ATTACHMENT 1 -

BRAMPTON TRANSIT

ZEB IMPLEMENTATION STRATEGY AND ROLLOUT PLAN

NET ZERO BY 2041

SUMMARY REPORT - REV. 07

TRANSITIONING TO A ZERO-EMISSIONS BUS FLEET

CUTRIC · CRITUC

CONTENTS

01

About Brampton Transit

ABOUT BRAMPTON TRANSIT

- Brampton Transit has a long history of striving for **sustainable services** including participating in the first trial for interoperability which provided opportunities to learn from a Canadian test.
- Electrification of Brampton Transit's fleet represents an important step towards meeting **2050 federal emissions targets**.
- The City of Brampton (City) and provincial government's additional targets further support Brampton Transit's **fleet electrification** efforts.
- Established in 1976, Brampton Transit operates **74 routes** connecting Brampton with neighbouring areas.
- In 2010, Brampton Transit launched Züm, a Bus Rapid Transit service, for **faster travel** along major Brampton corridors.
- Brampton Transit provided **over 40 million rides** annually in 2023.

Operating since 1976

40 million rides annually

476 vehicles

8 electric buses in operation

74 Routes

02

About CUTRIC

ABOUT CUTRIC

Driving Canadian leadership in clean and smart mobility

CUTRIC strives to make Canada a global leader in low-carbon smart mobility technologies across heavy-duty and light-duty platforms, including advanced transit, transportation, and integrated mobility applications.

About CUTRIC

The Canadian Urban Transit Research & Innovation Consortium (CUTRIC) is a socially responsible non-profit organization that spearheads, designs, and launches technology and commercialization projects that advance next-generation zero-carbon mobility and transportation solutions across Canada.

Projects

Memberships

CUTRIC has over 140 members spanning across the public transit, industry, utility, academic, consultancy and not-for-profit sectors.

Consulting

CUTRIC'S ZEB Consulting Services™ help transit agencies, utilities and other allied organizations reach their decarbonization and electrification goals scientifically and neutrally through feasibility and empirical analyses, full ZEB implementation planning and low-carbon smart mobility research.

Projects

CUTRIC partners with various industry leaders for marquee national projects including a hydrogen fuel cell electric and battery electric bus demonstration and integration trial, smart vehicle demonstration trials and an autonomous connected, electric and shared big data trust. CUTRIC performs predictive modelling to help transit agencies transition to a zero emissions fleet.

03

Project Overview

PROJECT OVERVIEW

Problem

Brampton Transit is committed to achieving an environmentally sustainable transit service by electrifying its fleet. With the transportation sector being a major contributor to greenhouse gas (GHG) emissions, the electrification of Brampton Transit's fleet is crucial in aligning with the federal government's 2050 emissions targets and the City's goal to reduce GHG emissions by 80 per cent by 2050. The existence of additional targets set by the City and provincial government, combined with the availability of federal funds through the Zero Emission Transit Fund (ZETF) program, supports Brampton Transit's move towards fleet electrification.

Brampton's Community Energy and Emissions Reduction Plan (CEERP) serves as the roadmap towards a low-carbon future. With a focus on people, air, water, land, energy, and waste, Brampton Transit will cultivate green jobs, enhance resilience, and transition to a sustainable economy.

Objectives

1. ASSESSMENT OF THE AGENCY'S EXISTING FLEET
2. FEASIBILITY ANALYSIS
3. RECOMMENDATIONS FOR TRANSITIONING TO ZEB FLEET
4. FLEET ELECTRIFICATION ROLLOUT PLAN
5. SHORT-TO-LONG TERM NEEDS & OPPORTUNITIES

PROJECT OVERVIEW

Current fleet

476 Ready for service buses

10.3 Average age (years)

Fleet	Number	Average age (years)
Diesel (12m)	335	11.1
Diesel-electric hybrid (12m)	43	12.4
Diesel-electric hybrid (18m)	90	7.4
Electric (12m)	8	2.2

Blocks Modelled

508 Weekday | 150 Sat | 134 Sun

Distance Modelled

Revenue: 27.5 million km per year

Non-Revenue: 3 million km per year

Routes Modelled

74

Buses Modelled

BEB: 6 configurations

FCEB: 2 configurations

04

Executive Summary

Executive Summary

Brampton Transit's Zero Emissions Bus Implementation and Rollout Plan lays out a pathway towards a zero emissions future for the public transit agency achieving 100 per cent fleet electrification by 2041.

This study assesses three scenarios for Brampton Transit's decarbonization plan:

- **Scenario One:** all buses transitioned to BEBs ("full BEB solution")
- **Scenario Two:** all buses transitioned to FCEBs ("full FCEB solution")
- **Scenario Three:** a mixed green fleet of BEBs and FCEBs ("mixed green fleet solution")

Scenario One
Full BEB solution

Scenario Two
Full FCEB solution

Scenario Three
Mixed green fleet solution

Key findings

- Brampton Transit is best positioned to decarbonize using a "midway" approach — **Scenario Three (mixed green fleet solution)** balancing BEB and FCEB technologies.

- This solution reduces emissions significantly in the City of Brampton and requires the fewest number of additional vehicles to achieve a net zero solution by 2041.

- A mixed fleet solution leverages depot and on-route charging for BEBs to ensure a high level of service and minimal disruption to service frequency.

- A mixed fleet solution can leverage grey hydrogen supplies in Ontario while shifting toward increasingly green hydrogen supplies by 2041.

- This solution is the most financially viable costing less than Scenario One (full BEB solution) or Scenario Two (full FCEB solution).

Funding Opportunities

Infrastructure Canada

Zero Emission Transit Fund

- $2.75 billion over 5 years (April 2021 - March 2026)
- Planning and capital projects

CIB BIC

Canada Infrastructure Bank's Zero Emission Buses Initiative

- Direct loan based on expected level of saving
- Vehicle purchasing
- $400 million for up to 450 BEBs by 2027

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Environmental and Climate Change Canada's Low Carbon Economy Fund

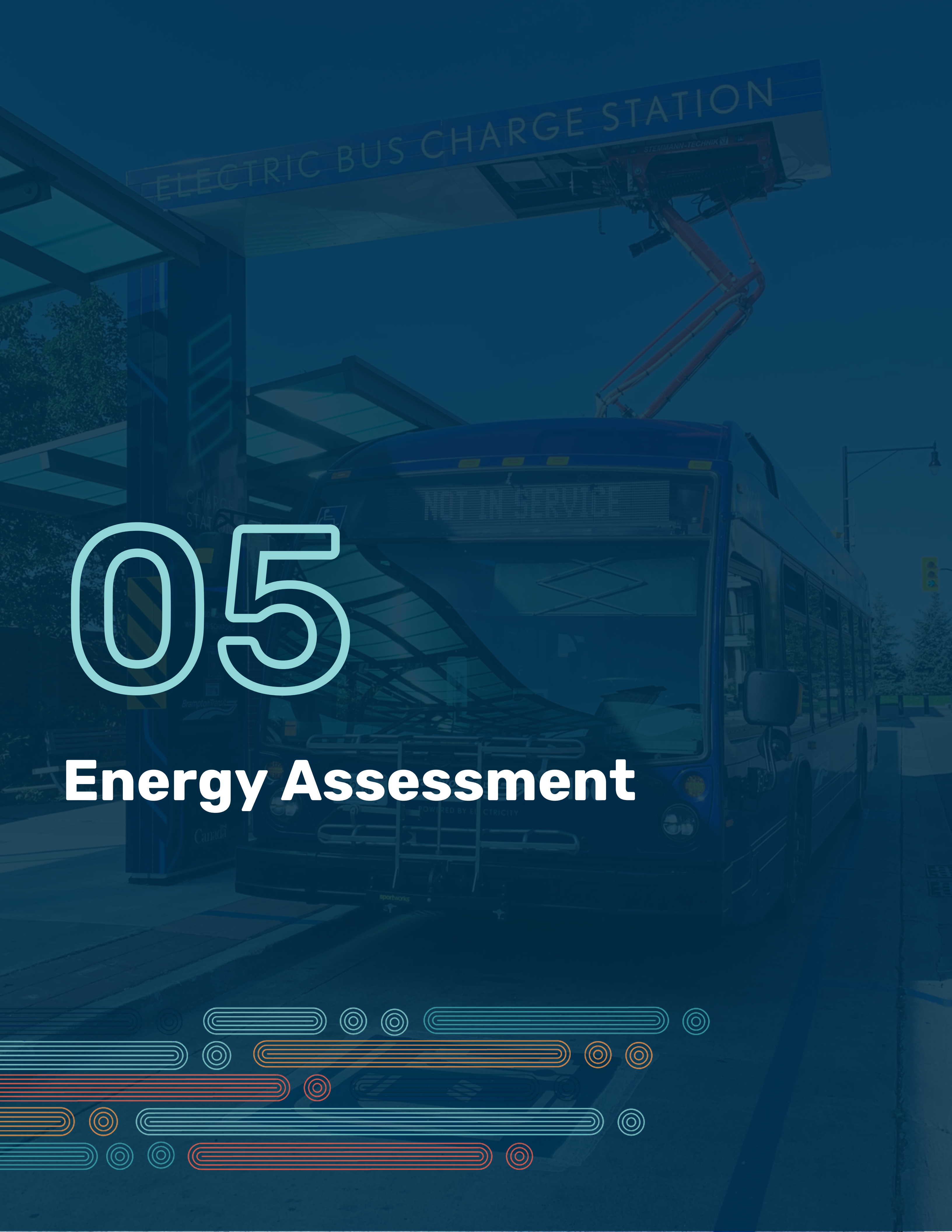
- $2.2 billion
- Open-ended projects that reduce emissions in addition to already planned initiatives

Infrastructure Canada

Permanent Public Transit Fund

- Proposed to replace ZEFT in 2026
- Would see an investment of $3 billion per year in permanent and predictable federal public transit funding

*All currency is in Canadian Dollars unless otherwise specified

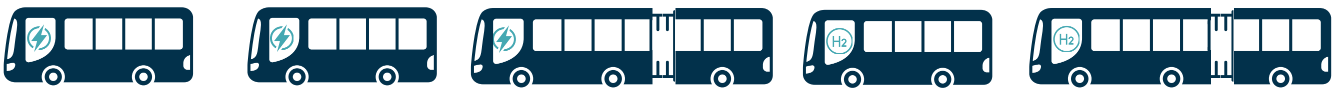


05

Energy Assessment

ENERGY ASSESSMENT

Weekday ZEB average efficiencies



Type 1 — 12m BEB
Electric Heater: 400+ kWh
DFAH: 500+ kWH

Type 2 — 12m BEB
Electric Heater: 500+ kWh
DFAH: 500+ kWH

Type 3 — 18m BEB
Electric Heater: 500+ kWh
DFAH: 600+ kWH

Type 4 — 12m FCEB
Electric Heater: 30+ kg

Type 5 — 18m FCEB
Electric Heater: 50+ kg

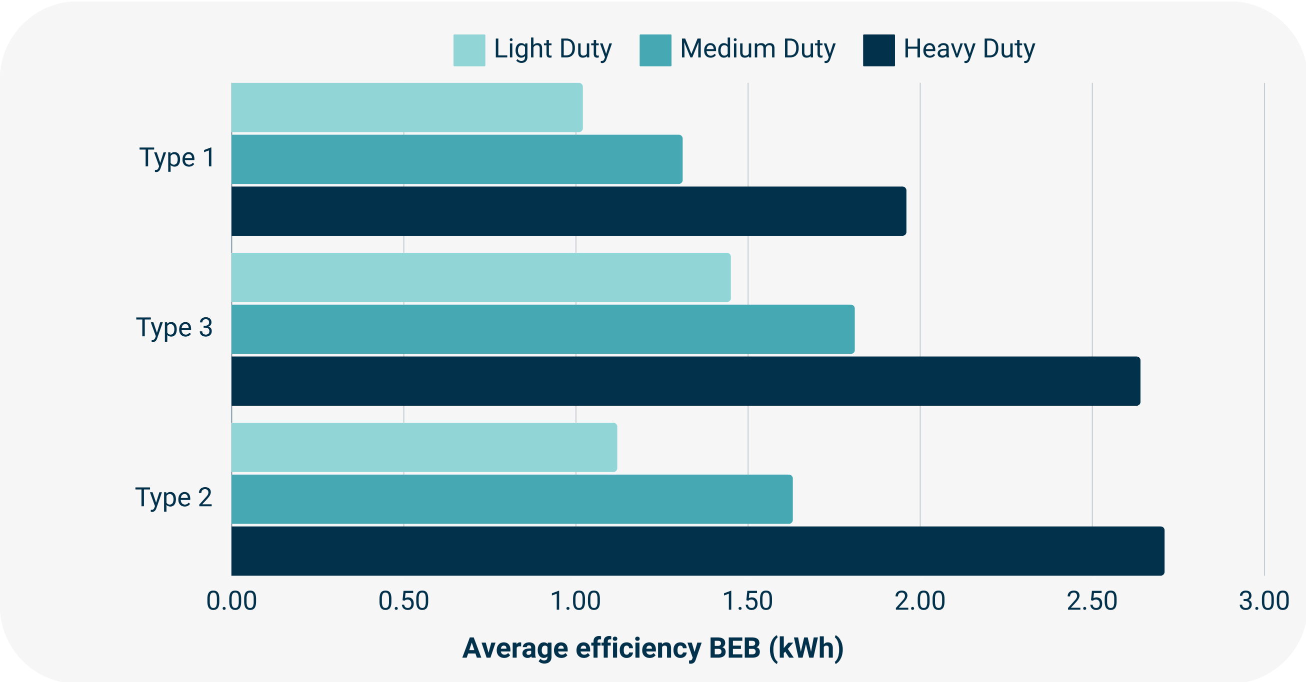
- Efficiencies are measured in kilowatt-hours per kilometer for battery electric buses (BEBs) and kilograms of hydrogen per 100 kilometers for fuel cell electric buses (FCEBs)
- Efficiencies are calculated by considering energy consumed during operation and the total distance traveled, including non-revenue parts of the service
- Table 1 showcases the weekday average energy efficiency of two ZEB models in the Brampton Transit system

