Appendix 1

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SASKATOON TRANSIT

FULL FLEET ZEB IMPLEMENTATION PLAN 2025


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Table of Contents

Disclaimer

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About Saskatoon Transit

Saskatoon Transit is a public transit service that services the City of Saskatoon, including fixed and on-demand transit service, connecting the City's more than 270,000 residents. In 2023, Saskatoon Transit provided 7.4 million rides and over 346,000 hours of service. It has been operational since 1913 (originally named the Saskatoon Municipal Railway) and operates 38 fixed transit routes with over 1400 stops. In 2020, Saskatoon Transit implemented a 12-month battery electric bus (BEB) pilot, confirming that a BEB could operate successfully during the winter. This pilot resulted in Saskatoon Transit adding two new BEBs to their fleet. Continuing to pursue a zero emissions future, the City has retained the Canadian Urban Transit Research and Innovation Consortium (CUTRIC) to develop a Full Fleet Zero Emissions Bus (ZEB) Implementation Plan for Saskatoon Transit to provide important insights into what the transition to ZEBs across Saskatoon Transit's full fleet will entail and shape future service, technological, and operational decisions.

Founded in 1913

38 fixed routes

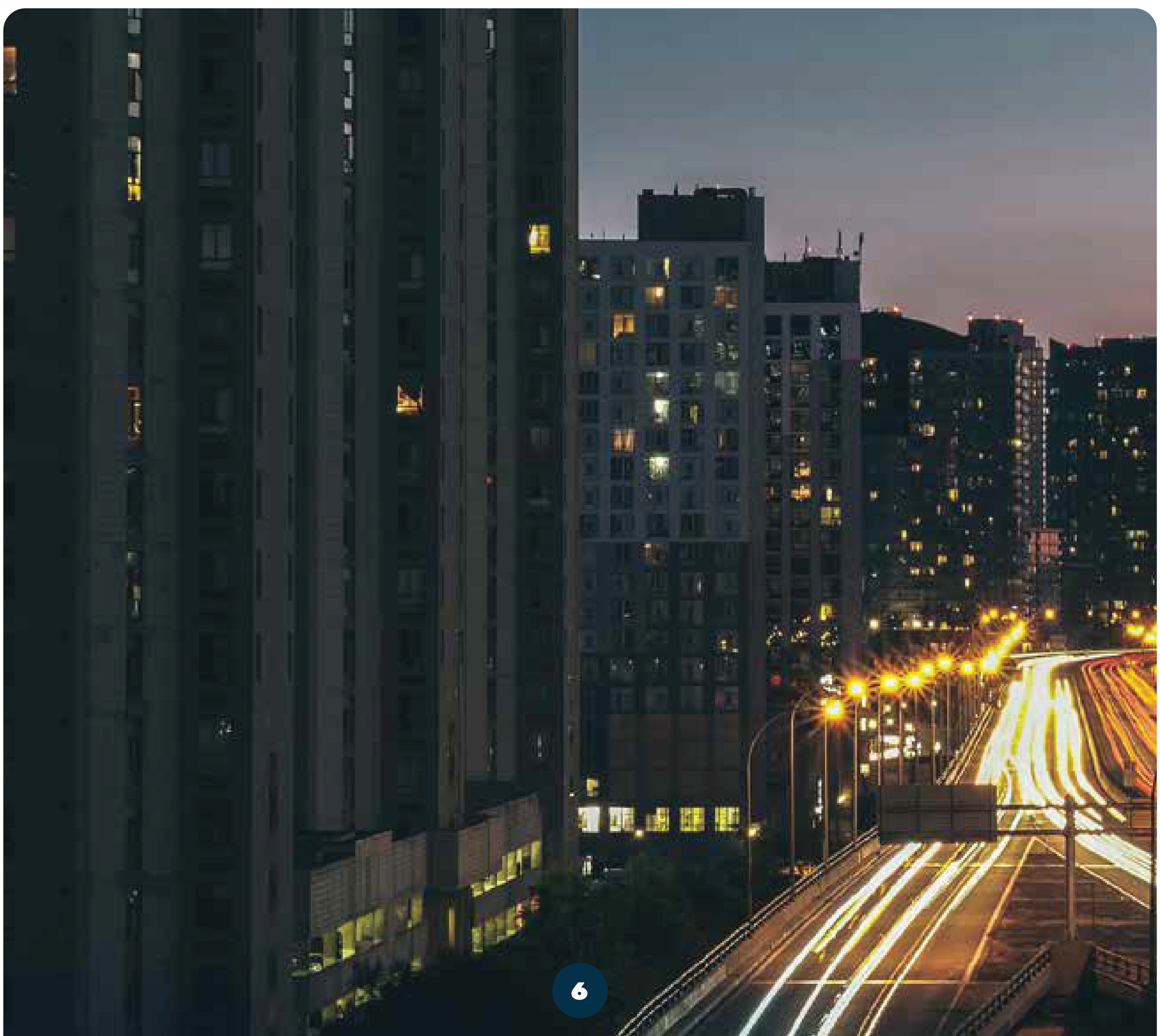
Over 1400 stops

7.4 million rides in 2023

SASKATOON transit

About CUTRIC

CUTRIC is a member-owned, non-profit organization that spearheads, designs and launches technology and commercialization projects that advance next-generation zero carbon mobility and transportation solutions across Canada. Over the years, CUTRIC has established itself as Canada's electric transit bus technological and financial innovation and knowledge leader. It has supported dozens of Canadian transit agencies in preparing their systems for electrification, mainly through the simulation tool RoutΣ. i 3.0™, which predicts energy consumption of various ZEBs on specific routes or blocks and calculates expected operational costs and GHG emission reductions. CUTRIC is proudly the Government of Canada's selected National Planning Service for its Zero Emission Transit Fund (ZETF).



About the ZETF

Launched in 2020 for capital funding and in 2021 for feasibility programming, the *Zero Emission Transit Fund (ZETF)* contains over $2.4 billion for Canadian transit agencies seeking to decarbonize immediately. The ZETF program is the most viable option for ZEB funding support for public transit agencies in Canada today. The program runs to 2026 and offers support for electrifying transit fleets at 50 per cent cost recovery of eligible costs. The funding helps fulfill the Government of Canada's commitment to assist transit agencies in procuring and deploying 5,000 ZEBs over five years from the program launch date (2021) and meeting the goals set out in the Emissions Reduction Plan (ERP).

The ZETF has two major funding streams:

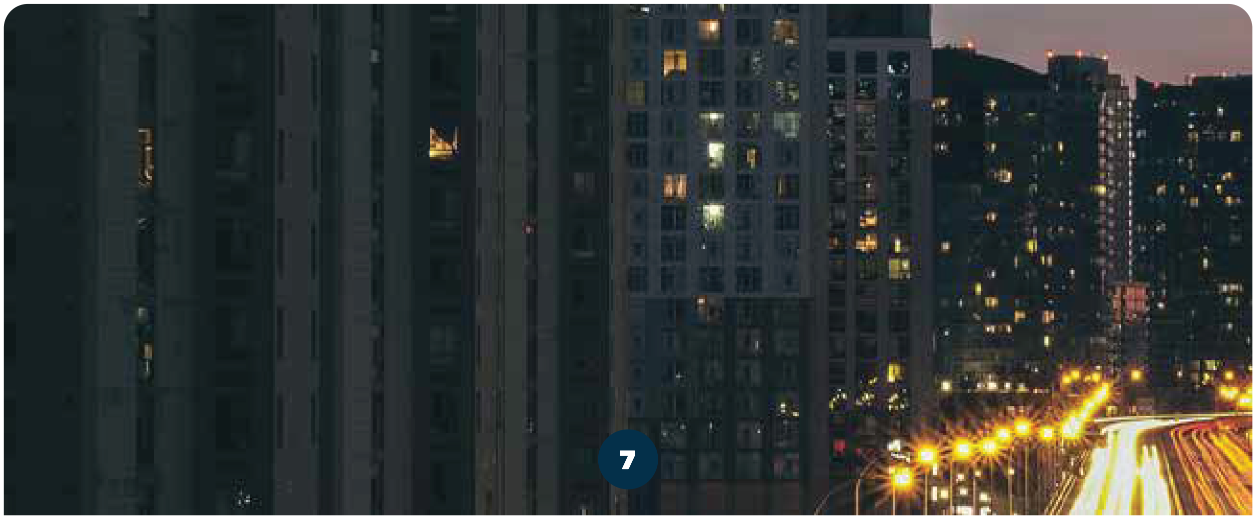
Planning Projects ($10 million):

Eligible projects include studies, modelling and feasibility analyses that support the development of future-larger-scale capital projects. CUTRIC is the preferred non-profit vendor for consultation work in this program, which all public transit agencies in Canada qualify for.

Capital Projects ($2.4 billion):

Eligible capital projects include buses, charging and refuelling infrastructure and other ancillary infrastructure needs. All public transit agencies in Canada qualify for this program once they have completed a feasibility and implementation planning study.

Housing, Infrastructure and Communities Canada | Logement, Infrastructures et Collectivités Canada



Project Overview

In 2022, CUTRIC was contracted by Saskatoon Transit to develop and complete a Full Fleet ZEB Implementation Plan. Staged in five phases, the project assessed economic, technological, social, environmental benefits, risks and constraints associated with facilitating a transition to a zero emissions fleet of vehicles. The project provided Saskatoon Transit with a comprehensive and accurate implementation plan for ZEBs and associated infrastructure. CUTRIC performed a state assessment where Saskatoon Transit's current fleet and site facility were assessed for electrification readiness. CUTRIC also conducted advanced feasibility and optimization modelling work to evaluate the performance of selected models of ZEBs (battery electric and hydrogen fuel cell electric buses). The total energy consumption and average energy usage when completing a one-way trip on selected routes were presented (including on-demand trips). This study explores the feasibility of a 1-to-1 replacement of diesel buses with ZEBs with depot and on-route charging capabilities, considering the current bus schedules and the operational constraints of the transit agency.

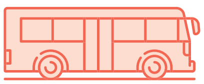
Project Objectives

- Explore feasibility of 1-to-1 replacement of diesel buses with ZEBs.
- Evaluate the current state of Saskatoon Transit's existing fleet and facility to determine readiness for electrification.
- Perform feasibility and optimization modelling for selected ZEB models.
- Develop recommendations for implementation of ZEBs to support Saskatoon Transit's emissions reductions targets.

Project Vision

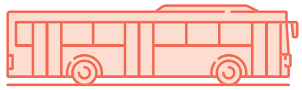
- The implementation plan provides an energy transition pathway to transition the transit agency from fossil fuels towards an zero emissions energy-powered future.

