to be ZEB because it's assumed ZEB infrastructure would need until 2026 to be implemented.

- ZEB Technology Scenarios
    - BEB Depot-Only Charging
    - BEB Depot and On-Route Charging
    - Mixed Fleet (BEB and FCEB)
    - FCEB-Only

# Fleet Assessment Results

Fixed Route

# Fleet Assessment Assumptions

Fleet Composition

- 35’: 31 diesel buses
- 40’: 55 diesel buses
- Procurement cycle: 12 years

Procurement Costs

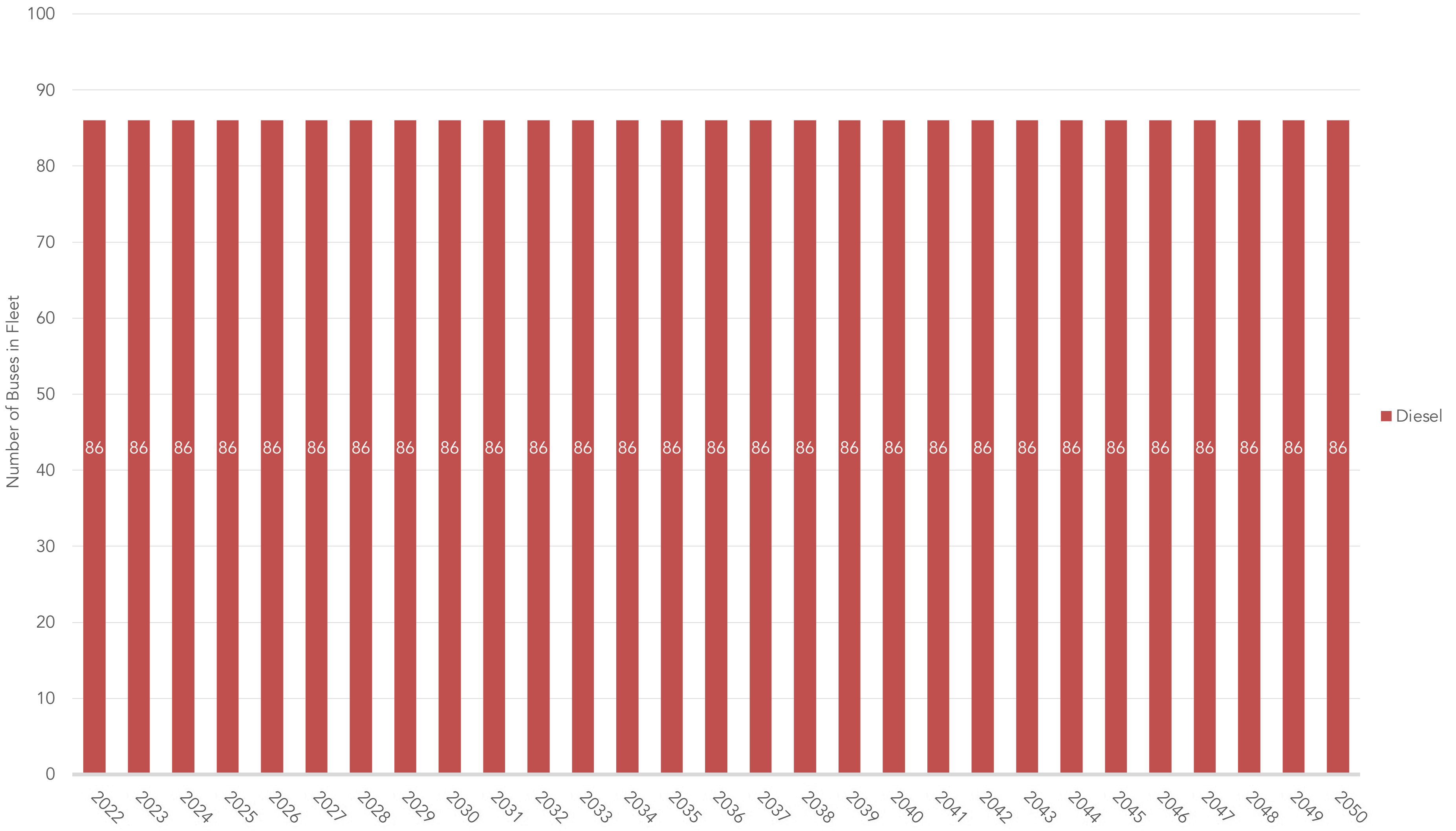
- Inflation rate of 2% applied through 2050, based on historical PPI for transportation equipment, bus bodies
- Extended battery warranty costs are accounted for in the price of the BEB ($75,000) and in the price for the FCEB ($17,000)
- Bus costs below are based on maximum price of each bus type from the 2022 WA State Contract (inflated by 12% for 2023 pricing), combined with configurable options costs provided by Intercity Transit from a recent bus purchase and battery warranty prices as mentioned in the bullet above.

| | Diesel | Electric | Fuel Cell |
|---|---|---|---|
| 35’ | $762k | $1.5M | $1.6M* |
| 40’ | $773k | $1.6M | $1.6M |

**35’ FCEBs currently not on the market; 40’ FCEB pricing assumed*

# Baseline Fleet Composition

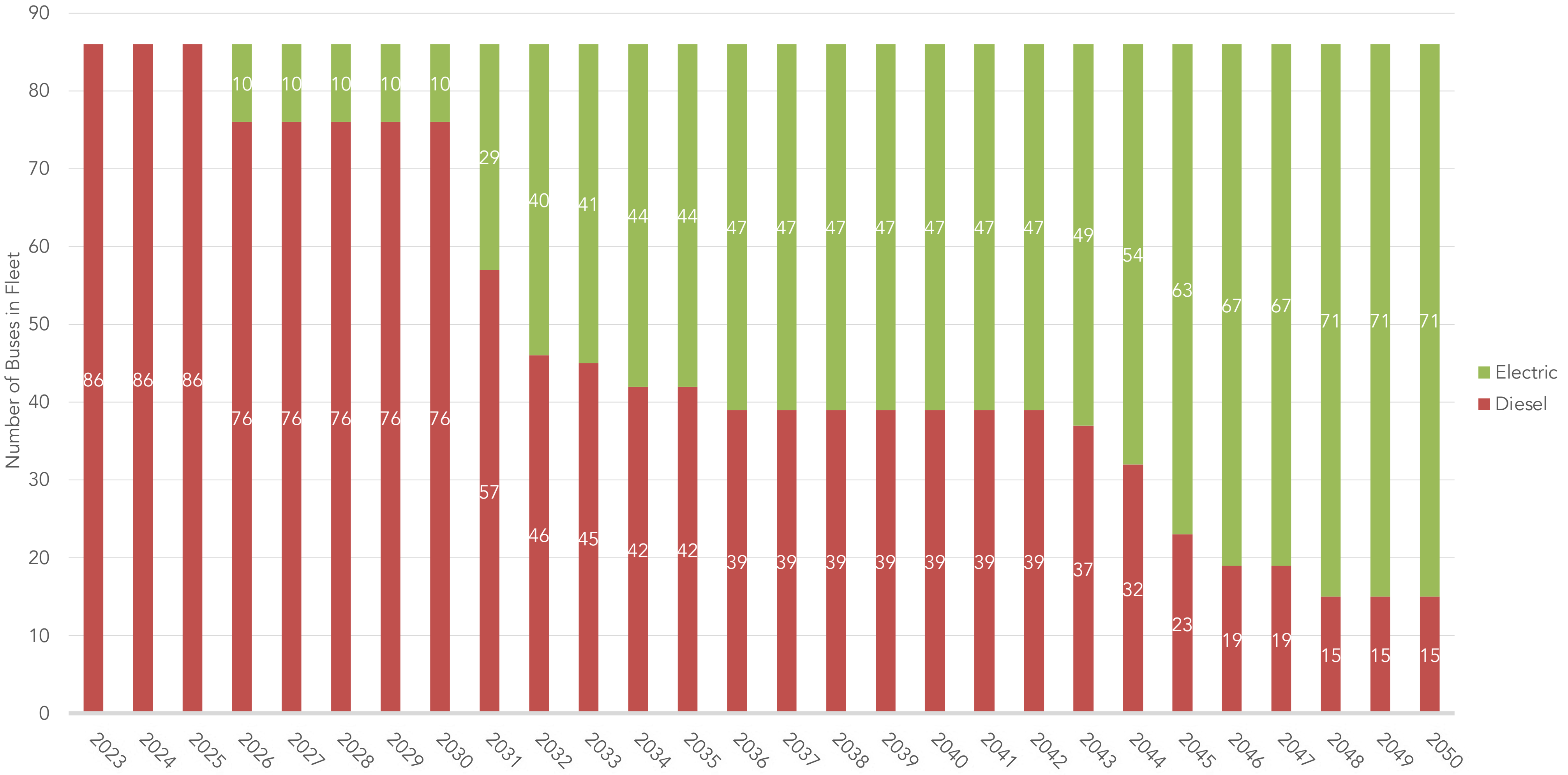
## Fixed-Route Service




Note: 'Diesel' includes both diesel and diesel-hybrid vehicles

# BEB Depot-Only Charging Fleet Composition

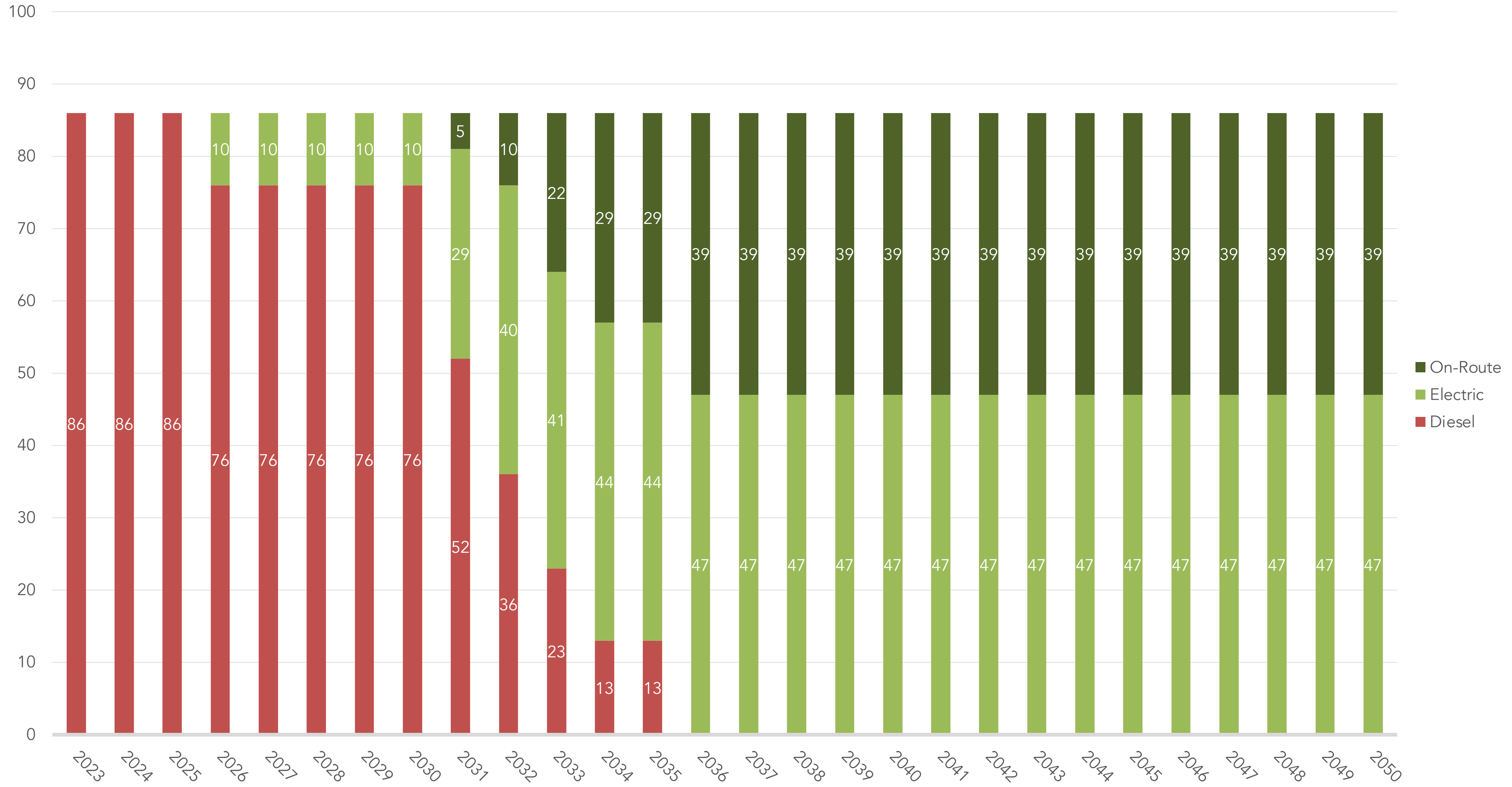
**Replaces all 35’ and 40’ diesel buses with FCEBs based on block feasibility.** All 35’ vehicles can be replaced by depot-only BEB alternatives. Since the feasibility of routes serviced by 40’ vehicles is dependent on BEB nameplate capacity improvements of 5% every other year, Intercity Transit’s depot-only BEB fleet will be 84% zero-emission by 2050. Other technology solutions will need to be considered to meet 100% zero-emission within this timeline.



# BEB Depot-Only Charging Fleet Procurement Schedule

# BEB Depot and On-Route Charging Fleet Composition

An overnight depot-charged BEB is deployed in place of a diesel bus, if the vehicle's block is feasible. An on-route charged BEB is deployed in place of a diesel bus, if the vehicle's block with overnight depot-charged BEB is infeasible. Once a bus is replaced with an on-route charged BEB, it stays on-route charged for perpetuity



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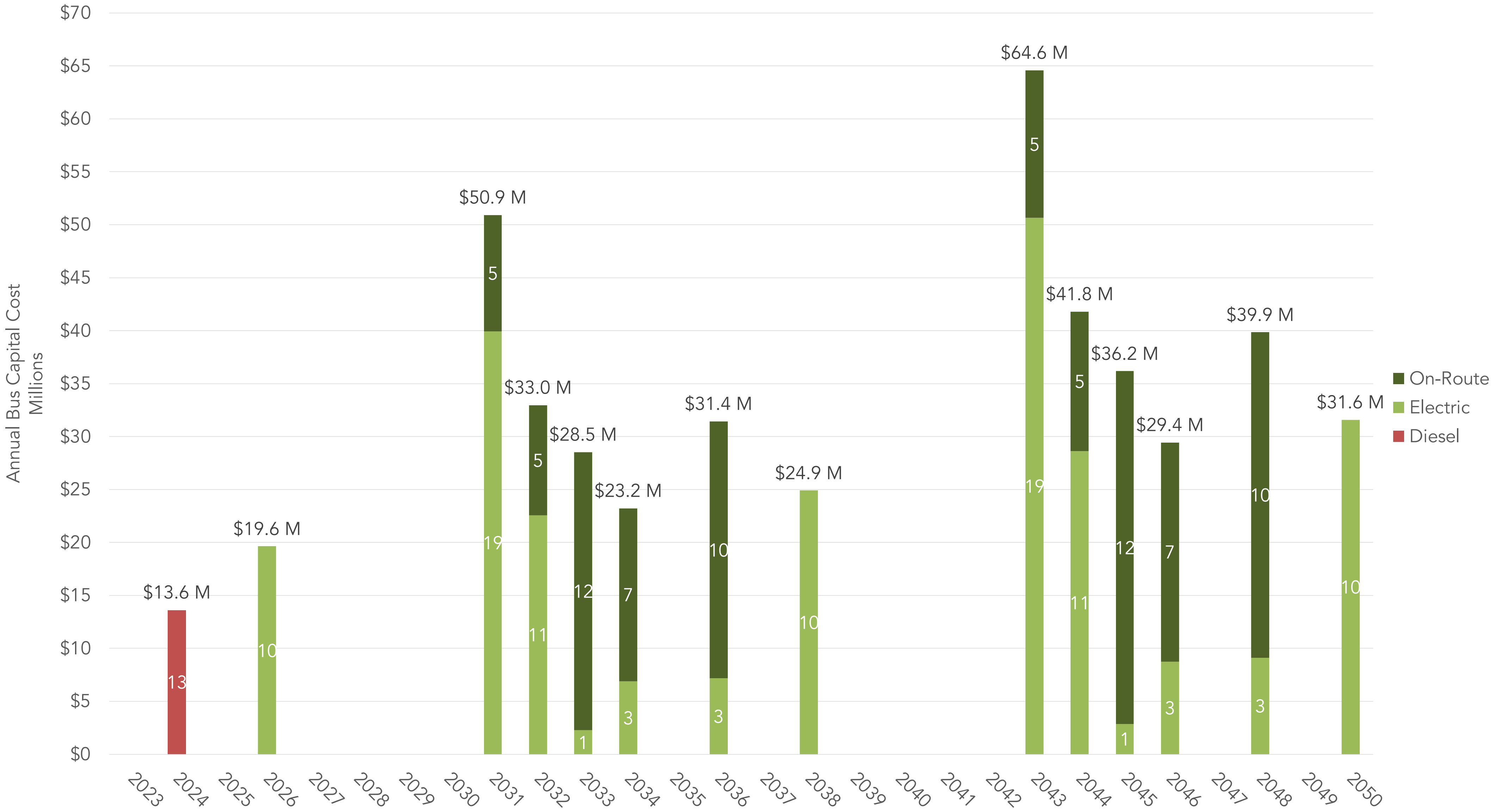
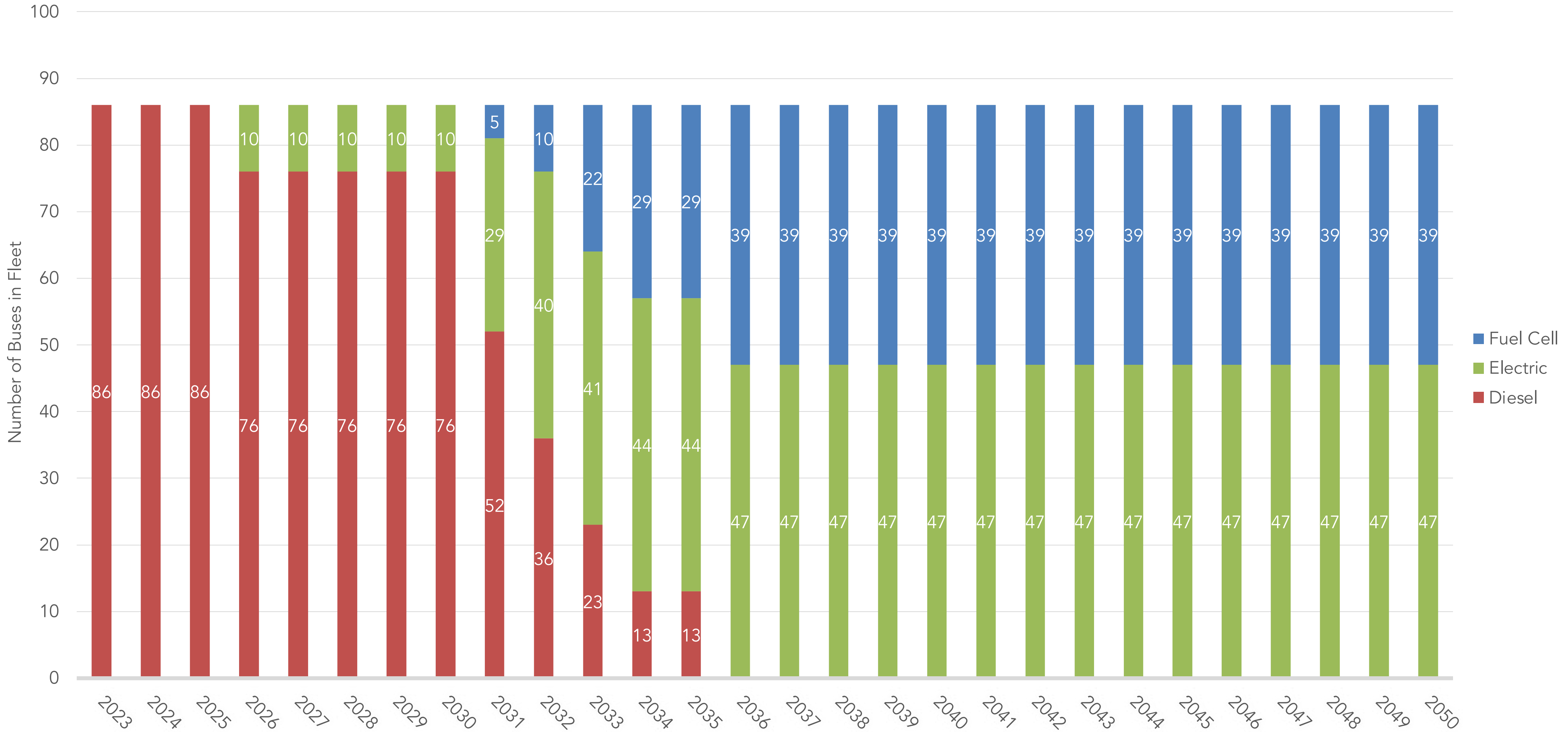


# Mixed (BEB and FCEB) Fleet Composition

A depot-charged BEB is deployed in place of a diesel bus, if the vehicle's block is feasible. An FCEB is deployed in place of a diesel bus, if the vehicle's block is infeasible with depot charged BEB. Once a bus is replaced with an FCEB, it stays FCEB for perpetuity



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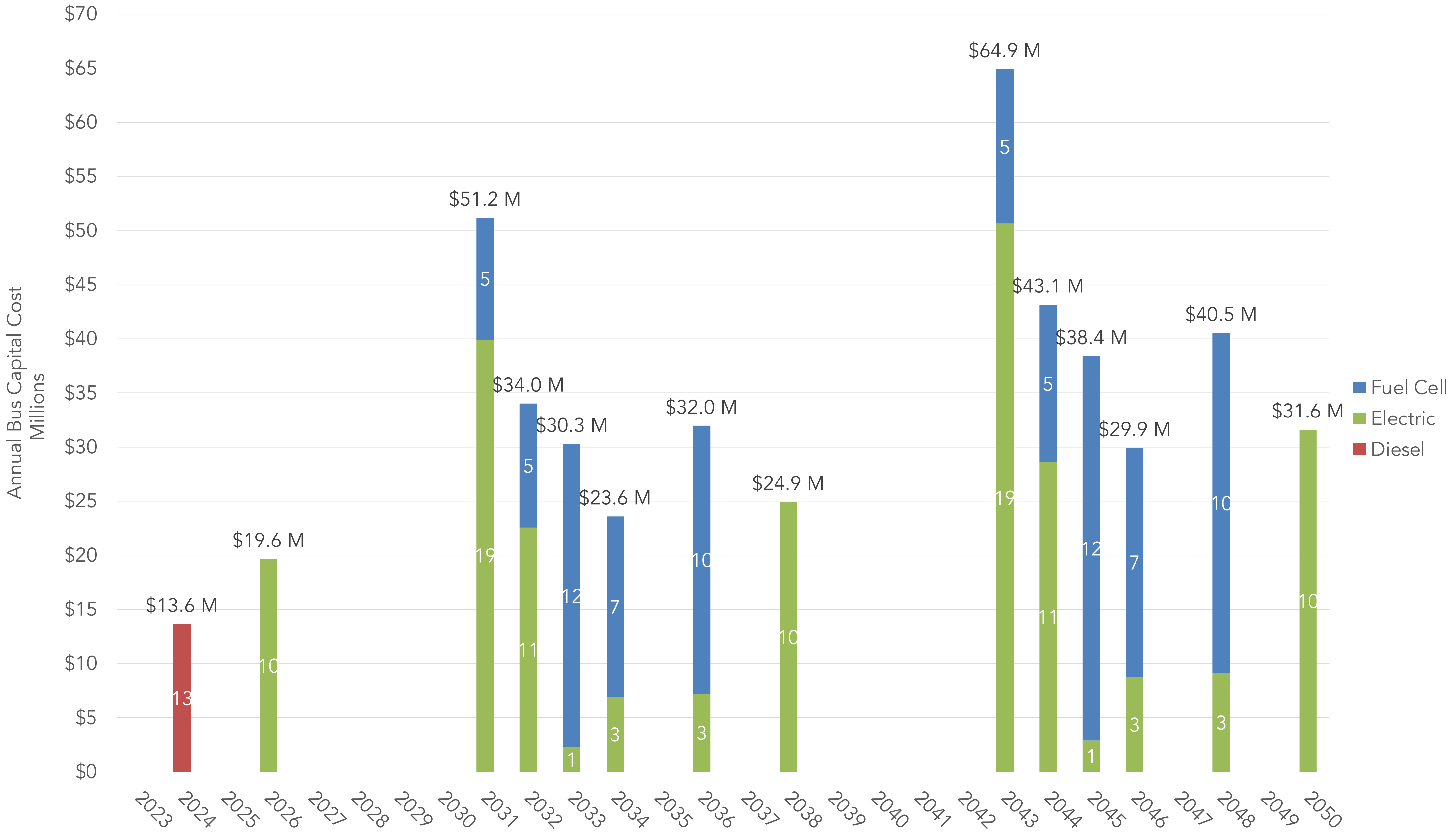
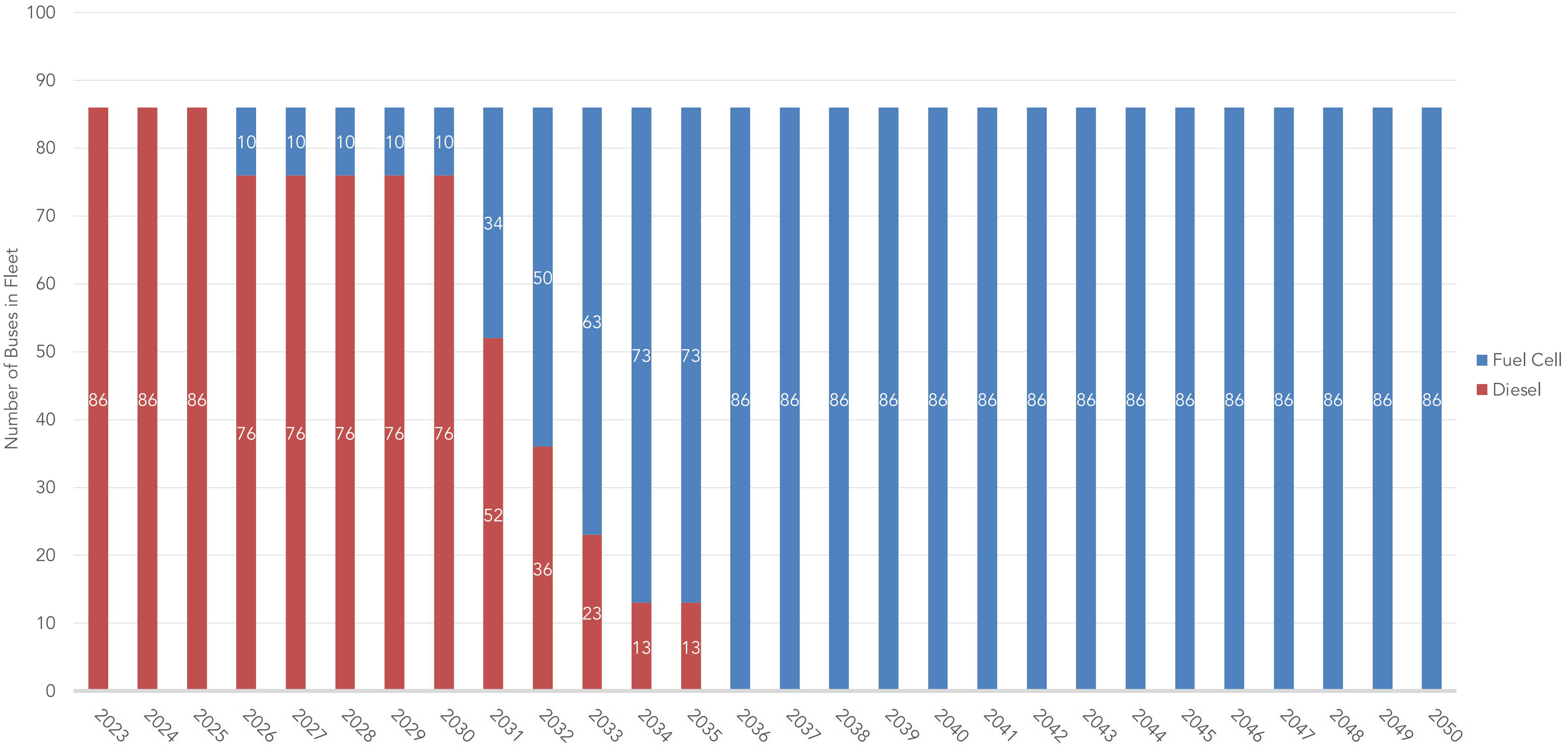
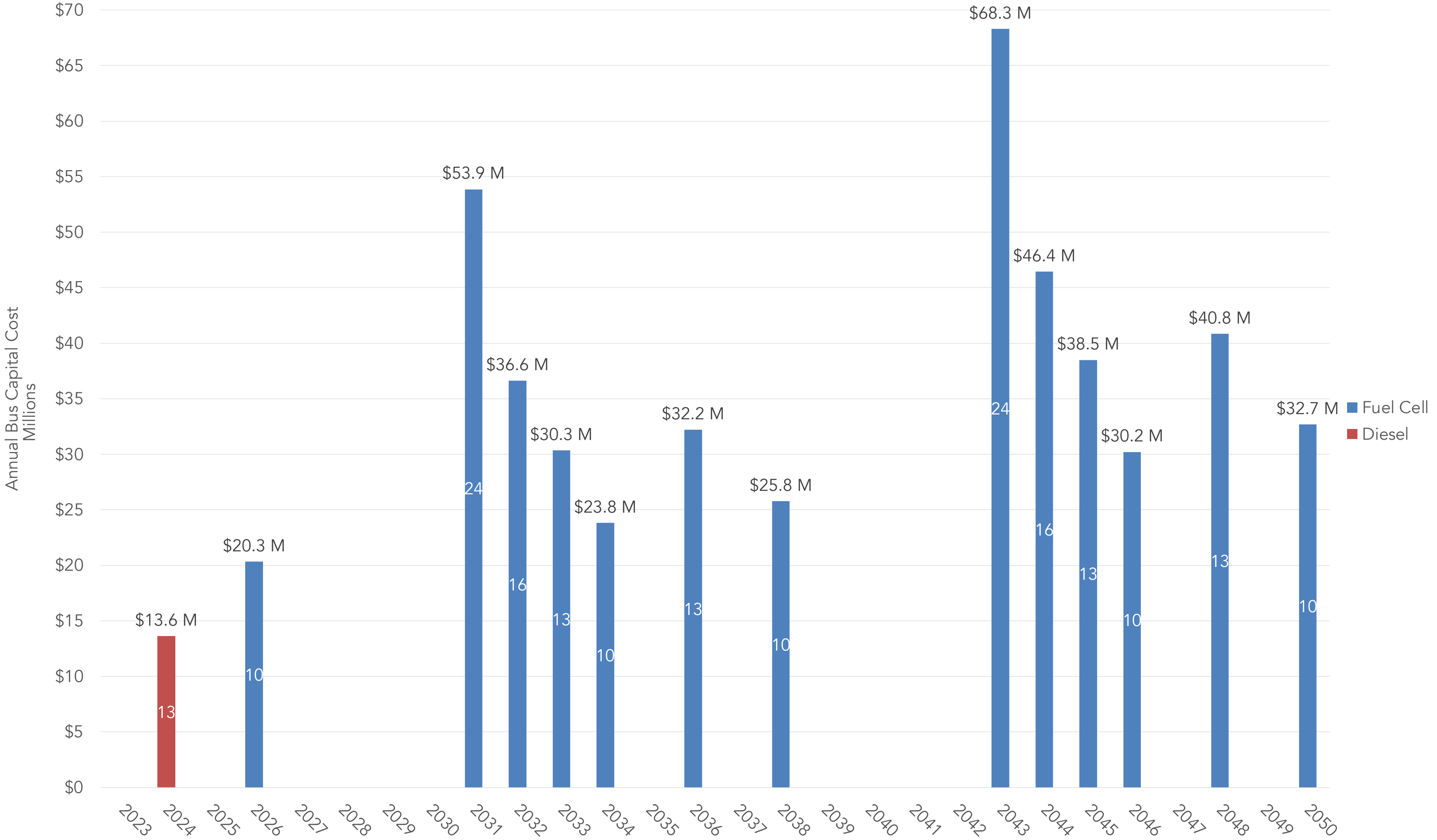