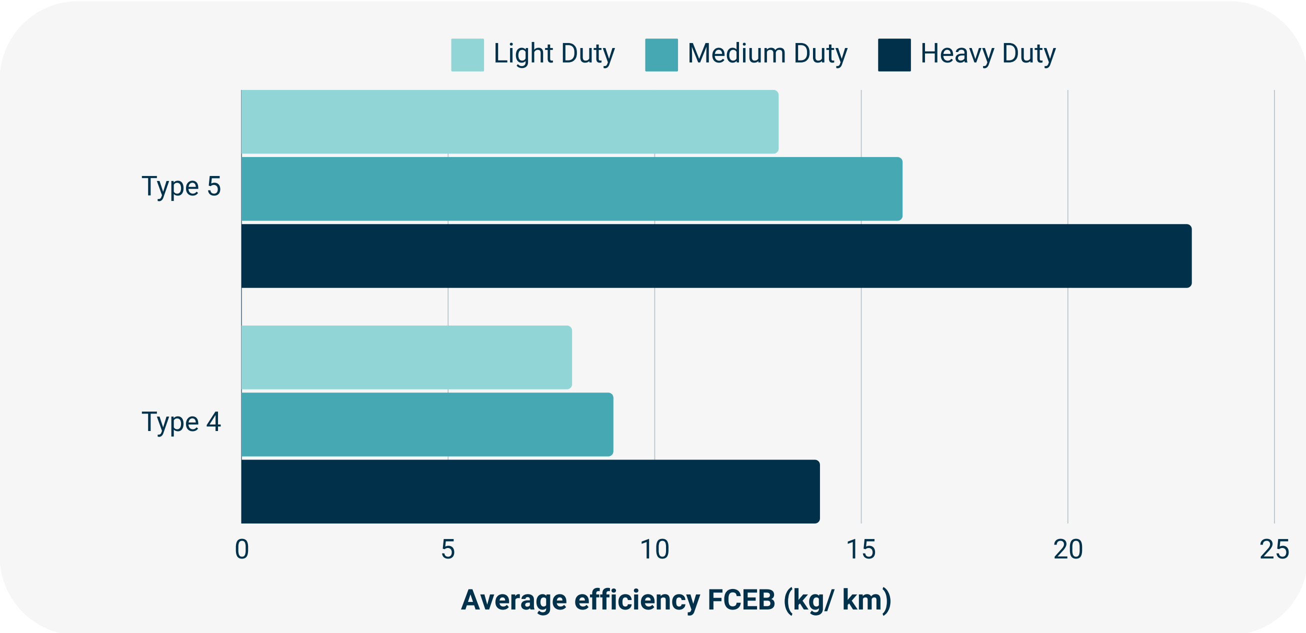
Bus	Type	Size	Specs Battery capacity (nominal charging)	Heater	Light BEB (kWh/km) FCEB (kgH2/100km)	Medium BEB (kWh/km) FCEB (kgH2/100km)	Heavy BEB (kWh/km) FCEB (kgH2/100km)
Type 1	BEB	12m	400+ kWh (~290 kW)	electric	1.02	1.31	1.96
			500+ kWh (~160 kW)	DFAH	1.02	1.14	1.49
Type 2	BEB	12m	500+ kWh (~330 kW)	electric	1.12	1.63	2.71
				DFAH	1.12	1.27	1.72
Type 3	BEB	18m	500+ kWh (~160 kW) 600+ kWh (~160 kW)	electric	1.45	1.81	2.64
				DFAH	1.45	1.57	1.98
Type 4	FCEB	12m	30+ kg	electric	7.13	9.10	13.5
Type 5	FCEB	18m	50+ kg	electric	12.6	15.7	22.5

Table 1: Average weekday efficiencies by vehicle configuration

ENERGY ASSESSMENT

Weekday ZEB average efficiencies by vehicle type



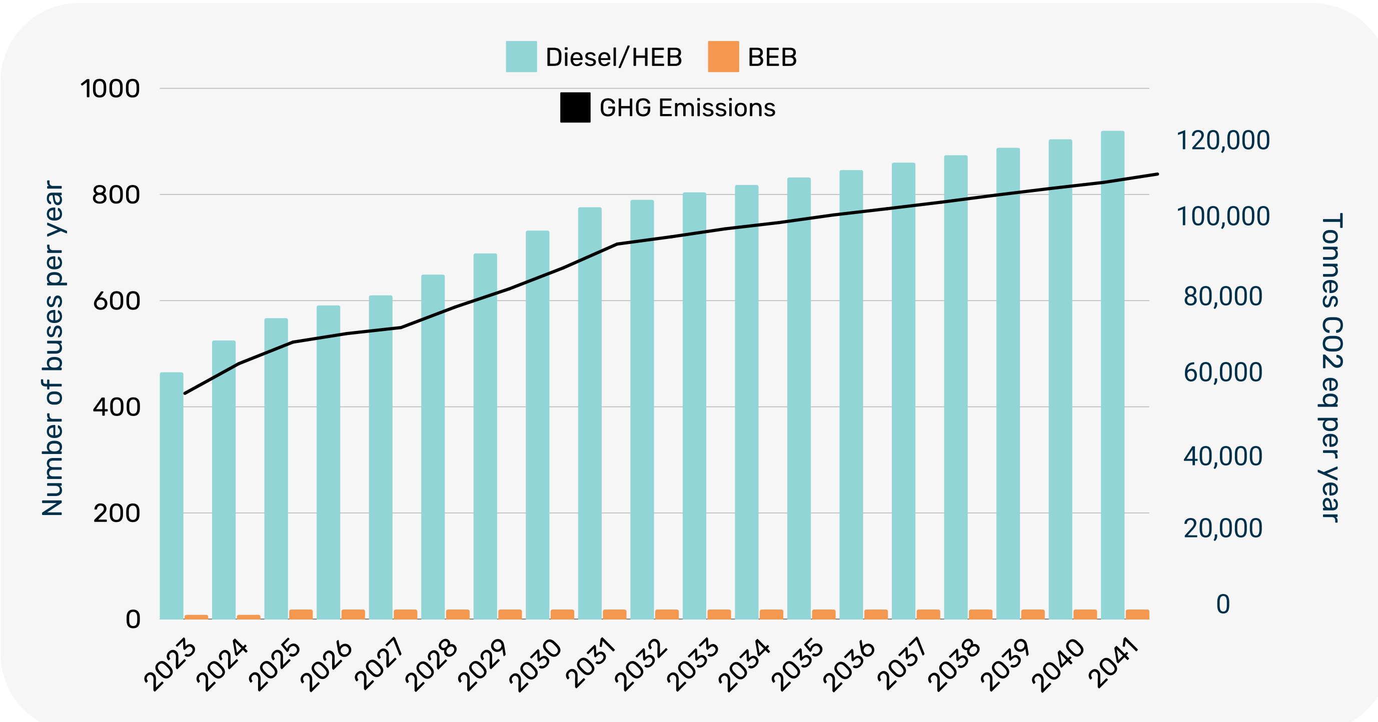


06

Fleet Rollout Plan

FLEET & CHARGING INFRASTRUCTURE

Base Case (diesel fleet)



2026

325 diesel buses

215 HEBs

18 BEBs

2030

311 diesel buses

382 HEBs

18 BEBs

2041

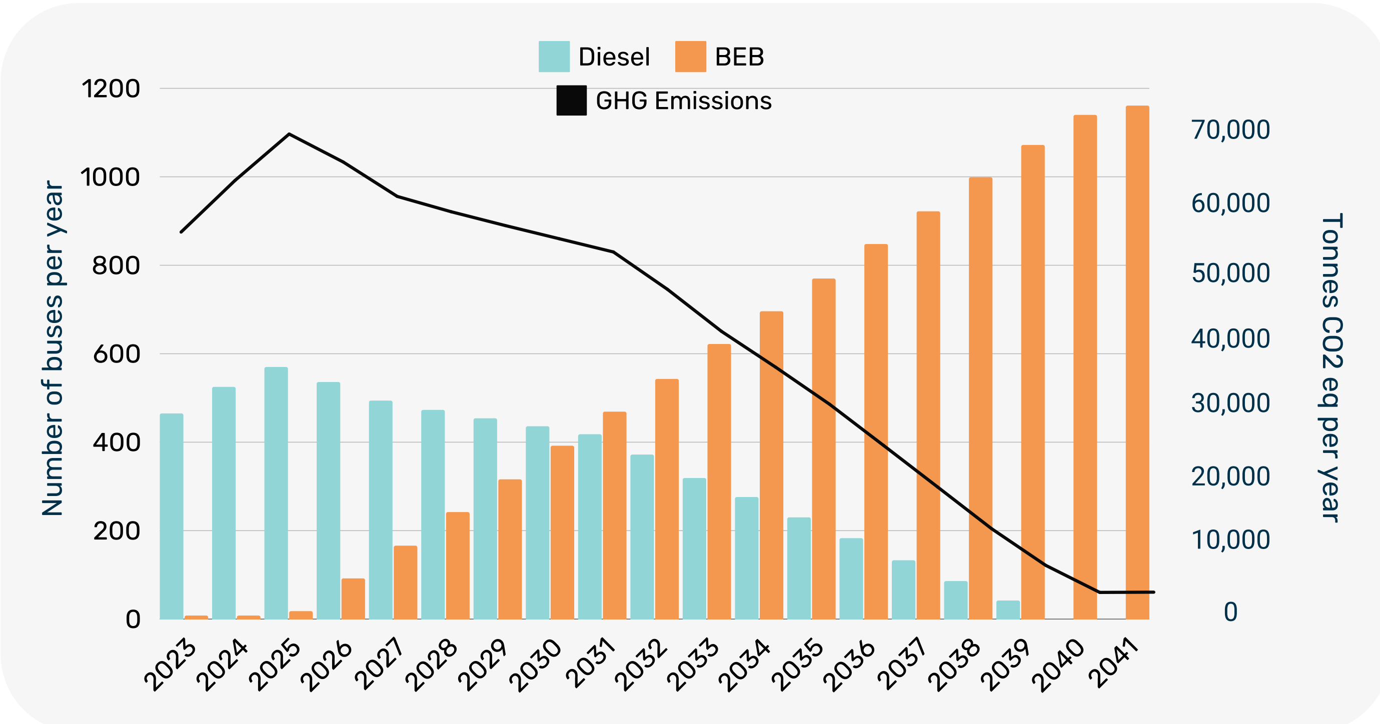
317 diesel buses

603 HEBs

18 BEBs

FLEET & CHARGING INFRASTRUCTURE

Scenario One (full BEB solution)



45 diesel buses removed

92 BEBs

2026

468 diesel buses removed

1161 BEBs

2041

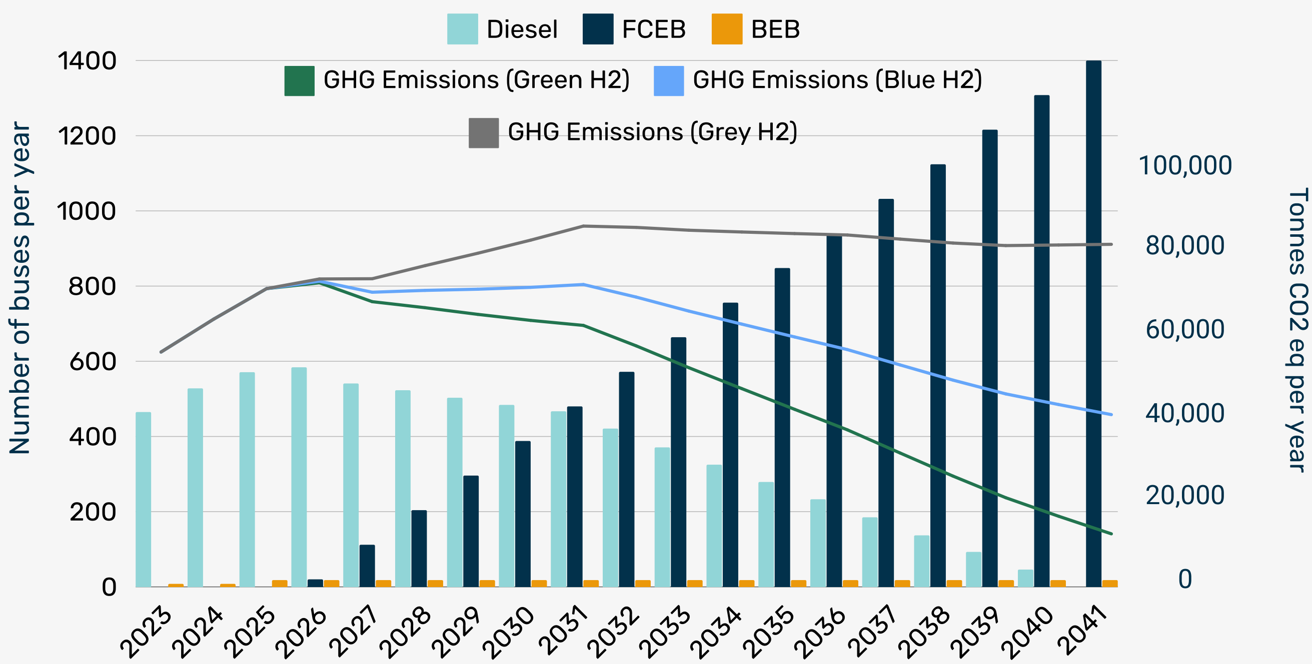
2030

145 diesel buses removed

392 BEBs

FLEET & CHARGING INFRASTRUCTURE

Scenario Two (full FCEB solution)