Project Modelling Assumptions



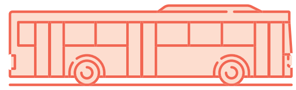
BEB 1

30-foot
250+ kWh



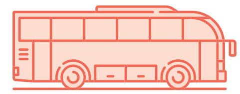
BEB 2

40-foot
500+ kWh



BEB 3

40-foot
500+ kWh



FCEB 1

40-foot
35+ H_2 kg

92 weekday blocks modelled

72 Saturday blocks modelled

44 Sunday blocks modelled

4 On-demand vehicles modelled

Climate Action Goals

In 2017, Saskatoon City Council adopted GHG emissions targets based on the City's corporate and community GHG emissions inventory. In 2019, the City also established the Low Emissions Community Plan (LEC), including a goal to electrify 100 per cent of the municipal transit fleet by 2030.

In 2017, the Province of Saskatchewan adopted *Prairie Resilience: A Made-in-Saskatchewan Climate Change Strategy*, a system-wide approach including over 40 commitments to make Saskatchewan more climate resilient. A key metric bolsters transit electrification as part of this plan is to reduce the total GHG emissions from the electricity sector by 40 per cent by 2030 compared to 2005 levels.

- Electrify 100 per cent of the municipal transit fleet by 2030 as per the 2017 *Prairie Resilience: A Made-in-Saskatchewan Climate Change Strategy*.
- Transit electrification to help reduce provincial electricity sector GHG emissions by 40 per cent by 2030 compared to 2005 levels.

Executive Summary

Saskatoon Transit, the public transit service that services the City of Saskatoon, operates 38 fixed transit routes and in 2023 provided 7.4 million rides.

To kickstart this journey, the City partnered with CUTRIC to develop a Full Fleet ZEB Implementation Plan for Saskatoon Transit to provide important insights into what the transition to ZEBs across Saskatoon Transit's full fleet will entail and shape future service, technological and operational decisions.

This study assessed three scenarios for Saskatoon Transit's fleet electrification plan:

- **Scenario One (full BEB solution):** Charging Strategy One (in-depot charging with block splitting)
- **Scenario One (full BEB solution):** Charging Strategy Two (in-depot and on-route charging with block splitting)
- **Scenario Two (full FCEB solution):** Refuelling Strategy One (depot-only refuelling with block splitting)
- **Scenario Three (mixed green fleet):** BEBs with in-depot charging and FCEBs with block splitting

For Scenario One (full BEB solution), the project's energy analysis identifies Charging Strategy Two (in-depot and on-route charging with block splitting) as the more successful approach. As a result, Charging Strategy One (in-depot charging with block splitting) is not explored further in this study beyond that initial analysis.

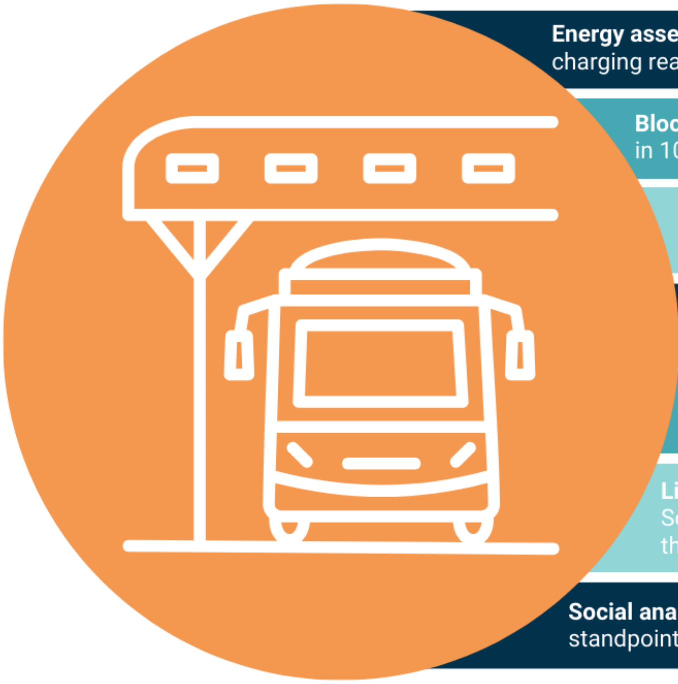
Scenario One
(full BEB solution)
Charging Strategy One
(in-depot charging with
block splitting)

Scenario One
(full BEB solution)
Charging Strategy Two
(in-depot and on-route
charging with block splitting)

Scenario Two
(full FCEB solution)
Refuelling Strategy One
(depot-only refuelling with
block splitting)

Scenario Three
(mixed green fleet)

Key findings in this study found



Energy assessment: Success rates for depot-only charging reasonably high.

Block splitting analysis: Unsuccessful blocks result in 100 per cent success rate if split once.

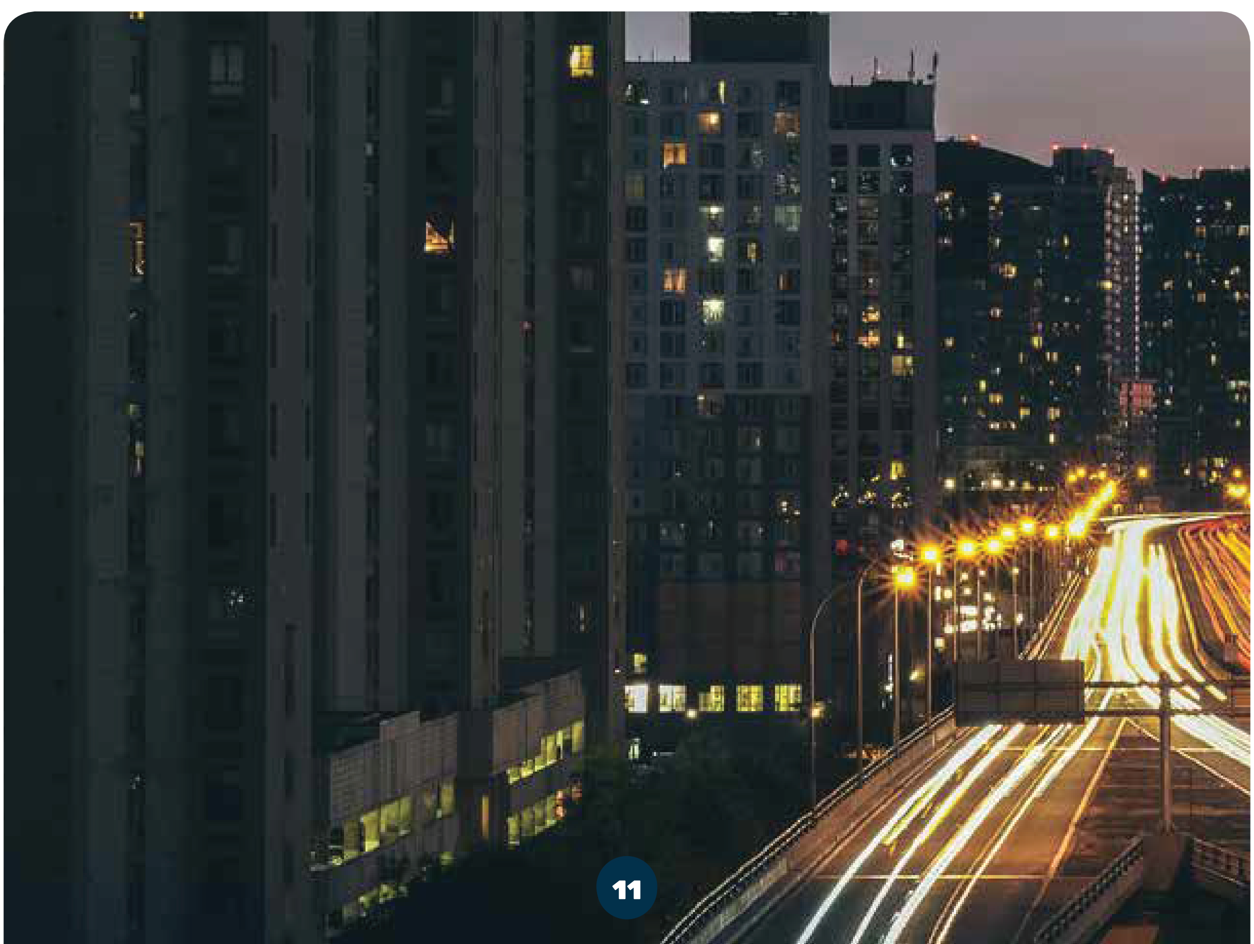
On-route optimization analysis: Four to five on-route chargers are proposed across four stop locations.

Facility assessment: Scenario Two (full FCEB solution) would have the lowest facility retrofit cost at $18.2 million.

Economic analysis: Scenario One (full BEB solution) would have the lowest total project cost of $479.2 million.

Life cycle analysis: GHG emissions are found to be lowest for Scenario Two (full FCEB solution) with grid hydrogen produced through wind power.

Social analysis: The highest priority routes to electrify from a social standpoint are Meadowgreen/City Centre and City Centre/Confederation.



Energy Assessment

Energy Consumption Rates

Efficiencies are calculated by considering energy consumed during operation and the total distance travelled, including non-revenue parts of the service.

Efficiencies are measured in kilowatt-hours per kilometre for battery electric buses (BEBs) and kilo-grams of hydrogen per 100 kilometres for fuel cell electric buses (FCEBs).

Three BEBs, labelled as BEB 1 (250+ kWh, 30-foot), BEB 2 (500+ kWh, 40-foot) and BEB 3 (550+ kWh, 40-foot) and one FCEB labelled as FCEB 1 (35+ kg, 40-foot) were modelled. These four vehicle configurations are different makes and models of the buses available on the market at the time of writing. Results are anonymized to remain neutral in assessing the various vehicles and will be referred to as their vehicle number throughout the report.

Duty cycles represent energy consumption scenarios buses may operate in. Medium-duty represents the average operational conditions whereas the heavy-duty cycle represents the “worst case” or most energy-intensive operating conditions.