# FCEB Only Fleet Composition

**Replaces all 35' and 40' diesel buses with FCEBs based on block feasibility.** 98% of Intercity Transit's blocks are feasible based on current-day technology (350-mile range). With FCEB improvements, however, all blocks are expected to be feasible by 2050



# FCEB Only Fleet Procurement Schedule



# Summary Fleet Cost Evaluation

## All ZEB Scenarios, 2023-2050

| | Baseline | BEB Depot Charging Only | BEB Depot and On-Route Charging | Mixed Fleet (BEB/FCEB) | FCEB Only |
|---|---|---|---|---|---|
| **Cumulative Fleet Costs** | $270.3M | $408.8M | $468.6M | $477.5M | $493.5M |
| Compared to Baseline | - | +$138.5M | +$198.3M | +$207.2M | +$223.2M |
| % of Blocks Achievable by 2050 | **0%** | **83%** | **100%** | **100%** | **100%** |

# Maintenance Assessment Results

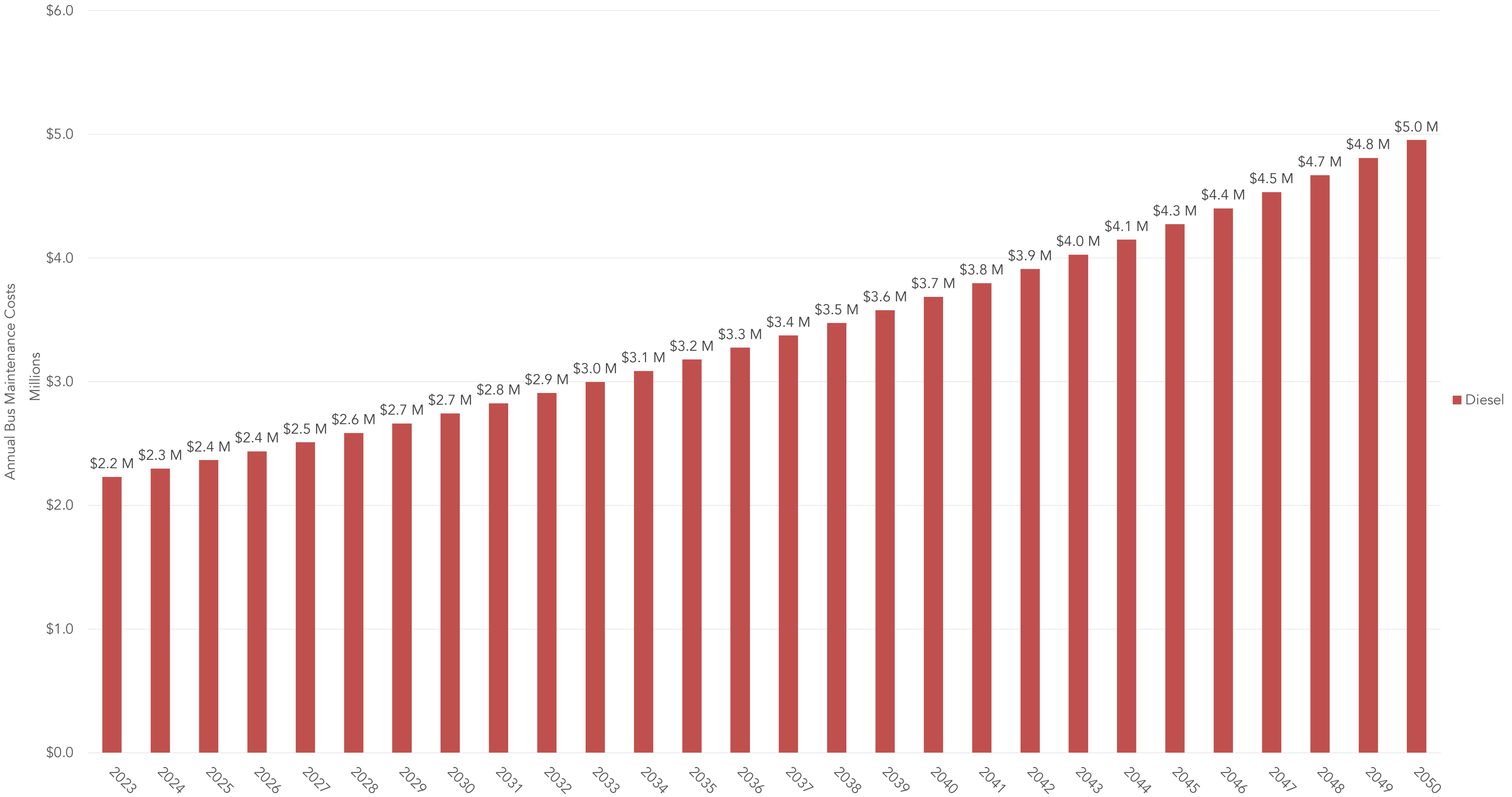
Fixed Route

# Maintenance Assessment Assumptions

- Inflation rate of 3% applied through 2050, based on historical CPI for labor
- 2022 maintenance costs for 35’ and 40’ diesel buses: **$0.59/mile**, as reported by Intercity Transit
- 2022 maintenance costs for 35’ and 40’ BEBs: **$0.41/mile**, based on a 30% reduction in BEB maintenance costs as compared to diesel buses, as reported by NREL
- 2022 maintenance costs for 35’ and 40’ FCEB: **$0.44/mile**, based on a 25% decrease in FCEB maintenance costs as compared to diesel buses, as reported by OCTA
- Avg. cost of midlife fuel cell overhauls: **$40,000**
- Only maintenance costs for fleet vehicles included in maintenance assessment; infrastructure maintenance will be included in the fuel assessment

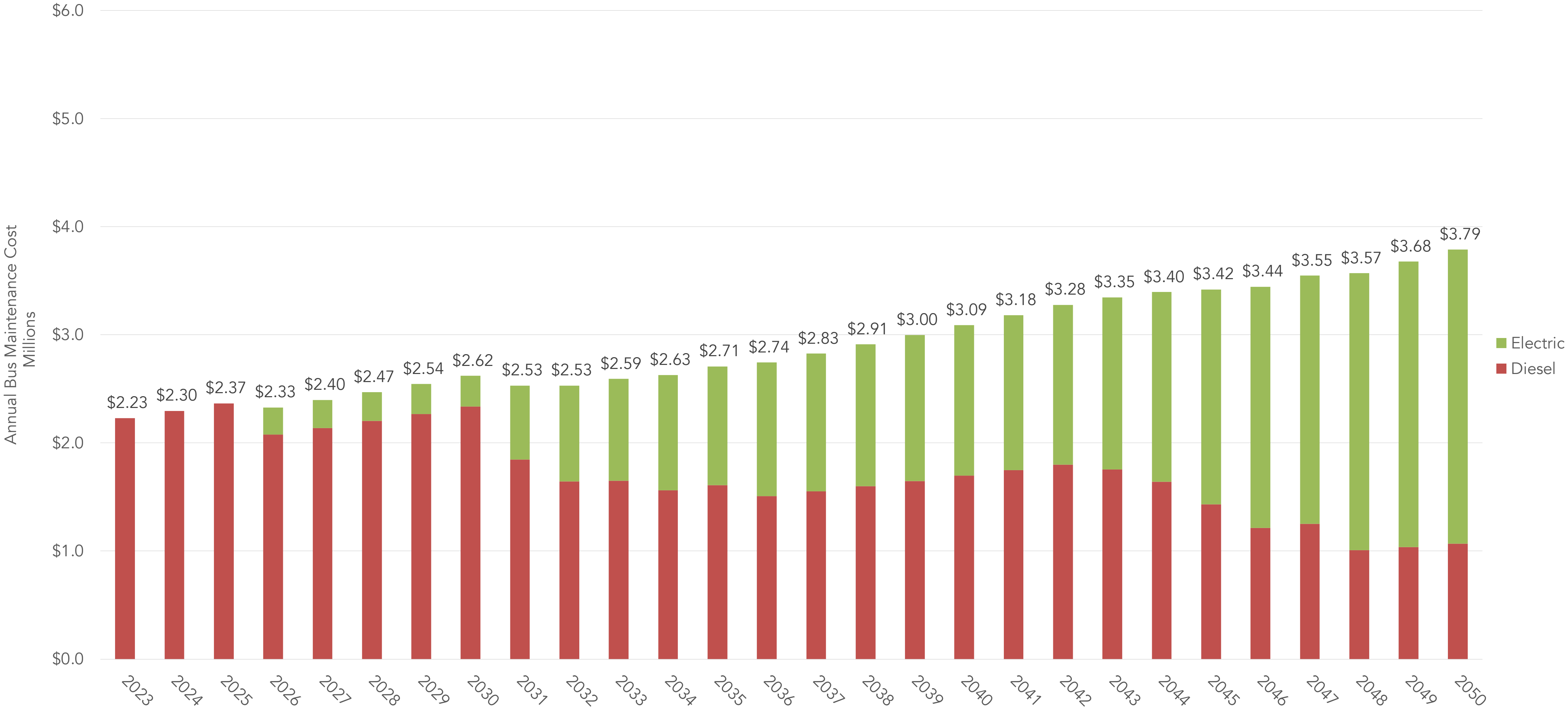
# Baseline Fleet Maintenance Costs*

## Fixed-Route Service



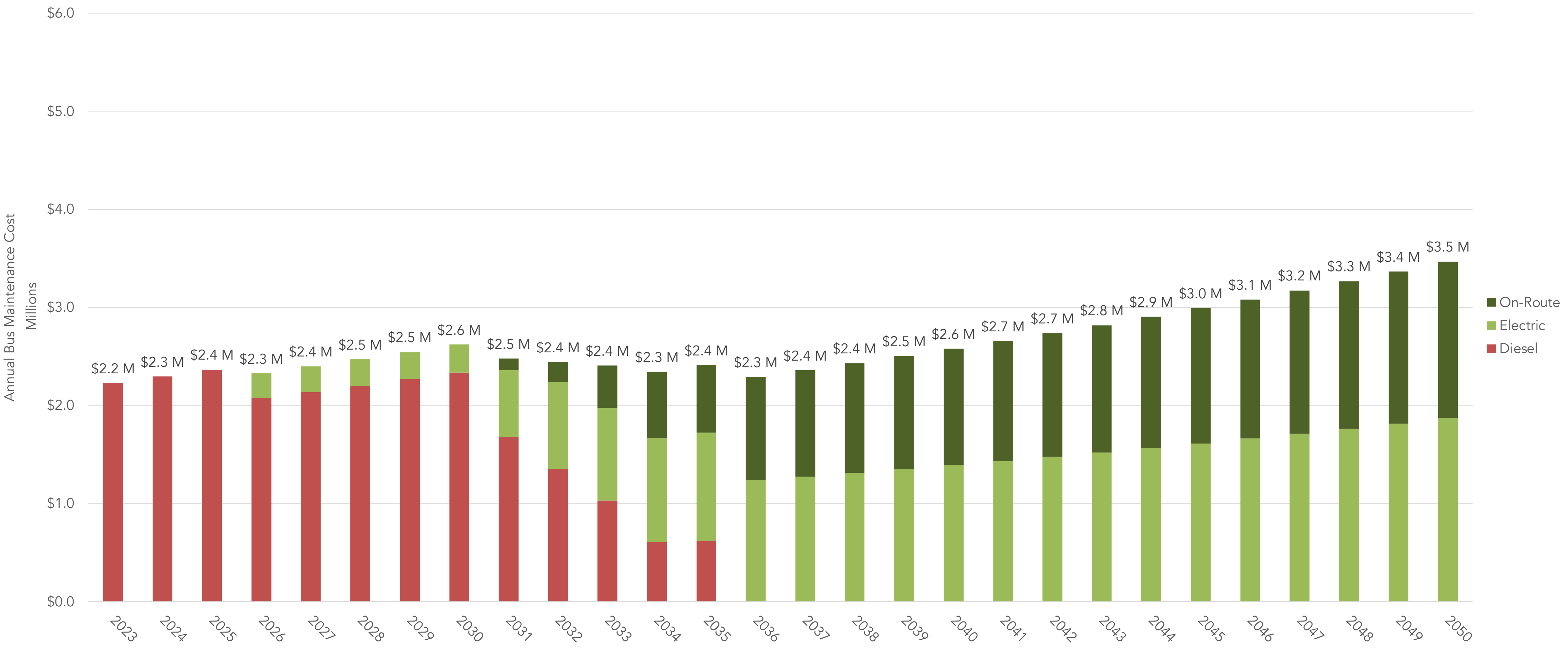

**Annual maintenance costs primarily driven by an inflation rate of 3% (based on the historical CPI for labor) applied through 2050, across vehicle parts and labor*

# BEB Depot-Only Charging Fleet Maintenance Costs




**Annual maintenance costs primarily driven by an inflation rate of 3% (based on the historical CPI for labor) applied through 2050, across vehicle parts and labor*

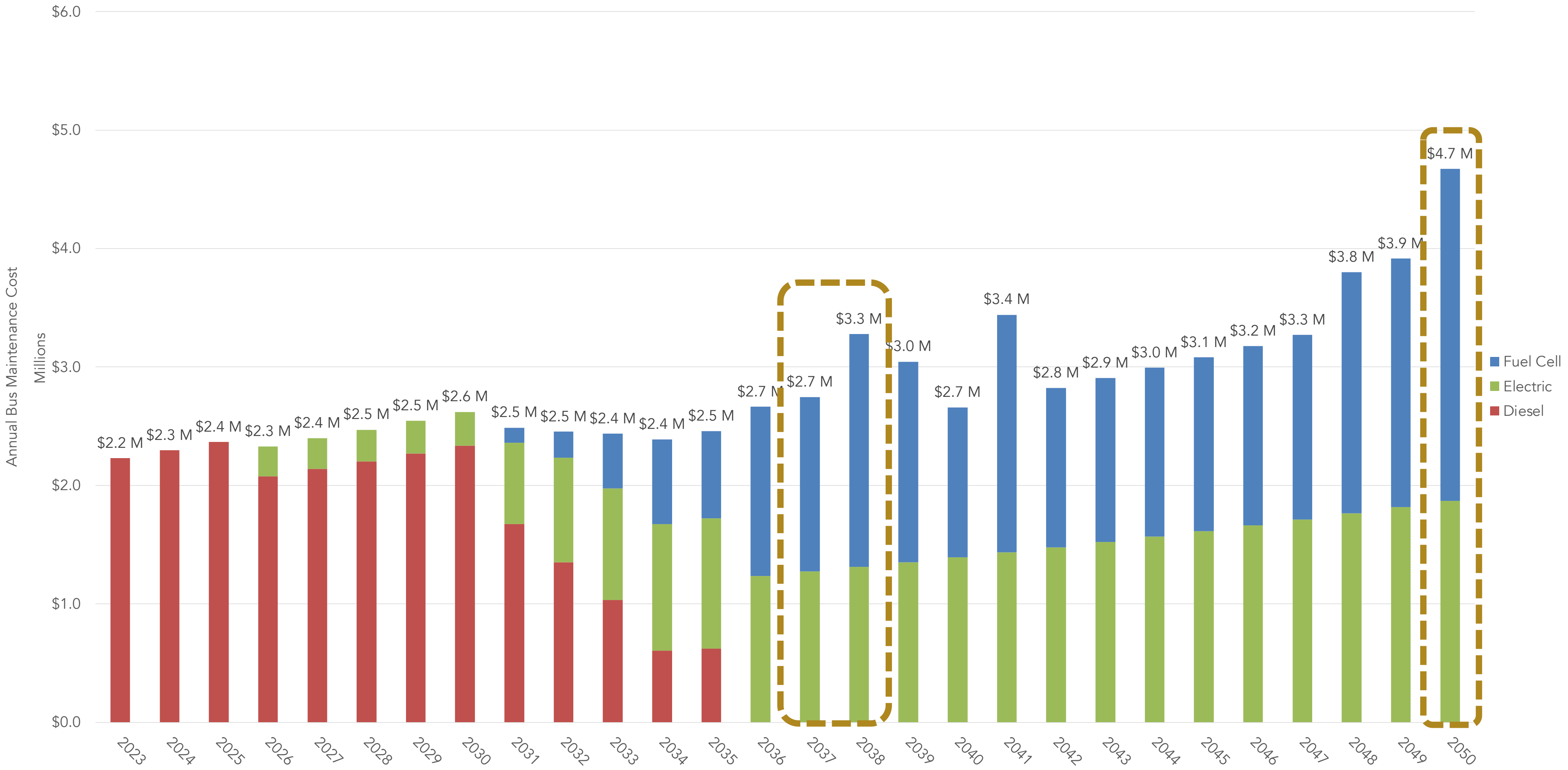
# BEB Depot and On-Route Charging Fleet Maintenance Costs




**Annual maintenance costs primarily driven by an inflation rate of 3% (based on the historical CPI for labor) applied through 2050, across vehicle parts and labor*

# Mixed (BEB and FCEB) Fleet Maintenance Costs

FCEB fleet incurs mid-life fuel cell overhaul costs

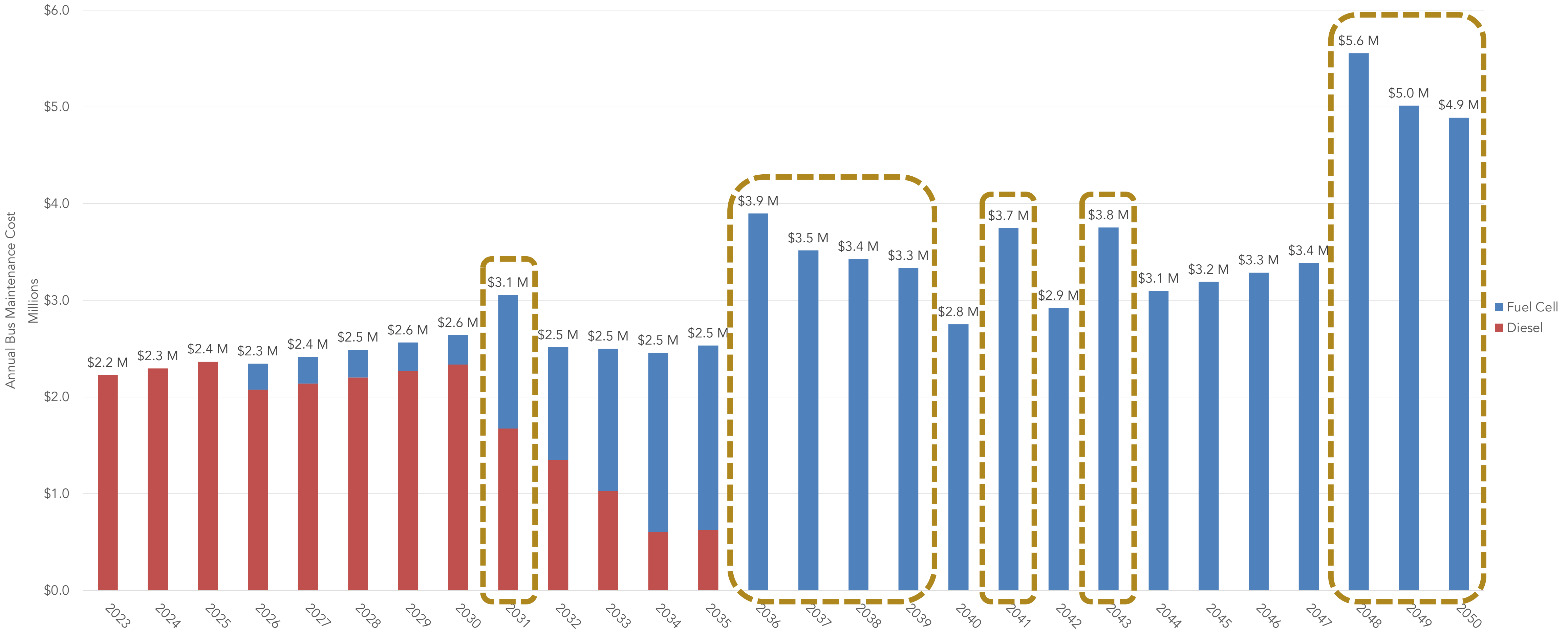



cte

*Annual maintenance costs primarily driven by an inflation rate of 3% (based on the historical CPI for labor) applied through 2050, across vehicle parts and labor*

# FCEB Only Fleet Maintenance Costs

FCEB fleet incurs mid-life fuel cell overhaul costs




**Annual maintenance costs primarily driven by an inflation rate of 3% (based on the historical CPI for labor) applied through 2050, across vehicle parts and labor*

# Summary Maintenance Cost Evaluation

## All ZEB Scenarios, 2023-2050

| | Baseline | BEB Depot Charging Only | BEB Depot and On-Route Charging | Mixed Fleet (BEB/FCEB) | FCEB Only |
|---|---|---|---|---|---|
| **Cumulative Maintenance Costs** | $95.7M | $81.4M | $74M | $79.9M | $88.2M |
| Compared to Baseline | - | -$14.3M | -$21.7M | -$15.8M | -$7.5M |
| % of Blocks Achievable by 2050 | **0%** | **83%** | **100%** | **100%** | **100%** |

# Fuel Assessment Results

Fixed Route

# Fuel Assessment Assumptions

## Fuel Consumption

- Diesel:
    - 35’ Fuel Efficiency: 5.49 MPDGE
    - 40’ Fuel Efficiency: 4.70 MPDGE
- Depot Electricity:
    - 35’/40’ BEB Fuel Efficiency: 2.08 kWh/mi
    - Depot Charger Rated Power: 150 kW
    - Dispensers per Charger: 2
    - Charger Utilization: 50%
    - Vehicle Utilization: 80% (based on a spare ratio of 20%)
    - Charger Efficiency: 90%

# Fuel Assessment Assumptions

## Fuel Consumption

- On-Route Electricity:
    - 35'/40' BEB Fuel Efficiency: 2.08 kWh/mi
    - On-Route Charger Rated Power: 350 kW
    - No. of Buses per Charger: 4
    - Charger Efficiency: 90%
    - % of On-Route Energy: 80% (i.e., on-route BEBs obtain 80% of their energy through opportunity charging, and the remaining 20% of energy is obtained at the depot through overnight charging)
- Hydrogen
    - 35'/40' FCEB Fuel Efficiency: 0.12 kg/mi
    - Hydrogen Safety Factor: 20% (hydrogen-related losses through venting and transportation are taken into account)

# Fuel Assessment Assumptions

## Fuel Costs

- Diesel:
    - Fluctuating inflation rate applied through 2050, based on the EIA's projection for diesel (transportation) fuel
    - 2022 price for diesel: $4.80/DGE, as reported by Intercity Transit
- Electricity:
    - Fluctuating inflation rate applied through 2050, based on the EIA's projection for electricity as a transportation fuel
    - Electricity costs assumed to be driven by Puget Sound Energy's (PSE) Schedule 26 for Large Demand General Service (>350 kW) (see Appendix for detailed charges).
        - Reactive demand charges are not taken into consideration

| Electricity Charges | Oct - Mar | Apr - Sept | Total Charges |
|---|---|---|---|
| Basic Charge (per Meter per Month) | | | **$109.08** |
| Demand Charges (per kW) | $15.24 | $11.16 | **$13.20*** |
| Energy Charges (per kWh) | | | **$0.080788** |

- Charger maintenance costs of $3,000 applied per depot and on-route charger

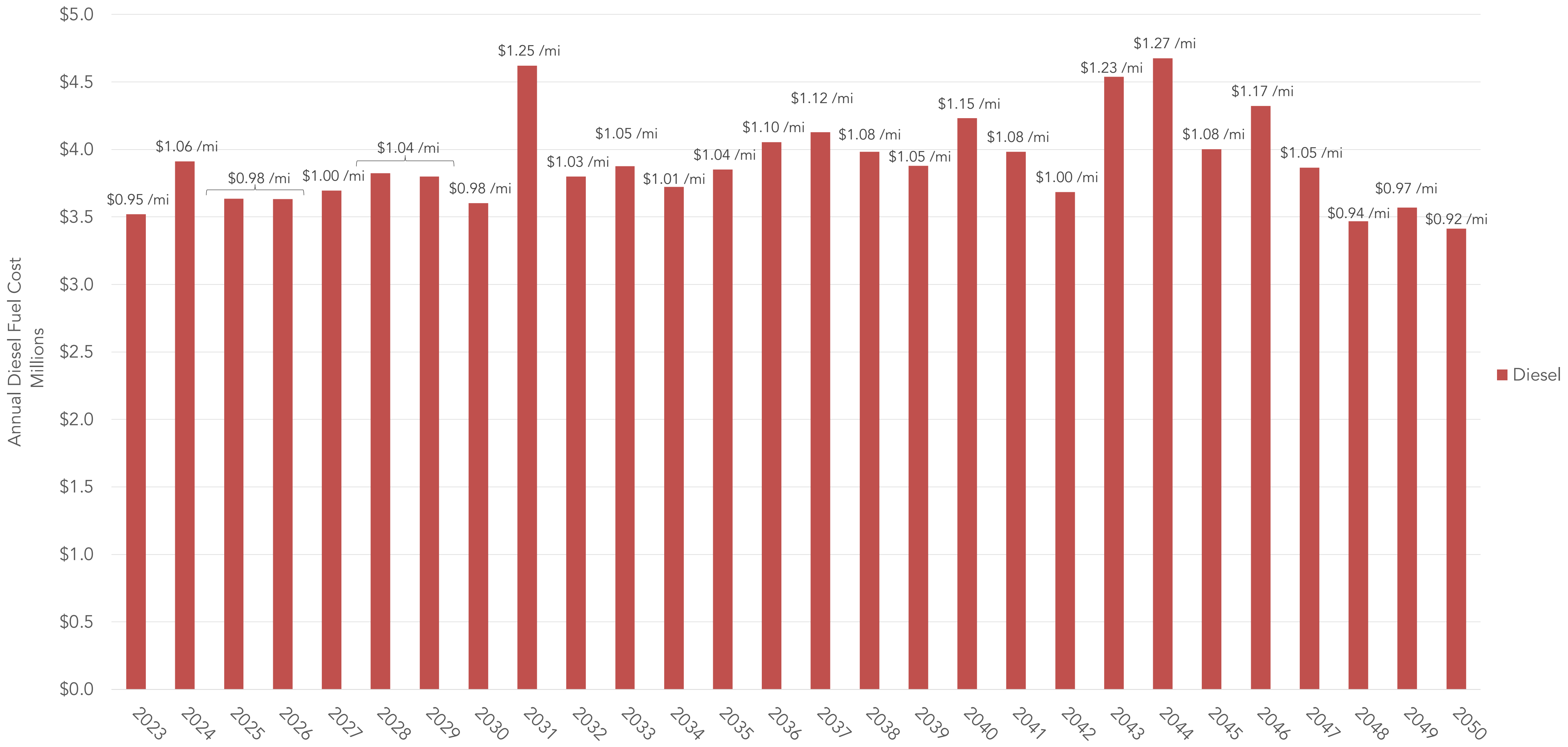
**Total demand charges applied to the fuel costs are an average of summer and winter electricity rates, provided the fuel consumption remains consistent throughout the year.*