0 diesel bus removed
20 FCEBs
18 BEBs

2026

All diesel buses removed
1400 FCEBs
18 BEBs

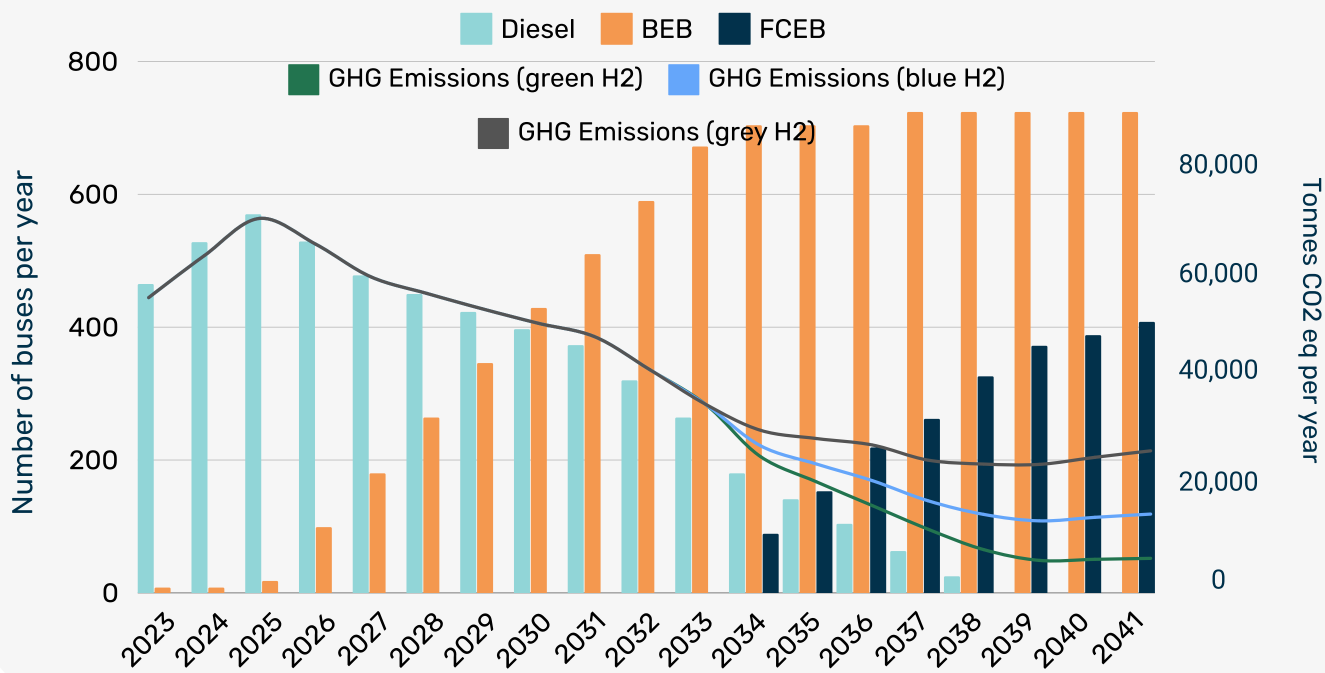
2041

2030

100 diesel buses removed
388 FCEBs
18 BEBs

FLEET & CHARGING INFRASTRUCTURE

Scenario Three (mixed green fleet solution)



41 diesel buses removed
99 BEBs
0 FCEBs

2026

All 468 diesel buses removed
724 BEBs
408 FCEBs

2041

2030

176 diesel buses removed
429 BEBs
0 FCEBs

07

Fleet & Charging Infrastructure

FLEET & CHARGING INFRASTRUCTURE

Land acquisition and on-route chargers

- To support decarbonization through Scenario One (full BEB solution) or Scenario Three (mixed green fleet solution) this study considers all transit terminals as potentially optimal locations to deploy on-route chargers, as part of a Strategy Two (depot with on-route) charging solution.
- Optimization analysis balances the issues of terminals that serve many vehicle blocks against terminals that have space to house chargers.
- Eight optimal locations result from the optimization analysis carried out for this study.
- Scenario One (full BEB solution) and Scenario Three (mixed green fleet solution) require on-route chargers.

Land acquisition cost methodology

1. Identified vacant land comparable sales that contain similar attributes to the Subject Sites.
2. Translated sale prices of all comparable sales to a common unit (i.e., $/square foot (SF)).
3. Applied adjustments to each comparable sale related to time of sale, zoning and location to derive an adjusted price per square foot for each comparable sale.
4. Identified the logical market value conclusion for each of the Subject Sites.

FLEET & CHARGING INFRASTRUCTURE

Land acquisition and on-route chargers

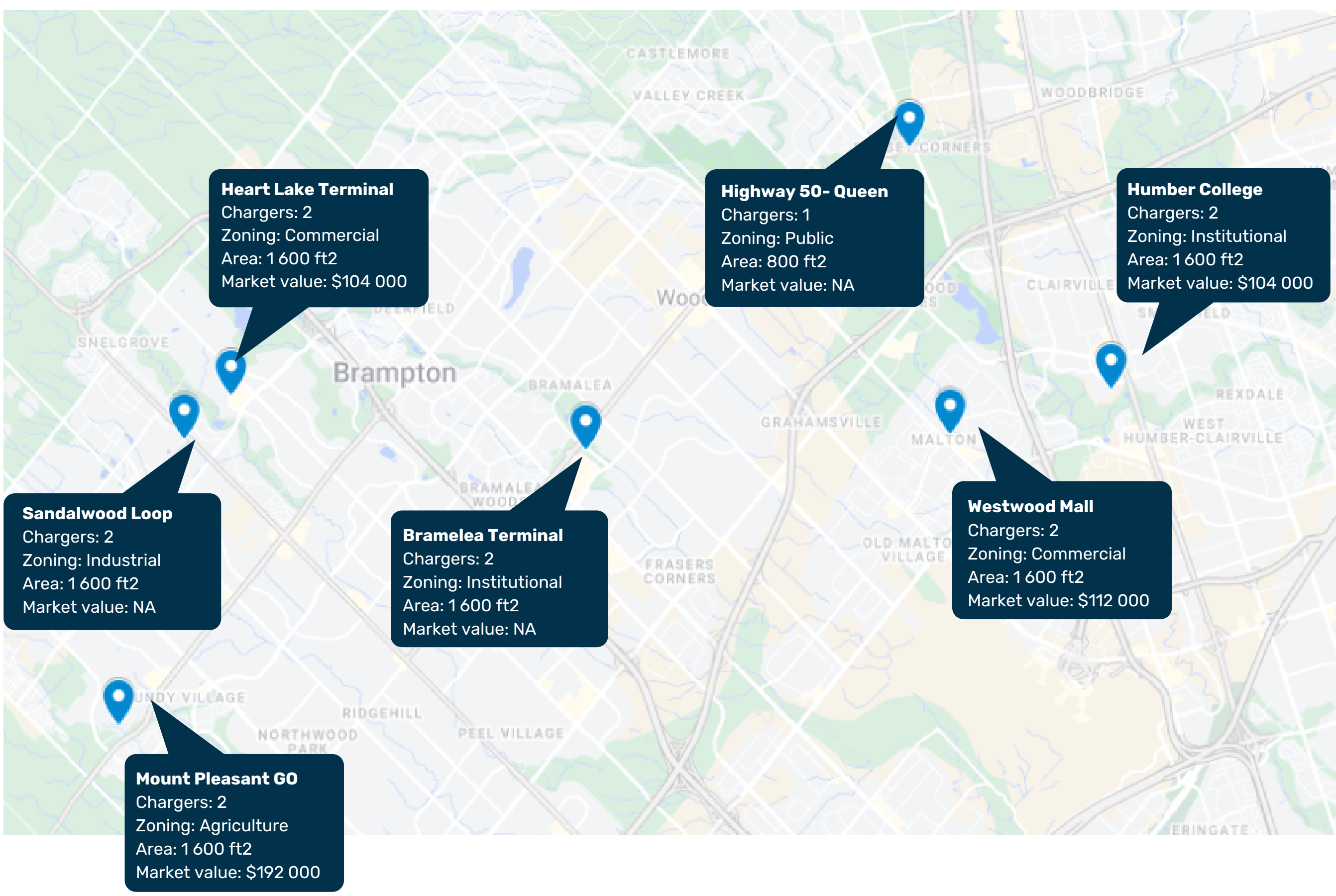
A real estate assessment considers the land parcels needed for on-route charging stations required for Scenario One (full BEB solution) or Scenario Three (mixed green fleet solution).

- Multiple land parcels in Brampton, Mississauga, and Toronto could host on-route chargers.
- Data sets show each site has sufficient land space to host one or more charging stations.

Note: Brampton Transit is carrying out a Transit Project Assessment Process to develop a new downtown transit terminal which may also consider BEB charging. This facility was not chosen as a site as the specifics were uncertain at the time of the analysis.

$512,000

Total cost of land aquisition



FLEET & CHARGING INFRASTRUCTURE

Schedule Optimization

To achieve electrification in Scenario One (full BEB solution) or Scenario Three (mixed green fleet solution), Brampton Transit requires schedule optimization.

- Schedule optimization assesses the availability of time for on-route charging as part of Strategy Two (depot with on-route charging). This time accounts for availability of chargers required to charge the bus.
- Table 2 shows an example of the schedule optimization for vehicle 101 of the weekday service, which covers part of Route 1 connecting the Mount Pleasant GO station to Queen Street at Highway 50.
- Any bus would be able to complete this route without dropping below acceptable battery charge thresholds of 20 per cent State of Charge (SOC).

Arrival	Departure	Downtime	Terminal Stop	New Arrival	New Departure	New downtime	Terminal Stop	Energy consumed (kWh)	Energy charged (kWh)	SOC (%)
-	3:48	-	CLARK	-	3:48	-	CLARK	0.0	0.0	100%
4:01	4:01	0:00	Downtown	4:01	4:01	0:00	Downtown	9.1	0.0	98%
4:47	4:48	0:01	Queen	4:47	4:54	0:07	Queen	46.1	24.4	96%
5:55	5:56	0:01	Mt Pleasant	6:01	6:16	0:15	Mt Pleasant	103.0	48.8	90%
7:12	7:14	0:02	Queen	7:32	7:40	0:08	Queen	159.1	73.1	84%
8:26	8:32	0:06	Mt Pleasant	8:52	9:13	0:21	Mt Pleasant	215.9	97.5	77%
9:54	9:58	0:04	Queen	10:35	10:45	0:10	Queen	271.9	121.9	71%
11:11	11:28	0:17	Mt Pleasant	12:08	12:17	0:09	Mt Pleasant	329.1	146.3	65%
12:50	12:52	0:02	Queen	13:39	13:48	0:09	Queen	384.9	170.6	59%
14:07	14:27	0:20	Mt Pleasant	15:03	15:33	0:30	Mt Pleasant	442.0	195.0	53%
15:52	15:57	0:05	Queen	16:58	17:11	0:13	Queen	498.3	219.4	47%
17:19	17:29	0:10	Mt Pleasant	18:33	18:44	0:11	Mt Pleasant	555.2	243.8	41%
18:55	18:56	0:01	Queen	20:10	20:31	0:21	Queen	611.6	268.1	35%
20:08	20:09	0:01	Mt Pleasant	21:43	21:55	0:12	Mt Pleasant	668.3	292.5	28%
21:19	21:19	0:00	Queen	22:14	-	-	CLARK	744.3	292.5	28%
21:38	-	-	CLARK	-	-	-	-			

Table 2: Adjusted schedule, weekday service sample - block 101

FLEET & CHARGING INFRASTRUCTURE

Schedule Optimization

- Scenario One (full BEB solution) and Scenario Three (mixed green fleet solution) will require an increase of approximately nine per cent in service hours.
- Scenario Two (full FCEB solution) will only require an increase of approximately two per cent in service hours.
- On-route charging has a significant impact in the total service hours because of extra charging and platform time added to the system.
- Zero emissions buses (ZEBs) generally present a significantly shorter range when compared to diesel buses, extra service time is required to allow for on-route charging, refuelling and block splitting.
- Brampton Transit expects to grow its current service levels by approximately 76 per cent by 2041. This analysis accounted for both the service growth and the additional buses required in a ZEB fleet.

		Base Case (diesel fleet)	Scenario One (full BEB)		Scenario Two (full FCEB)	Scenario Three (mixed green fleet)	
		Diesel	Type 1 & 3	Type 2	Type 4 & 5	Type 1,3,4 & 5	Type 2,4 & 5
Current Service	BEBs without DFAH	1.58	1.72	1.61	1.61	1.72	1.61
	BEBs with DFAH		1.70	1.76		1.70	1.75
Growth Fleet (2041)	BEBs without DFAH	2.79	3.04	2.83	2.83	3.03	2.84
	BEBs with DFAH		3.00	3.09		3.00	3.09

Table 3: Annual required service hours (million hours)

FLEET & CHARGING INFRASTRUCTURE

Vehicles

For the growth fleet, only configurations with BEB Types 1 and 3 were considered as these configurations were used in the economic analysis (Section Eight)

The heavy-duty cycle is used when calculating the total fleet size required to electrify the Brampton Transit system.