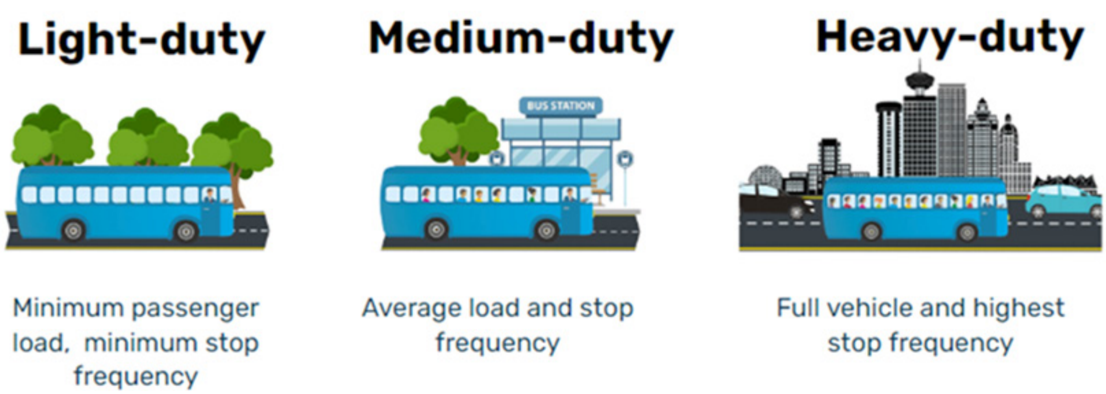


Figure 1: Average consumption rates of 40-foot BEBs with diesel heaters in Scenario One (full BEB solution), Charging Strategy One (in-depot charging with block splitting)

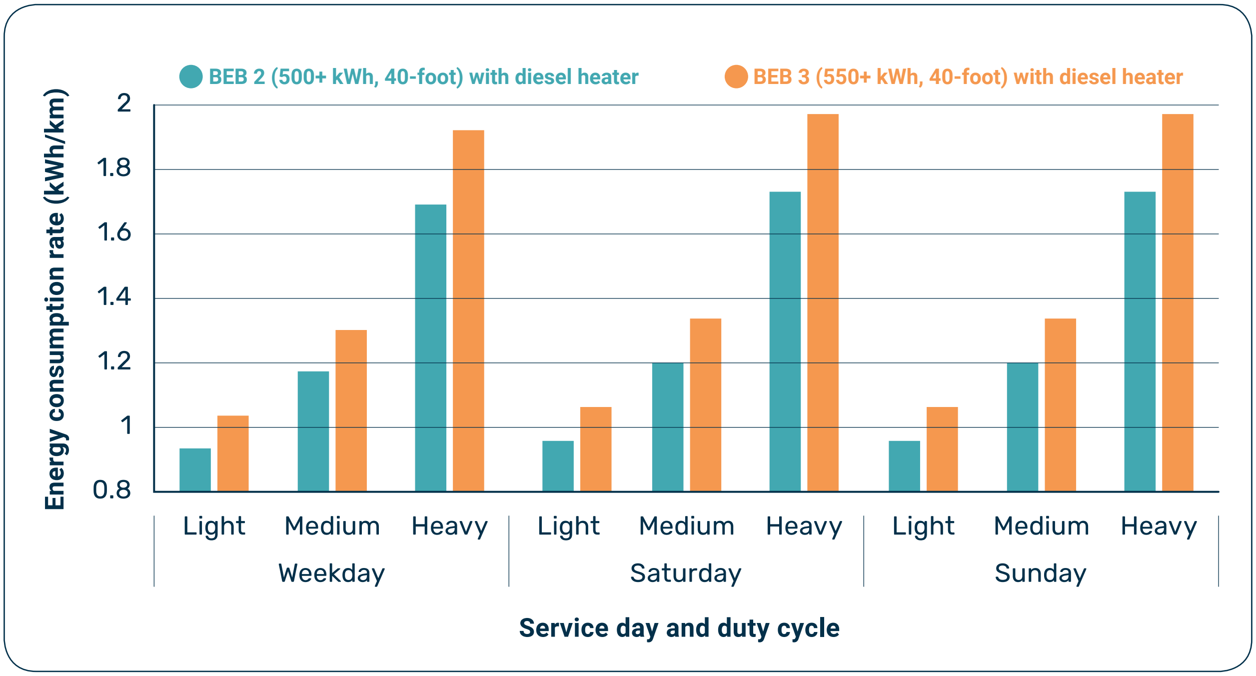


Figure 2: Consumption rates of 40-foot FCEBs in Scenario Two (full FCEB solution)

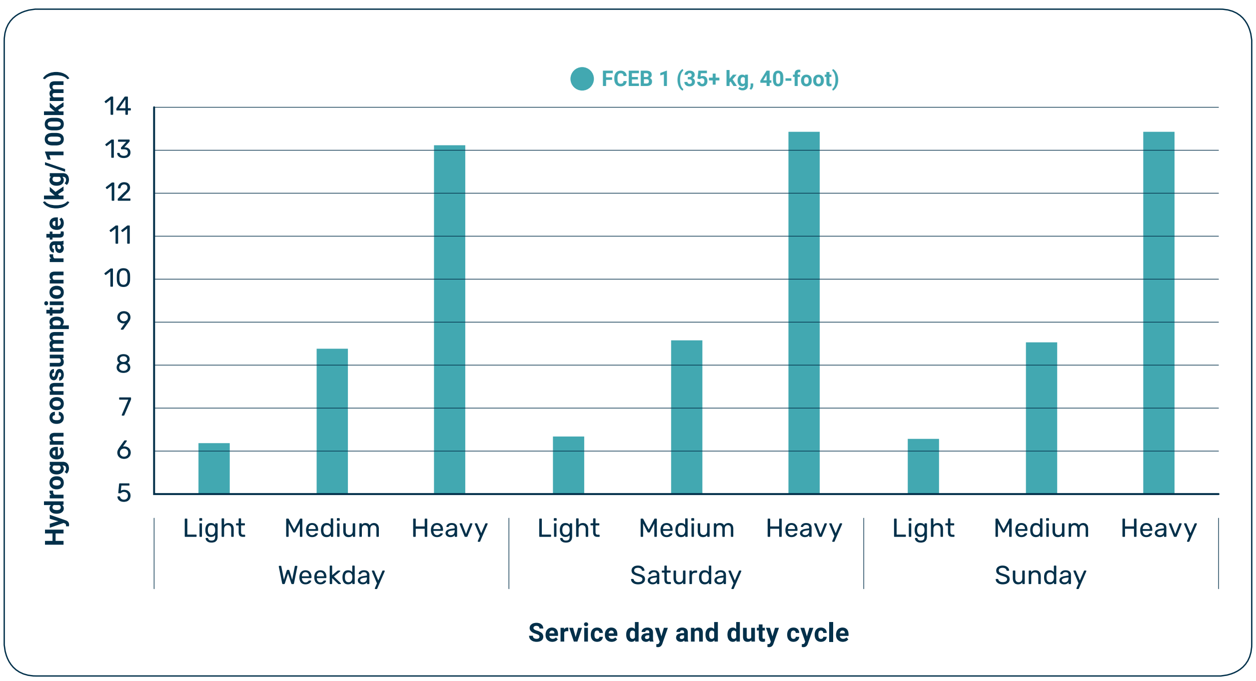


Figure 3: Comparison of 30-foot shuttle BEBs (BEB 1) consumption rates with 40-foot BEBs in Scenario One (full BEB solution), Charging Strategy One (in-depot charging with block splitting) on 30-foot bus blocks

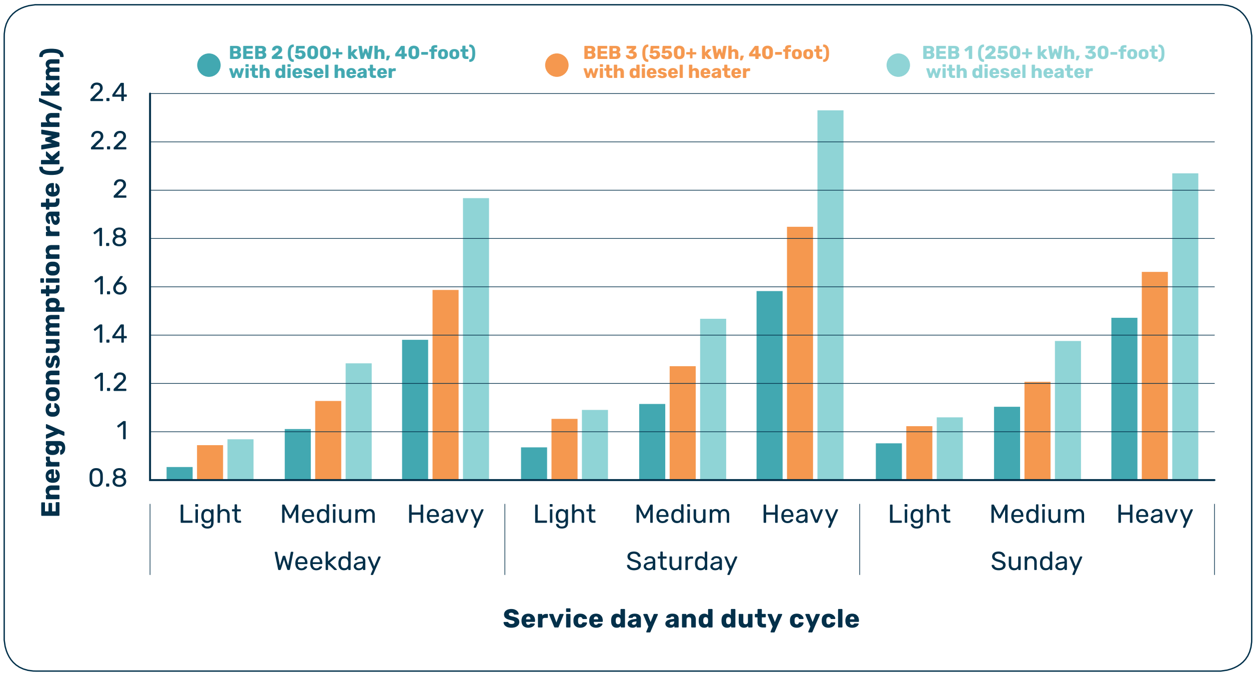


Table 1: On-demand energy consumption statistics

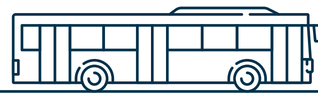
Average consumption rate by distance (kWh/km)	Standard deviation of consumption rate by distance (kWh/km)	Average consumption rate by time (kWh/h)	Standard deviation of consumption rate by time (kWh/h)	Average energy used (kWh)
0.50 to 0.55	0.01	3.28 to 35.8	3.0 to 3.2	187.5 to 204.8

Success Rates

The success rates are defined as the fraction of the modelled vehicles that can be successfully electrified on a one-to-one basis.

The criterion used for determining whether a vehicle is unsuccessful is determined if the battery SOC drops below the 20 per cent mark at any point along the vehicle journey for a BEB, or if the hydrogen tank reaches 0 kg for an FCEB.