# Fixed Route Assumptions

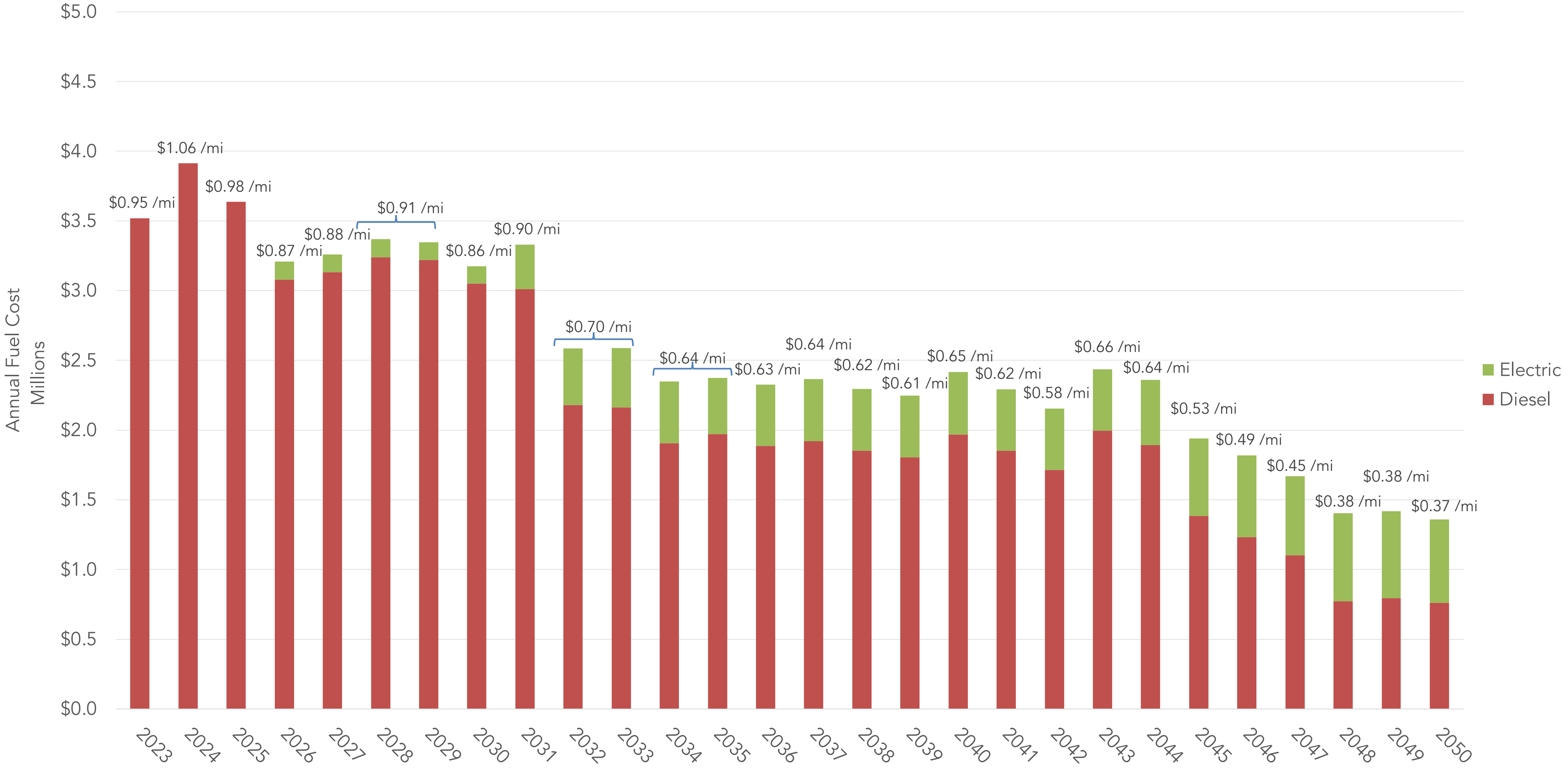
## Fuel Costs

- Hydrogen:
  - Fluctuating inflation rate applied through 2050, based on the EIA's projection for compressed natural gas (transportation) fuel
  - Additional sensitivity analysis provided for the *Mixed* and *FCEB-Only* ZEB scenarios, to project a reduction in hydrogen costs by 3% YOY beginning in 2026 – assuming infrastructure has been built out for regional hydrogen production
  - 2023 price for hydrogen: $8.61/kg, based on the average Year 1 and Year 2 costs outlined in the GETBus + PlugPower temporary hydrogen fueling contract, dated March '23

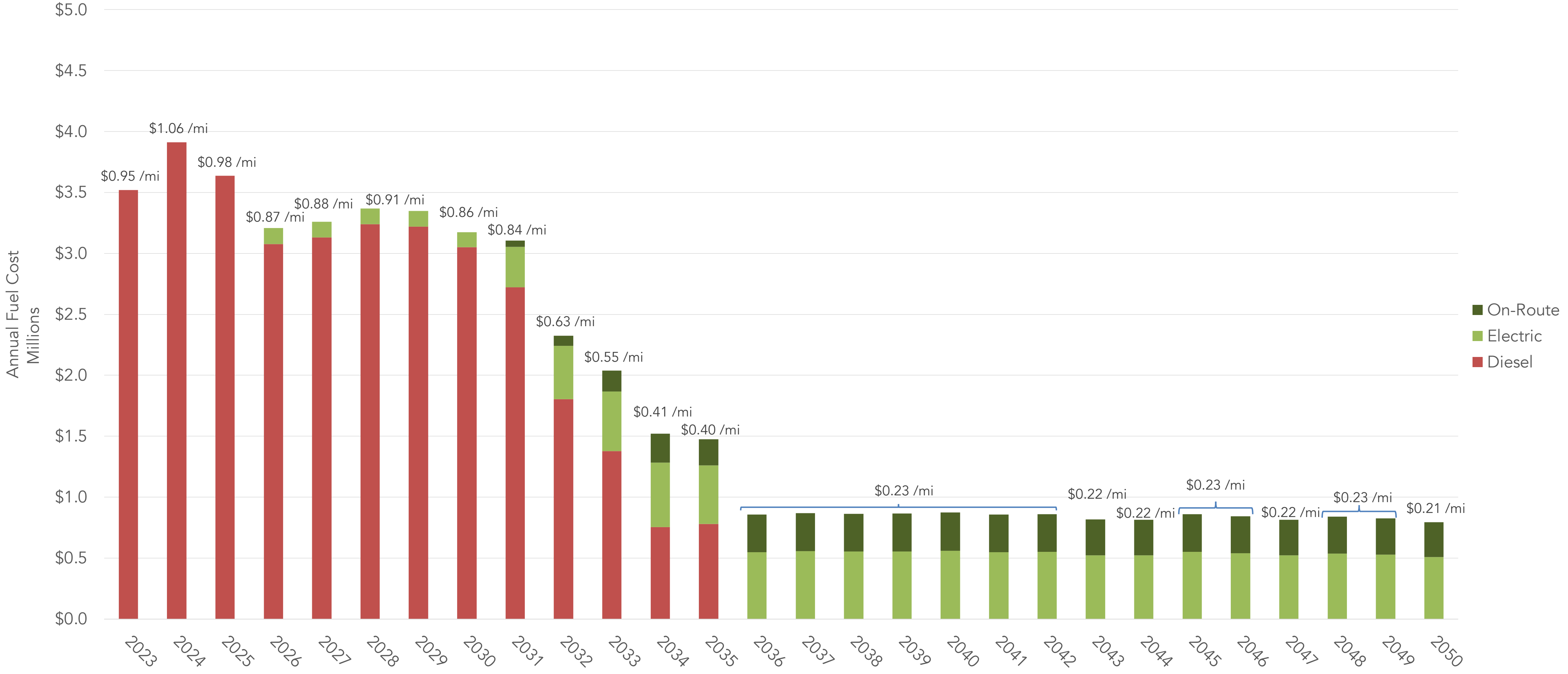
# Baseline Fleet Fuel Costs



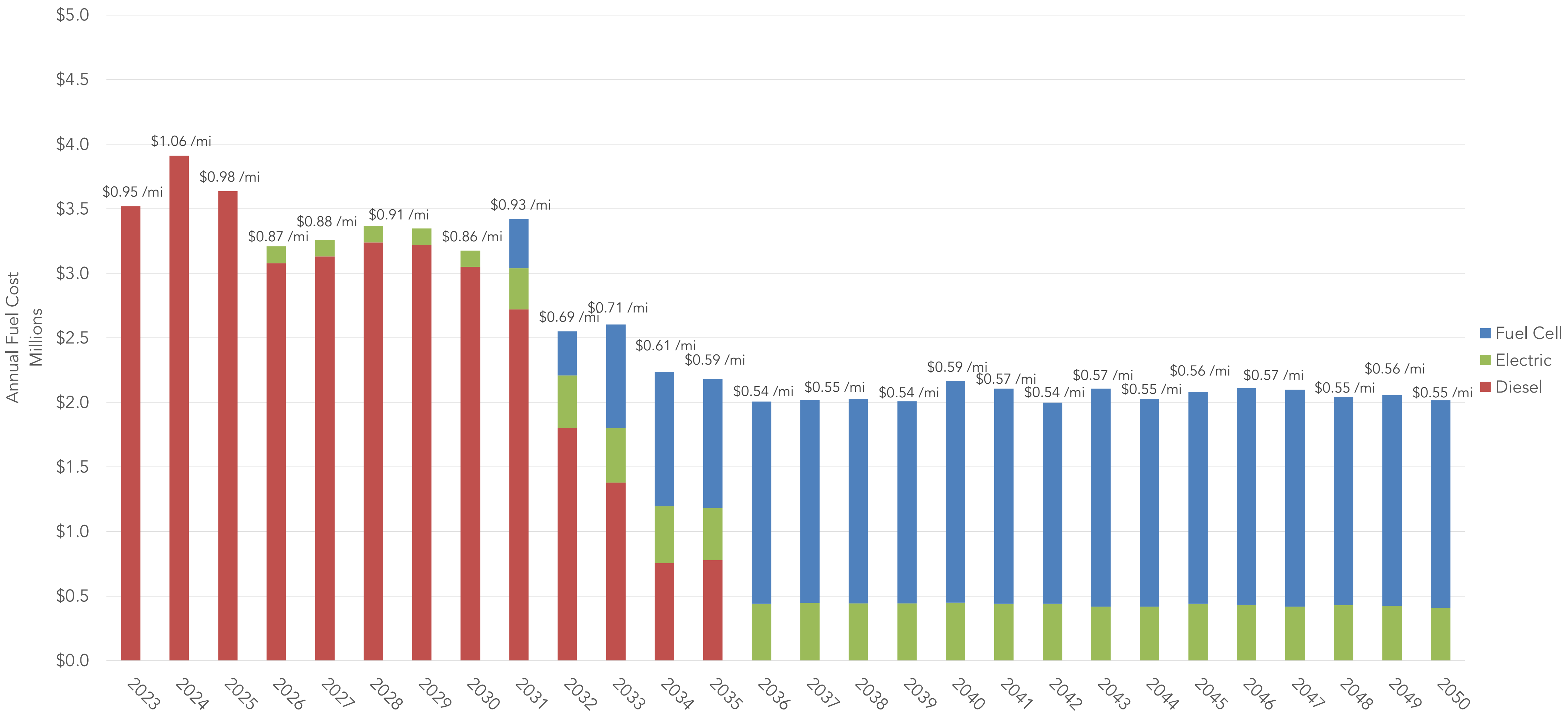
# BEB Depot-Only Fleet Fuel Costs



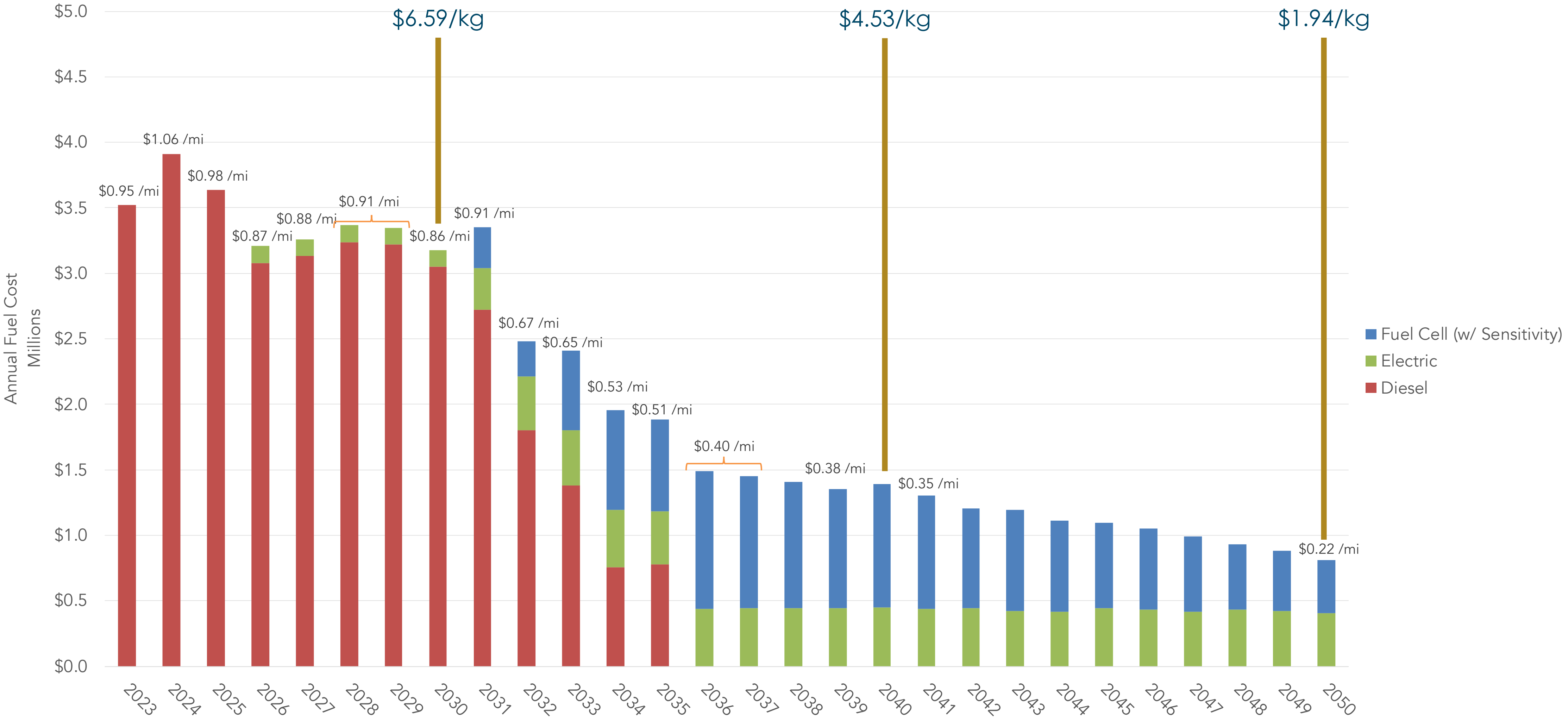
# BEB Depot and On-Route Fleet Fuel Costs



# BEB Depot and FCEB Fleet Fuel Costs

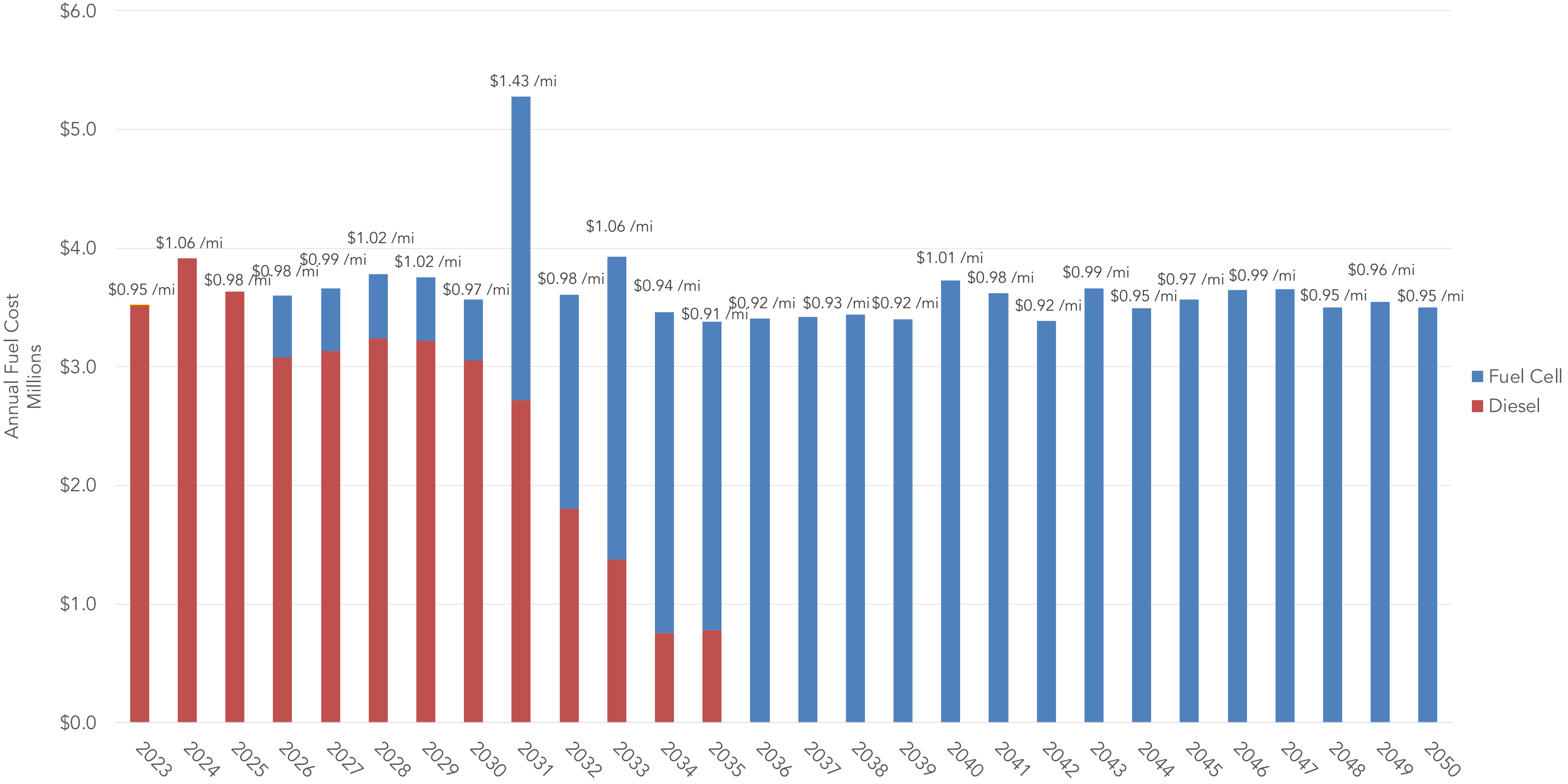


# Sensitivity Analysis - BEB Depot and FCEB Fleet Fuel Costs

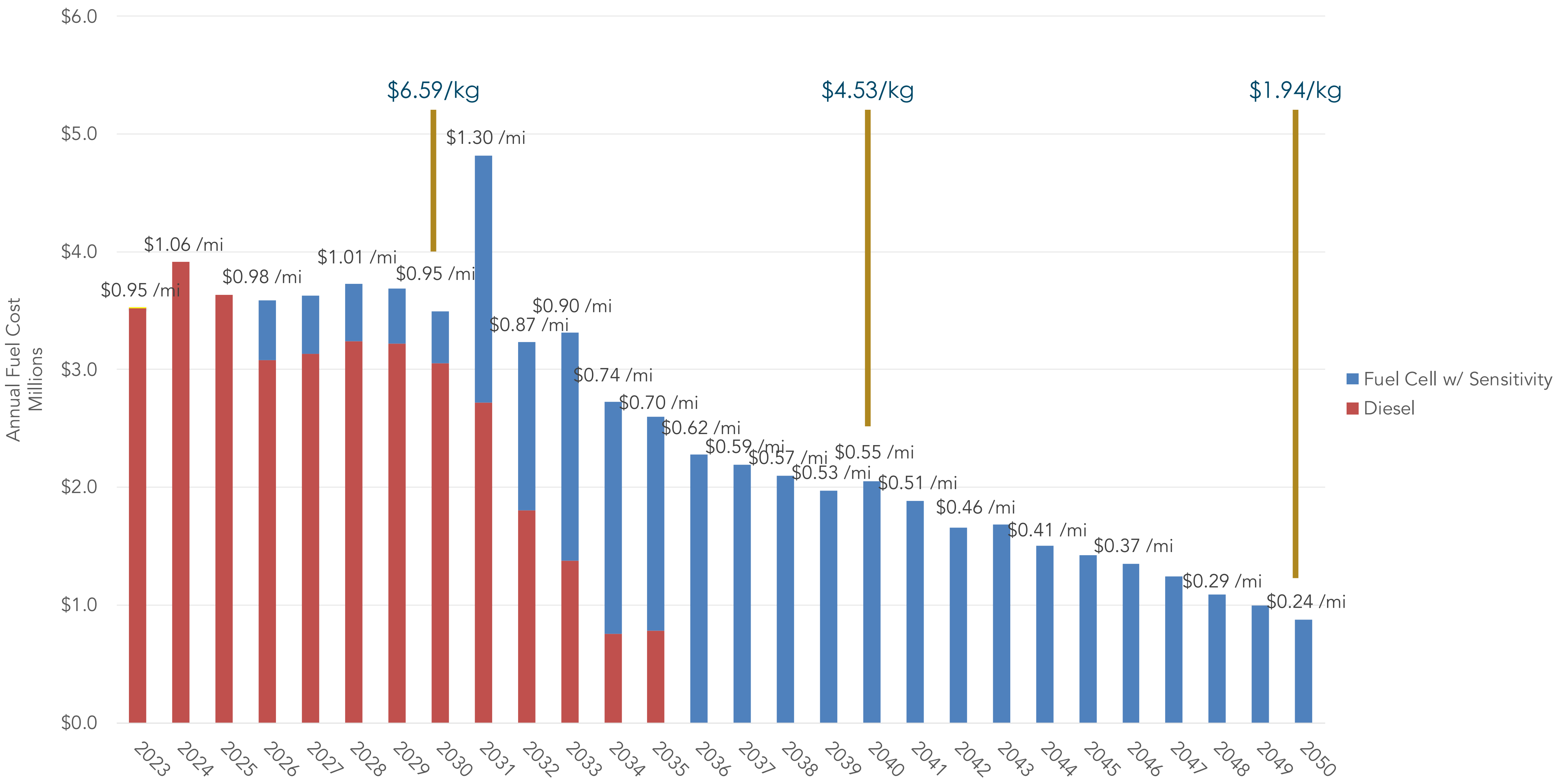



*A sensitivity analysis based on a 3% YOY reduction in hydrogen fuel costs indicates that by 2040, hydrogen will be priced at $4.53/kg, and $1.94/kg in 2050.*

# FCEB Fleet Fuel Costs



# Sensitivity - FCEB Fleet Fuel Costs




*A sensitivity analysis based on a 3% YOY reduction in hydrogen fuel costs indicates that by 2040, hydrogen will be priced at $4.53/kg, and $1.94/kg in 2050.*

# Summary Fuel Cost Evaluation

## All ZEB Scenarios, 2023-2050

| | Baseline | BEB Depot Charging Only | BEB Depot and On-Route Charging | Mixed Fleet (BEB/FCEB) | Mixed Fleet (BEB/FCEB) (w/ Sensitivity) | FCEB Only | FCEB Only (w/ Sensitivity) |
|---|---|---|---|---|---|---|---|
| **Cumulative Fuel Costs** | **$109.3M** | **$71.1M** | **$50.1M** | **$71.3M** | **$57.2M** | **$102.1M** | **$70.2M** |
| Compared to Baseline | - | -$38.2M | -$59.1M | -$38M | -$52.1M | +$7.2M | -$39.1M |
| % of Blocks Achievable by 2050 | **0%** | **83%** | **100%** | **100%** | **100%** | **100%** | **100%** |

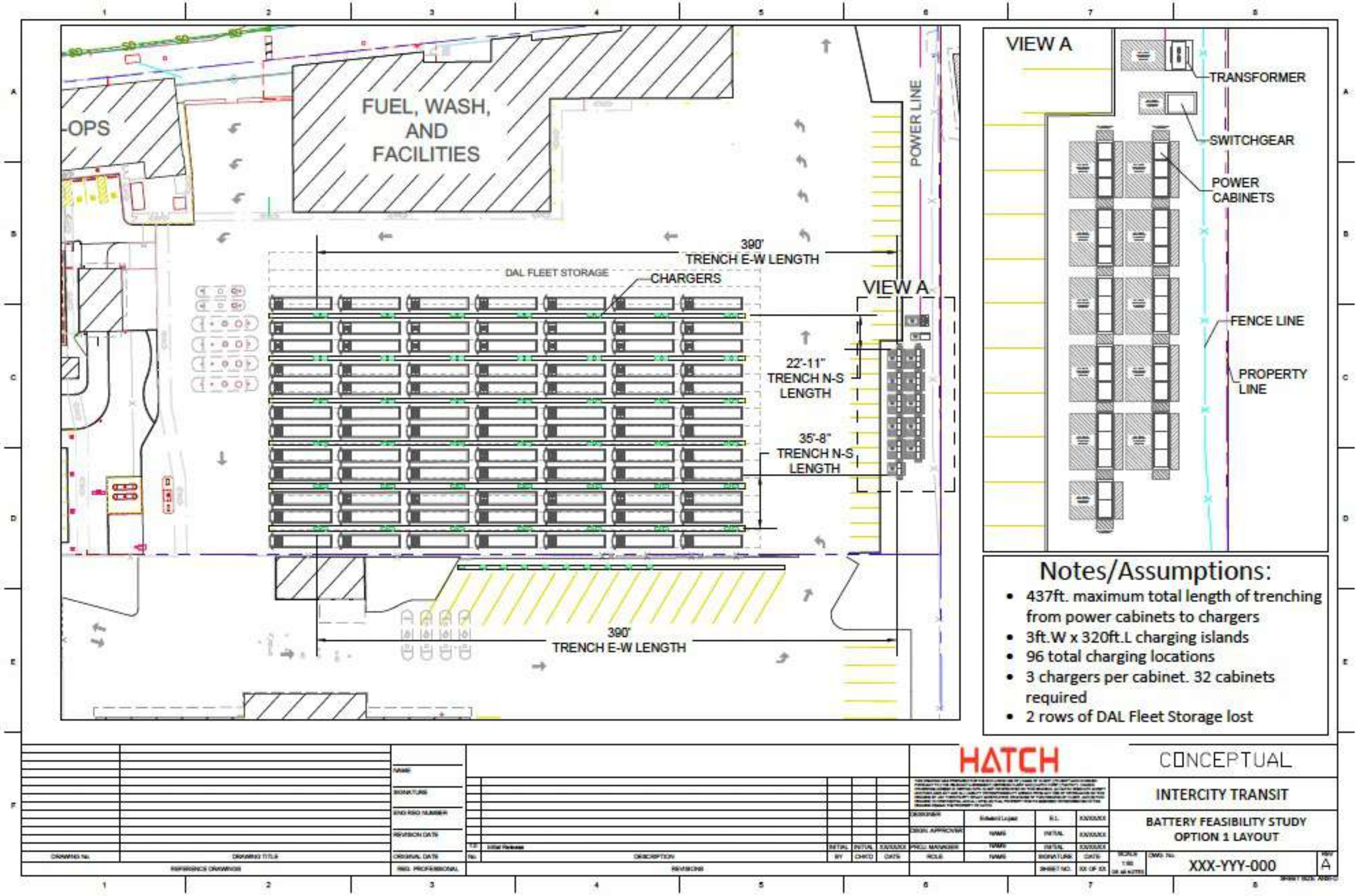
# Infrastructure Assessment Results

Fixed Route

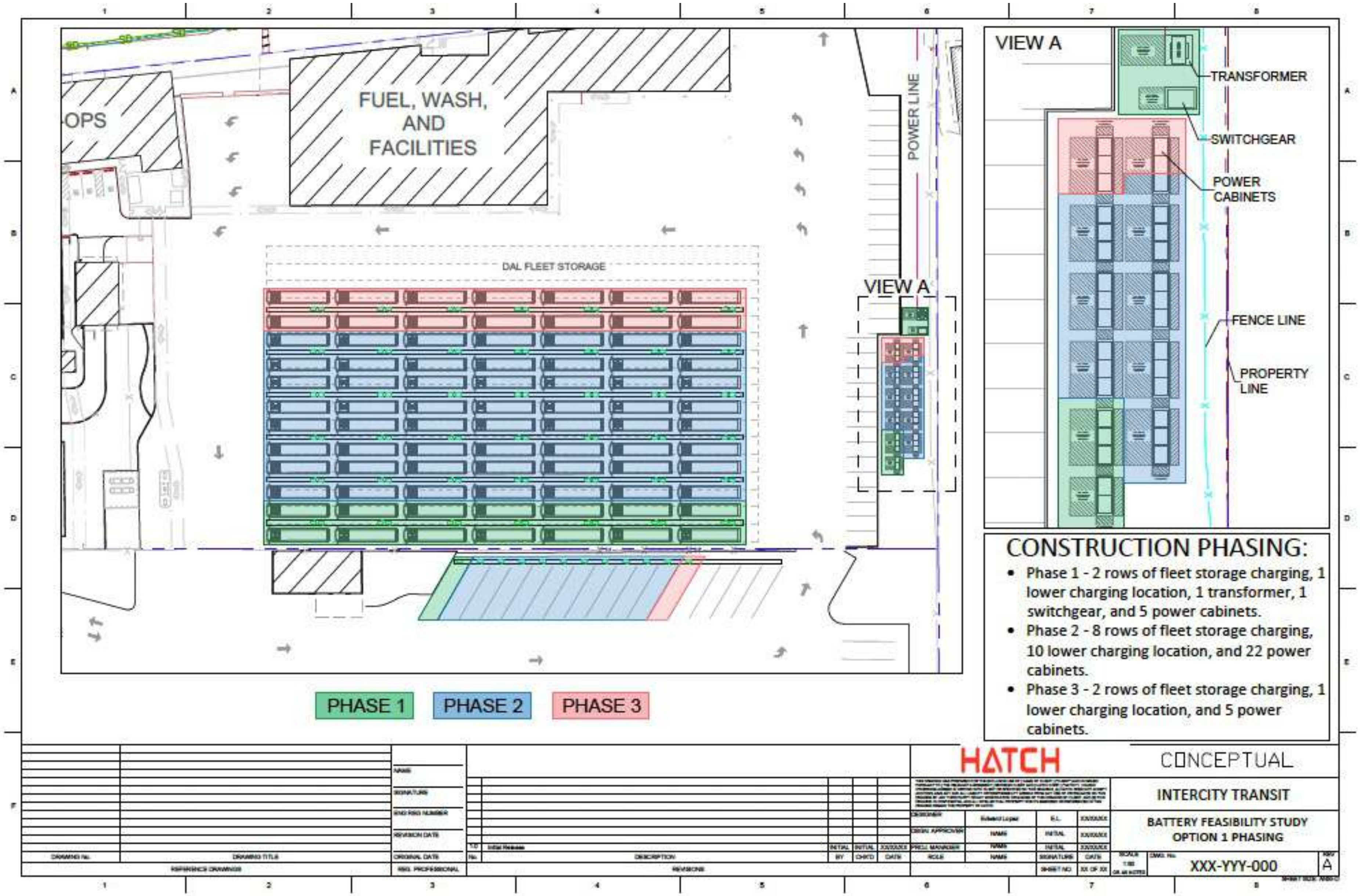
# Infrastructure Assessment Assumptions

- CTE and Hatch assumed Intercity Transit's *Baseline* fleet is a continuation of today's operations, and therefore infrastructure costs are not considered for this business-as-usual scenario
- No land acquisition costs are included in the project costs.
- An inflationary rate of 3% YOY was applied to the infrastructure costs through 2050, based on the historical CPI for labor