- **Scenario One (full BEB solution)**
  - Assuming Strategy Two (depot and on-route charging) for BEBs
  - Configuration One with Types 1 and 3 results in a current fleet of 633 BEBs
  - Configuration Two with Type 2 results in a current fleet of 674 BEBs (+6.5 per cent compared to Configuration One)

- **Scenario Two (full FCEB solution)**
  - Fleet of 720 buses (+51.2 per cent compared to the base case)

- **Scenario Three (mixed green fleet solution)**
  - Fleet of between 558 to 640 vehicles

<table>
<tr><th rowspan="3" colspan="2"></th><th rowspan="2" colspan="2">Base Case</th><th rowspan="2" colspan="2">Scenario One
(full BEB solution)</th><th rowspan="2">Scenario Two
(full FCEB solution)</th><th colspan="4">Scenario Three
(mixed green fleet solution)</th></tr>
<tr><th colspan="2">Configuration One</th><th colspan="2">Configuration Two</th></tr>
<tr><th>Diesel/ hybrid</th><th>BEB</th><th>Configuration One Types 1 & 3</th><th>Configuration Two Type 2</th><th>Types 4 & 5</th><th>Types 1 & 3</th><th>Types 4 & 5</th><th>Types 1 & 3</th><th>Types 4 & 5</th></tr>
<tr><td rowspan="4">Current Service</td><td rowspan="2">BEBs without DFAH</td><td rowspan="4">468</td><td rowspan="4">8</td><td rowspan="2">633</td><td rowspan="2">674</td><td rowspan="4">720</td><td>355</td><td>247</td><td>318</td><td>322</td></tr>
<tr><td colspan="2">Total = 602</td><td colspan="2">Total = 640</td></tr>
<tr><td rowspan="2">BEBs with DFAH</td><td rowspan="2">590</td><td rowspan="2">570</td><td>394</td><td>181</td><td>413</td><td>145</td></tr>
<tr><td colspan="2">Total = 575</td><td colspan="2">Total = 558</td></tr>
<tr><td rowspan="4">Growth fleet (2041)</td><td rowspan="2">BEBs without DFAH</td><td rowspan="4">920</td><td rowspan="4">18</td><td rowspan="2">1,240</td><td rowspan="2">-</td><td rowspan="4">1,400
(+18 BEBS)</td><td>767</td><td>418</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Total = 1,185</td><td colspan="2">-</td></tr>
<tr><td rowspan="2">BEBs with DFA</td><td rowspan="2">1,161</td><td rowspan="2">-</td><td>724</td><td>408</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">Total = 1,132</td><td colspan="2">-</td></tr>
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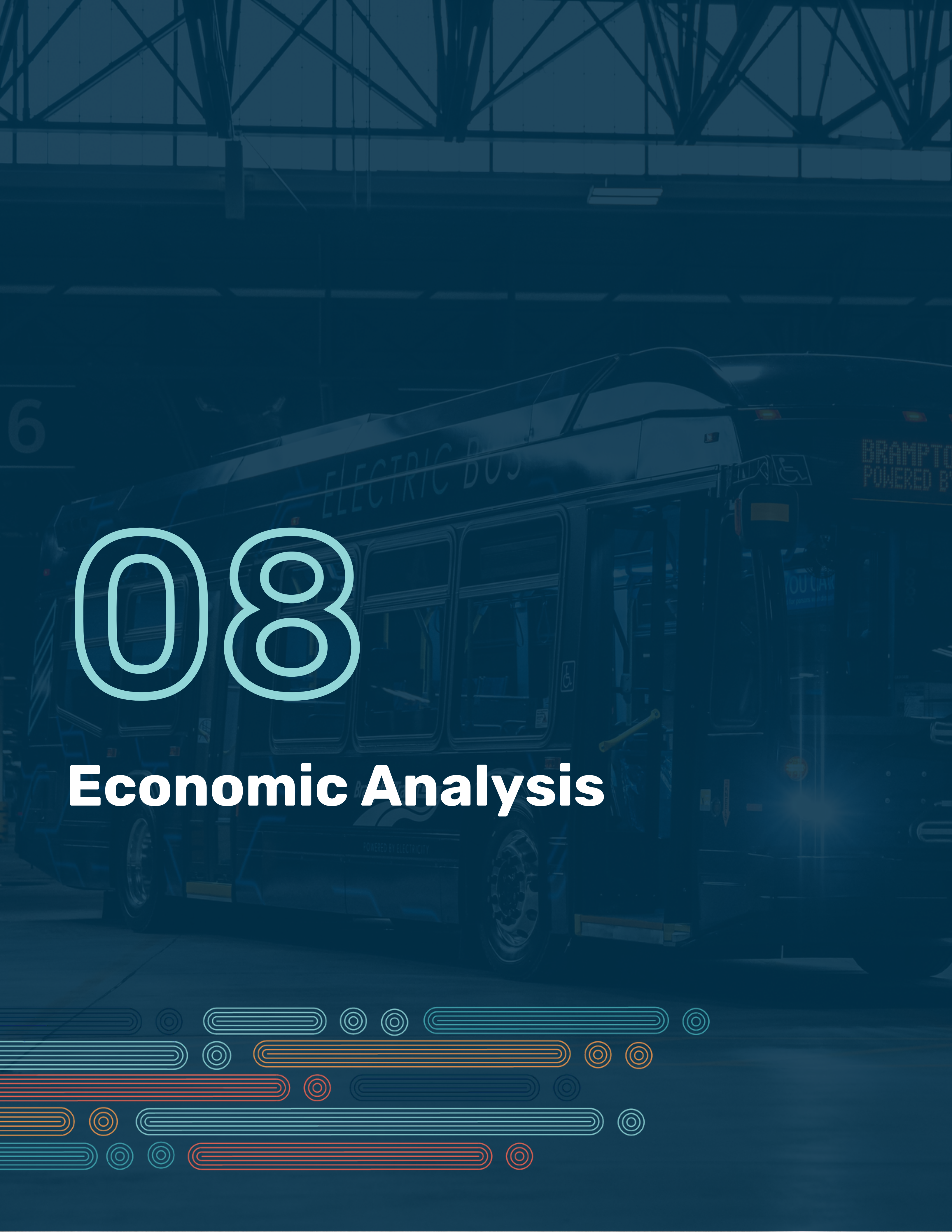
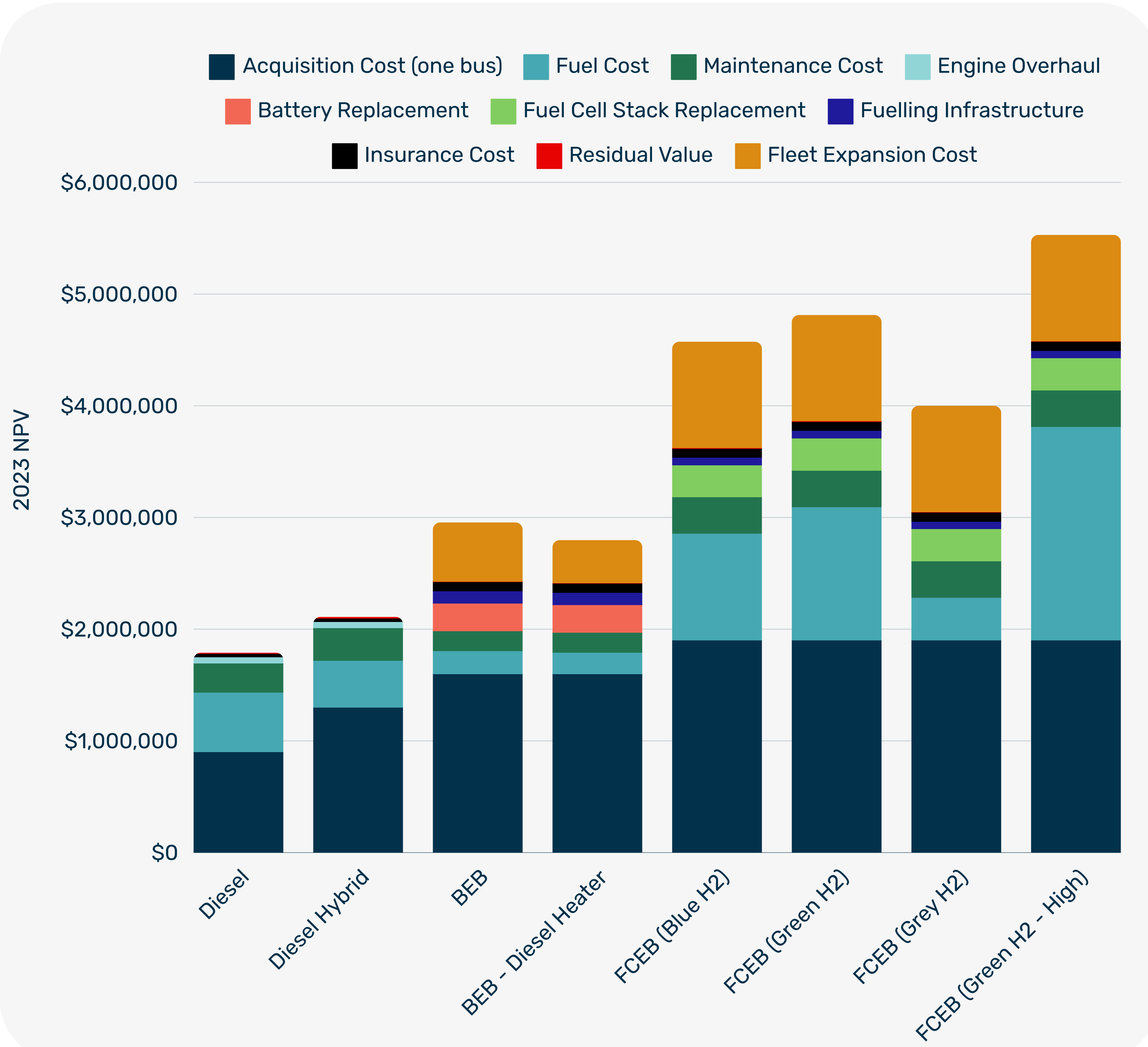
Table 4: Required ZEB fleet size



08

Economic Analysis

ECONOMIC ANALYSIS
Total cost of ownership (TCO) - 12m
15 year life cycle

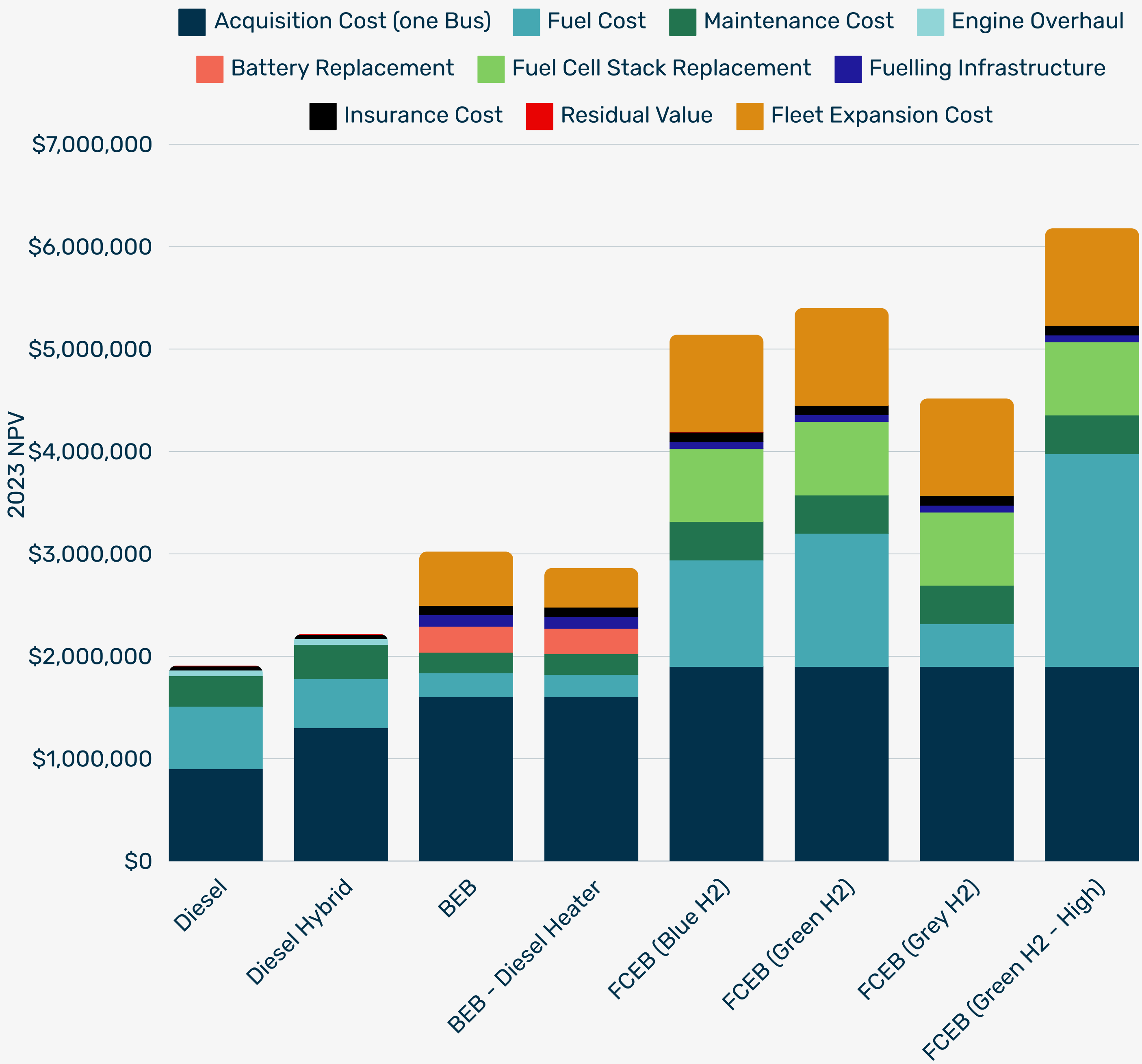


Total Cost of Ownership comparison per bus in NPV (15 year, 12m bus)