40-foot BEB success rates (medium-duty cycle):



In-depot only charging: over **80%**

With block splitting (by halves): **100%**

FCEB success rates (medium-duty cycle): over **90%**

Figure 4: Success rates of 40-foot BEBs in Scenario One (full BEB solution), Charging Strategy One (in-depot charging with block splitting)

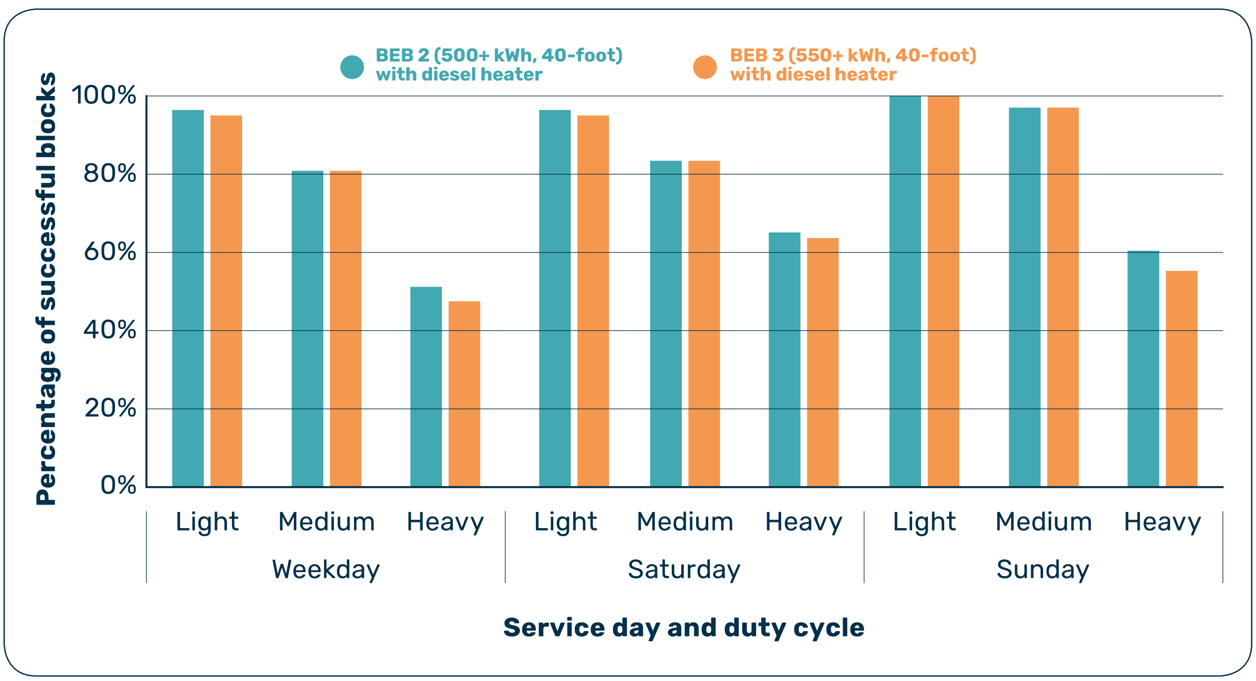


Figure 5: Success rates of 40-foot FCEBs in Scenario Two (full FCEB solution)

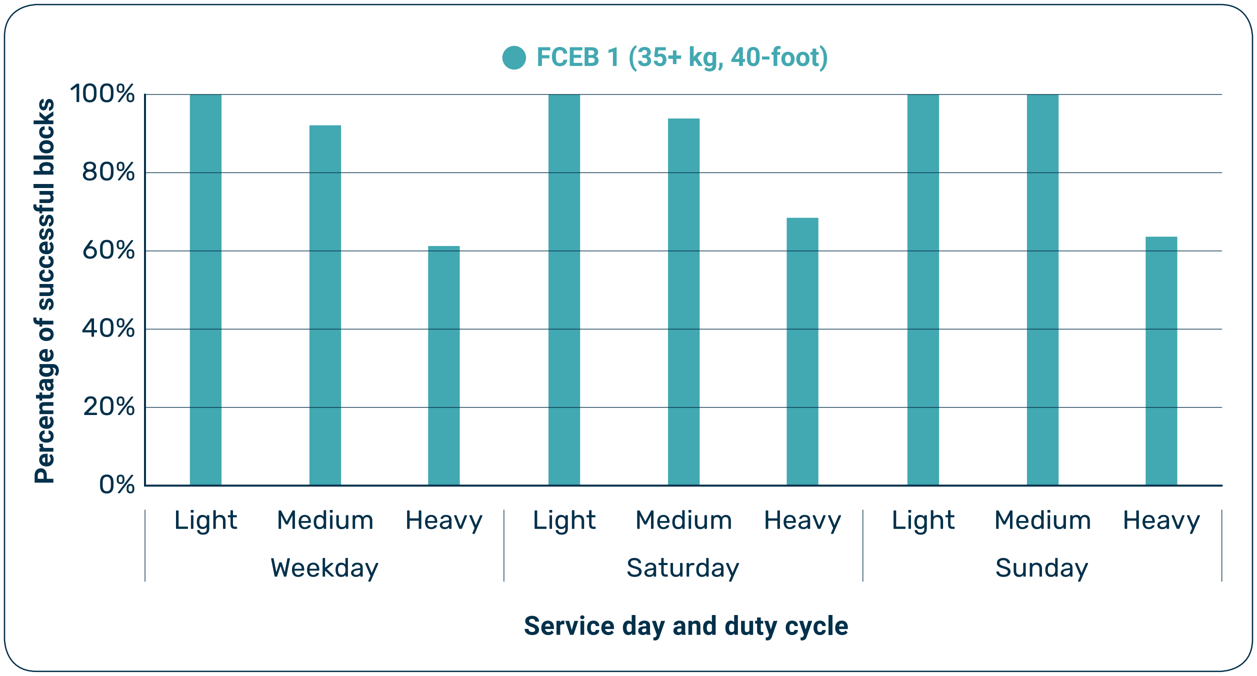
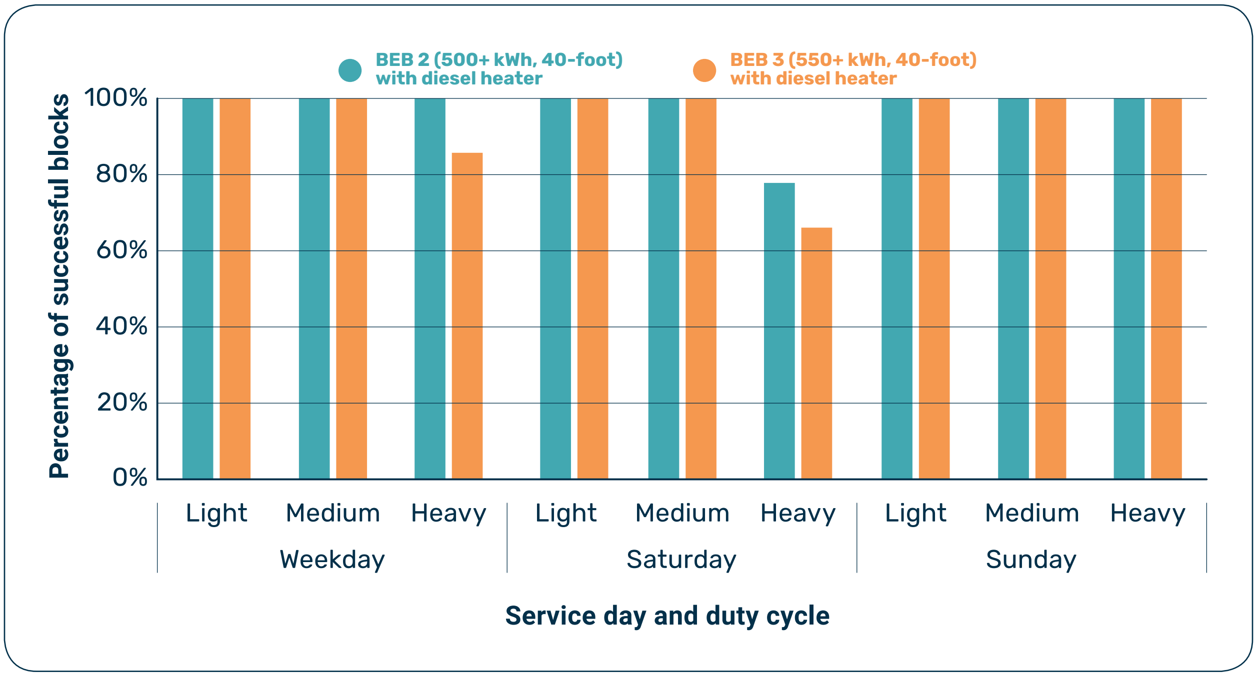
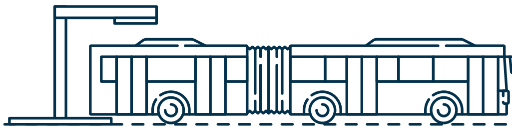


Figure 6: Success rates of 40-foot BEBs, block split by halves in Scenario One (full BEB solution), Charging Strategy One (in-depot charging with block splitting)



Asset optimization



Where blocks are not successful using depot-only charging, block splitting and on-route charging are considered to improve success rates

Medium- and heavy-duty block optimization, Scenario One (full BEB solution), Charging Strategy Two (in-depot and on-route charging with block splitting), 40-foot BEBs

WEEKDAY MEDIUM-DUTY CYCLE

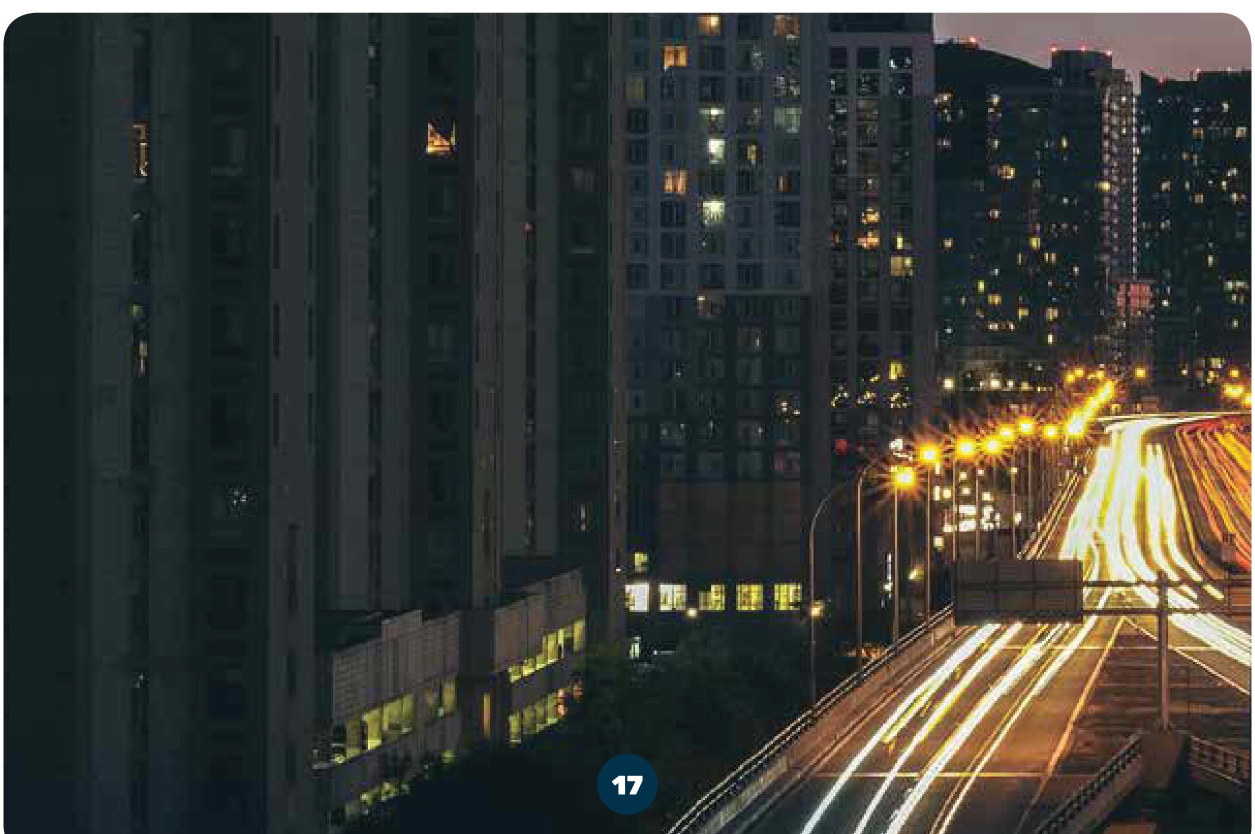
14 BEB Blocks require on-route charging and