# Depot Charging Infrastructure Layout

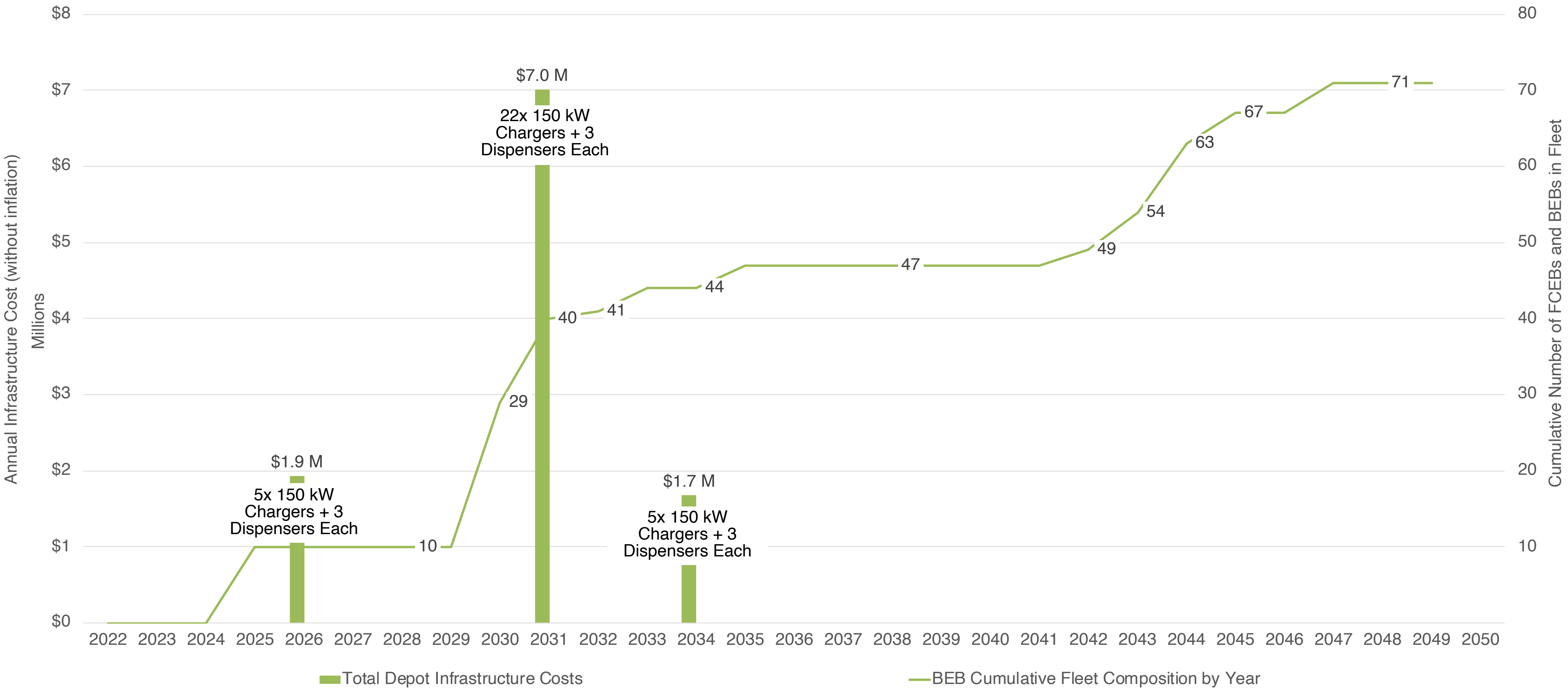


# Depot Charging Infrastructure Layout



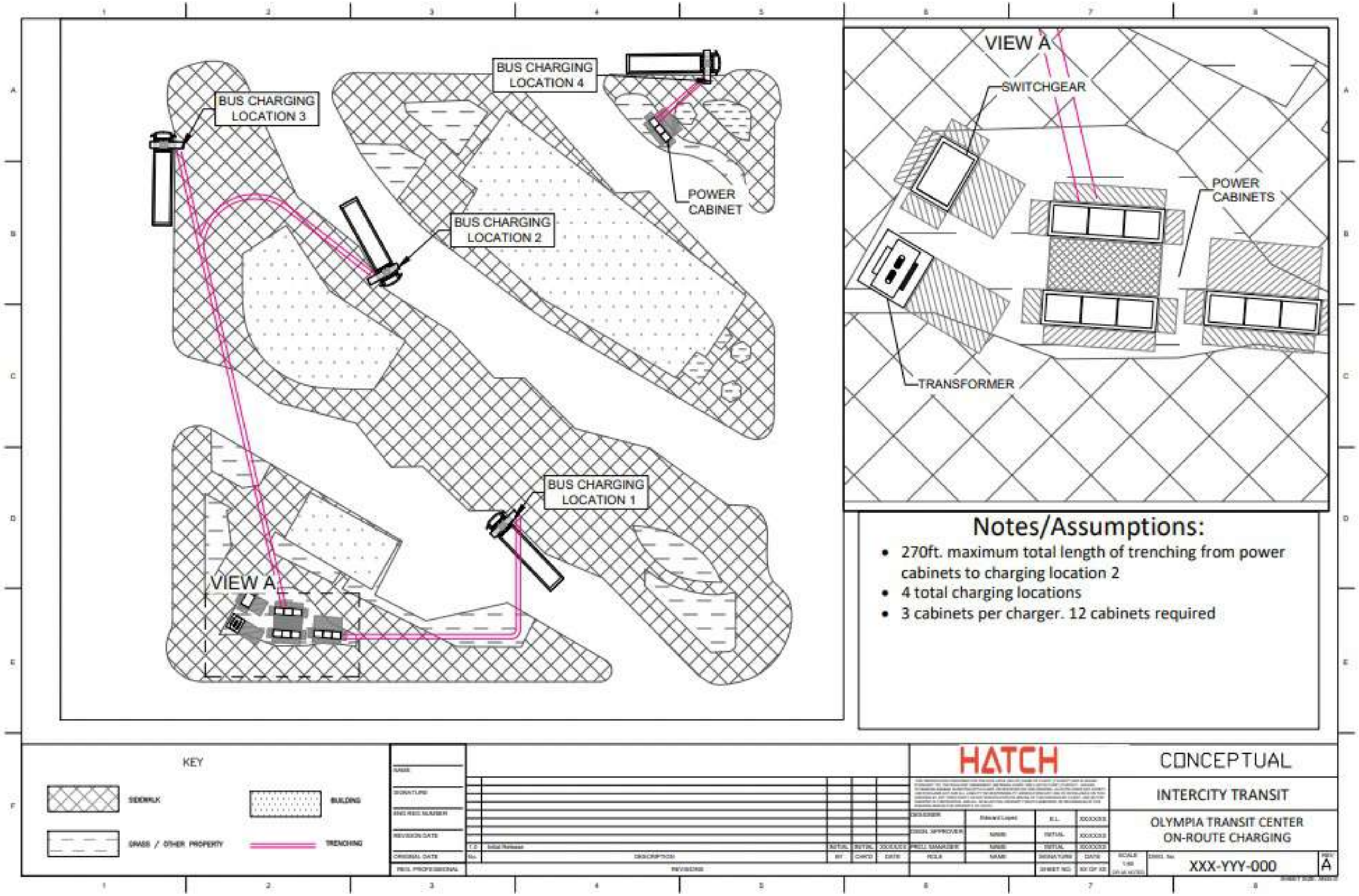
# Depot-Only BEB Scenario

## Infrastructure Assessment (83% ZEB by 2050)



# On-Route Charging Infrastructure Layouts - OTC

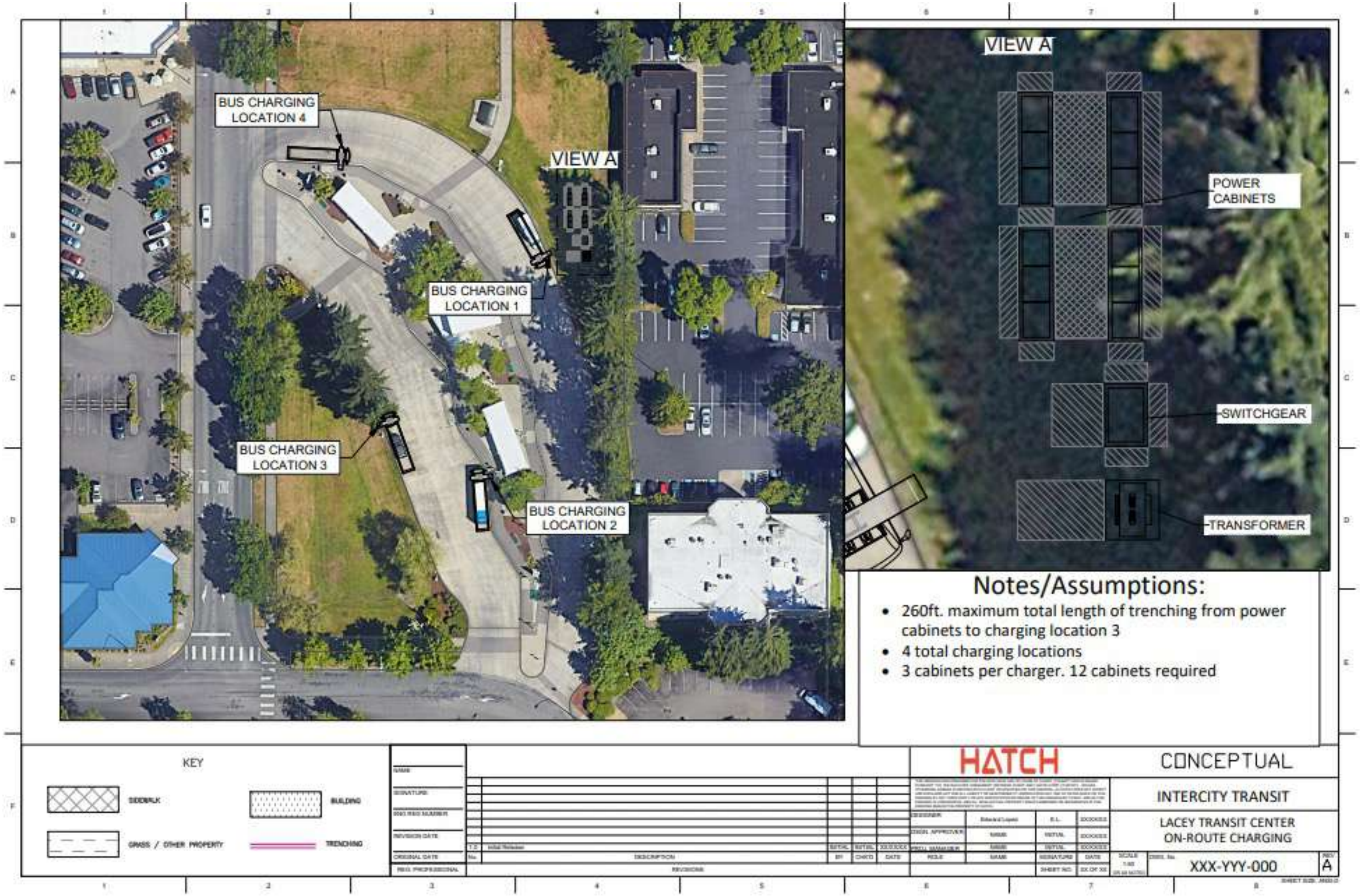
# On-Route Charging Infrastructure Layouts - OTC



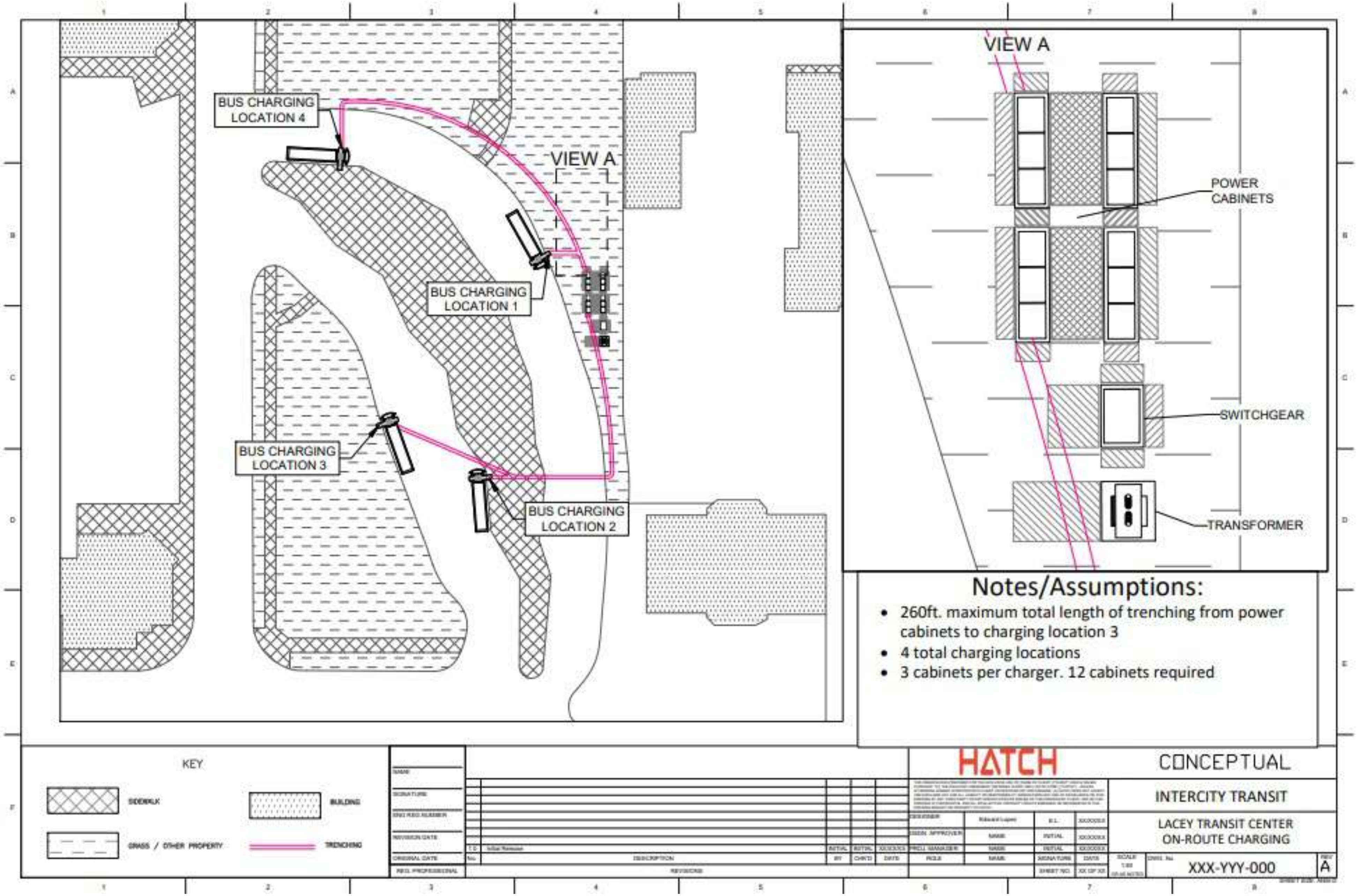

## Notes/Assumptions:

- 270ft. maximum total length of trenching from power cabinets to charging location 2
- 4 total charging locations
- 3 cabinets per charger. 12 cabinets required

# On-Route Charging Infrastructure Layouts - LTC



# On-Route Charging Infrastructure Layout - LTC

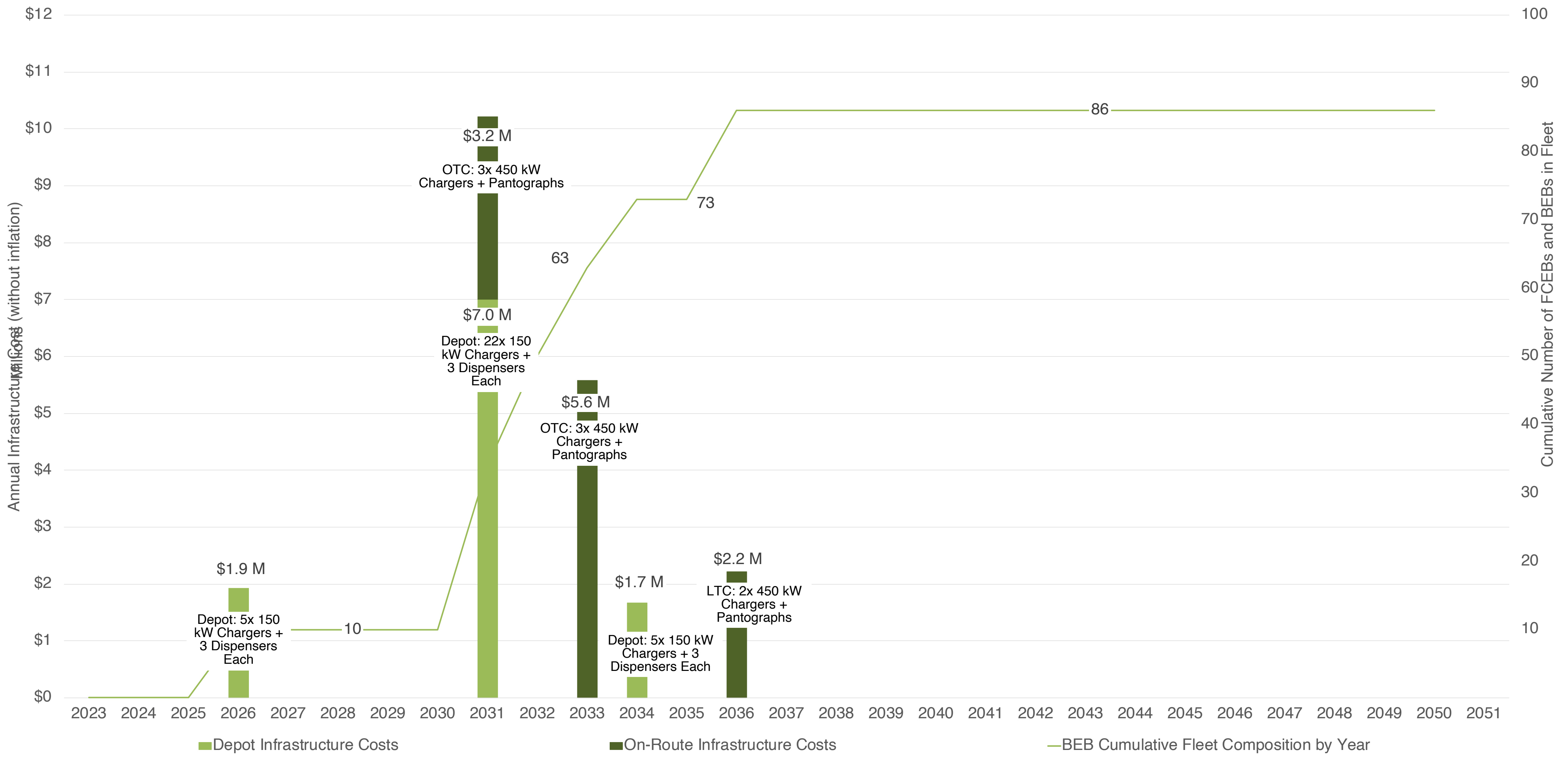



## Notes/Assumptions:

- 260ft. maximum total length of trenching from power cabinets to charging location 3
- 4 total charging locations
- 3 cabinets per charger. 12 cabinets required

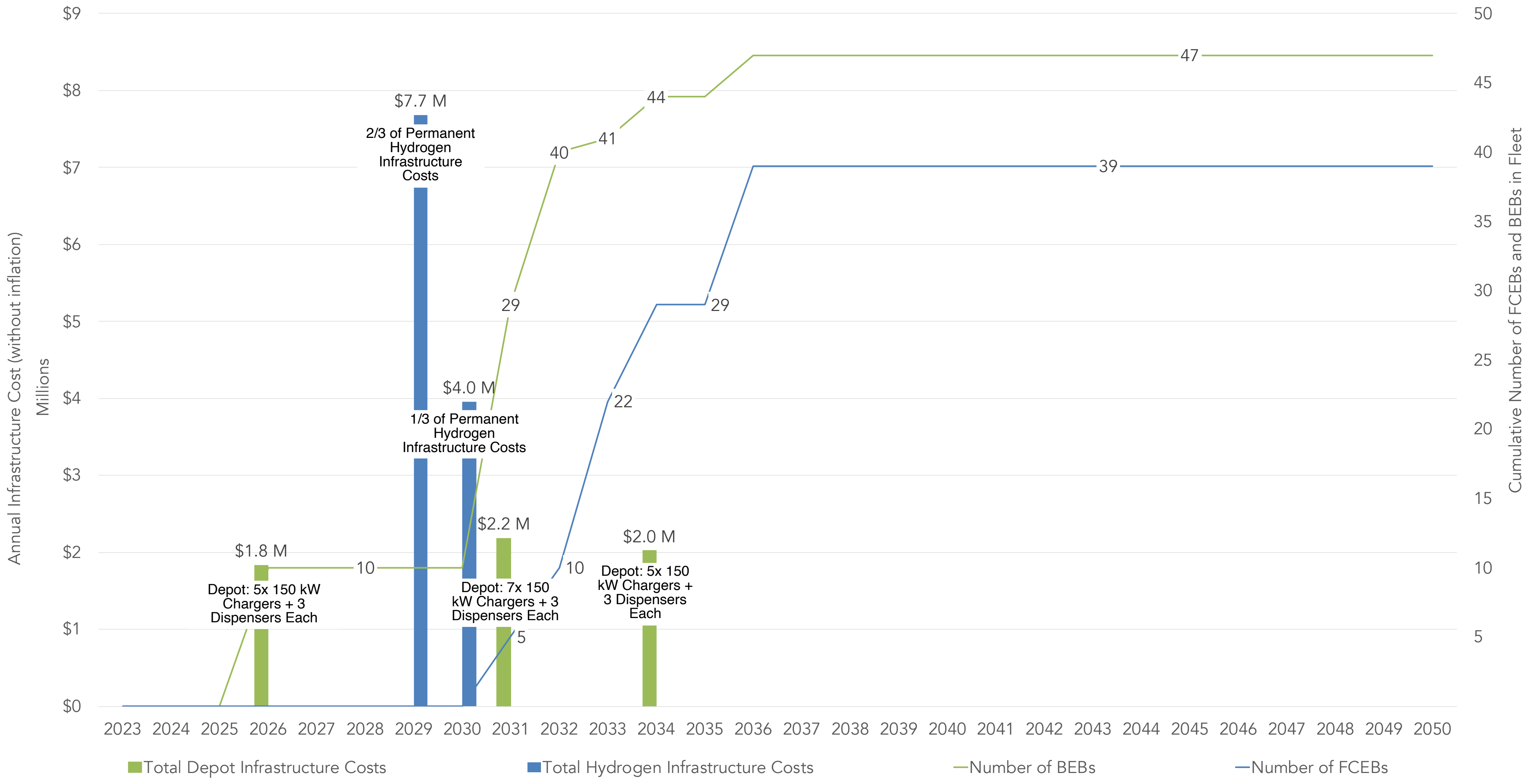
# Depot and On-Route BEB Scenario

## Infrastructure Assessment (100% ZEB by 2050)

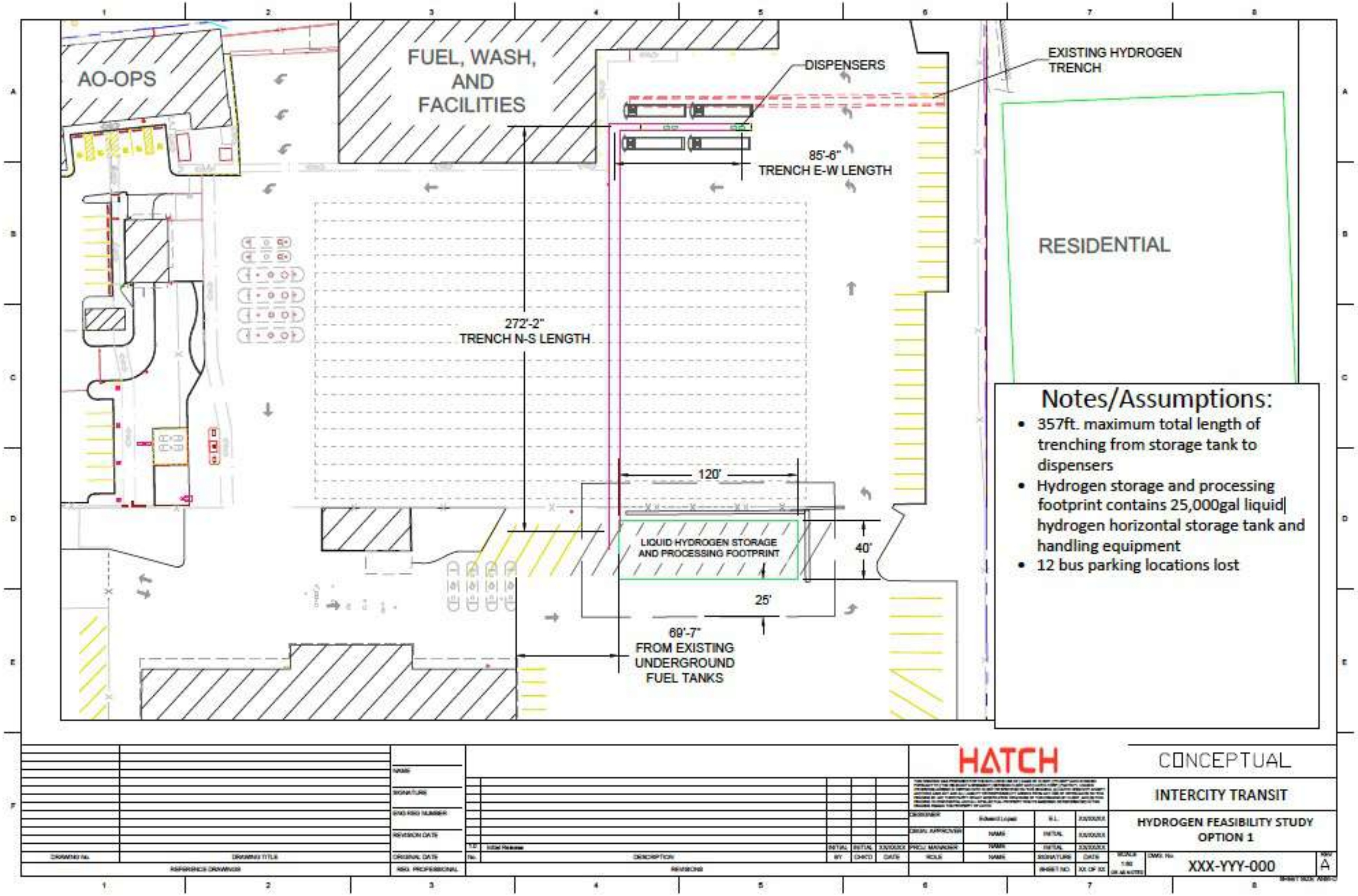


# Depot BEB and FCEB Scenario

## Infrastructure Assessment (100% ZEB by 2050)



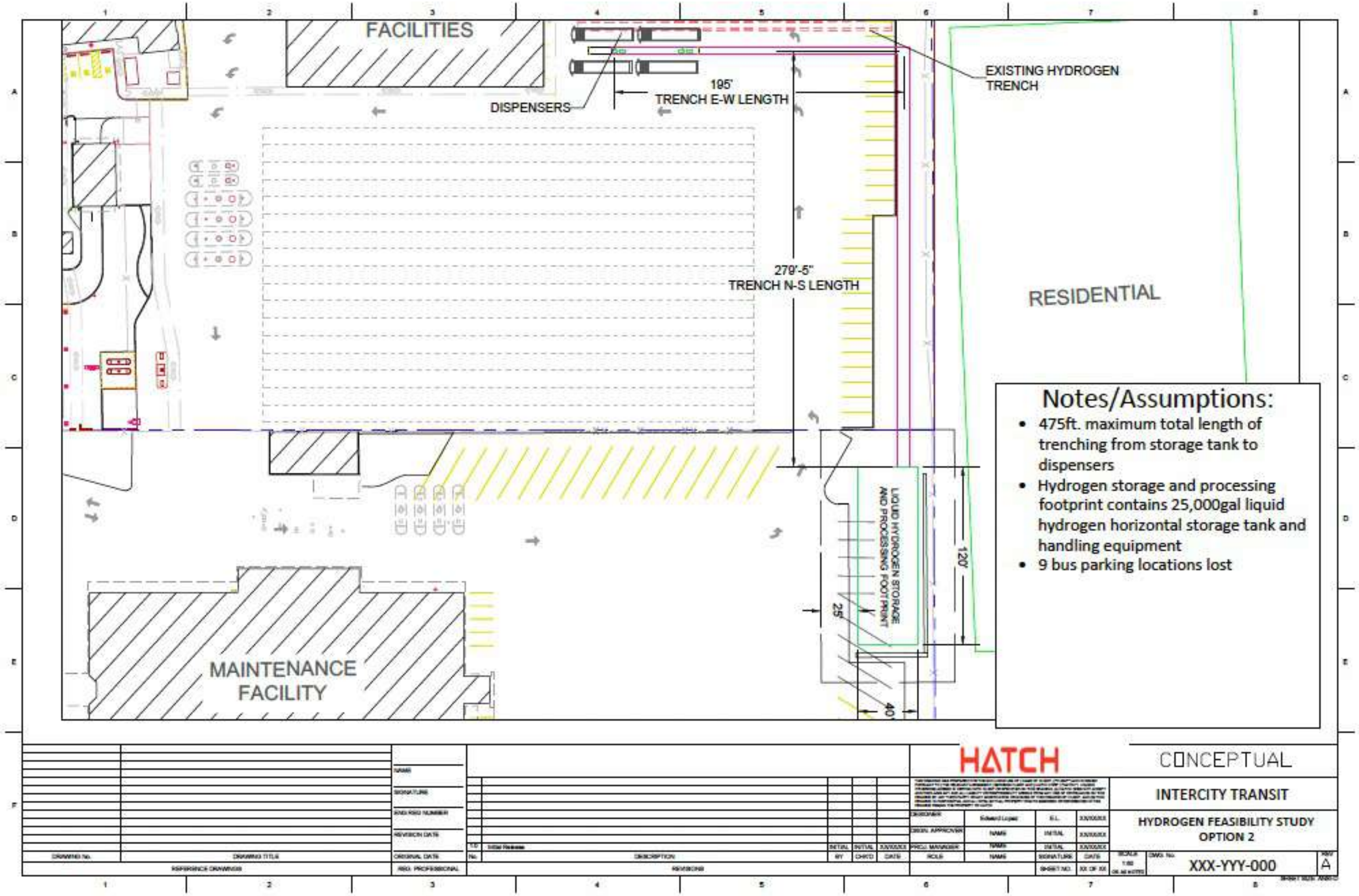
# Hydrogen Fueling Infrastructure Layout