ECONOMIC ANALYSIS

Total cost of ownership (TCO) - 12m

18 year life cycle

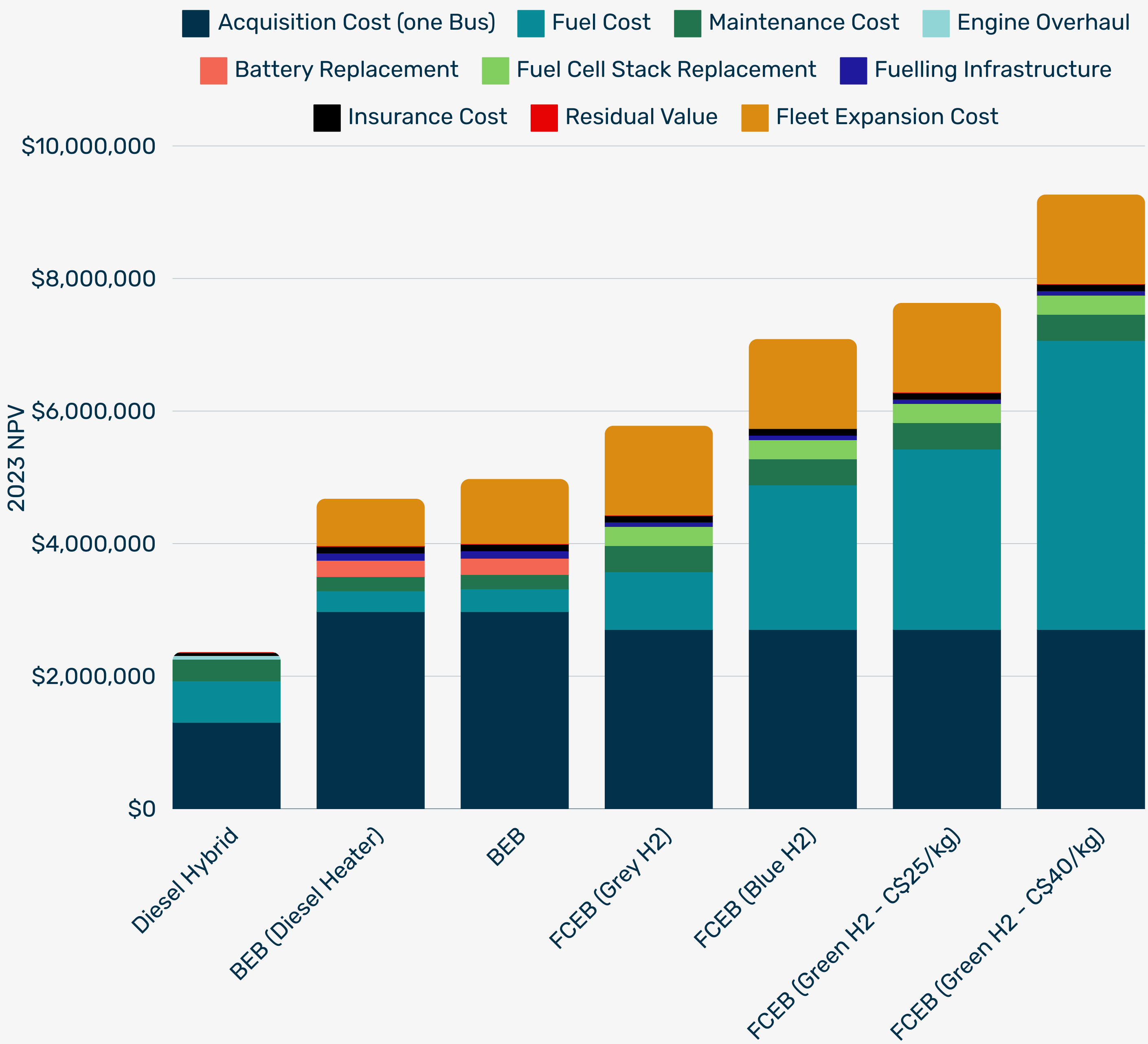


Total Cost of Ownership comparison per bus in NPV (18 year, 12m bus)

ECONOMIC ANALYSIS

Total cost of ownership (TCO) - 18m

15 year life cycle

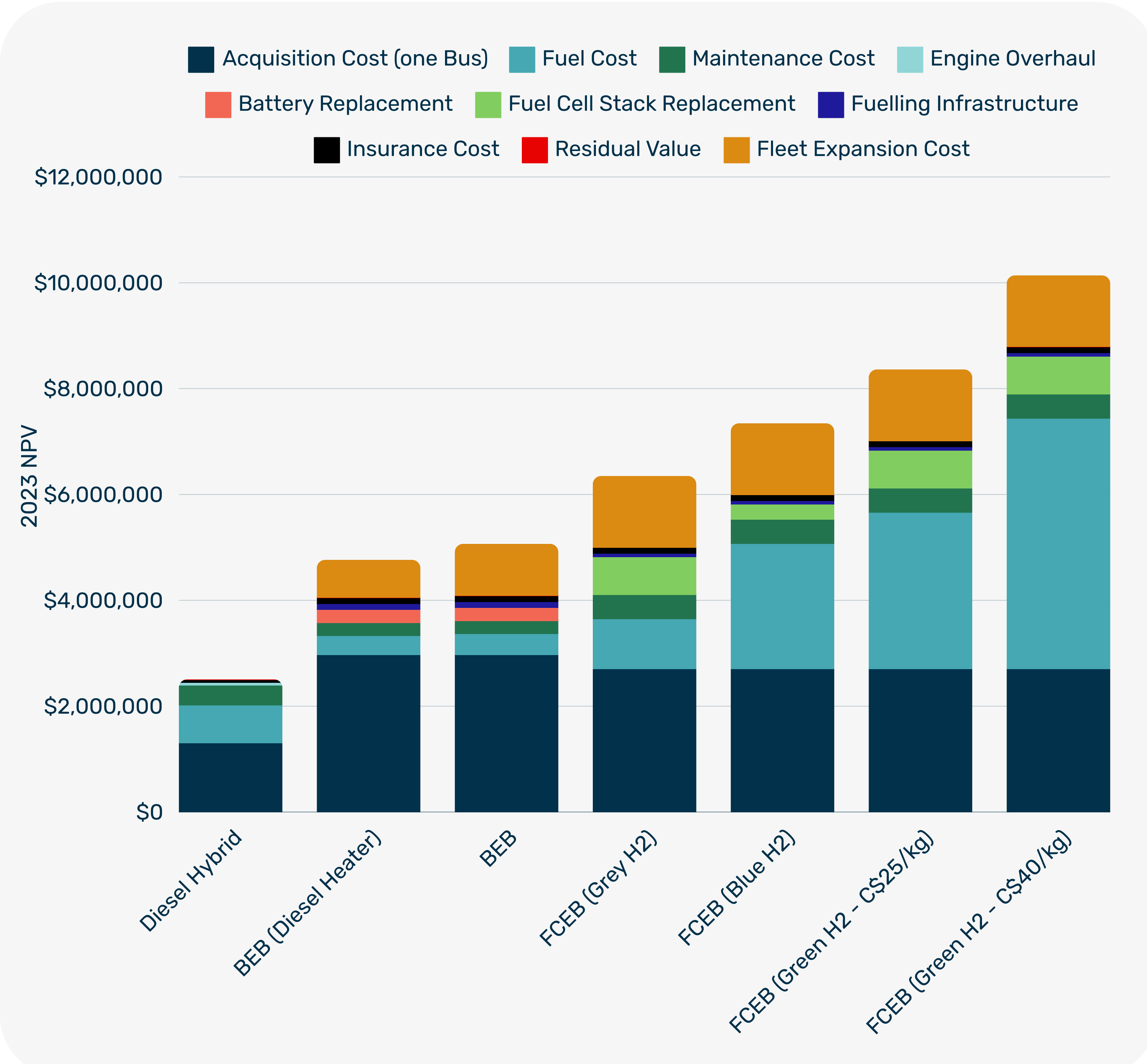


Total Cost of Ownership comparison per bus in NPV (15 year, 18m bus)

ECONOMIC ANALYSIS

Total cost of ownership (TCO) - 18m

18 year life cycle



Total Cost of Ownership comparison per bus in NPV (18 year, 18m bus)

ECONOMIC ANALYSIS

Assumptions

- **Scenario One:** Battery Electric Bus (BEB) scenario in which all buses are replaced with battery electric buses only.
- **Scenario Two:** Fuel Cell Electric Bus (FCEB) scenario in which all buses are replaced with fuel cell electric buses powered by a hydrogen fuel cell converting hydrogen to electricity onboard the vehicle.
- **Scenario Three:** Mixed green fleet scenario in which there is a balance and combination of BEBs and FCEBs in the zero emissions fleet.
- **Base Case Scenario:** Ongoing replacement of diesel and HEBs

Parameter	Value
Monetary Units	All costs are expressed in 2023$
Construction Start Year	Beginning of 2024
Operations Start Year	Beginning of 2024
Evaluation Period	18 years (2024 – 2041)
Discount Rate	3.5%
Assumed growth in level of service over 18 years (2024-2041)	76%
Useful life of asset	Option 1: 15 years
	Option 2: 18 years

Table 5: Assumptions for economic analysis

ECONOMIC ANALYSIS

Assumptions - Capital Expenditure

	Value
CAPEX	
12m Diesel aquisition cost	$900,0000
18m Diesel aquisition cost	$1,300,000
12m Diesel-Electric aquisition cost	$1,300,000
12m BEB acquisition cost	$1,600,000
18m BEB acquisition cost	$2,970,000
12m FCEB acquisition cost	$1,900,000
18m FCEB acquisition cost	$2,700,000
Sandalwood facility retrofit – Scenario One (full BEB solution)	$100,597,543
Clark facility retrofit – Scenario One (full BEB solution)	$51,497,056
Sandalwood facility retrofit – Scenario Two (full FCEB solution)	$2,978,820
Clark facility retrofit – Scenario Two (full FCEB solution)	$3,000,530
Sandalwood facility retrofit – Scenario Three (mixed green fleet solution)	$86,182,363
Clark facility retrofit – Scenario Three (mixed green fleet solution)	$46,015,086
On-route charging stations cost	$10,696,278
BEB battery replacement costs	$260,000 every 6 or 7 years
FCEB battery replacement costs	$300,000 every 6 or 7 years
High-powered chargers maintenance	$10,000/year

Table 6: Assumptions for economic analysis

ECONOMIC ANALYSIS

Assumptions - Operational Expenses

	Value
OPEX	
Diesel & hybrid vehicle-km travelled (VKT)	57,627 km/year/bus
Scenario one - full BEB solution (VKT)	46,930 km/year/bus
Scenario two - full FCEB solution (VKT)	39,796 km/year/bus
Scenario three - mixed green fleet solution (VKT)	48,112 km/year/bus
Diesel & hybrid bus maintenance	$1.19 - $1.43 /km
BEB maintenance	$0.54 - $0.65 /km
FCEB maintenance	$0.99 - $1.20 /km
Diesel price	$1.34/L
Hydrogen price (grey, blue and green)	$8/kg, $20/kg and $25/kg
High hydrogen price point	$40/kg
Annual electricity consumption (Scenario One (full BEB solution)	$9,129,775

Table 7: Assumptions for economic analysis

ECONOMIC ANALYSIS

Life cycle cost per scenario (net present value) -15 year

All scenarios: buses without diesel heaters

Base case scenario

CAPEX: $1.89 billion

Residual: $(182 million)

OPEX: $6.01 billion

TOTAL: $7.72 billion

Scenario One (full BEB solution)

% Inc: 19%

CAPEX: $3.81 billion

Residual: $(317 million)

OPEX: $5.71 billion

TOTAL: $9.21 billion

Scenario Two (full FCEB solution)

% Inc: 26%

CAPEX: $4.18 billion

Residual: $(384 million)

OPEX: $5.95 billion

TOTAL: $9.74 billion

Scenario Three (mixed green fleet solution)

% Inc: 19%

CAPEX: $3.70 billion

Residual: $(268 million)

OPEX: $5.74 billion

TOTAL: $9.17 billion

ECONOMIC ANALYSIS

Life cycle cost per scenario (net present value) -18 year

All scenarios: buses without diesel heaters

Base case scenario

CAPEX: $1.63 billion

Residual: $(76.1 million)

OPEX: $6.01 billion

TOTAL: $7.56 billion

Scenario One (full BEB solution)

% Inc: 22%

CAPEX: $3.71 billion

Residual: $(223 million)

OPEX: $5.71 billion

TOTAL: $9.20 billion

Scenario Two (full FCEB solution)

% Inc: 30%

CAPEX: $4.26 billion

Residual: $(359 million)

OPEX: $5.95 billion

TOTAL: $9.84 billion

Scenario Three (mixed green fleet solution)

% Inc: 21%

CAPEX: $3.54 billion

Residual: $(169 million)

OPEX: $5.74 billion

TOTAL: $9.11 billion

ECONOMIC ANALYSIS

BEBs with DFAH (net present value) - 18 year

All scenarios: buses with diesel heaters

Scenario One (full BEB solution)

% Savings: 2.6%
Compared to electric heater

CAPEX: $3.50 billion

Residual: $(215 million)

OPEX: $5.67 billion

TOTAL: $8.95 billion

Scenario Three (mixed green fleet solution)

% Savings: 1.9%
Compared to electric heater

CAPEX: $3.40 billion

Residual: $(161 million)

OPEX: $5.71 billion

TOTAL: $8.94 billion

The Base Case and Scenario Two (full FCEB solution) were not included as these scenarios have only a small number of BEBs so the impact of DFAH is minimal.

ECONOMIC ANALYSIS

Sensitivity analysis

Hydrogen price points

Hydrogen price points are set as follows:

- Grey hydrogen $8
- Blue hydrogen $20 (a hypothetical hydrogen production method)
- Green hydrogen $25
- “Inflated” green hydrogen $40

	15-year useful life			18-year useful life		
	Scenario Two	Scenario Three		Scenario Two	Scenario Three	
	FCEB	**Mixed green fleet solution** (without DFAH)	**Mixed green fleet solution** (with DFAH)	**FCEB**	**Mixed green fleet solution** (without DFAH)	**Mixed green fleet solution** (with DFAH)
Grey Hydrogen ($8/kg)	9.74	9.17	9.00	9.84	9.11	8.94
Blue Hydrogen ($20)	9.88	9.19	9.02	9.98	9.14	8.97
Green Hydrogen ($25)	9.94	9.20	9.03	10.04	9.15	8.98
High Green Hydrogen ($40)	10.11	9.23	9.06	10.22	9.18	9.01

Table 8: Life cycle costs for Scenario Two and Scenario Three assuming different hydrogen price points (in billion $, Present Value)

Scenario Two (full FCEB solution) includes the breakdown “with and without diesel heaters” as it integrates Brampton Transit’s existing 18 BEBs (eight in operation and 10 in procurement).