3 BEB Blocks require block-splitting

WEEKDAY HEAVY-DUTY CYCLE

26 BEB Blocks require on-route charging and

21 BEB Blocks require block-splitting



On-route charging analysis

Figure 7: Proposed charging schedule for Stop 5909 (weekday medium-duty cycle)

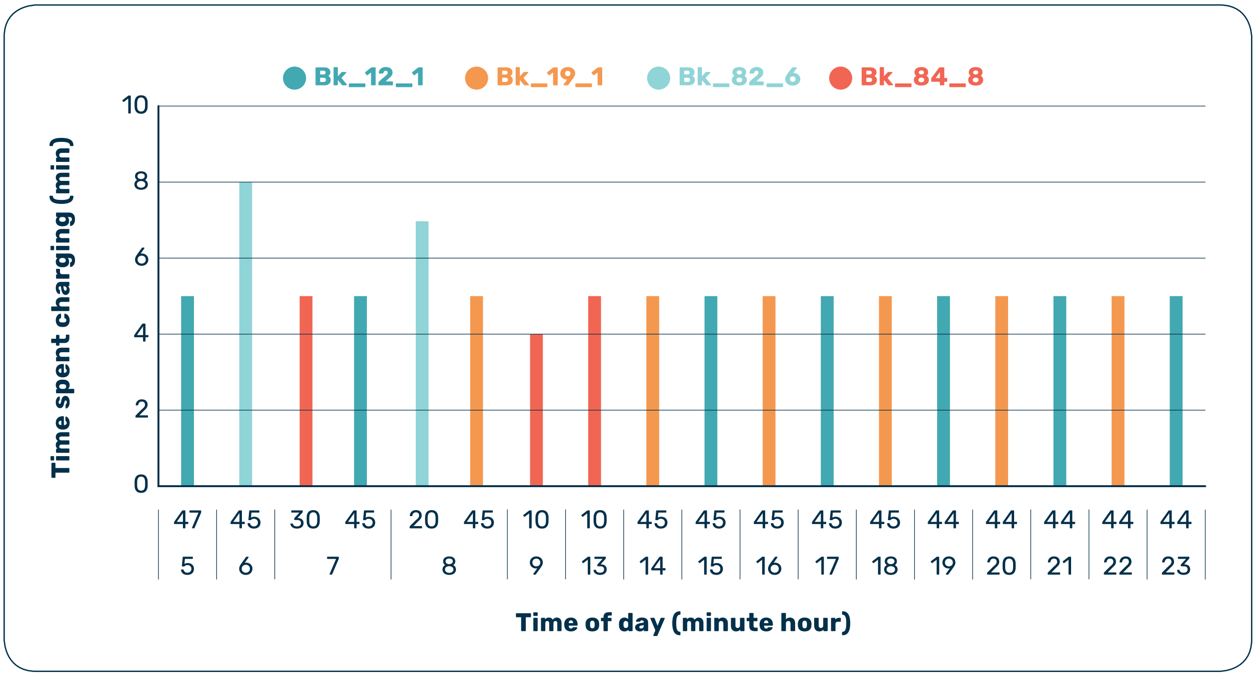


Figure 8: Proposed charging schedule for Stop 5907 (weekday medium-duty cycle)

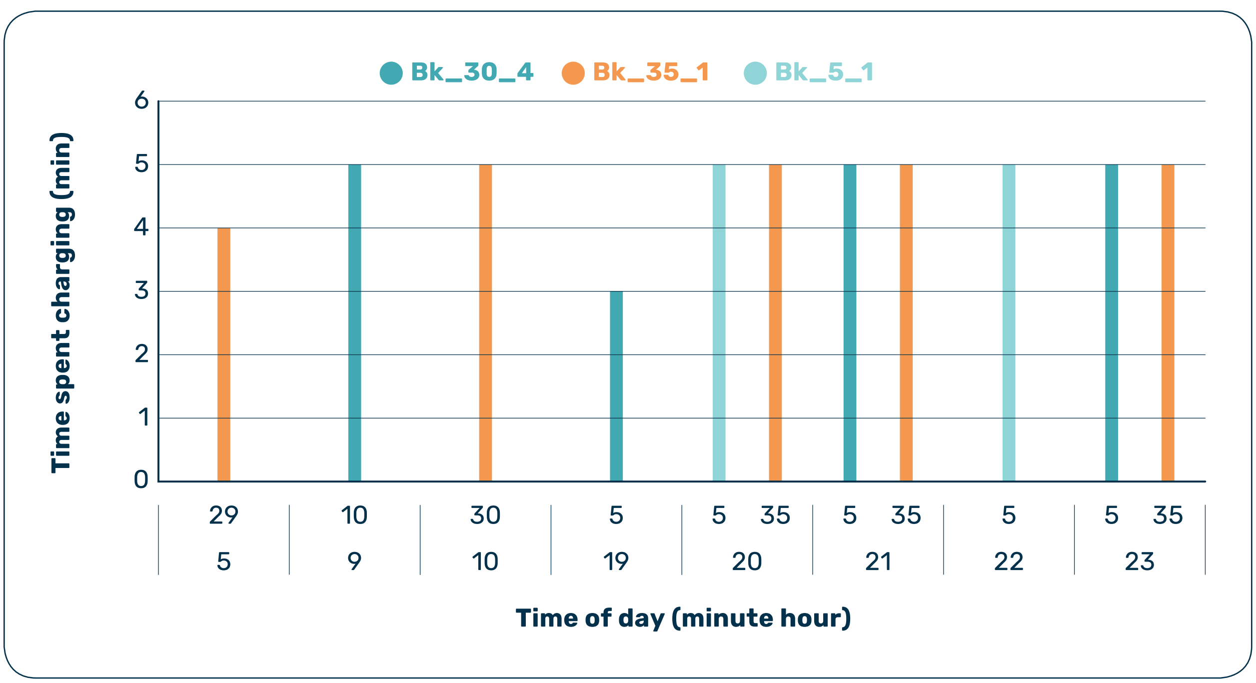


Figure 9: Proposed charging schedule for Stop 5906 (weekday medium duty cycle)

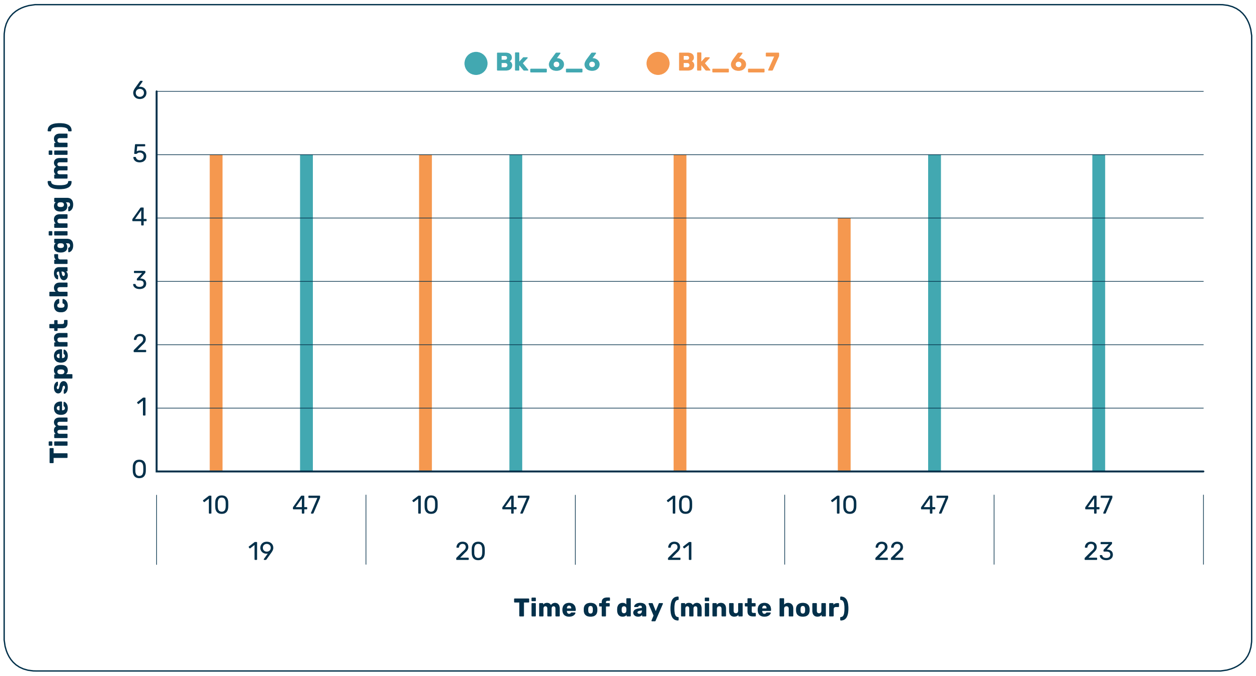


Figure 10: Time required for on-route charging beyond scheduled downtime (weekday medium duty cycle)