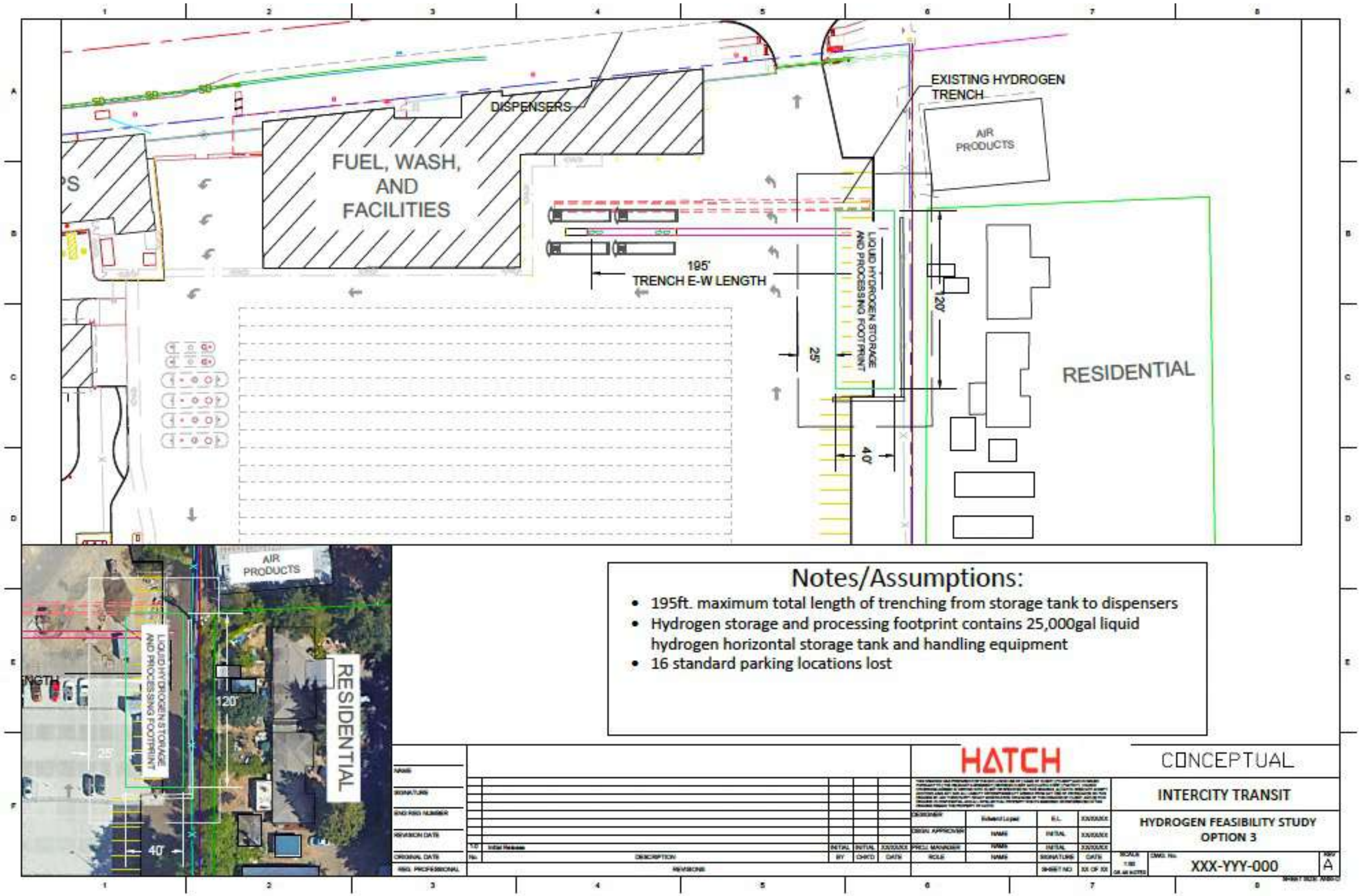

## Notes/Assumptions:

- 357ft. maximum total length of trenching from storage tank to dispensers
- Hydrogen storage and processing footprint contains 25,000gal liquid hydrogen horizontal storage tank and handling equipment
- 12 bus parking locations lost

# Hydrogen Fueling Infrastructure Layout



# Hydrogen Fueling Infrastructure Layout

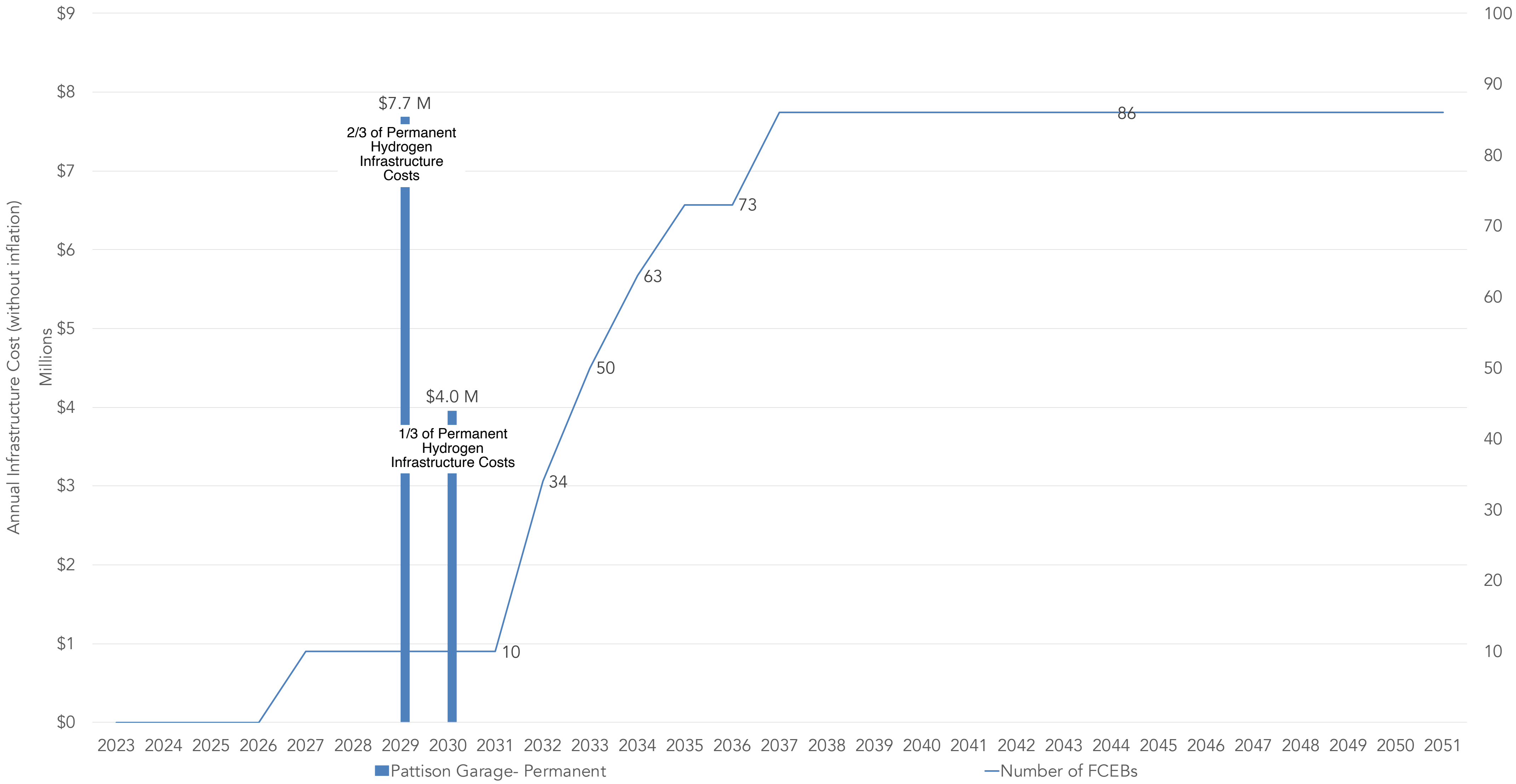



Notes/Assumptions:

- 195ft. maximum total length of trenching from storage tank to dispensers
- Hydrogen storage and processing footprint contains 25,000gal liquid hydrogen horizontal storage tank and handling equipment
- 16 standard parking locations lost

# FCEB-Only Scenario

## Permanent Infrastructure Assessment (100% ZEB by 2050)



# FCEB-Only Scenario – Demonstration Solution

## Demonstration Temporary Infrastructure Assessment

- Mobile Hydrogen Refueling Solution for the first 10 FCEBs deployed in 2026: **$1.095 M** per year (for equipment and fuel costs)

| Temporary Tube Trailer | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|
| **Mobile Equipment Lease (Inflated 6% YOY)** | $208,893.96 | $221,427.60 | $234,713.26 | $248,796.05 | $263,723.82 |
| **Fueling Costs (Inflated 10% YOY)** | $1,223,280.95 | $1,345,609.04 | $1,480,169.94 | $1,628,186.94 | $1,791,005.63 |
| **Mobile Equipment Lease Total** | **$ 1.4 M** | **$1.6 M** | **$ 1.7 M** | **$1.9 M** | **$ 2.1 M** |

# Summary Cost Evaluation

## All ZEB Scenarios, 2023-2050

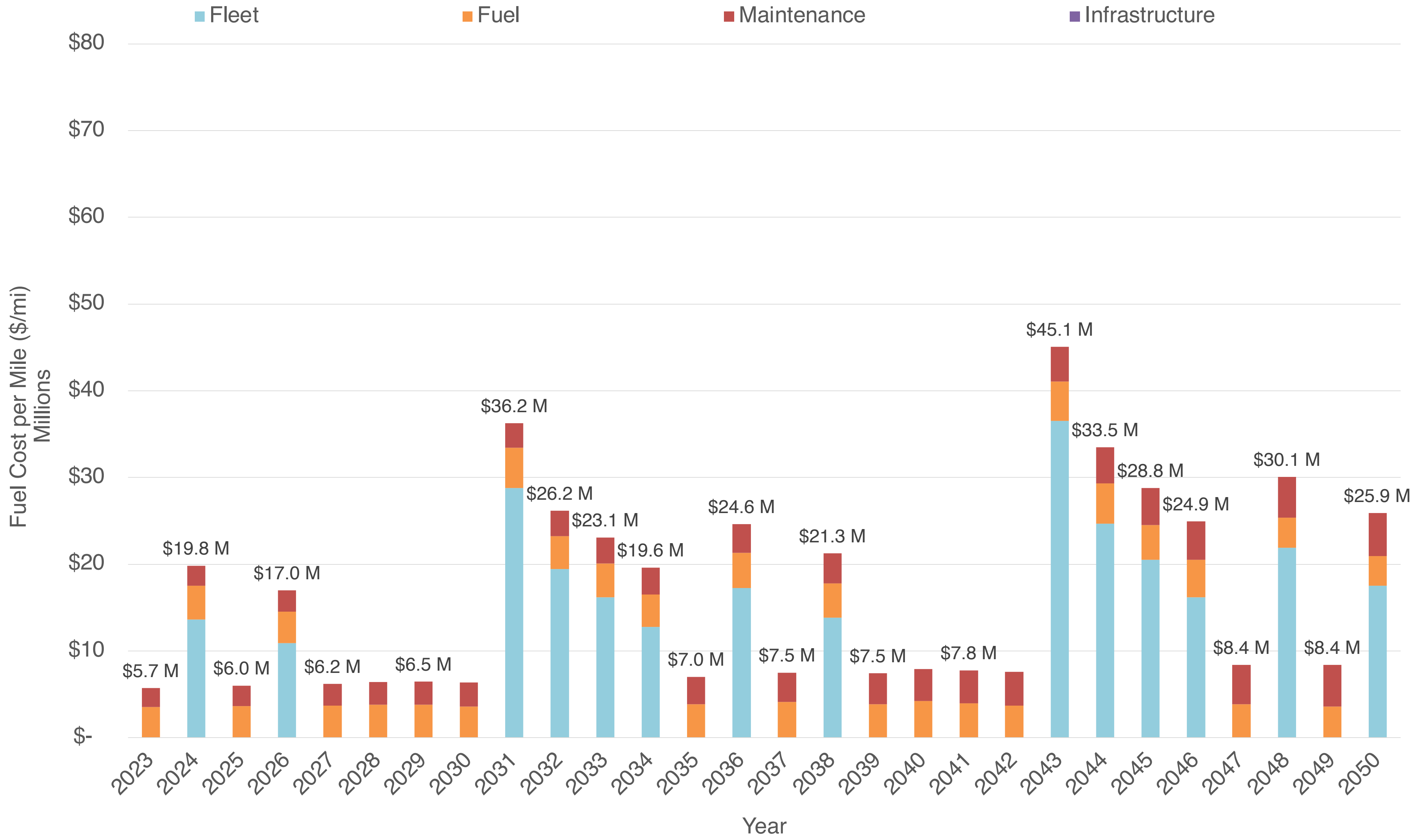
| | Baseline | BEB Depot Charging Only | BEB Depot and On-Route Charging | Mixed Fleet (BEB/FCEB) | FCEB Only |
|---|---|---|---|---|---|
| **Cumulative Infrastructure Costs** | **-** | **$10.6M** | **$21.16M** | **$17.7M** | **$11.6M** |
| Compared to Baseline | - | +$10.6M | +$21.16M | +$17.7M | +$11.6M |
| % of Blocks Achievable by 2050 | **0%** | **83%** | **100%** | **100%** | **100%** |