09

Facilities Assessments

FACILITIES ASSESSMENTS

Scenario One (full BEB solution)

A full battery-based solution requires:

- 260 overhead pantograph chargers at Sandalwood
- 120 overhead pantograph chargers at Clark
- Supply of backup power using a combination of generators and battery energy storage systems and space required

Sandalwood facility retrofit

$101 million
Total retrofit cost

17 MVA
Total installed charging power

11 MW
Estimate peak service demand

Clark facility retrofit

$51 million
Total retrofit cost

7 MVA
Total installed charging power

5 MW
Estimate peak service demand

FACILITIES ASSESSMENTS

Scenario Two (full FCEB solution)

A full hydrogen-based solution requires:

- Hydrogen delivery system (delivers fuel to the agency)
- Hydrogen storage tank(s)
- Vaporizer (for liquid storage)
- Compressor
- Chiller
- Dispensing system (delivers the fuel to the vehicle)

Sandalwood facility retrofit

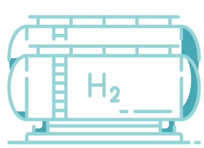
$3 million
Total retrofit cost

20 000 kg
H2 storage capacity

Clark facility retrofit

$3 million
Total retrofit cost

10 000 kg
H2 storage capacity



FACILITIES ASSESSMENTS

Scenario Three (mixed green fleet solution)

A mixed green fleet solution requires:

- Charging infrastructure
- Hydrogen fuelling infrastructure

Sandalwood facility retrofit

$86 million
Total retrofit cost

20 000 kg
H2 storage capacity

17 MVA
Installed charging power

11 MW
Estimate peak service demand

Clark facility retrofit

$46 million
Total retrofit cost

10 000 kg
H2 storage capacity

7 MVA
Installed charging power

5 MW
Estimate peak service demand

FACILITIES ASSESSMENTS

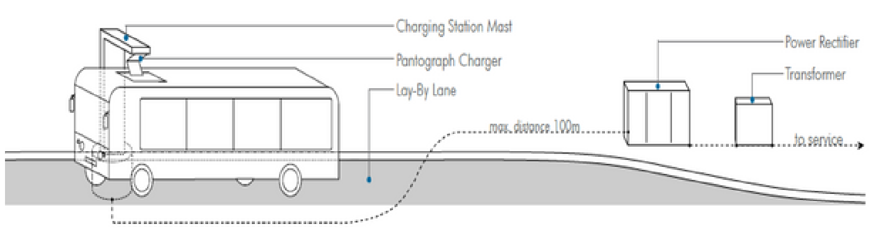
On-route charging locations

Eight on-route charging sites are assessed to support the installation of transformers, switchboards, rectification units and charging masts required for opportunity chargers.
Table 11 does not include Mount Pleasant Village as charging infrastructure is already installed.

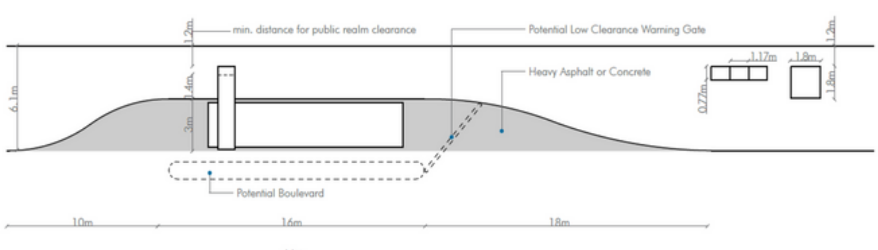
- Equipment and installation costs range from $700 thousand to $2.7 million per site.

On-route Charging Sites	Estimated retrofit cost
Mount Pleasant GO Station (4)	$2,658,533
Queen Street (1)	$681,704
Bramalea Terminal (2)	$1,448,704
Sandalwood Loop (2)	$1,448,704
Heart Lake Terminal (2)	$1,448,704
Westwood Mall (2)	$1,448,704
Humber College (2)	$1,448,704

Table 11: On-route charging locations retrofit costs (number of chargers)



Conceptual layout for on-route site electrical infrastructure



Conceptual on-route charger plan – top-down view

FACILITIES ASSESSMENTS

Assumptions and constraints

Constraints

1. **Electrical capacity:** The facility's electrical system must support the additional electrical demand of charging infrastructure under the worst-case scenario.
2. **Space constraints**: Limited space may be available to install charging infrastructure (power cabinets, dispensers, etc.) within a facility or on the surrounding property.
3. **Cost:** The cost of retrofitting the facility to install charging infrastructure can be high and must be carefully considered in the planning process.
4. **Demand patterns:** The facility's expected charging demand patterns must be considered when designing the charging infrastructure to ensure the charging stations are properly sized and distributed.
5. **Compatibility with existing infrastructure:** The charging infrastructure must be compatible with the facility's existing electrical system and other infrastructure.
6. **Maintenance requirements:** The maintenance requirements of the charging infrastructure must be considered, including the need for regular cleaning, maintenance and repairs.
7. **User needs:** The needs and preferences of users of the charging infrastructure must be considered when designing the charging infrastructure, including ease of access to charging infrastructure by vehicle operators.

Assumptions

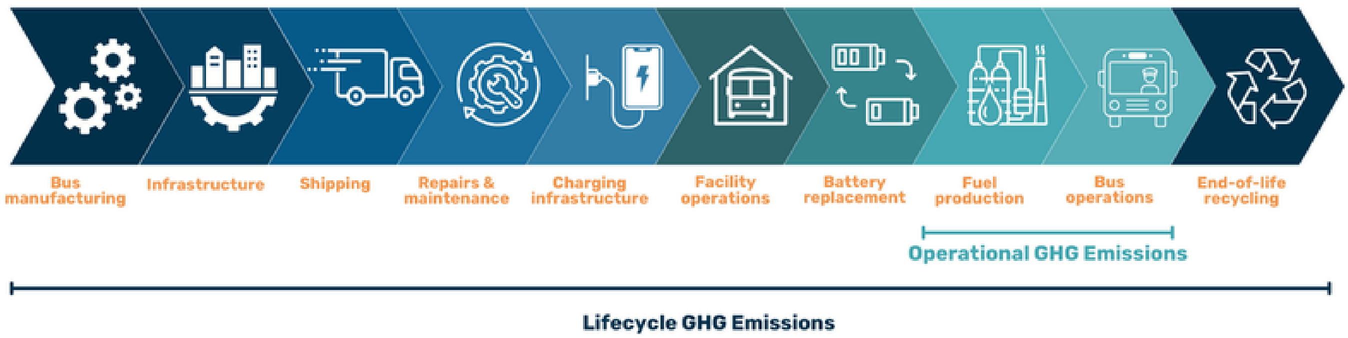
1. **Electrical load:** Facilities will not see a significant increase before BEB deployment.
2. **Rollout timeline:** BEBs will be deployed incrementally; a solution that can be phased and scaled is considered.
3. **Operations impact:** The impact on ongoing operations within the facilities is to be minimized.
4. **Redundancy:** Redundancy in the charging solution is required due to the critical nature of transit operations, including high- and low-voltage electrical systems.
5. **Available technologies:** Analysis is based on the best available solutions in the market at the time of publication.
6. **Maintenance needs, safety and ease of access:** Critical infrastructure is considered.

10

Environmental Life Cycle Analysis

ENVIRONMENTAL LIFE CYCLE ANALYSIS

Life cycle versus Operational GHG emissions



Life Cycle GHG Emissions include the following all emissions associated with:

- Manufacture, life and disposal of assets
- Fuel and associated infrastructure
- Maintenance and components
- And much more

Life Cycle Emissions give a full analysis of emissions.

Operational GHG Emissions include the following all emissions associated with:

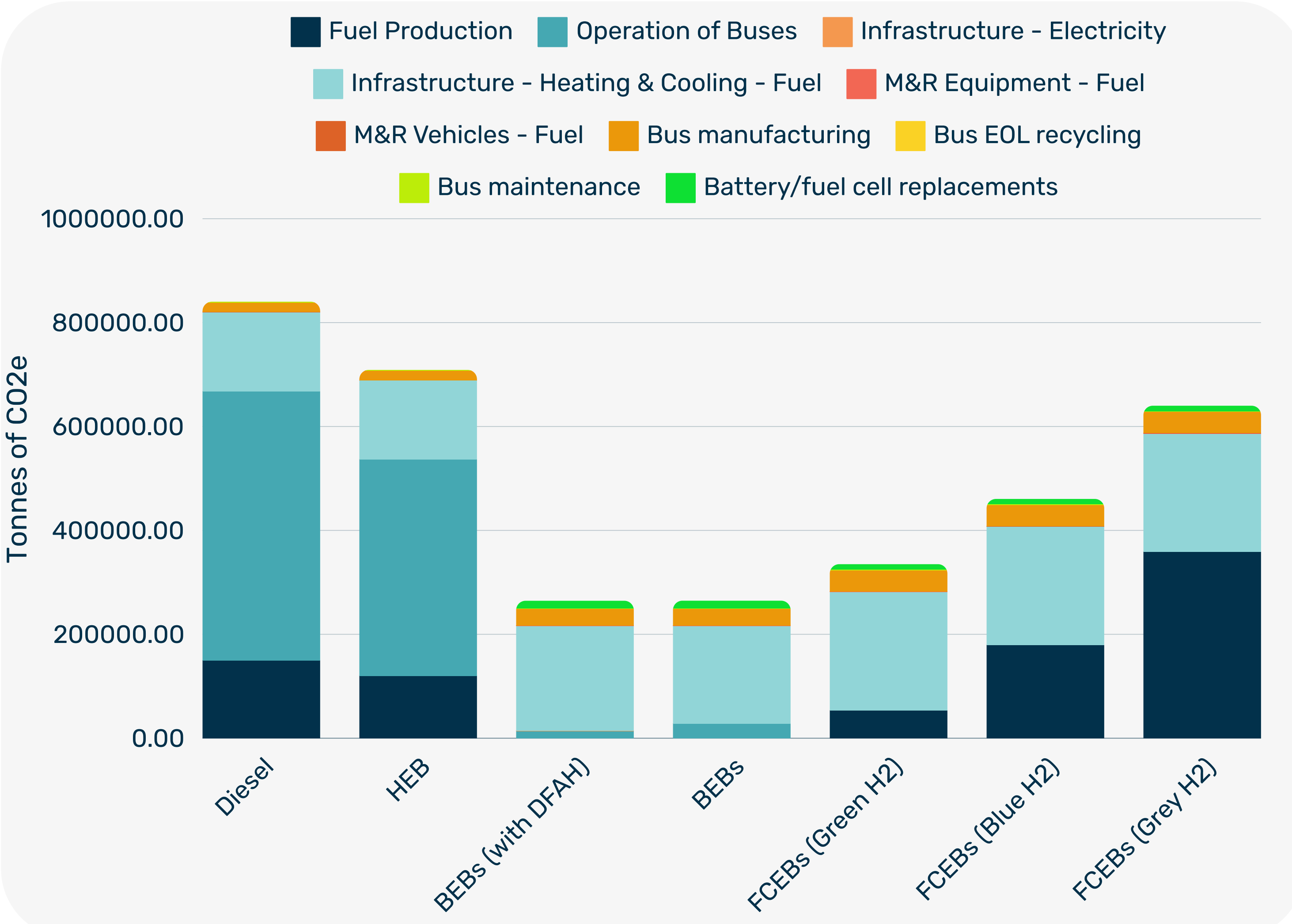
- Fuel production
- Bus operations

Operational Emissions show emissions directly under the control of transit agencies

ENVIRONMENTAL LIFE CYCLE ANALYSIS

12m bus life cycle emissions: 15-year useful life

- Overview of the environmental implications by bus type
- Emissions assesses the potential decrease in global warming resulting by vehicle type