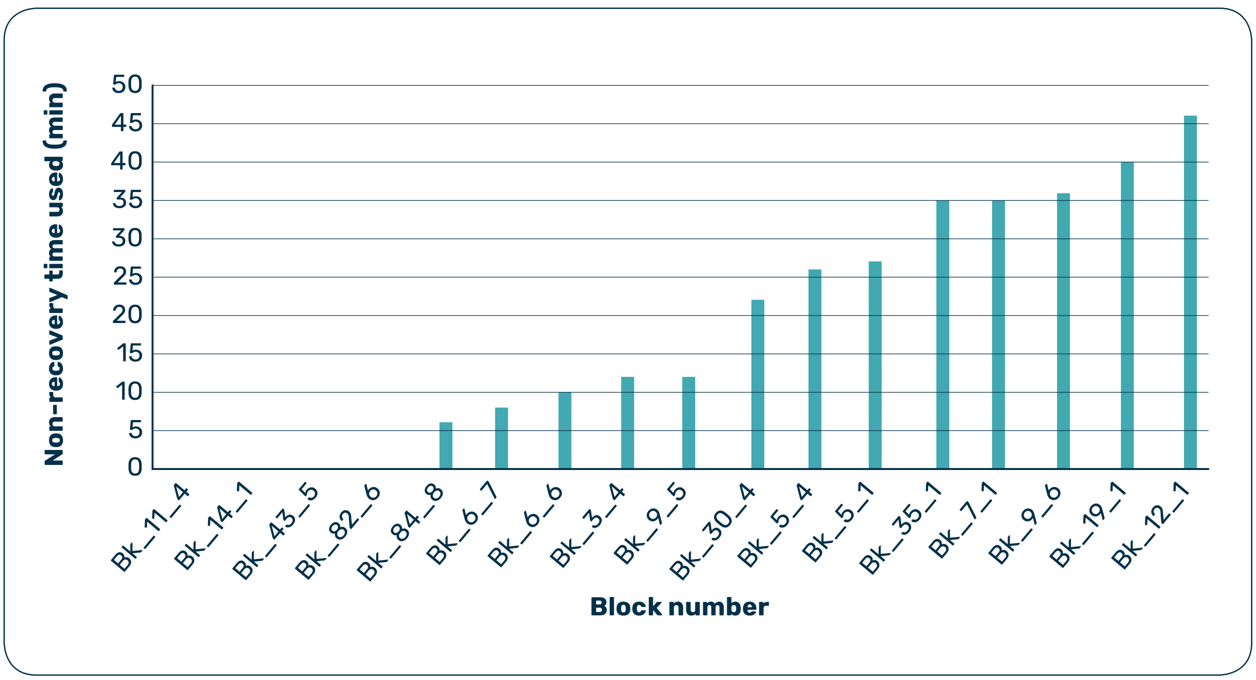
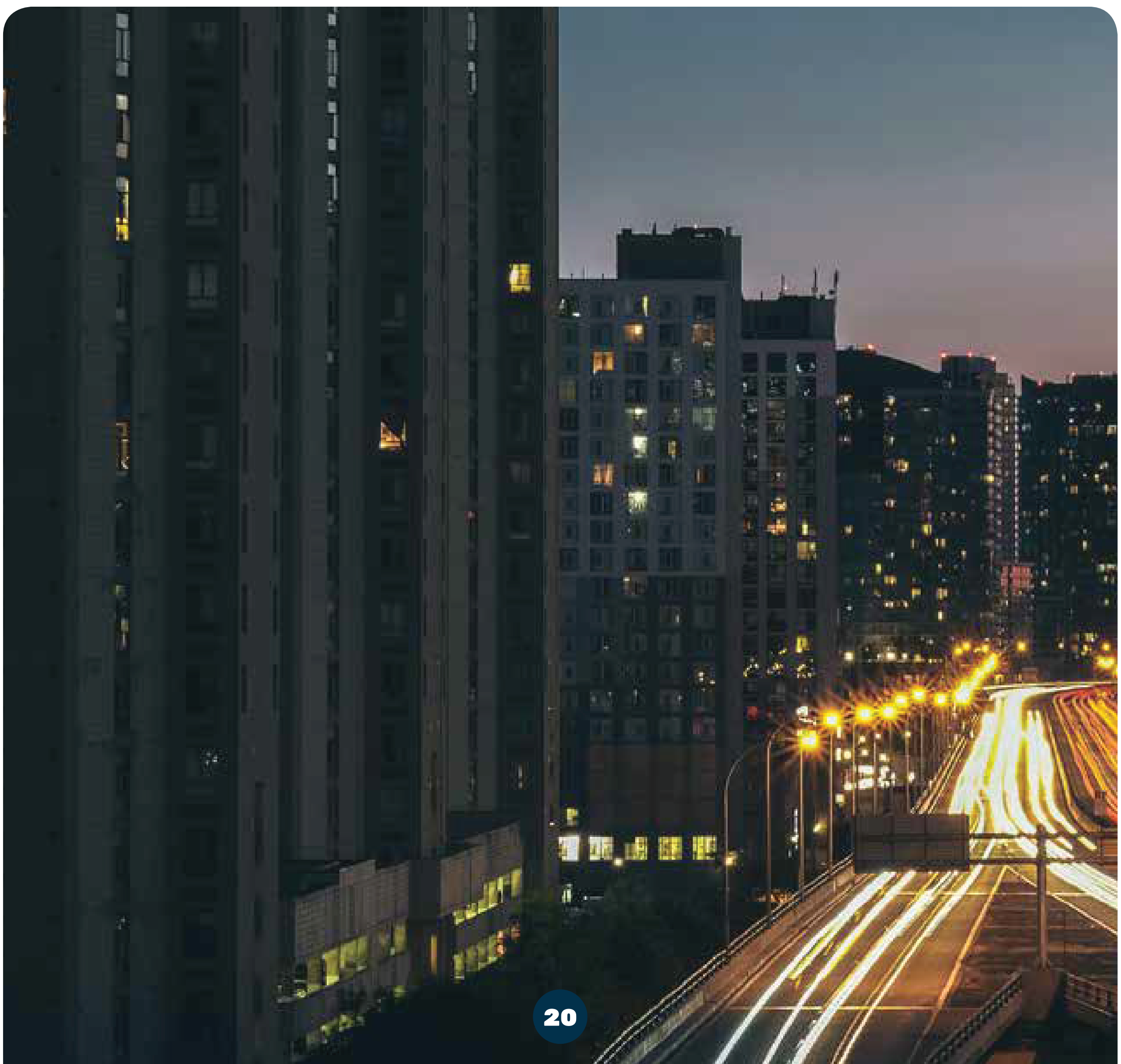


Table 2: Proposed charging session time for on-demand transit vehicles (weekday medium duty cycle)

	Charge session times						
	0 min	5 mins	10 mins	15 mins	20 mins	25 mins	30 mins
Total on-demand runtimes	2.8 h	2.8 to 3.4 h	2.8 to 4.4 h	2.8 to 5.8 h	2.8 to 8.0+ h	2.8 to 8.0+ h	2.8 to 8.0+ h



On-route charging requirements: Scenario One (full BEB solution), Charging Strategy Two (in-depot and on-route charging with block splitting)

Medium-duty cycle

4

Charging locations & On-route chargers

Heavy-duty cycle

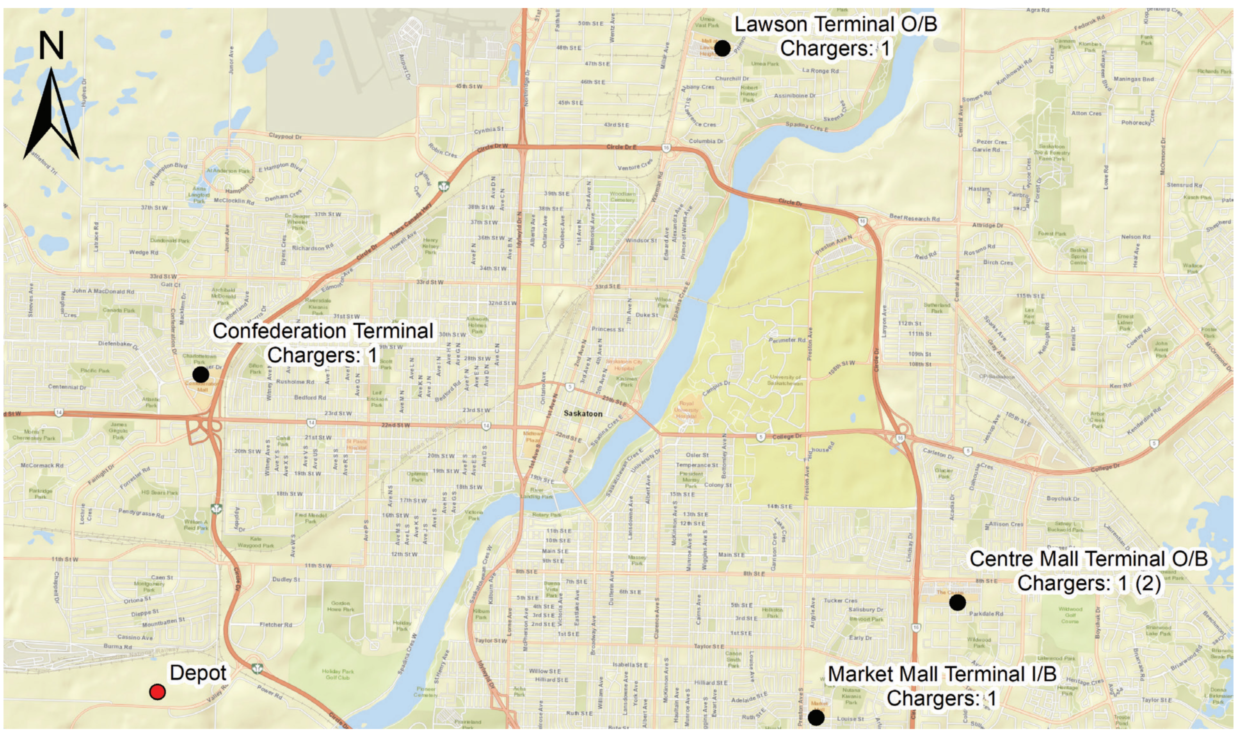
4

Charging locations

5

On-route chargers

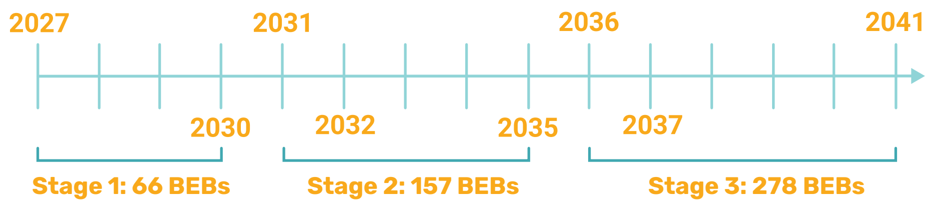
Figure 11: Saskatoon Transit's depot and potential on-route charging locations



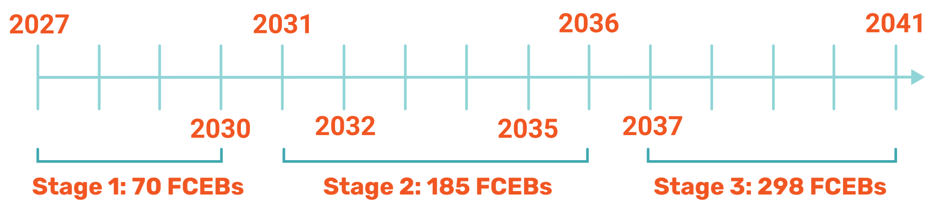
Fleet Implementation

Fleet scenarios are further refined to reflect the current replacement and growth Schedules of Saskatoon Transit and to parse out Scenario One (full BEB solution), Scenario Two (full FCEB solution) and Scenario Three (mixed green fleet). These scenarios are proposed for implementing a ZEB fleet using energy analysis results.