# Total Cost of Ownership Results

Fixed Route

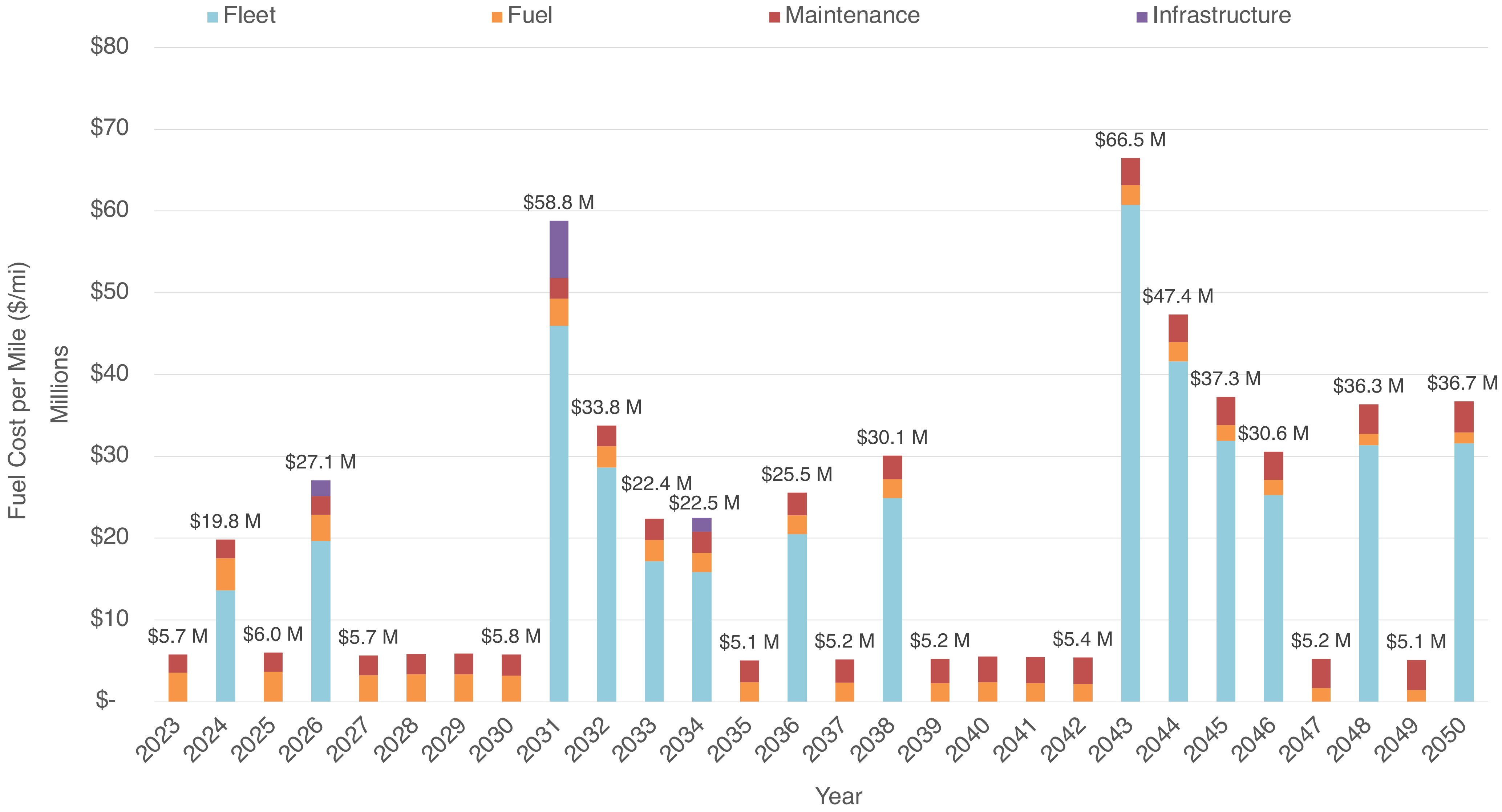
# Baseline Scenario

## Total Cost of Ownership (0% ZEB by 2050)



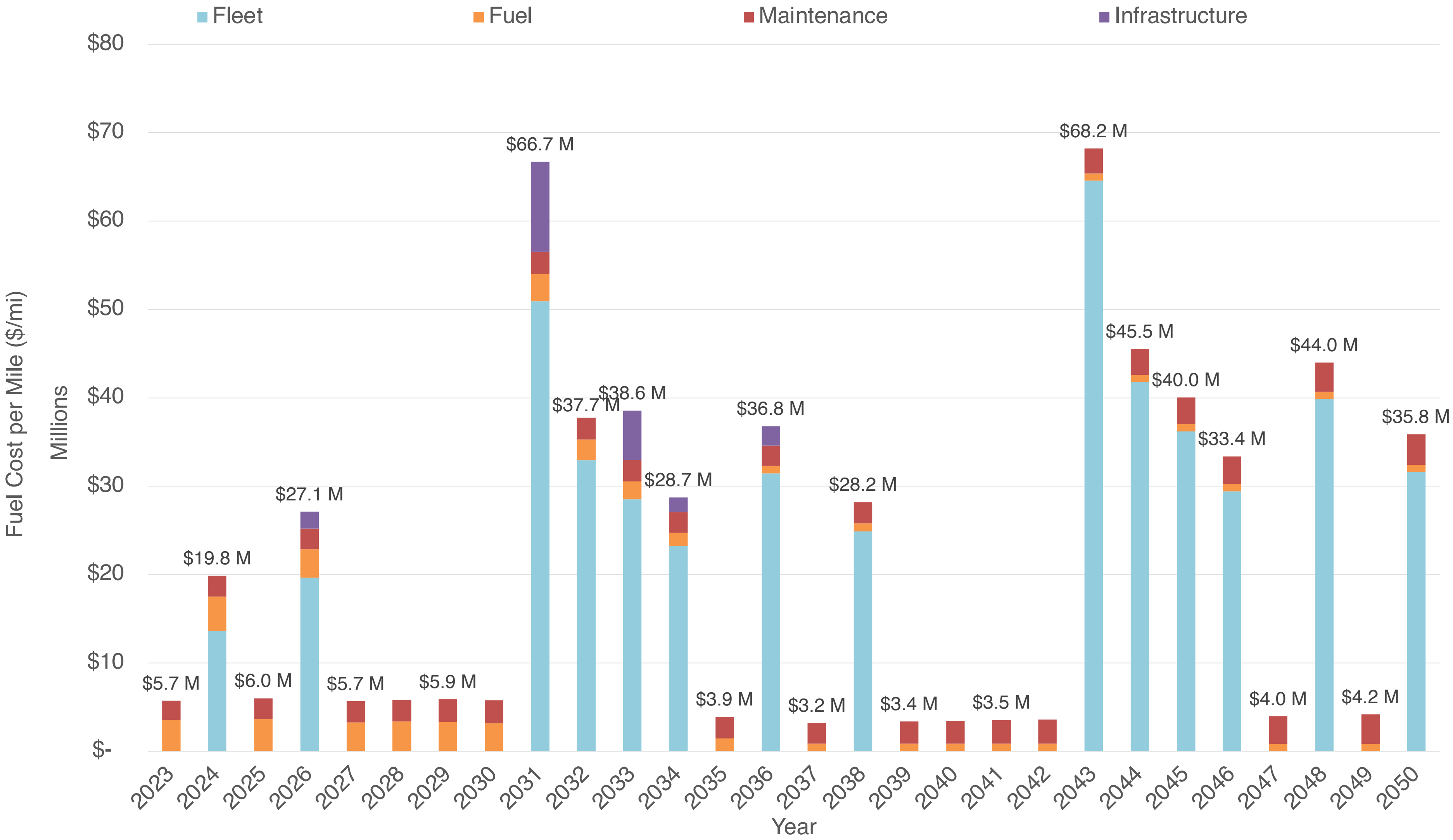
# Depot-Only BEB Scenario

## Total Cost of Ownership (83% ZEB by 2050)



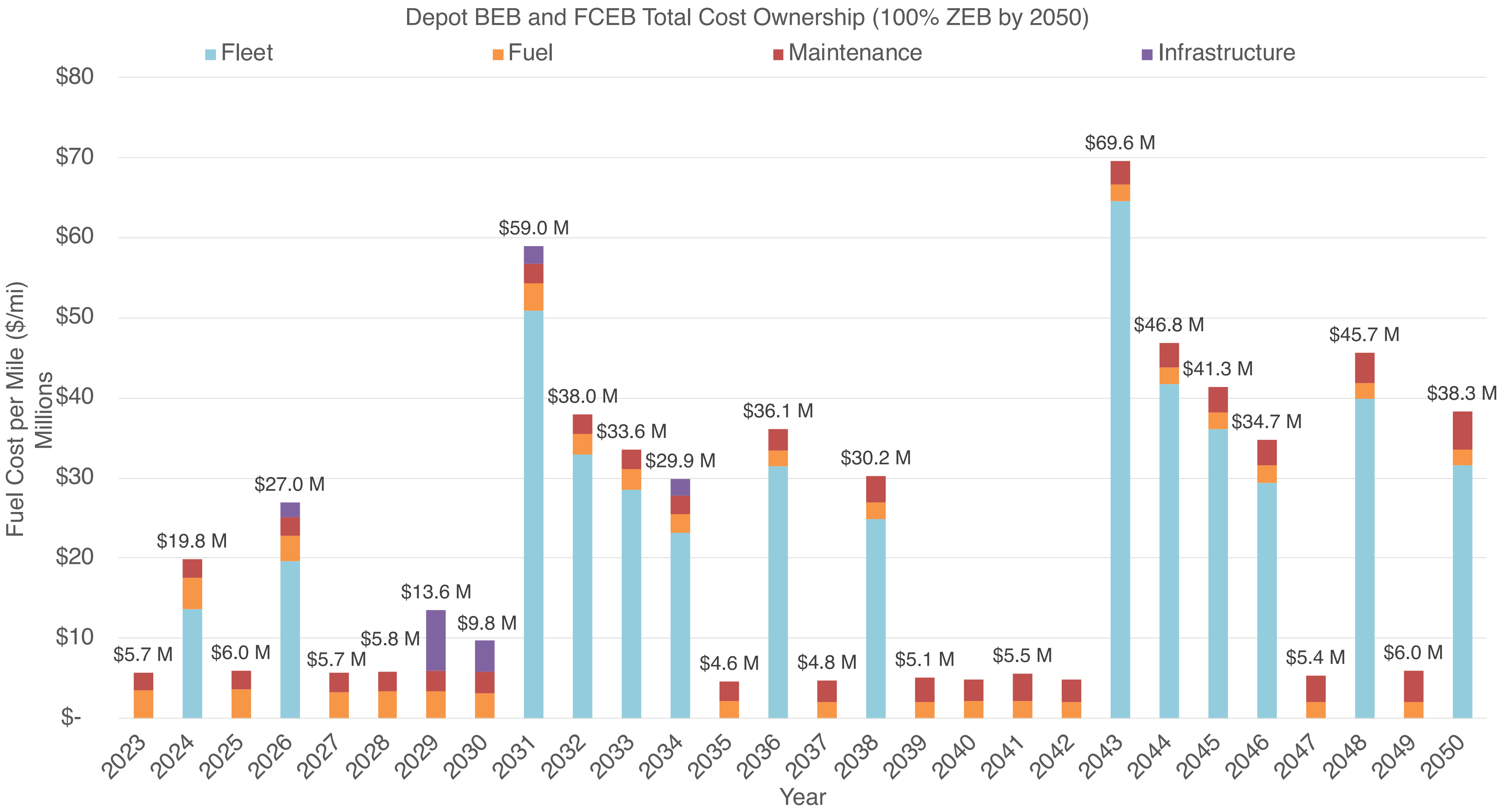
# Depot and On-Route BEB Scenario

## Total Cost of Ownership (100% ZEB by 2050)



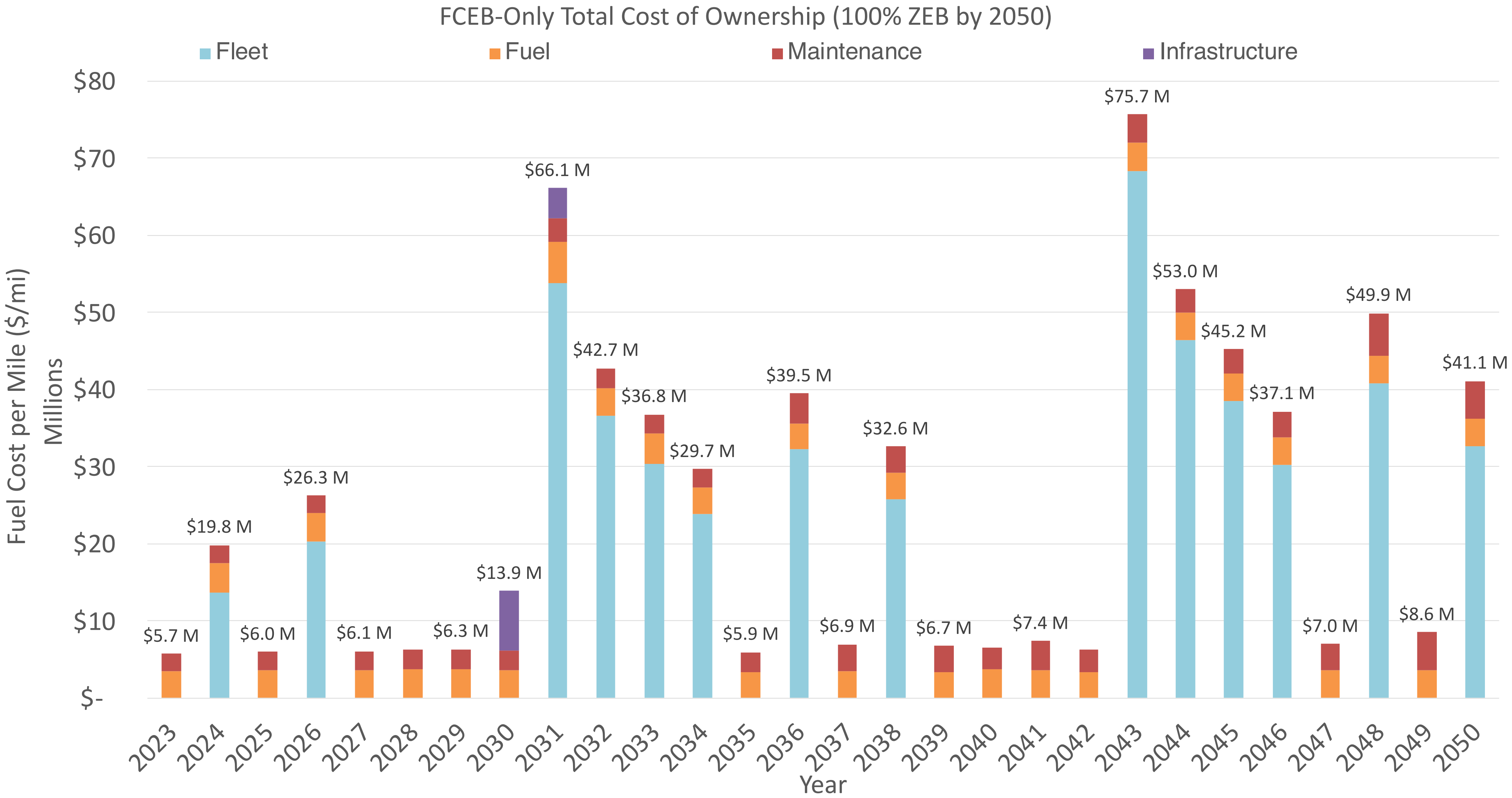
# Depot BEB and FCEB Scenario

## Total Cost of Ownership (100% ZEB by 2050)



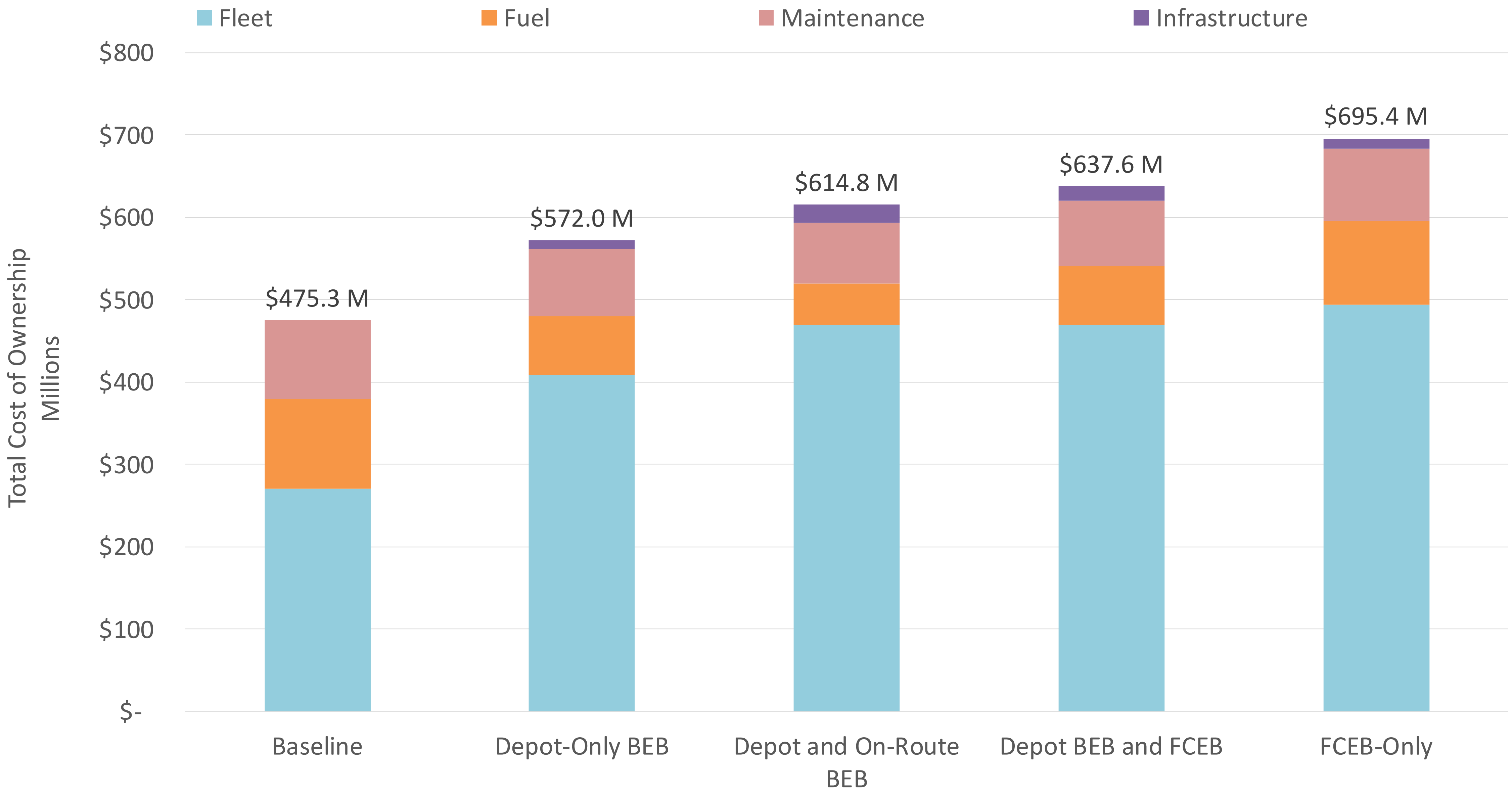
# FCEB-Only Scenario

## Total Cost of Ownership (100% ZEB by 2050)



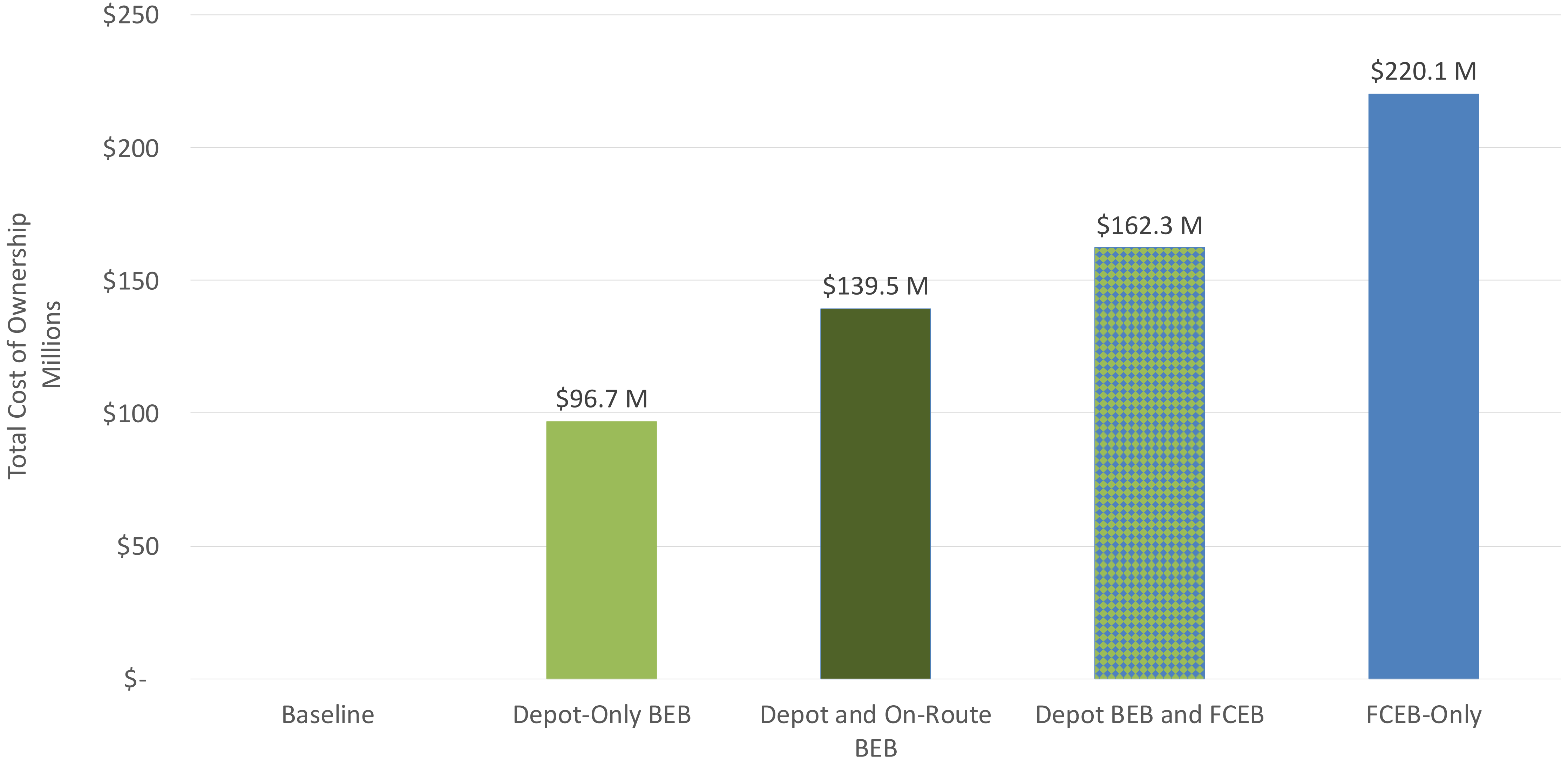
# Total Cost of Ownership

## All ZEB Scenarios, 2023-2050



# Total Cost of Ownership: Compared to Baseline

## All ZEB Scenarios, 2023-2050



# Summary Cost Evaluation

## All ZEB Scenarios, 2023-2050

| Total Cost of Ownership | Baseline | BEB Depot Charging Only | BEB Depot and On-Route Charging | Mixed Fleet (BEB/FCEB) | FCEB Only |
|---|---|---|---|---|---|
| Fleet | $270,264,000 | $408,825,000 | $468,644,000 | $468,644,000 | $493,523,000 |
| Fuel | $109,293,000 | $71,148,000 | $50,543,000 | $71,297,000 | $102,052,000 |
| Maintenance | $95,730,000 | $81,464,000 | $73,971,000 | $79,948,000 | $88,172,000 |
| Infrastructure | $- | $10,598,200 | $21,599,000 | $17,677,000 | $11,636,000 |
| **Total** | **$ 475.3 M** | **$ 572 M** | **$ 614.8 M** | **$637.6M** | **$ 695.4M** |
| Compared to Baseline | - | + $ 96.8 M | + $ 139.5 M | + $ 162.3 M | + $ 220.1 M |
| % of Blocks Achievable by 2050 | **0%** | **83%** | **100%** | **100%** | **100%** |

# Electrification Scheduling Impact

# Scheduling Assessment – 2023

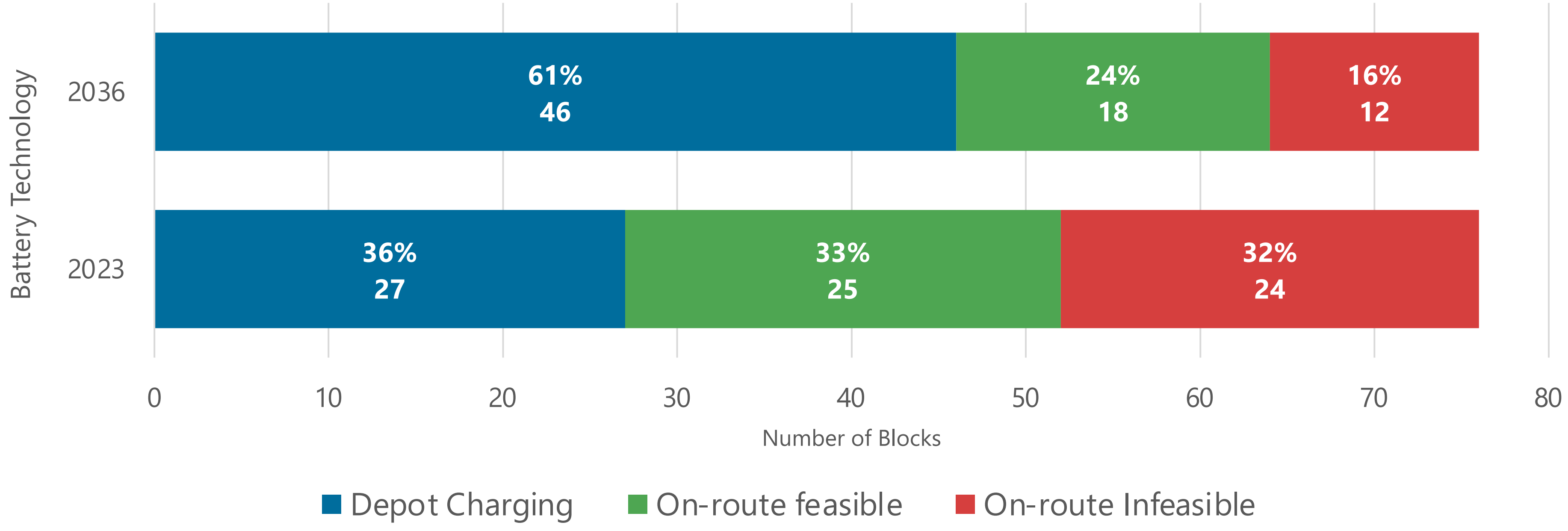
- Took CTE's depot feasibility analysis based on March 2020 service levels and assumed:
  - All infeasible blocks attempted on-route
  - Strenuous efficiency by route
  - On-route chargers at Olympia TC and Lacey TC
- Battery capacity nameplate: 35′ (491kWh) and 40′ (523 kWh)
- On-board real capacity reduced to 81% of nameplate
- Minimum state of charge (SoC) set at 20% of on-board
- 300 kW on-route charger (overhead SAE J3105-1 pantograph)
- 5% of transmission loss from max power
- Use of full layover time for charging at max power

# Scheduling Assessment – 2036

- Compared the scheduling assessment in the base year (2023) with a future technology pathway in 2036
- Battery capacity nameplate: 35′ (691kWh) and 40′ (735 kWh)
- Because of assumed increase in battery capacity:
  - More blocks are feasible with depot charging
  - Remaining infeasible blocks attempted on-route

# Aggregated Results

- 76 total blocks
- With no scheduling changes:
  - In 2023, about one-third of blocks cannot be electrified
  - In 2036, only one-sixth of blocks cannot be electrified



# Infeasible Blocks in 2023

- Not enough layover at one of the on-route charging locations to maintain state of charge
- Nine routes with infeasible blocks:
  - 12, 45, 612, 62A, 62B, 64, 65, 68, 94
- 5 blocks (green shade) need less than 15 mins
- 8 blocks (yellow shade) need 15 to 30 mins
- 11 blocks (red shade) need more than 30 mins

| Infeasible Block | Routes | Additional kWh Required as Percentage of On-Board Battery Capacity | Additional Layover Required Minutes |
|---|---|---|---|
| 9401 | 45, 94 | 79% | 70 |
| 9902 | 612 | 51% | 45 |
| 6803 | 65, 68 | 50% | 44 |
| 9405 | 45, 94 | 46% | 41 |
| 6801 | 65, 68 | 44% | 39 |
| 6802 | 65, 68 | 44% | 39 |
| 6806 | 65, 68 | 44% | 39 |
| 6808 | 65, 68 | 44% | 39 |
| 1203 | 12 | 41% | 36 |
| 1202 | 12, 62B | 40% | 36 |
| 6807 | 65, 68 | 35% | 31 |
| 6804 | 65, 68 | 33% | 29 |
| 1201 | 12 | 31% | 27 |
| 6402 | 64 | 29% | 24 |
| 6403 | 64 | 25% | 21 |
| 9404 | 94 | 23% | 21 |
| 6805 | 65, 68 | 22% | 20 |
| 6204 | 62A, 62B | 18% | 16 |
| 6203 | 62A, 62B | 18% | 16 |
| 9402 | 45, 94 | 15% | 13 |
| 6401 | 64 | 15% | 12 |
| 6404 | 64 | 15% | 12 |
| 9403 | 94 | 11% | 10 |
| 6207 | 62A | 7% | 6 |

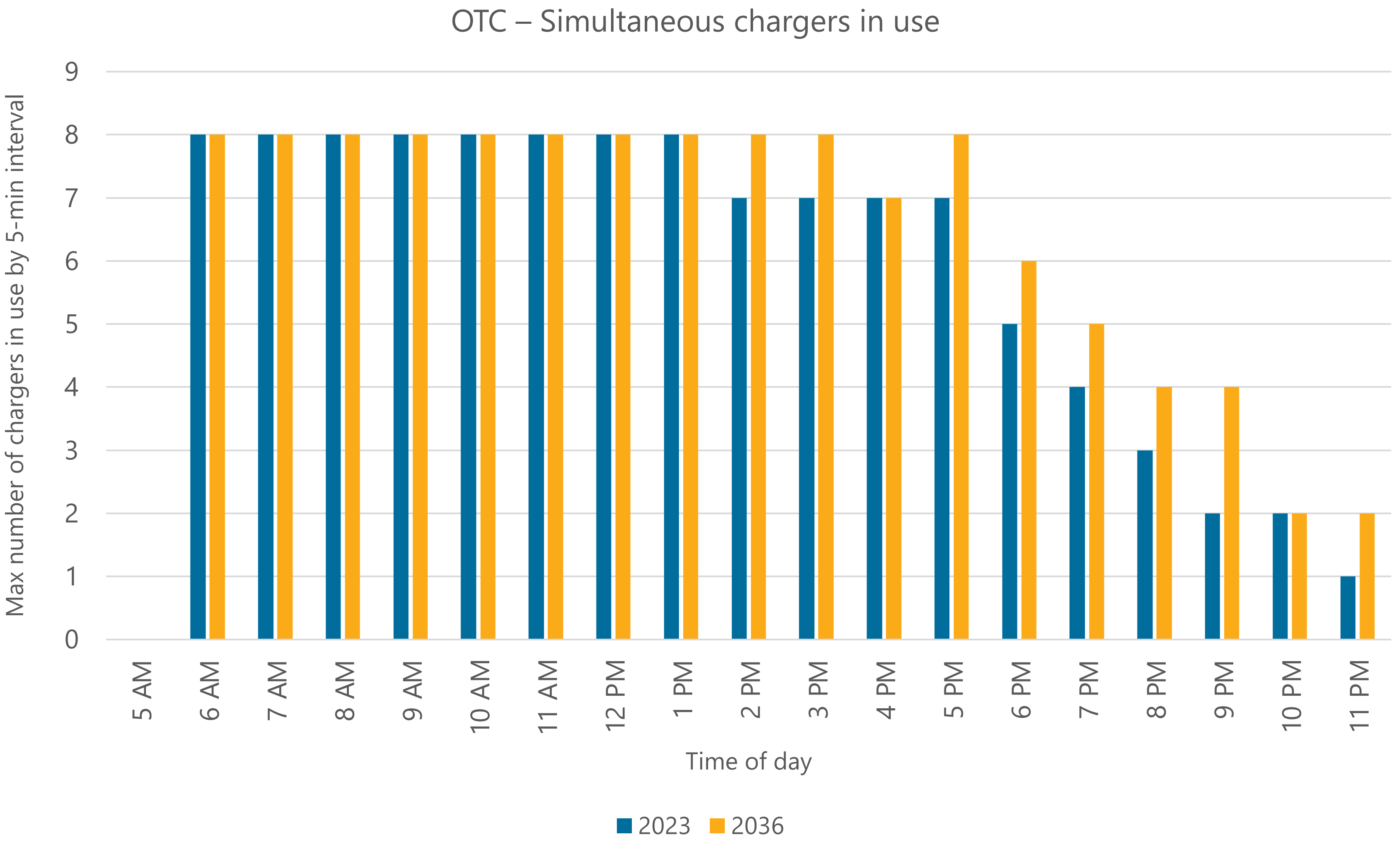
# Detailed Results - 2036

- Six routes with infeasible blocks:
  - 12, 612, 62B, 65, 68, 94
- Only two blocks need more than 15 mins

| Infeasible Block | Routes | Additional kWh Required as Percentage of On-Board Battery Capacity | Additional Layover Required Minutes |
|---|---|---|---|
| 9401 | 94 | 33% | 41 |
| 9902 | 612 | 13% | 16 |
| 6803 | 65, 68 | 12% | 15 |
| 9405 | 94 | 9% | 12 |
| 6801 | 65, 68 | 8% | 10 |
| 6802 | 65, 68 | 8% | 10 |
| 6806 | 68 | 8% | 10 |
| 6808 | 68 | 8% | 10 |
| 1203 | 12 | 6% | 7 |
| 1202 | 12, 62B | 6% | 7 |
| 6807 | 65 | 2% | 2 |

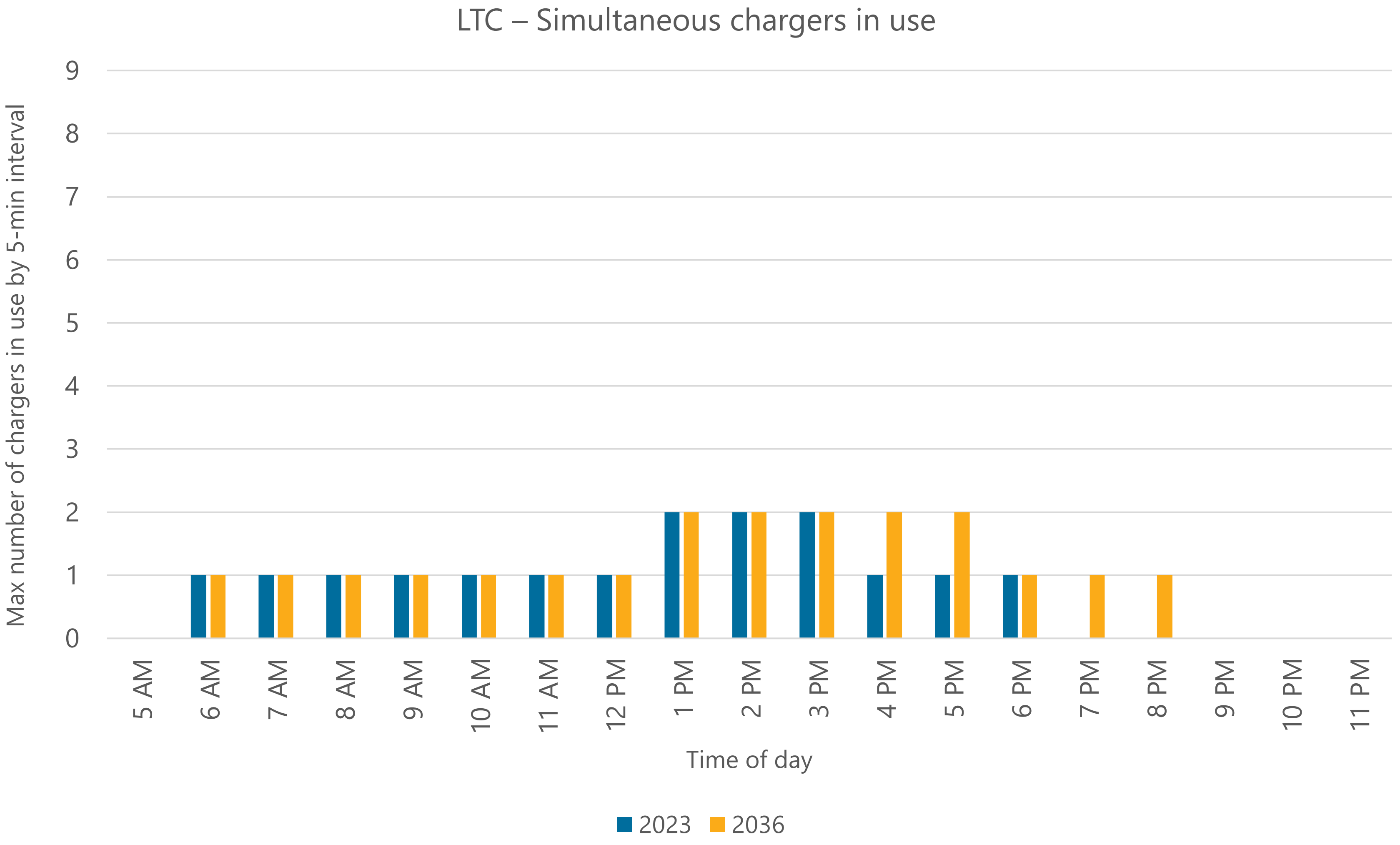
# Olympia Transit Center – Chargers in Simultaneous Use

- 6 AM to 6 PM with many instances with 8 chargers in use
- About 2,700 kW of peak demand
- With an extended battery capacity (2036) more chargers are required towards later in the day



# Lacey Transit Center – Chargers in Simultaneous Use

- Max of 2 chargers
- About 600 kW of peak demand
- In 2023, longer blocks become unfeasible after 6 p.m. therefore, no chargers are needed
- In 2036, better battery technology expands range up to 8 p.m.



# GHG Emissions Inventory

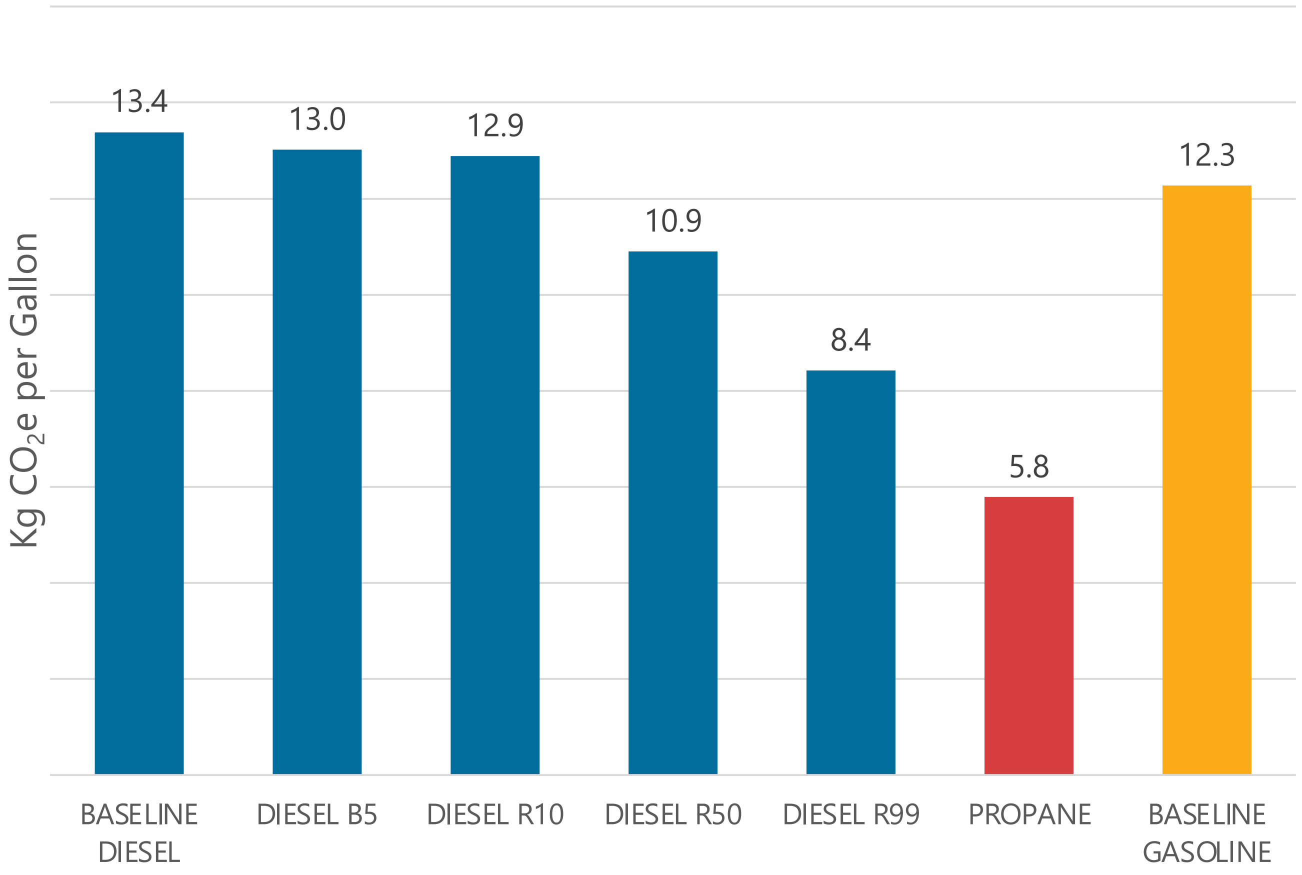
# GHG Emission Overview

- **Historic** fleet GHG emissions calculation, 2010-2022
  - Calculated Intercity's carbon footprint based on fuel consumption and mileage records for each vehicle in the fleet
  - GHG emissions results by service mode and fuel type, accounting for fuel type changes

- **Projected** Fixed Route fleet GHG emissions calculation, 2023-2050
  - Estimated Intercity's **fixed-route** carbon footprint based on the fleet's projected technology makeup (scenarios) and energy consumption
  - Developing an Excel-based calculator to allow Intercity to evaluate GHG emissions as they incorporate new zero-emission vehicles and service modes