69% 575.73 ktCO2eq less GHG per bus

61% 511.36 ktCO2eq less GHG per bus

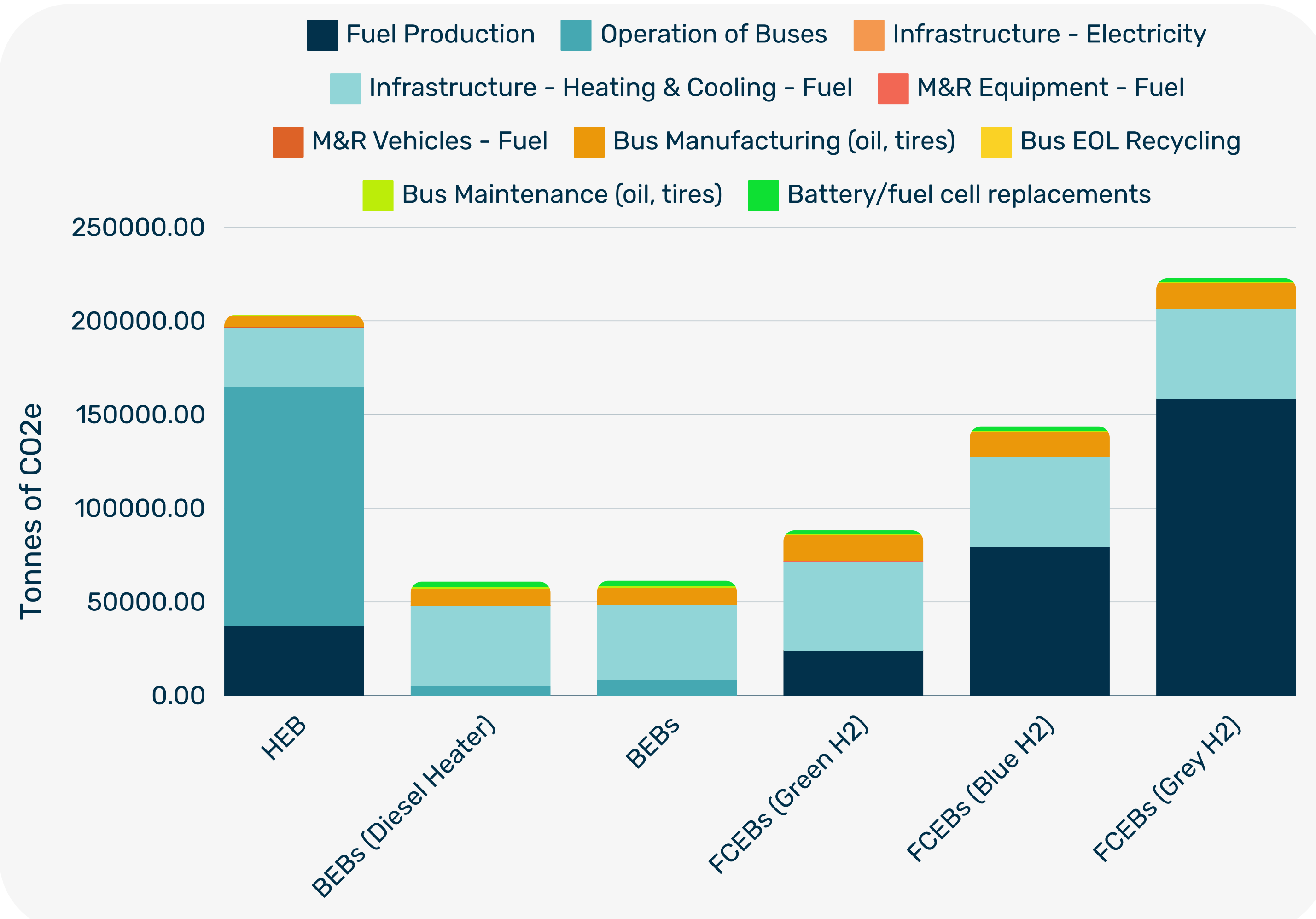
46% 385.75 ktCO2eq less GHG per bus

25% 206.31 ktCO2eq less GHG per bus

GHG emissions compared to diesel bus

ENVIRONMENTAL LIFE CYCLE ANALYSIS

18m bus life cycle emissions: 15-years useful life



70%
142.53 ktCO2eq
less GHG per bus

58%
117.09 ktCO2eq
less GHG per bus

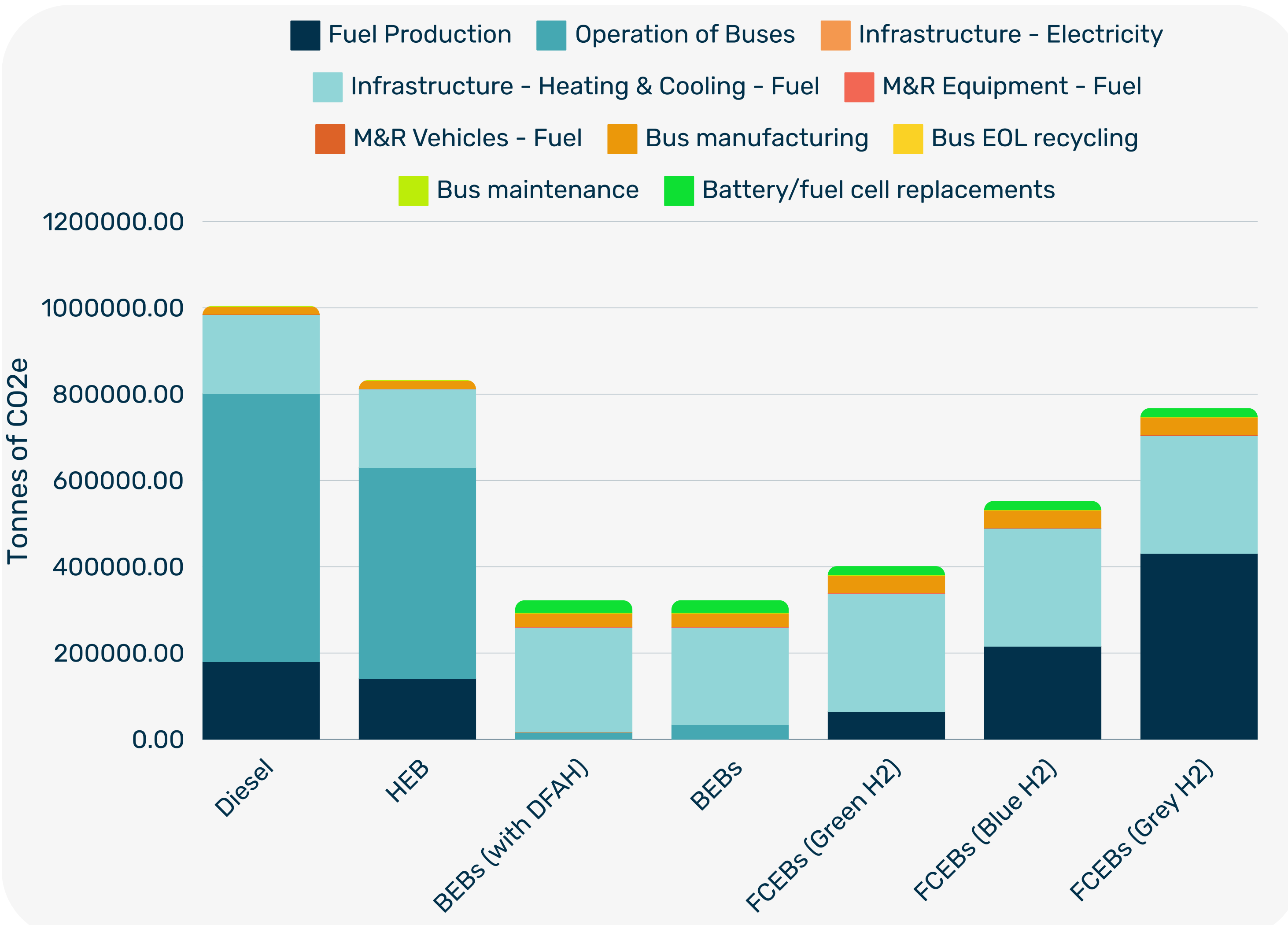
30%
61.69 ktCO2eq
less GHG per bus

-9%
-17.47 ktCO2eq
less GHG per bus

GHG emissions compared to HEB

ENVIRONMENTAL LIFE CYCLE ANALYSIS

12m bus life cycle emissions: 18-year useful life



68% 682.17 ktC02eq less GHG per bus

61% 608.86 ktC02eq less GHG per bus

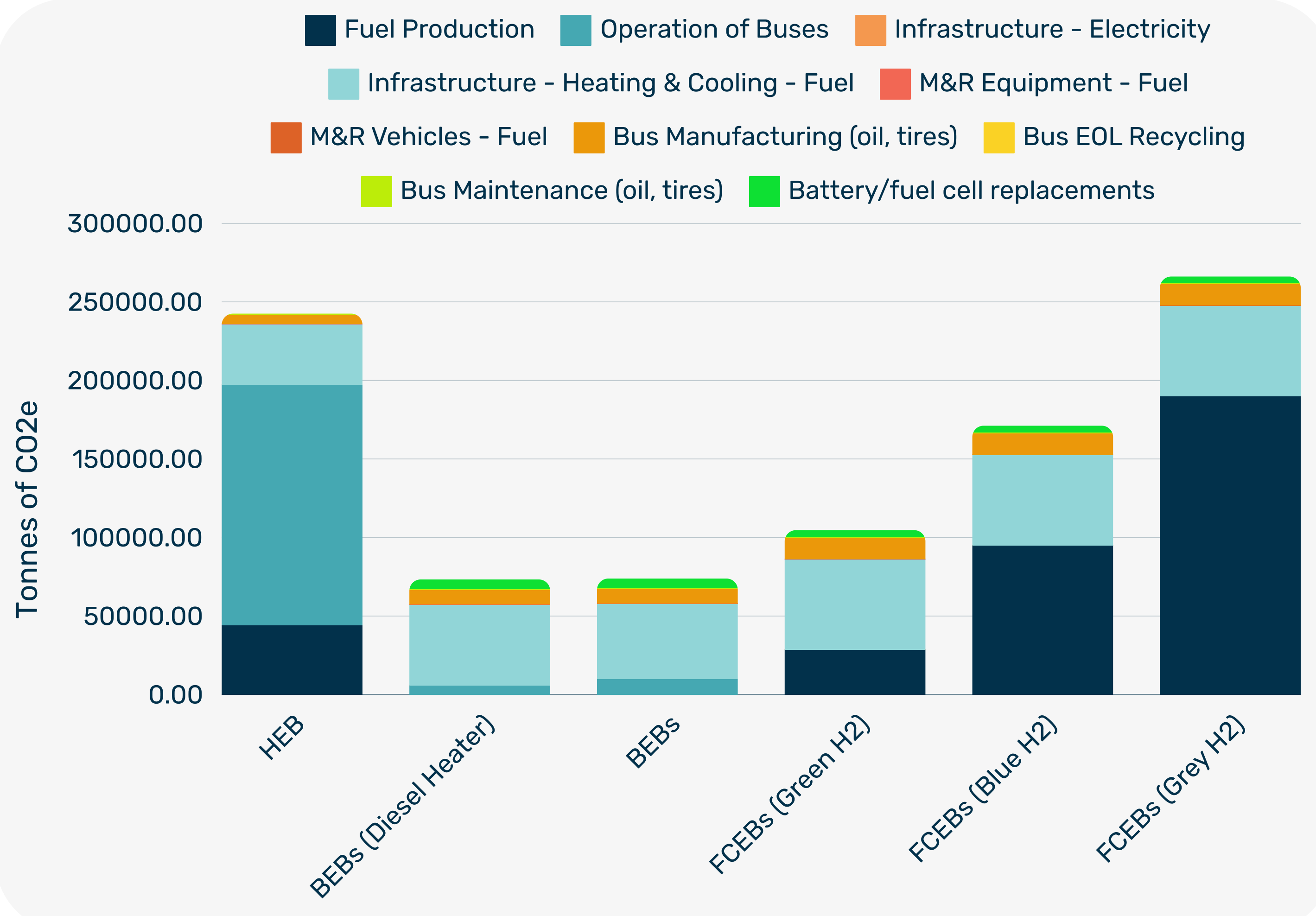
46% 458.14 ktC02eq less GHG per bus

24% 242.81 ktC02eq less GHG per bus

GHG emissions compared to diesel bus

ENVIRONMENTAL LIFE CYCLE ANALYSIS

18m bus life cycle emissions: 18-years useful life



70% 169.27 ktC02eq less GHG per bus

H2 58% 139.92 ktC02eq less GHG per bus

H2 30% 73.43 ktC02eq less GHG per bus

H2 -9% -21.55 ktC02eq less GHG per bus

GHG emissions compared to HEB

11

Social Impact Analysis

SOCIAL IMPACT ANALYSIS

Assessment for areas for social impact

- Noise-sensitive areas, highlighting density of care and senior homes, hospitals, schools and transit routes
- Annual median after-tax income in Brampton and across transit routes
- Density of population aged 65 and over in Brampton and transit routes
- Density of population with no high school diploma and no post-secondary diploma, aged 25 to 64
- Density of households spending over 30 per cent or more of income on shelter

SOCIAL IMPACT ANALYSIS

Prioritized routes (socio-economic)

ZEBs can advance social equity and improve social outcomes when deployed in vulnerable areas where people are affected by noise pollution, air pollution, lack of public transit, and racial, gender-based, and economic discrimination.

Six routes are identified as high priority: South Industrial (10)*, Grenoble (12), Southgate (16), Central Industrial (40), County Court (54), and Kingknoll (56).

**Only runs on weekdays*

Route	Route Name	Age score	Education score	Housing score	Income score	Noise score	Final score	Ease of electrification
AVG	Average (full system)	0.28	0.55	0.54	0.12	0.76	2.24	-
10*	South Industrial	0.5	1	0.5	0.5	1	3.5	Very achievable
12	Grenoble	0.5	1	0.5	0	1	3	Achievable
16	Southgate	0.5	0.5	0.5	0.5	1	3	Achievable
40	Central Industrial	0.5	1	0.5	0.5	0.5	3	Achievable
54	County Court	0.5	0.5	0.5	0.5	1	3	Challenging
56	Kingknoll	0.5	0.5	0.5	0.5	1	3	Challenging

Table 13: Routes identified through social impact analysis

Very achievable: depot-only charging
Achievable: on-route charging needed
Challenging: will require block splitting

12

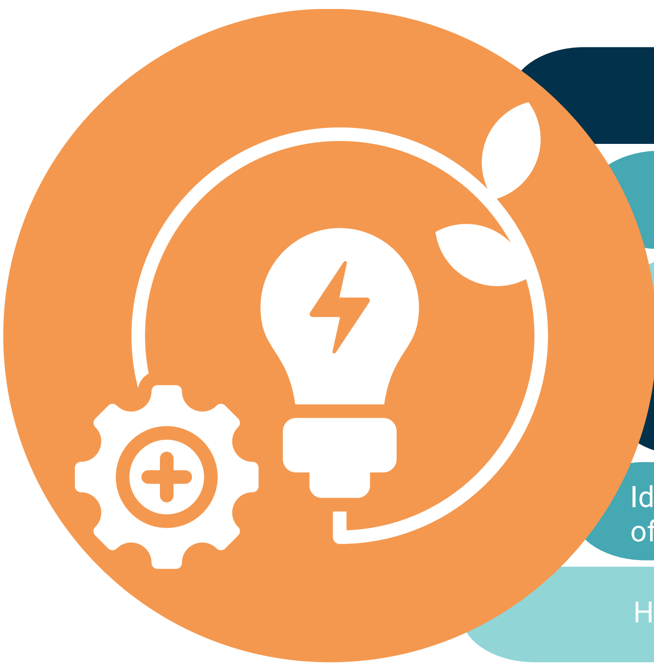
Energy as a Service

ENERGY AS A SERVICE

To mitigate Brampton Transit's risks in decarbonization, seeking a strategic long-term partner for co-investment and ownership of energy infrastructure is crucial. This partner would handle the design, build, operations, and maintenance of infrastructure for electricity and hydrogen to support the expanding zero-emissions transit fleet. Energy as a Service (EaaS) presents a viable option under this approach.