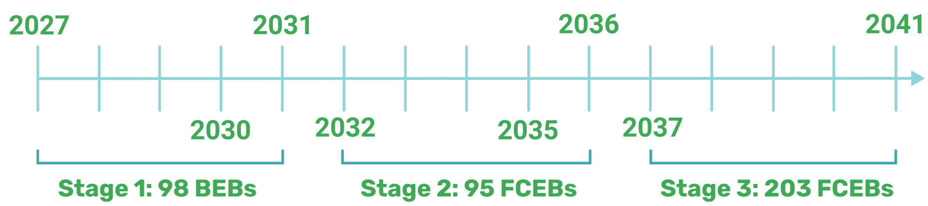
Scenario One
(full BEB solution)



Scenario Two
(full FCEB solution)



Scenario Three
(mixed green fleet)

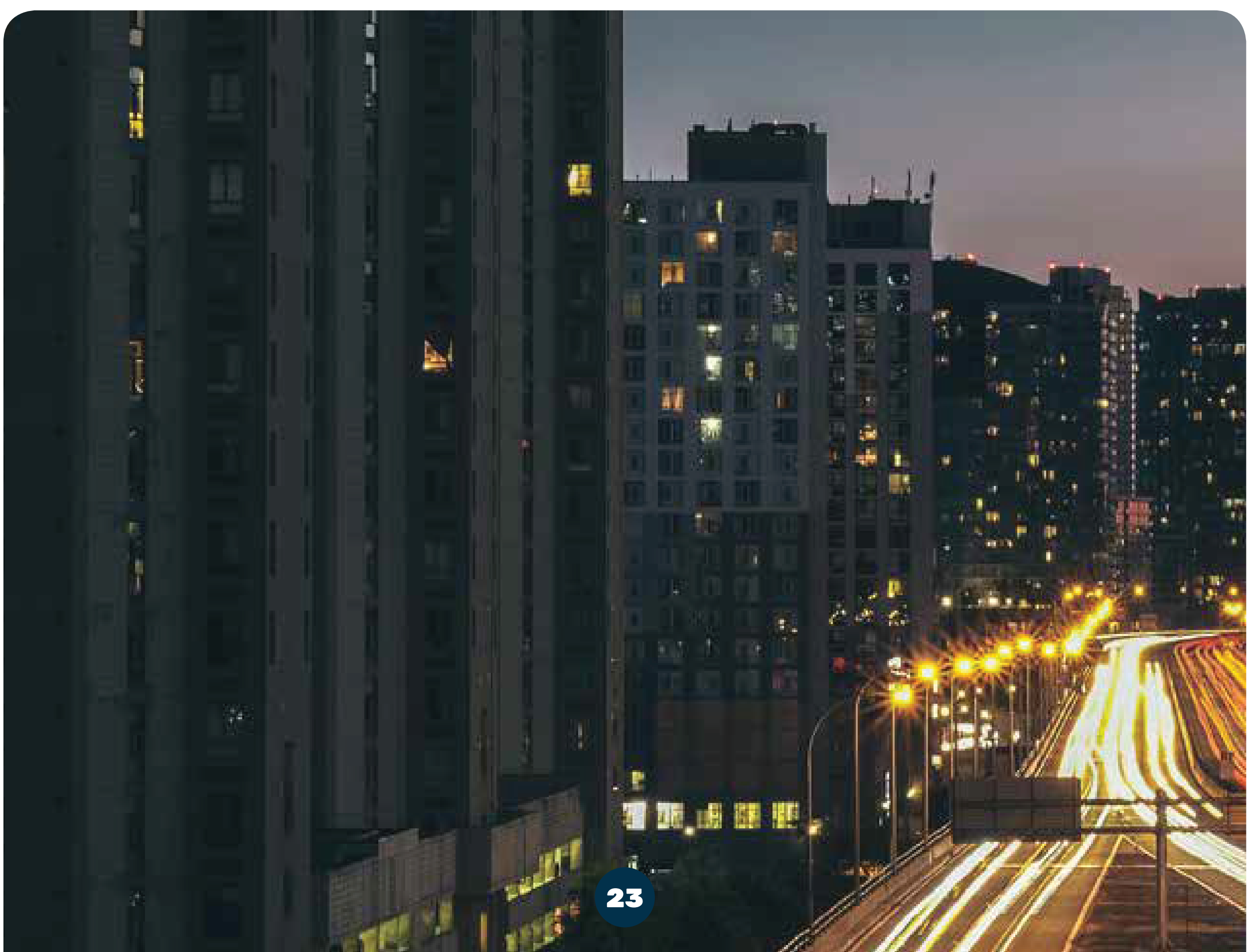


ZEB rollout timelines

Table 3. ZEB fleet configuration in 2041 for Scenario One (full BEB solution) Charging Strategy Two (in-depot and on-route charging with block splitting), Scenario Two (full FCEB solution) with depot refuelling and block splitting and Scenario Three (mixed green fleet), BEBs with in-depot charging and FCEBs

Number of bus type in 2041 fleet

	Diesel 30-foot	Diesel 40-foot	Diesel 60-foot	BEB 40-foot	BEB 60-foot	FCEB 40-foot	FCEB 60-foot
Scenario One (full BEB solution) Charging Strategy Two (in-depot and on-route charging with block splitting)	0	0	0	235	43	0	0
Scenario Two (Full FCEB solution)	0	0	0	0	0	258	40
Scenario Three (Mixed green fleet solution)	0	0	0	83	15	177	26

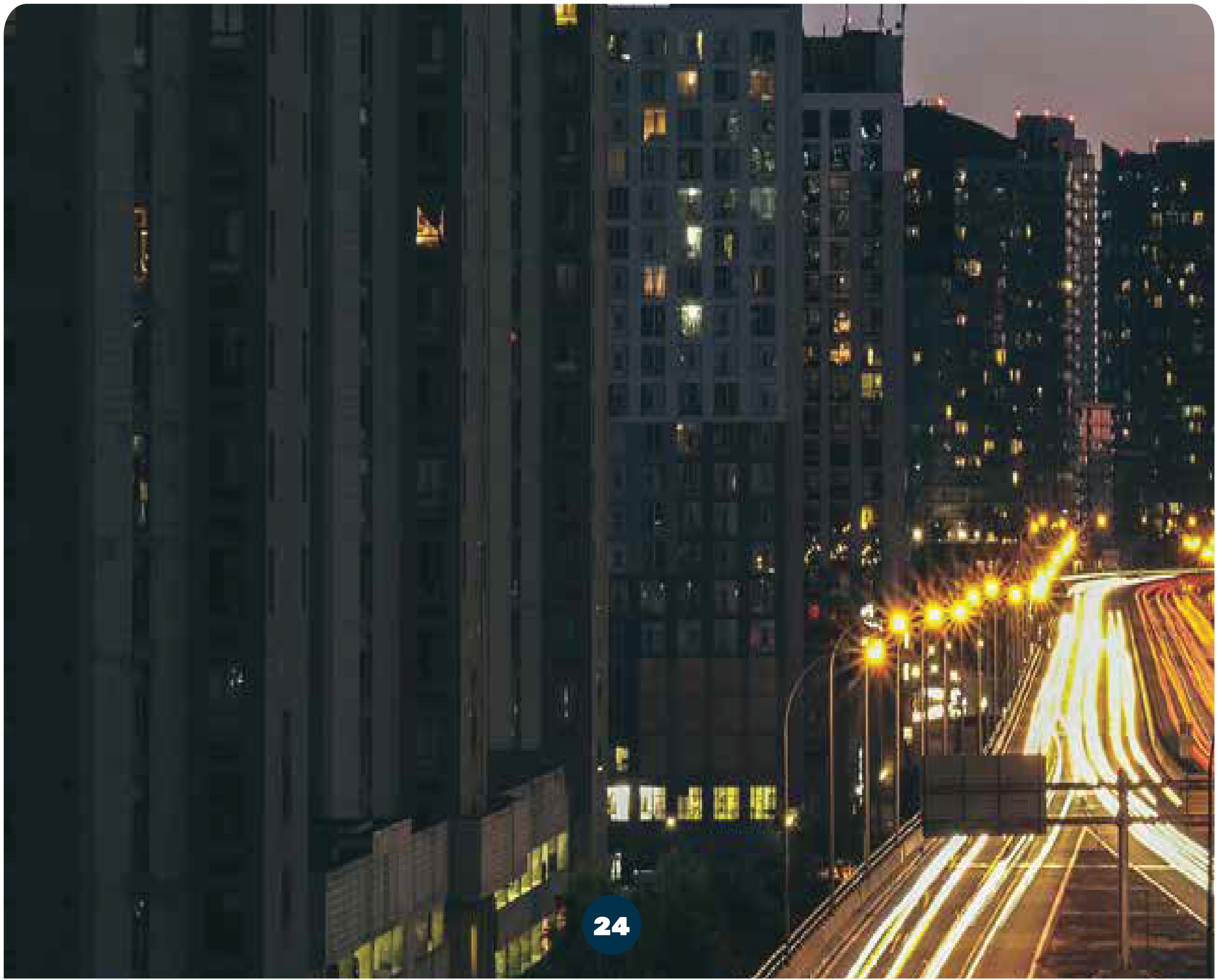


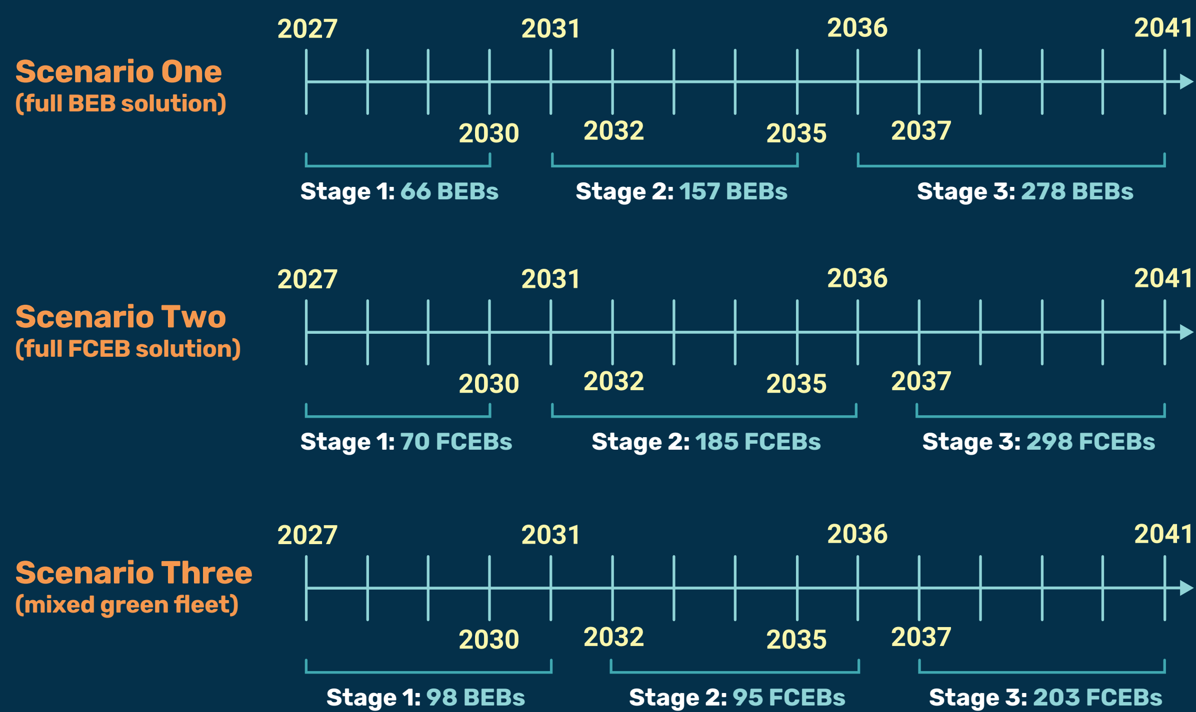
Facility Retrofits

The facility assessment presents an assessment of the Civic Operations Centre and associated changes that will need to take place to support ZEBs. A Class 5 cost estimate is outlined for Scenario One (full BEB solution), Scenario Two (full FCEB solution) and Scenario Three (mixed green fleet) over three stages.