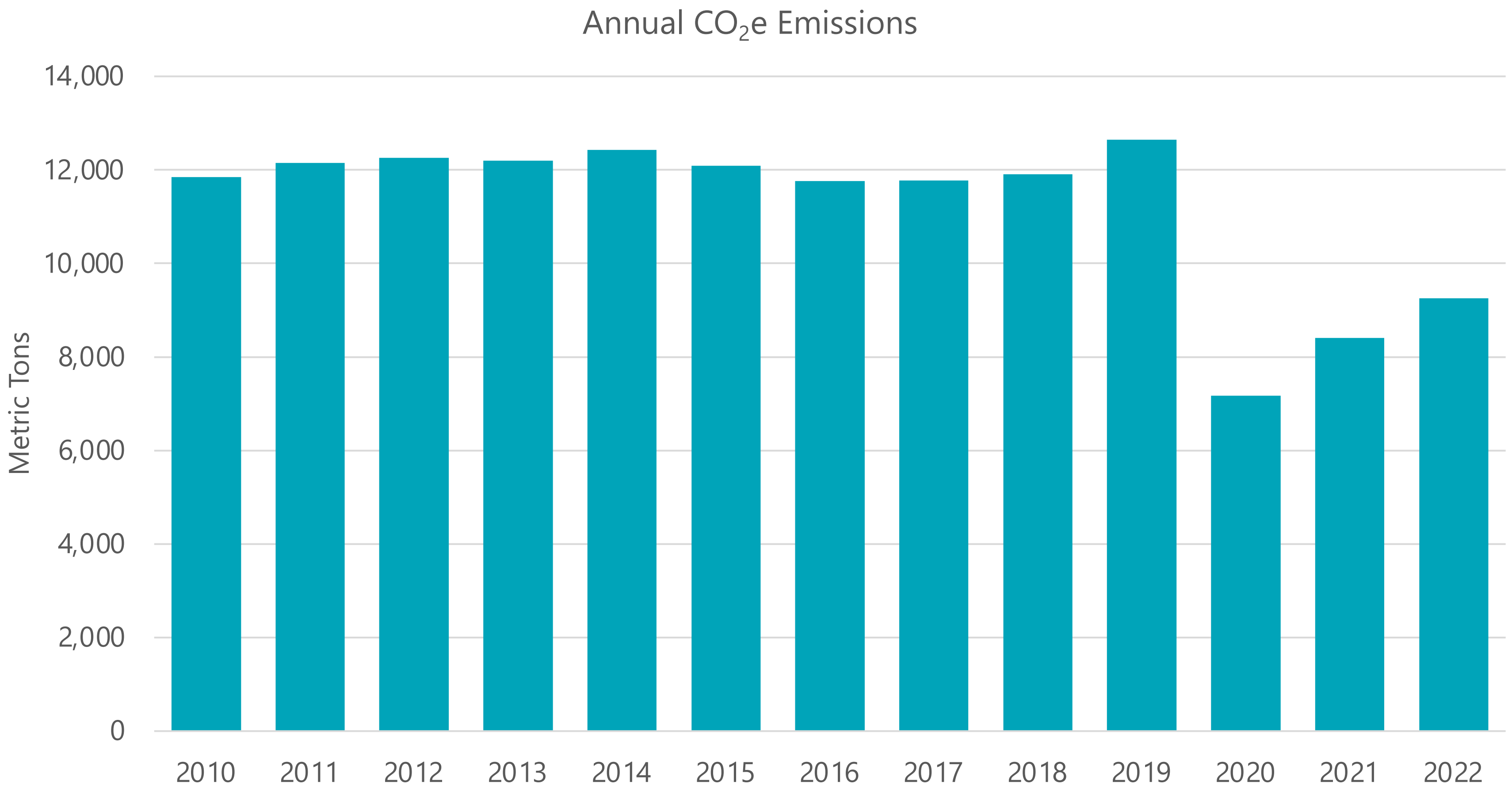
# Well to Wheel Emission Factors

- Emissions factors obtained from U.S. Environmental Protection Agency
- U.S. Renewable Fuel Standard (RFS) program analyzes $CO_2$ emissions from production, transportation and use of renewable fuels
- Intercity Diesel transition
  - B5 – 2008
  - R10 – July 2020
  - R50 – Oct 2021
  - R99 – Jan 2023



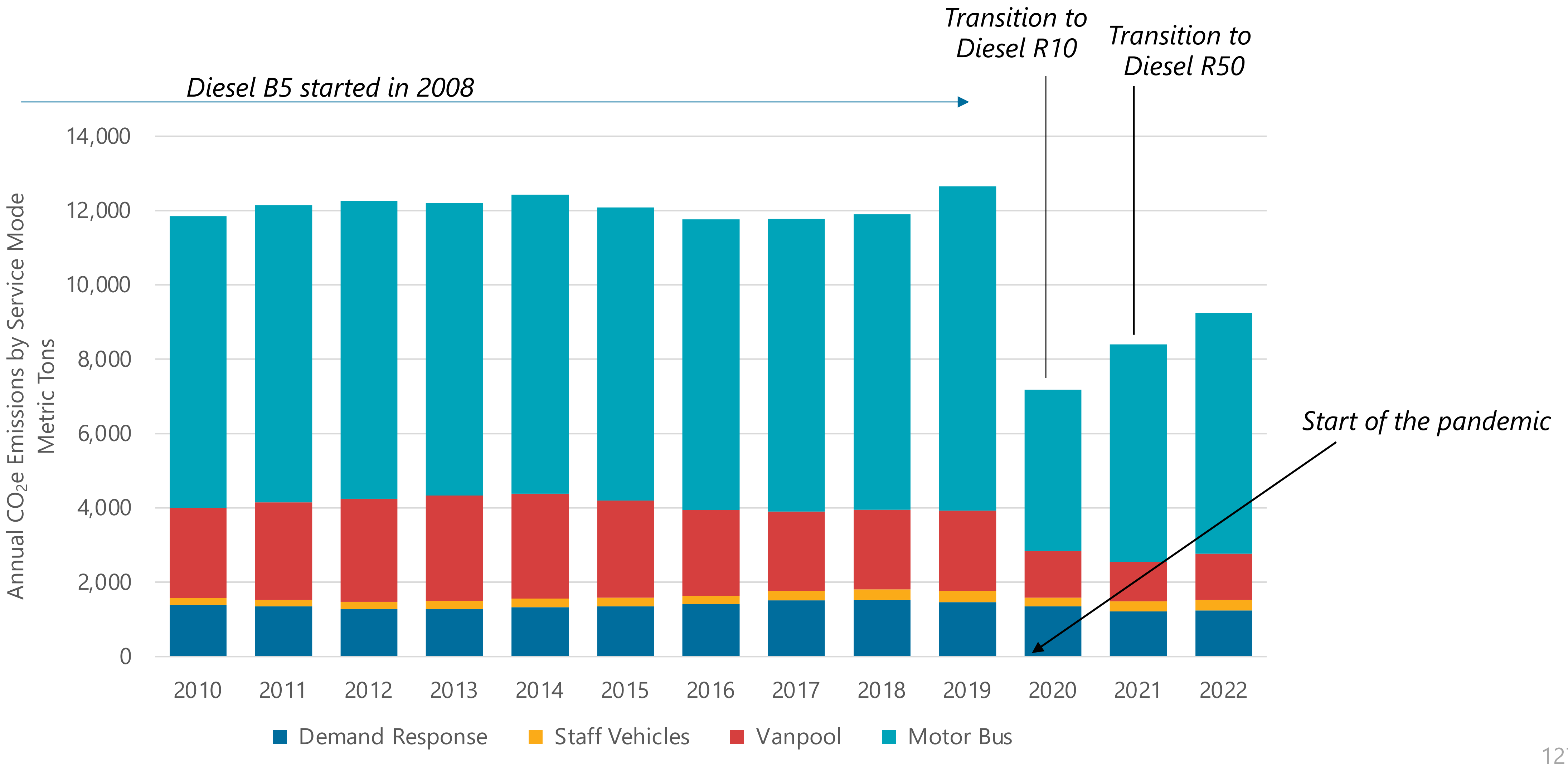
# Total GHG Emissions Trend (All Modes)

- Emissions were relatively constant between 2010 and 2019
- The COVID-19 pandemic curbed emissions in 2020 to ~60% of 2019



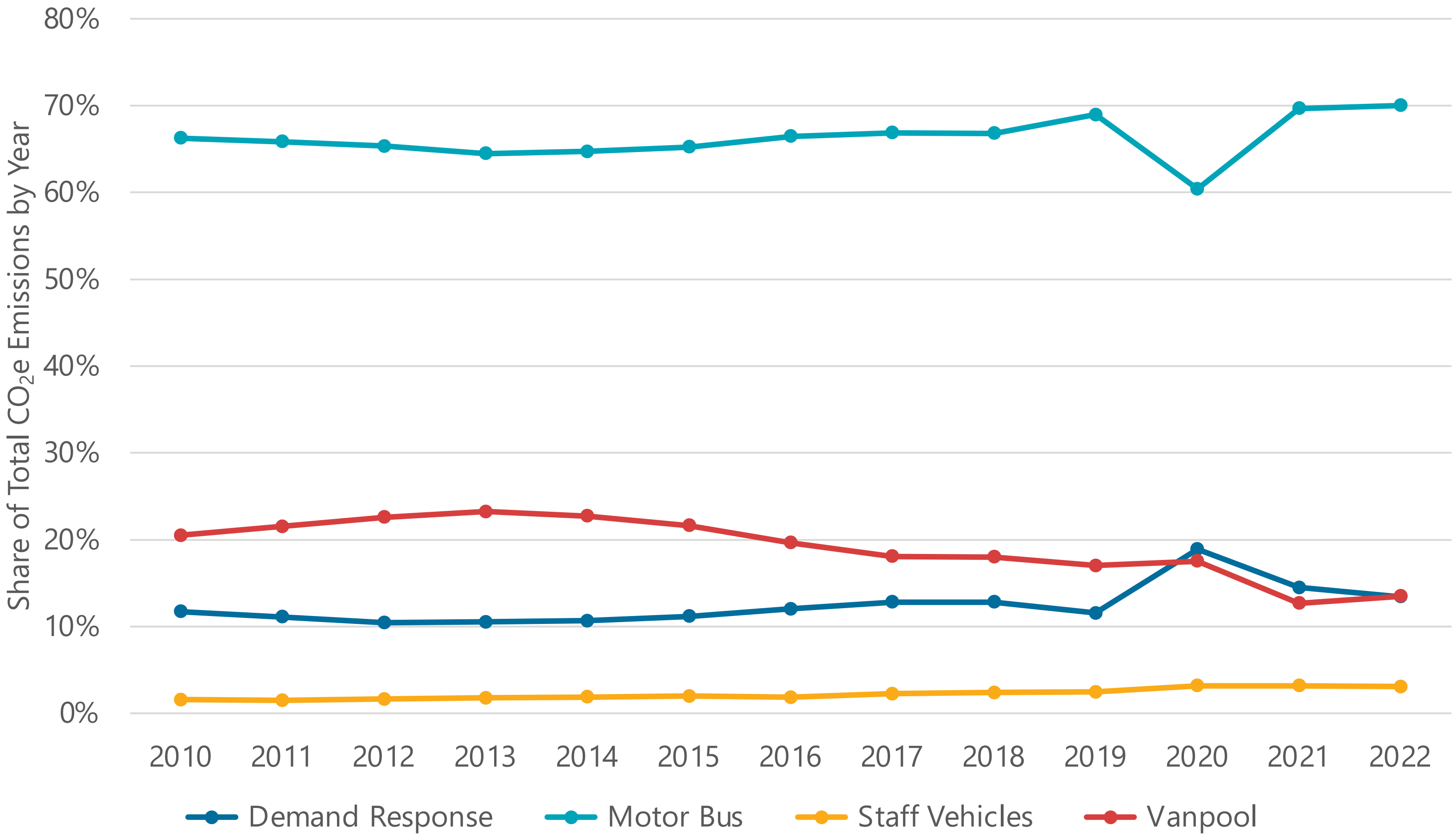
# GHG Emissions by Mode

- Motor Bus (fixed-route) vehicles contribute the largest share of emissions



# GHG Emissions by Mode

- Demand response share of emissions in 2020 increased, presumably as a result of DR running additional services during the pandemic



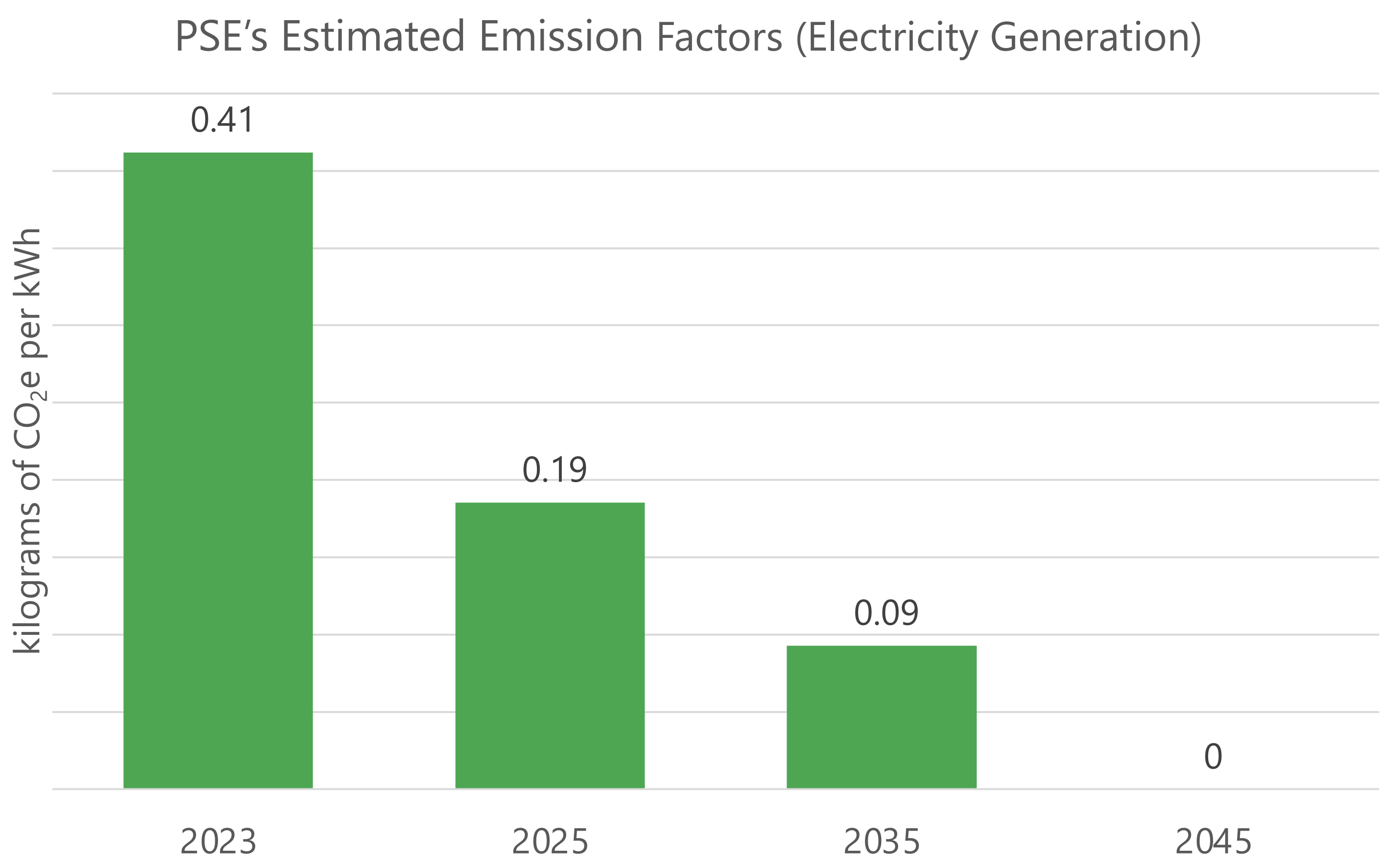
# Projected Fixed-Route Emissions, 2023-2050

## Key Assumptions:

- Fleet adoption technology scenarios: timeline follows scenarios developed by CTE
  - BEB Depot Only
  - BEB Depot and On-route
  - BEB Depot and FCEB
- Lifecycle GHG emissions fuel type alternatives
  - Diesel: assumed to be renewable diesel (R99) throughout period
  - Electricity: considers current and expected PSE generation mix
  - Hydrogen: includes assessment of grey, blue, and green hydrogen

# Electricity Assumptions for GHG Projections

- 2023 uses latest PSE 2021 grid resources mix
- Coal eliminated from grid mix in 2025[a]
- Reach carbon free electric supply by 2045[a]
- Emissions assumed to be half of 2025 by 2035



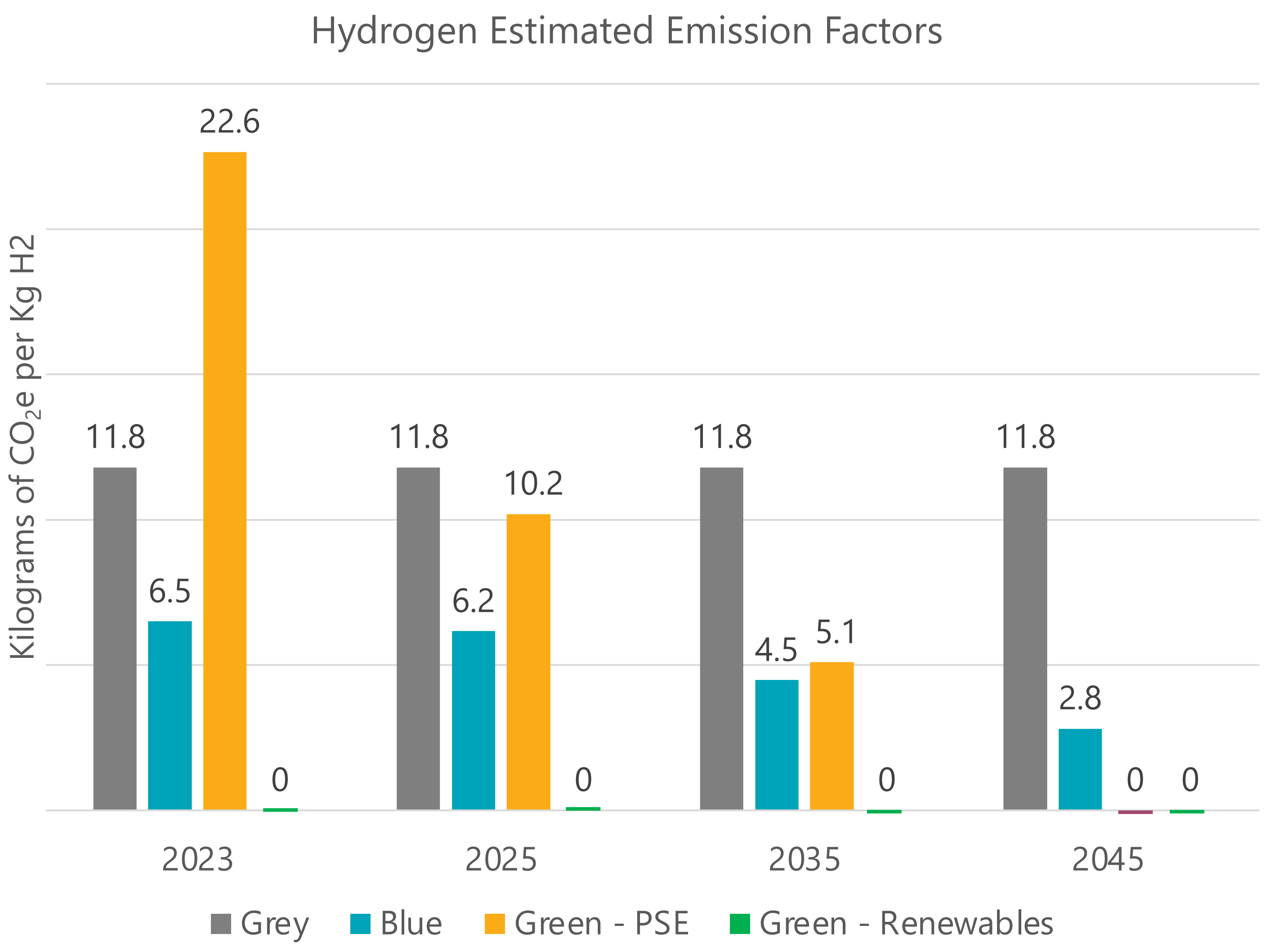

(a) PSE Pathway to Beyond Net Zero Carbon by 2045

# Hydrogen Procurement

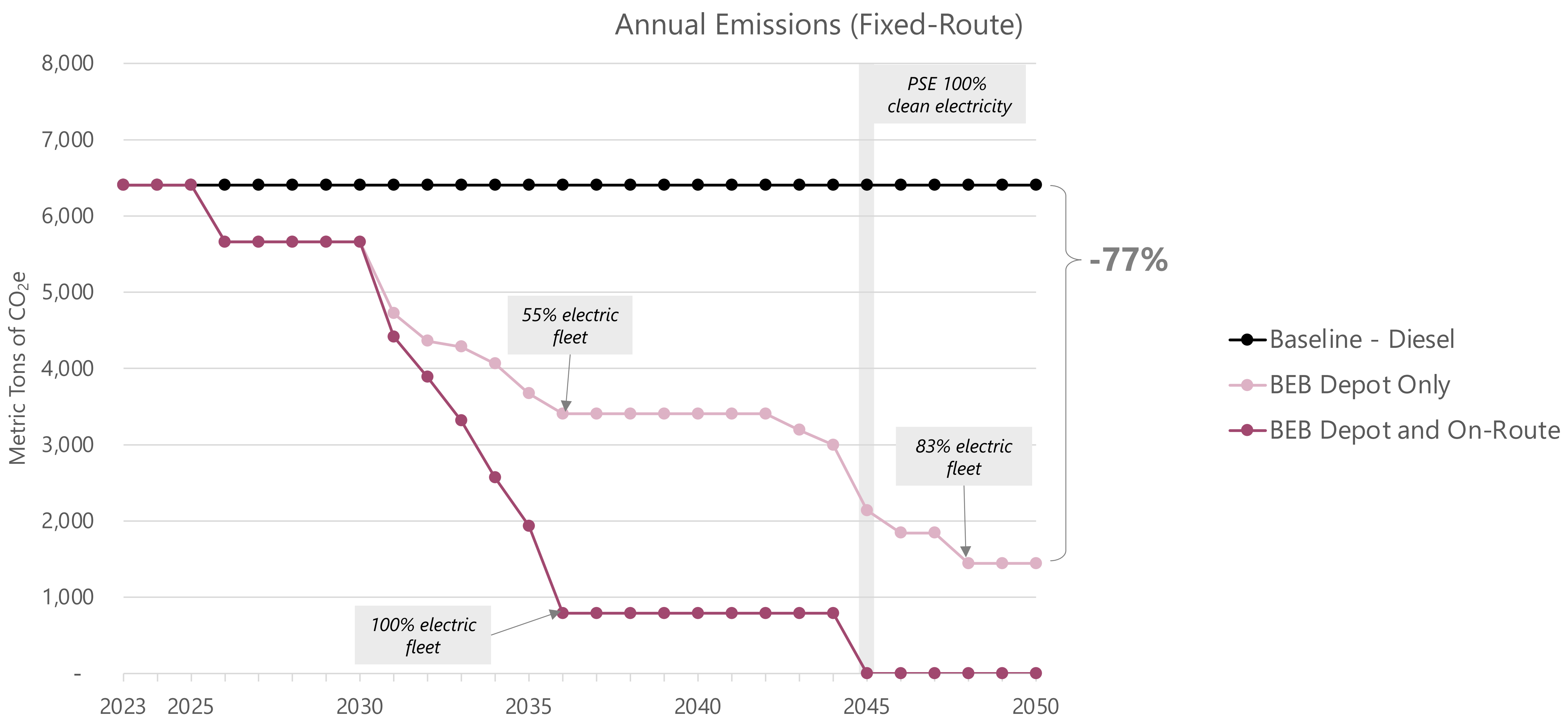
- Two hydrogen production processes:
  - From fossil fuels typically through Steam Methane Reforming (SMR), GHG emissions anchored to chemical process and natural gas supply chain
  - From water and electricity (electrolysis), GHG emissions related to electricity source
- Grey hydrogen: most cost-effective and common process using fossil fuels
- Blue hydrogen: fossil fuels with carbon capture and storage (CCS) can reduce up to 90% of GHG emissions from grey hydrogen
- Green hydrogen: produced with electrolysis under the assumption that electricity is generated using renewables

# Hydrogen Assumptions for GHG Projections

- Grey hydrogen: natural gas emissions rate of 1.5% and no CCS through 2050
- Blue hydrogen:
  - 2023 natural gas emissions rate of 1.5% and low-CCS (55%)
  - 2050 natural gas emissions rate of 0.2% and high-CSS (93%)
- Green Hydrogen:
  - 55 kWh to produce one kg. of hydrogen
  - Same carbon intensity from PSE