With EaaS, the customer pays a fixed fee based on service consumption, while the technology provider retains ownership of the system and covers all operating costs.

Goals for this scope element



- Introduce the EaaS business model
- Develop EaaS scope definitions for Brampton Transit
- Outline potential commercial contract options
- Develop EaaS qualitative assessment criteria
- Identify potential EaaS partners/stakeholders and their offerings
- Highlight procurement strategy options

ENERGY AS A SERVICE

EaaS vendor engagement and workshops

Original EaaS workshops were conducted with vendors selected after market research and outreach. The market research includes 11 companies, while outreach includes nine companies, including public and private organizations, with varying degrees of EaaS experience in transit.

Outreach & Workshop
Has a relevant EaaS solution

- SIEMENS
- alectra energy solutions
- FLO
- PowerON Energy Solutions (An OPG Company)
- jule (powered by ecamion)

Outreach
No market-ready EaaS solutions

- ABB
- Hitachi Energy
- bp pulse
- TECIUM IOT

Market Research
Lack relevant EaaS solution

- Schneider Electric
- AMERESCO

In March 2024, eight vendors were contacted again for any updates to their existing offering.

Outreach & Workshop
Has a relevant EaaS solution

- SIEMENS
- alectra energy solutions
- AlphaStruxure
- FLO
- PowerON Energy Solutions (An OPG Company)
- ABB
- jule (powered by ecamion)

Outreach
No market-ready EaaS solutions

- Hitachi Energy
- TECIUM IOT

ENERGY AS A SERVICE

Scope differentiators offered by vendors

Table 14 shows the EaaS vendors that, upon initial engagement, have solutions or offerings that provide the highlighted scope differentiators discussed above. This is current as of the time of writing and is subject to change as EaaS offers maturity and adapts to customer needs.

It is also noted that this assessment of vendors is preliminary, and subsequent evaluations by Brampton Transit may provide insight into the ability of each EaaS provider to include scope options.

Company	Energy Carriers Offered (Hydrogen & Electricity	Energy Products - Software (CMS & DMS) Operational Orchestration	Fee Structure - Fixed (Electricity Pricing)	Energy Products - Vehicles (Battery leasing)	Facility Works - Holistic Facility Modifications & Retrofit
ABB	✓	✓			✓
Alectra	✓	✓	✓		✓
Aux Energy	✓	✓	✓		✓
Jule	✓	✓	✓		
PowerOn	✓	✓	✓		✓
Siemens	✓	✓	✓		
Alpha Struxure	✓	✓	✓		✓

Table 14: Scope differentiators offered by vendors

- All information is based on interviews conducted January to February (2023) and March 2024

ENERGY AS A SERVICE

Summary

To ensure optimal performance in the evolving zero-emission landscape, the following key points should be considered:

- **Efficient EaaS procurement process:** Streamline and expedite Energy as a Service (EaaS) procurement from Brampton Transit's perspective.
- **Flexibility in project onboarding:** Enable Brampton Transit to onboard projects based on funding availability, thereby promoting agility.
- **Limited scope definition for EaaS engagements:** Engage early with EaaS vendors to support scoping and project schedule definition as part of pricing discussions.
- **Information sharing and requests:** Provide detailed utility requirements through the ZEB Implementation Plan and submit site capacity upgrade requests based on this information to avoid project bottlenecks in the future.

13

Conclusions

CONCLUSIONS

Electrification solution

The ZEB Implementation Strategy and Rollout Plan detailed in this report demonstrates achieving a net zero objective for Brampton Transit by 2041 is possible but extremely challenging and costly. Delaying the transition to 2050 may help to spread cost and risk factors over time, but will not reduce the overall complexity of a full fleet transition.

This report presents three scenarios for electrification of Brampton Transit's fleet.

- **Scenario One** ("full BEB solution") presents a solution where all buses are transitioned to BEBs
- **Scenario Two** ("full FCEB solution") represents a transition of the fleet to all FCEBs
- **Scenario Three** ("mixed green fleet solution") is a solution with a mixed green fleet of BEBs and FCEBs

As one of the first agencies in Canada to establish a plan for full fleet decarbonization by mid-century, Brampton Transit will experience unknown complexities in its mission. As a result, it will be a leader and a champion that other agencies will learn from over time.

This study supports an approach to full fleet decarbonization that prioritizes Scenario Three (mixed green fleet solution). This solution balances the advantages and disadvantages of both BEB and FCEB technologies to deploy a flexible future fleet. Scenario Three (mixed green fleet) is the lowest-cost option at $8.94 billion (NPV) which is incrementally better than Scenario One (fully BEB solution) at $8.95 billion (NPV) and significantly better than Scenario Two at $9.85 billion (NPV) [2].

Although this solution requires hydrogen supplies, which may not be readily available in electrolytic or green hydrogen forms, Brampton Transit can access grey hydrogen supplies at scale within the marketplace. This grey hydrogen supply chain will be a part of the early-stage transition plan to achieve net zero emissions, while waiting for green supplies to enter the marketplace at a greater scale and reduced cost.

Scenario One (full BEB solution) is the second-best option for Brampton Transit, as it carries significant benefits in terms of cost and the greatest emissions savings over all other scenarios. Scenario Two (full FCEB solution) is positioned as the third-best option given the associated cost.

[2] These values are based on DFAH and an 18-year useful life.

CONCLUSIONS

Scenario One (full BEB solution)

1,161
BEBs with DFAH in 2041

18
On-route chargers

$8.95b
Life cycle transition 18 years, DFAH

$3.26M
12m bus TCO with 18-year life cycle

97%
Operational GHG emission reduction by 2041

22 MW
Charging capacity

- Major facility retrofits to Sandalwood and Clark facilities needed with a total cost of **$151 million** - additional third facility **needed immediately**
- Aquisition of five parcels of land with a total cost of **$512,000**
- Retrofits at on-route charging sites needed at Mount Pleasant GO, Queen Street, Bramalea, Mississauga, Sandalwood loop, Humber, Heart Lake, Westwood with a total cost of **$4.8 million**
- A transition cost of **$8.94 billion** assumes BEBs with DFAH and an 18-year asset life cycle
- Significant **schedule changes** needed to accommodate the necessary charging requirements

CONCLUSIONS
Scenario One (full BEB solution)

Quick Facts

- Requires between 570 and 674 buses in total (depending on vehicle configuration) to meet current service levels, which is equivalent to 20 to 42 per cent more vehicles than the base case fleet
- Requires facility retrofits and installation of approximately 22 MW of charging capacity between Sandalwood and Clark facilities
- Requires 18 on-route chargers across eight terminals amounting to 600 per cent more chargers than Brampton Transit has deployed to date
- Expected service growth will require a fleet of between 1,161 and 1,240 BEBs by 2041

CONCLUSIONS

Scenario One (full BEB solution)

Advantages

- Leverages the installation and handling of a readily available electricity fuel supply chain
- Requires significant electrical infrastructure upgrades (both downstream and upstream from the facilities' transformers), which is readily available in the marketplace today
- GHG emissions associated with the operation of BEBs are shown to be less than those of FCEBs, even when considering the cleanest form of hydrogen
- Achieves the greatest GHG savings for Brampton Transit

Disadvantages

- Requires substantial growth in the fleet size with hundreds of additional buses necessary to achieve full decarbonization over the base case scenario
- High replacement ratios creates demand for more space for buses to serve the same ridership population as today
- Requires relatively large electrical infrastructure and 18 on-route chargers distributed among eight transit terminals
- Does not consider any unknown factors of complexity that may arise with a BEB-only solution, such as a system-wide power outage

CONCLUSIONS

Scenario Two (full FCEB solution)

1,418
1,400 FCEBs and 18 BEBs in 2041

30,000 kg
H2 storage capacity needed

$9.85b
Life cycle transition 18 years

$5.25M
12m bus TCO over 18 year life cycle (Green H2)

85%
Operational GHG emission reduction per bus (Green H2) by 2041

5.9M kg
kg of hydrogen per year in 2041

- Facility retrofits to Sandalwood and Clark facilities needed with a total cost of ownership of **$5.5 million (significantly lower than BEB)**
- A total of **30,000 kg of H2 storage capacity** is needed at the Sandalwood and Clark facilities and **5.9 million kg** of hydrogen is needed per year
- Incremental costs over an 18 year life cycle are **30 per cent higher** than the base case scenario
- Transition cost of **$9.85 billion** assumes an 18-year asset life cycle

CONCLUSIONS

Scenario Two (full FCEB solution)

Quick Facts

- Considers various hydrogen production types:
  - Electrolytic or “green” hydrogen produced from the electricity grid, which is considered a low carbon intensity hydrogen fuel type.
  - “Blue” hydrogen produced from steam methane reformation (SMR), which integrates carbon capture solutions to store emissions and reduce the overall carbon intensity of the fuel. It is considered a greener solution compared to “grey” hydrogen defined below but a dirtier solution that is more carbon intense than “green” hydrogen.
  - “Grey” hydrogen produced from steam methane reformation (SMR) with no mitigating technology to reduce the carbon intensity of the fuel. This production method is considered the dirtiest form of hydrogen but is abundantly available at scale within Canada today.
- Requires 1,400 FCEBs and 18 BEBs to meet service levels in 2041, which is equivalent to 51 per cent more vehicles than the base case, but requires no depot or on-route chargers (at current service levels)
- Requires new hydrogen supply agreements with vendors and may require the use of more carbon-intense grey options in the short term

CONCLUSIONS

Scenario Two (full FCEB solution)

Advantages

- Requires the smallest increase in service hours while achieving full fleet decarbonization
- Does not require the substantial electrical infrastructure associated with charging BEBs
- Brampton Transit would not need to purchase, lease, or engage in land use agreements for pieces of (private or public) land that are required to install the necessary electrical infrastructure, located locally or in other municipalities
- Refuelling FCEBs is operationally similar to refuelling diesel buses, which facilitates the adoption of the new technology by transit staff

Disadvantages

- BEBs charging both in-depot and on-route can have a much longer range than FCEBs that have access to only one fuelling episode per day
- Results in the largest number of vehicles required to achieve full decarbonization in Brampton
- Requires the continuous procurement of large quantities of hydrogen fuel, which is extremely expensive in Ontario today in "green" forms
- Costs for FCEBs are approximately 20 per cent more expensive than BEBs in today's marketplace

CONCLUSIONS

Scenario Three (mixed green fleet solution)

1,132
724 BEB with DFAH
408 FCEBs by 2041

1.3M kg
H2 needed per year

$8.94b
Life cycle transition 18 years

$3.26M/$5.25M
12m BEB / 12m FCEB over 18 year life cycle

95%
Operational GHG emission reduction

18
On-route chargers

Major facility retrofits to Sandalwood and Clark facilities needed with a total cost of **$132 million**

A total of 30,000 kg of storage capacity for 5.9 million kg H2 annual and **8 MW of electricity** is needed at the Sandalwood and Clark facilities

Transition cost of **$8.94 billion** assumes BEBs with DFAH and an 18-year asset life cycle.

A total of **1.3 to 2.2 million kg of H2 per year** is needed to cover Brampton Transit's service levels

CONCLUSIONS

Mixed fleet scenario

Quick Facts

- Requires between 558 and 640 buses in total depending on the vehicle configuration, which is equivalent to 17 to 34 per cent more vehicles than the base case fleet
- Requires facility retrofits and installation of approximately 8 MW of charging capacity between Sandalwood and Clark facilities
- Requires 18 on-route chargers across eight terminals which amounts to 600 per cent more chargers than Brampton Transit has deployed to date
- Requires new hydrogen supply agreements with vendors and may require the use of more carbon-intense grey options in the short term
- “Mixed” fleet ratio would be comprised of 318 to 413 BEBs and 181 to 322 FCEBs (depending on configuration) resulting in the smallest total fleet size to decarbonize the current fleet of buses
- Equates to the minimal total cost, but not the maximum potential reduction of GHG emissions, across all three solutions
- Expected service growth will require a fleet of 1,185 ZEBs with approximately 767 BEBs and 418 FCEBs by 2041 without DFAH or 724 BEBs and 408 FCEBs for a ZEB fleet of 1,132 with DFAH

CONCLUSIONS

Scenario Three (mixed green fleet solution)

Advantages

- Integrates both technologies for fleet flexibility
- Reduces the total number of vehicles and chargers needed to achieve full decarbonization, which significantly reduces the challenges associated with storage space in the two transit facilities
- Serves as the least costly option of all three scenarios in net present value (2023 dollars)
- Offers a compromise between less costly buses with BEBs and the smallest increase in added service hours with FCEBs

Disadvantages

- Requires management of two types of buses, two parts inventories, two training programs in workforce development, two types of fuelling infrastructure, abidance of two sets of standards and safety regulations, and procurement of two types of fuel

CONCLUSIONS

Scenario comparison

	Base Case (diesel & HEB)	Scenario One (full BEB solution)	Scenario Two (full FCEB solution)	Scenario Three (mixed green fleet solution)
Operational GHG emission reduction 18 year life cycle BEBs without DFAH Green H2	0%	97%	85%	95%
Total cost of ownership per bus (NPV) - 18 year life cycle (12m)	$1.77 million	$3.26 million	$5.25 million	BEB: $3.26 million FCEB: $5.25 million
Life cycle cost of transition (NPV) - 18 year life cycle BEBs with DFAH	$7.56 billion	$8.95 billion (18% increase over base case)	$9.85 billion (30% increase over base case)	$8.94 billion (18% increase over base case)
H2 consumption annually	-	-	5.9 million kg	1.3 to 2.2 million kg
On-route chargers needed	-	18	-	18
Annual energy consumption (2041)	-	106 to 131 GWh	-	106 to 131 GWh
Fleet size in 2041 BEBs with DFAH	938	1,161	1,418	1,132