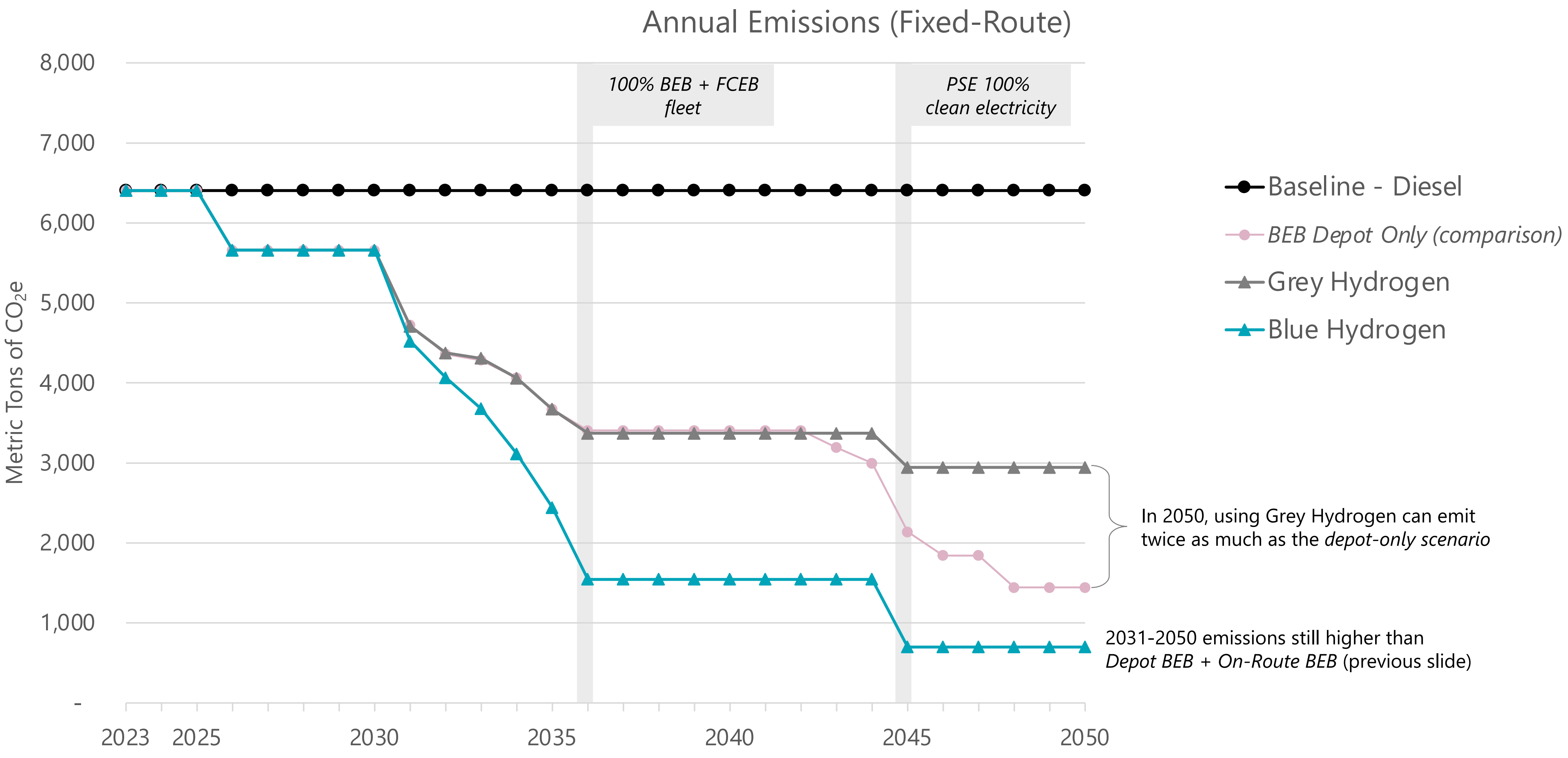


# Baseline - BEB Depot Only - BEB Depot and On-Route



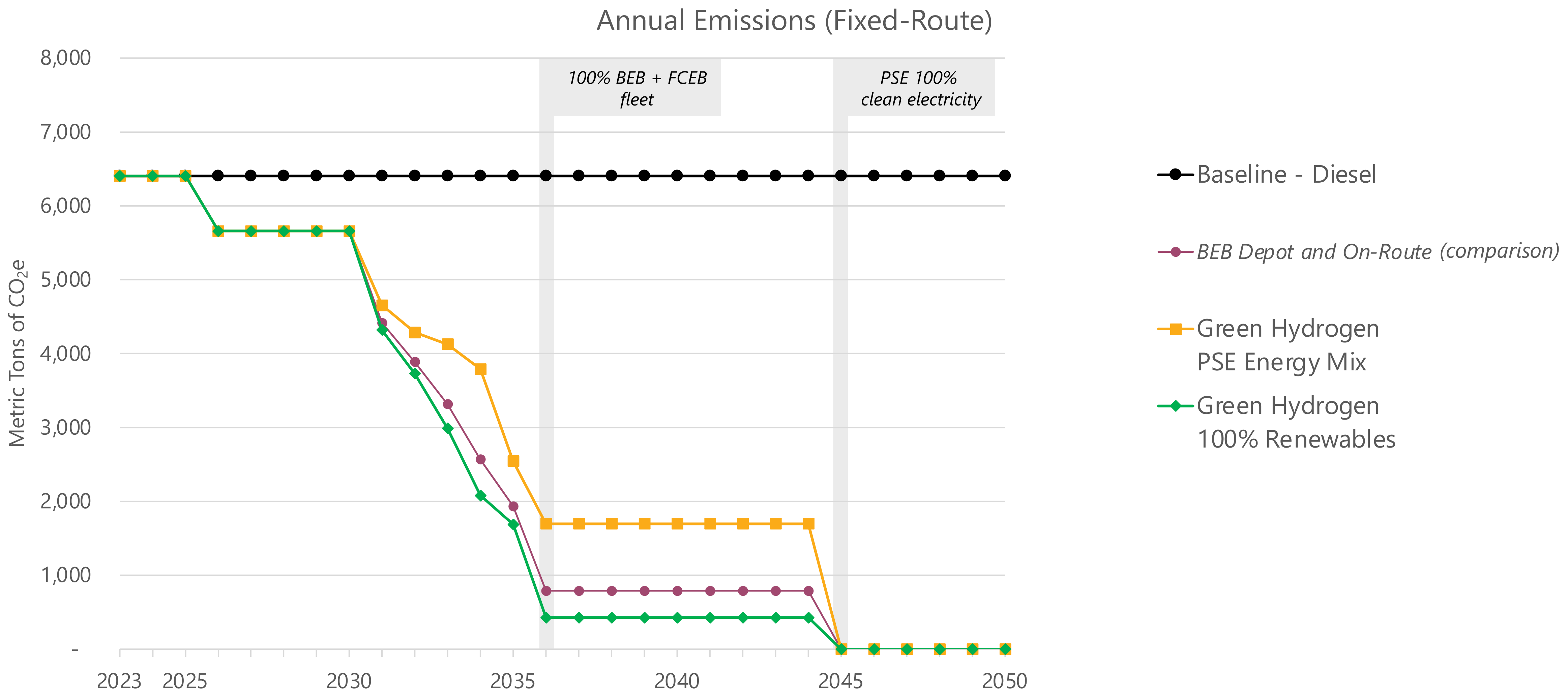
# Baseline - BEB Depot and FCEB

## Grey and Blue Hydrogen



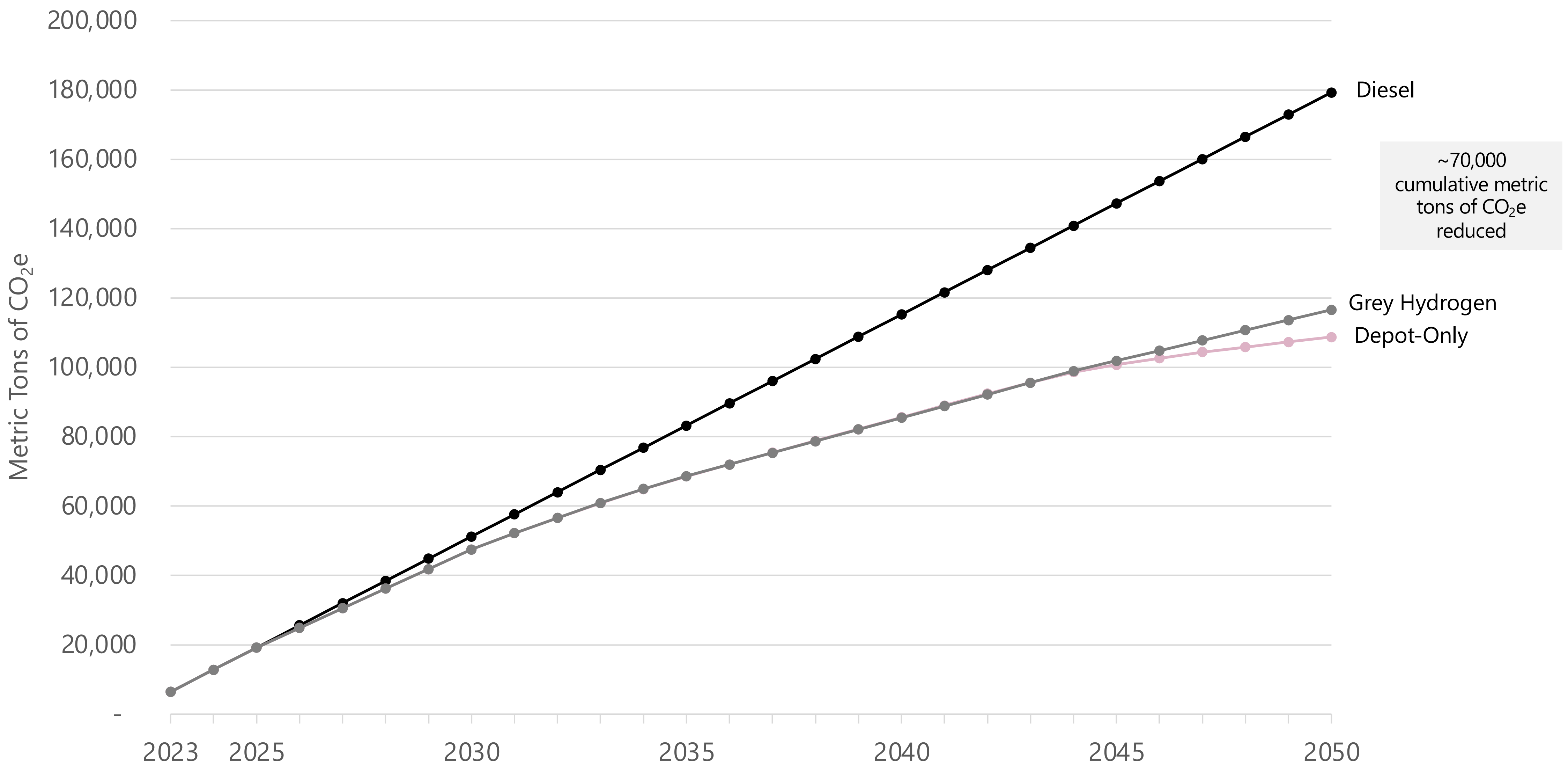
# Baseline - BEB Depot and FCEB

## Green Hydrogen

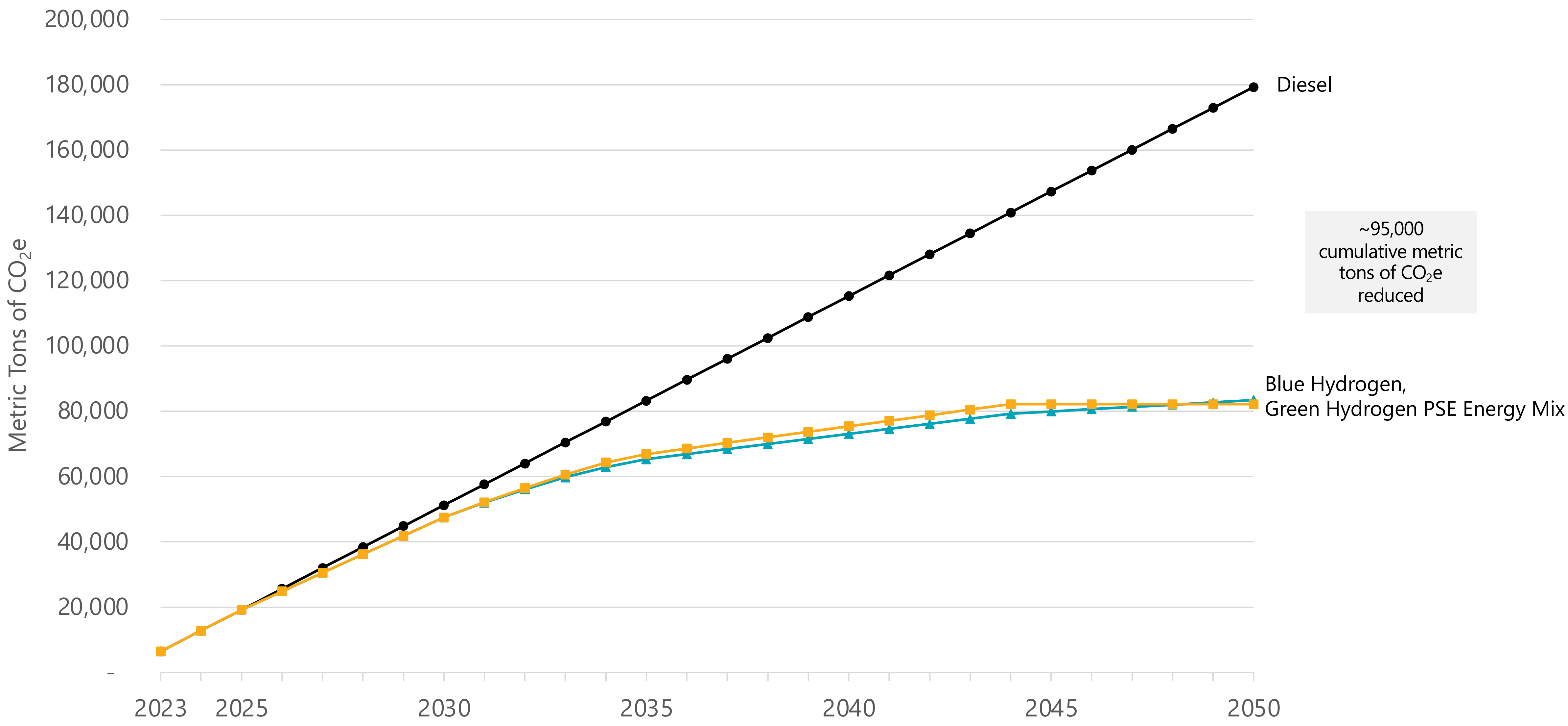



- PSE Energy Mix assumes hydrogen is produced through electrolysis using electricity from the average PSE energy mix
- 100% Renewables assumes hydrogen is produced through electrolysis using carbon-free electricity, e.g., solar

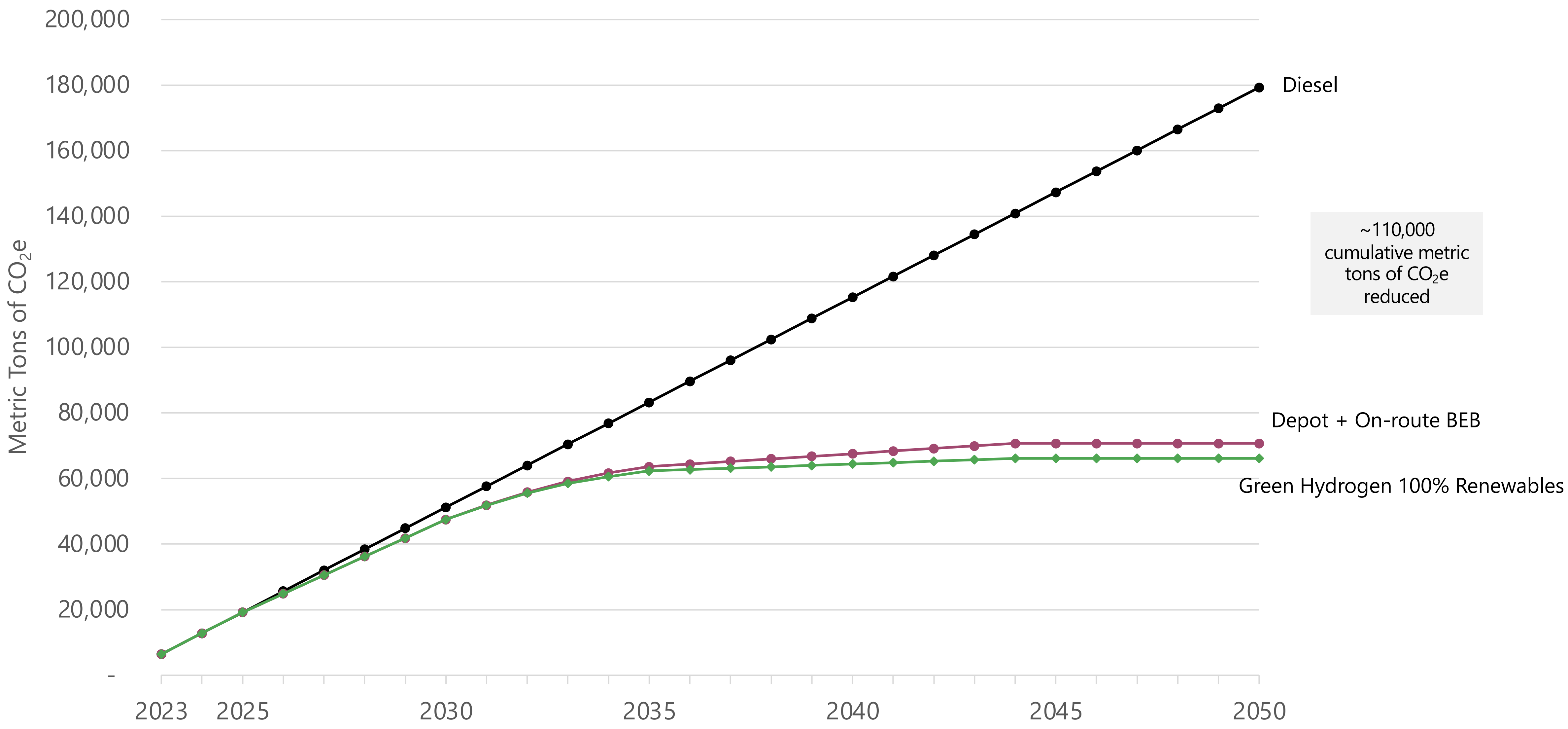
# Cumulative Emissions – All scenarios



# Cumulative Emissions – All scenarios



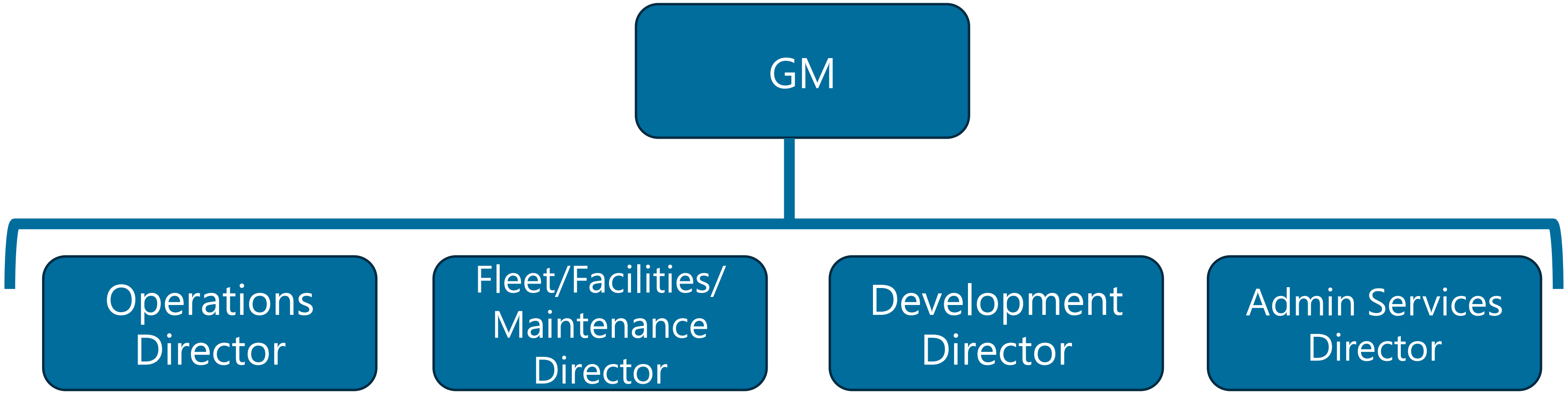
# Cumulative Emissions – All scenarios



# Change Management Overview

# Change Management Considerations

- Shifting the composition of the fleet requires changes in all aspects of the operation, such as:
  - Operations
  - Maintenance
  - Planning and scheduling
  - Administration



# Operations

- Operator driving habits can significantly impact vehicle range
  - Retrain drivers to operate electric buses efficiently
  - Consideration of driver acceleration and deceleration, weather, grade, and charging operations
  - Increase operator and the public awareness of proper safety protocols for preventing collisions with quieter vehicles
- Vehicles may require more space at the depot to charge effectively
  - Depot layout may need to be reconfigured
  - Can be minimized with by overhead charging apparatuses
  - May require additional staffing in depot to move vehicles around during the day

# Maintenance

- Electric buses are fundamentally different machines than ICE buses, and require a different set of skills to maintain
  - Training on electrical propulsion systems
  - Additional safety measures and training to protect against falls (more systems on bus roofs to maintain)
  - New daily/periodic inspection protocols
  - New protocols to prevent injury from the electrical systems
  - Additional staff to operate and manage the charging infrastructure
  - Transitioning and maintaining parts inventory
  - Establishing new preventive maintenance cycles
  - Work order hours estimating – many new types of repairs and routine maintenance

# Planning and Scheduling

- Scheduling and routing must consider bus range and charging locations
  - Ensuring adequate charging facilities
  - Consideration when building vehicle blocks regarding total distance
  - May require fundamental shifts in how operator work is created
  - Future service changes must consider ZEV constraints
  - Triggers for expansion of charging capability
  - Do constraints mean more buses to deliver expanded service?

- Emergency Contingencies
  - Develop a contingency plan for continuation of service in the event of a power outage, inclement weather, natural disaster, or when charging infrastructure needs maintenance

# Administration

- Energy procurement – Electricity
  - Negotiate appropriate on- and off-peak period usage charges, demand charges
  - Ensure adequate staff to audit billing from PSE
  - Multi-site meters and auditing
  - Separating propulsion energy from building energy
  - Procurement of power beyond grid provider
- Energy Procurement – Hydrogen
  - Intercity Transit may become a member of a joint venture or production consortium to ensure continuous supply
  - Hydrogen is not yet a market commodity – pricing and pricing prediction are new science
- Reporting
  - How will energy consumption be reported? Based on BTU’s or emission characteristics or both?

# Demand Response Service Initial Analysis Results

# Assumptions

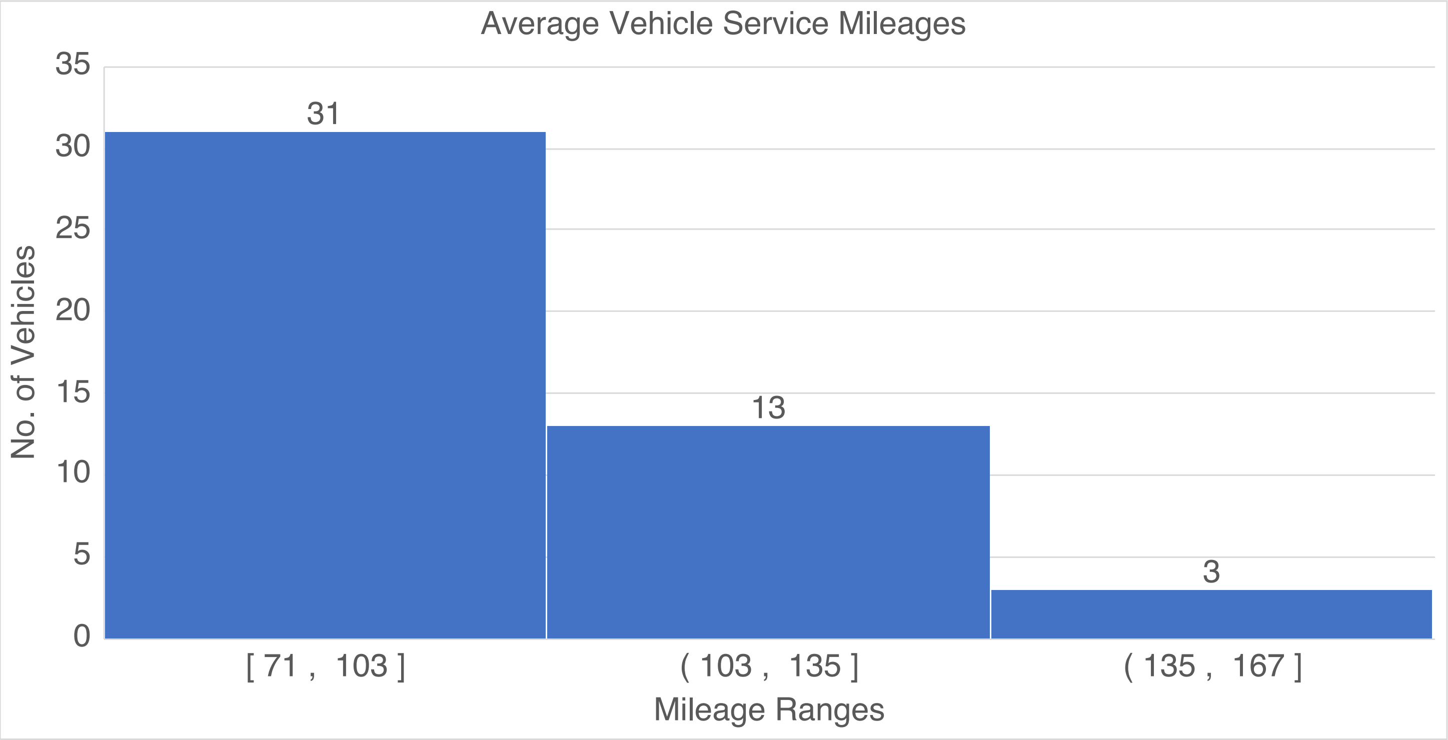
## Demand Response Service: Dial-A-Lift (DAL) Fleet

- A nameplate capacity of **92 kWh** was assumed for the transit vans performing DAL service, based on the average nameplate capacity of currently available vehicle models
- CTE assumed a **5%** improvement in battery nameplate capacities every other year, based on technological improvements, therefore leading to an average nameplate battery capacity estimate of **182 kWh** through **2050**.
  - CTE limits nameplate capacity improvements to 200 – 250 kWh for the battery-electric transit van category by 2050.
- Daily vehicle mileages for the month of **October 2019** were taken into consideration, to account for the most recent, busiest month of service.
- CTE analyzed how vehicle mileages varied across the **47 DAL vehicles** in active service during this month, averaging between **71 and 167 mi** of service.
- Provided that operator midday/lunch breaks and locations are defined by when and where trips are scheduled during the service day, CTE did not consider daily service mileage capabilities based on opportunities to midday charge the vehicles at the depot.

# Average Service Mileages by Vehicle

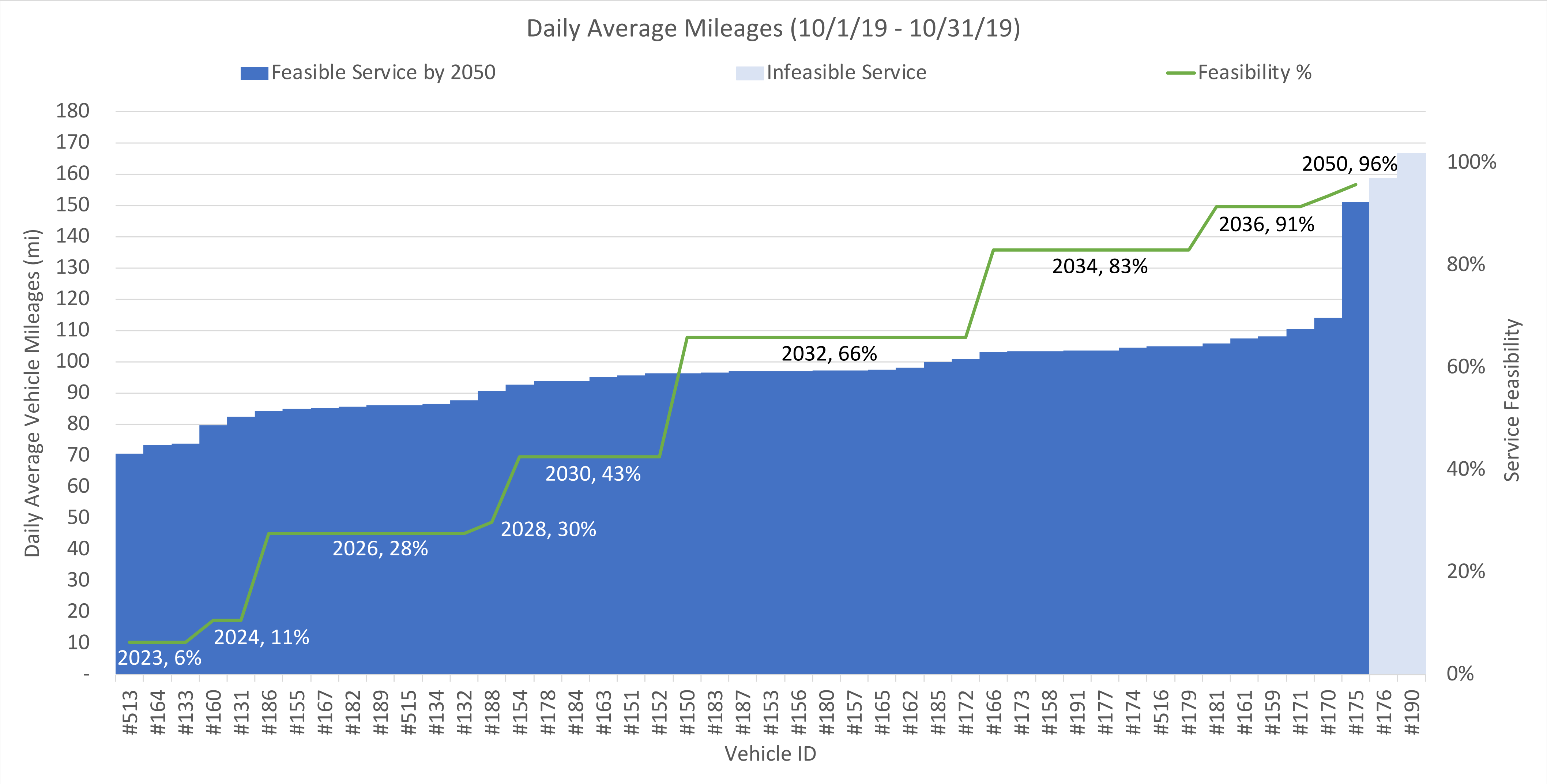
## Demand Response Service: Dial-A-Lift (DAL) Fleet

- 31 of the shortest DAL daily service mileages (**71 – 103 mi**) will be feasible by **2032**, accounting for a service feasibility of **66%.**
- 13 of the mid-range DAL service mileages (**103 – 135 mi**) will be feasible by **2038**, increasing feasibility to **94%.**
- By **2050**, only 1 of 3 of the long-range DAL trips **(135 – 167 mi)** will be feasible, resulting in **96%** overall service feasibility by 2050.
  - Daily service mileages above **152 mi** remain infeasible based on current projections in battery capacity improvements



# DAL Fleet Feasibility through 2050

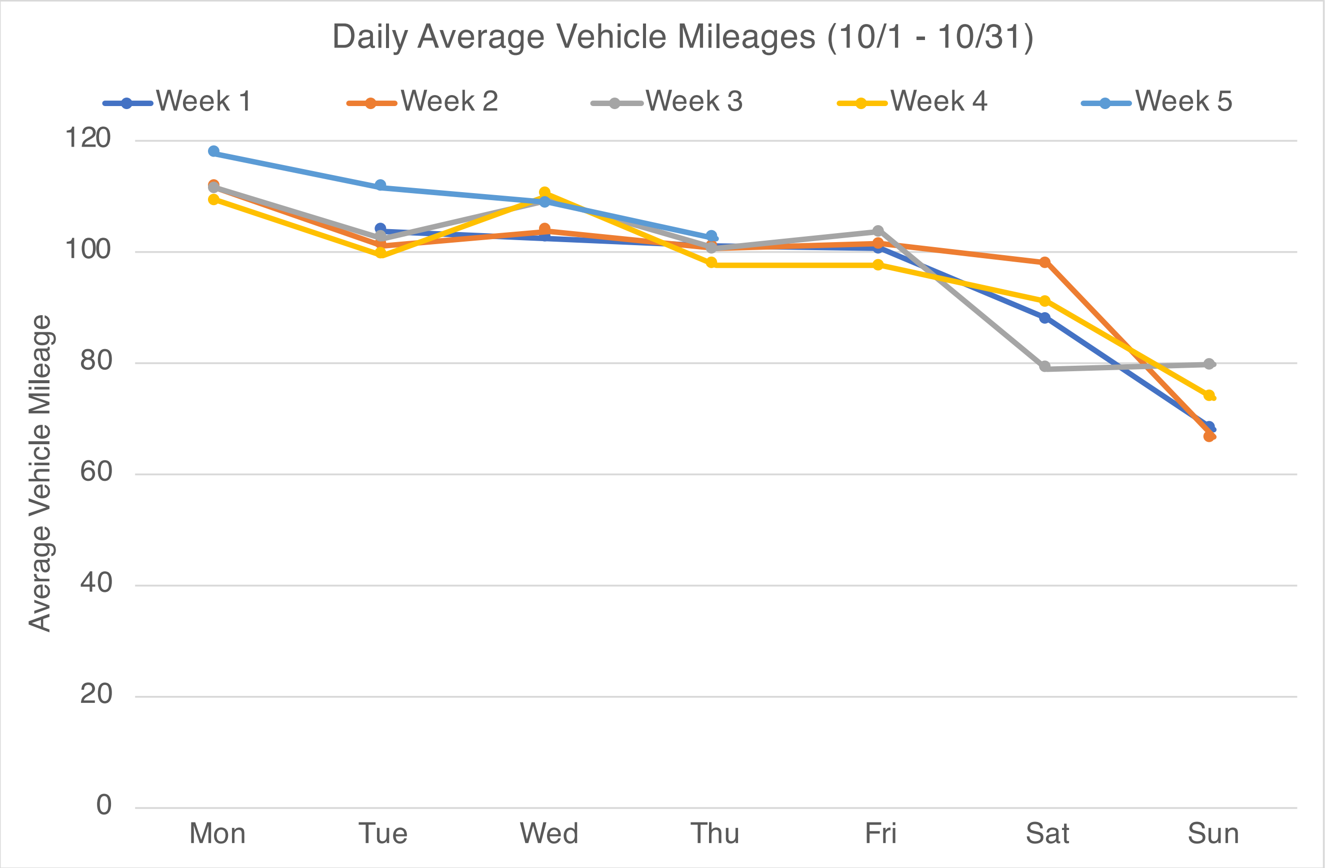
## Average Service Mileages by Vehicle



# Average Service Mileages by Day

## Demand Response Service: Dial-A-Lift (DAL) Fleet

- **Sunday** service mileages range between **60 – 80 miles** of service. These ranges are feasible in **2023**.
- **Thursday through Saturday** service mileages range between **80 – 100 miles** of service. These ranges will be feasible by **2032**.
- **Monday through Wednesday** trips range between **100 – 120 miles** of service and tend to be the busiest days of service. These ranges will be feasible by **2050**.



# Key Takeaways

## Demand Response Service: Dial-A-Lift (DAL) Fleet

- Feasibility for the DAL fleet was defined based on daily average service mileages per vehicle, in October 2019. **96% of DAL service will be feasible by 2050.**
- Intercity Transit could consider specifically assigning battery-electric transit vans to shorter service mileages, without major changes to scheduling, in stages based on daily average vehicle service mileages:
  - **71 – 103 mi** will be feasible by **2032**
  - **103 – 135 mi** will be feasible by **2038**
  - DAL service mileages **under 152 mi** will be feasible by **2050**
- Operationally, Intercity Transit may **group similar trips** together, versus maintaining service mileage limitations for the battery-electric DAL fleet.
- Assigning DAL trips based on battery-electric range limitations **limits flexibility of service** during the day (e.g.: last-minute requests or modifications of service in real-time).
- There may be an opportunity to run a larger portion of weekend service with battery-electric vehicles.

# Project Next Steps

# Project Next Steps

- Finalize Fixed Route Fleet Analysis
- Complete Demand Response Fleet Analysis
- Prepare Project Final Report

# Thank you.

## Questions?