Assumptions:

- All of Saskatoon Transit's operations will remain based primarily out of the Saskatoon Civic Operations Centre
- The Saskatoon Civic Operations Centre can accommodate the additional load of 11 chargers to support up to 32 BEBs without using a charge management system
- BEBs will be deployed incrementally





Scenario One

93 in-depot chargers

278 in-depot dispensers

Scenario Two

20,000 kg H2 storage on-site

12 H2 fuel dispensers

Scenario Three

33 charging cabinets

99 charging dispensers

12,000 kg H2 storage on-site

8 H2 fuel dispensers

Scenario One

Cost Estimate: **$47.7** million

Scenario Two

Cost Estimate: **$18.2** million

Scenario Three

Cost Estimate: **$27.7** million

On-route chargers replacement cost: **$520,000**

In-depot chargers replacement cost: **$231,000**

H2 fuelling station replacement cost: **$1,000,000**

Economic Analysis

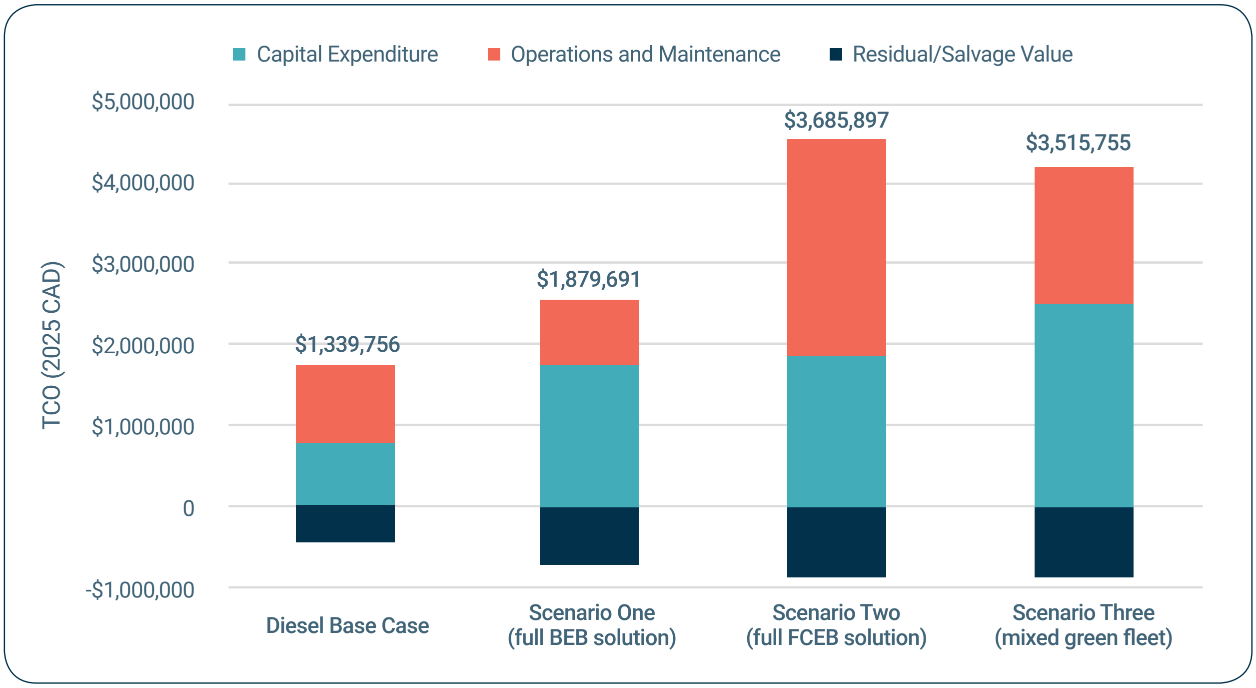
Base Case Scenario/Electrification Scenario Costs

Discount rate	3.5 per cent
Rolling stock acquisition	BEB: $1.0 to $2.2 million FCEB: $1.8 million Diesel bus: $900,000 to $1.3 million
Annual parts replacement	ZEB: $500/kWh Diesel bus: $0.06/km/bus
Annual maintenance cost	ZEB: $0.94/km/bus Diesel bus: $0.47/km/bus
Average fuel/electricity price	BEB: $0.143/kWh FCEB: $25/kg (green hydrogen) Diesel bus: $0.68/km

Total Cost of Ownership

The total cost of ownership considers the total life cycle cost per bus cost for Scenario One (full BEB solution), Scenario Two (full FCEB solution) and Scenario Three (mixed green fleet). This analysis allows Saskatoon Transit to compare the costs associated with various propulsion technologies.

Figure 12. 12 year TCO comparison between scenarios



Scenario Two (full FCEB solution) has the greatest TCO, largely due to its high bus acquisition cost. The cost of hydrogen, especially electrolytic hydrogen using energy from the grid, is substantial compared to the cost of electricity for the BEB. The Scenario Two (full FCEB solution) TCO also accounts for the cost of one fuel cell stack replacement, which was found to be the likely overhaul interval based on industry publications and manufacturer warranty specifications. High operation and maintenance, high fuel cost, and high acquisition costs are major factors in increasing Scenario Two (full FCEB solution)'s TCO.

Life Cycle Analysis

The life cycle analysis presents a GHG emissions reduction assessment, considering Scenario One (full BEB solution), Scenario Two (full FCEB solution) and Scenario Three (mixed green fleet). This analysis allows Saskatoon Transit to compare the emissions associated with various propulsion technologies. Greenhouse gas emissions are measured in global warming potential (GWP) which is a measure of how much a GHG traps heat in the atmosphere compared to carbon dioxide (CO_2). Air pollutants that are not GHGs but affect air quality are also measured.

GHG Emissions Reductions

Figure 13. 40-foot bus fleet life cycle emissions – Scenario One (full BEB solution) and Scenario Two (full FCEB solution)

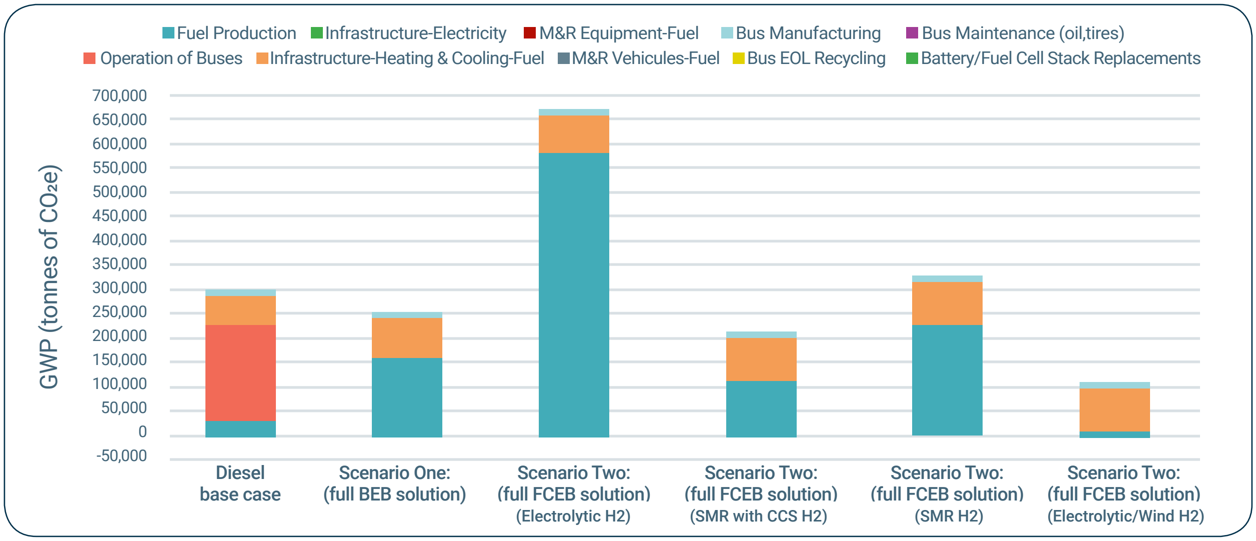


Figure 14. 40-foot bus fleet life cycle emissions – Scenario Three (mixed green fleet)

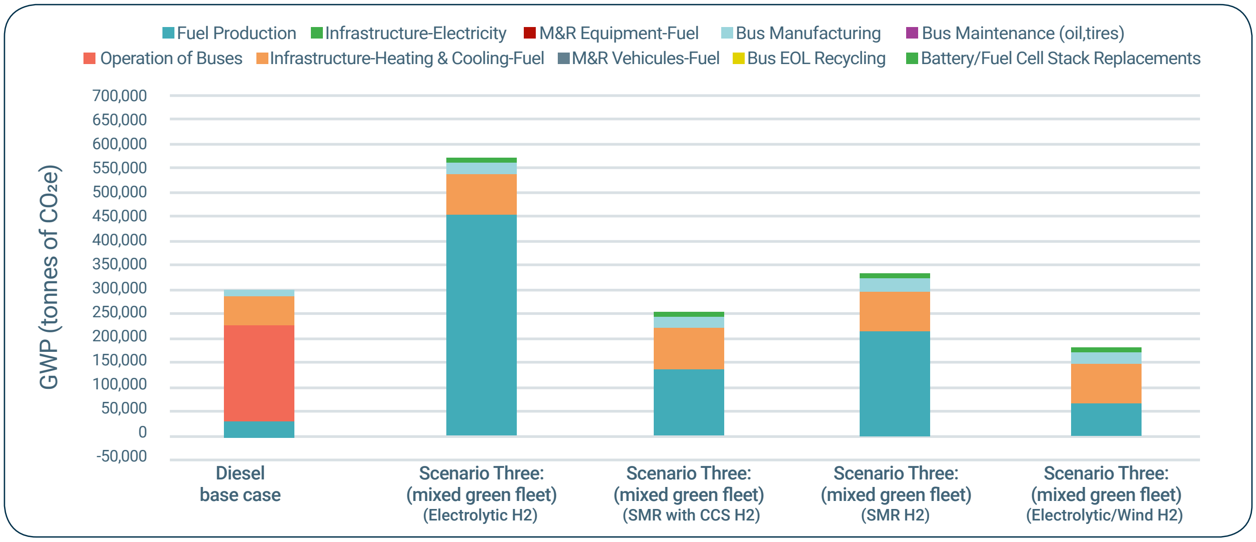


Figure 15. Yearly GHG Emissions for Base Case Scenario (diesel fleet)

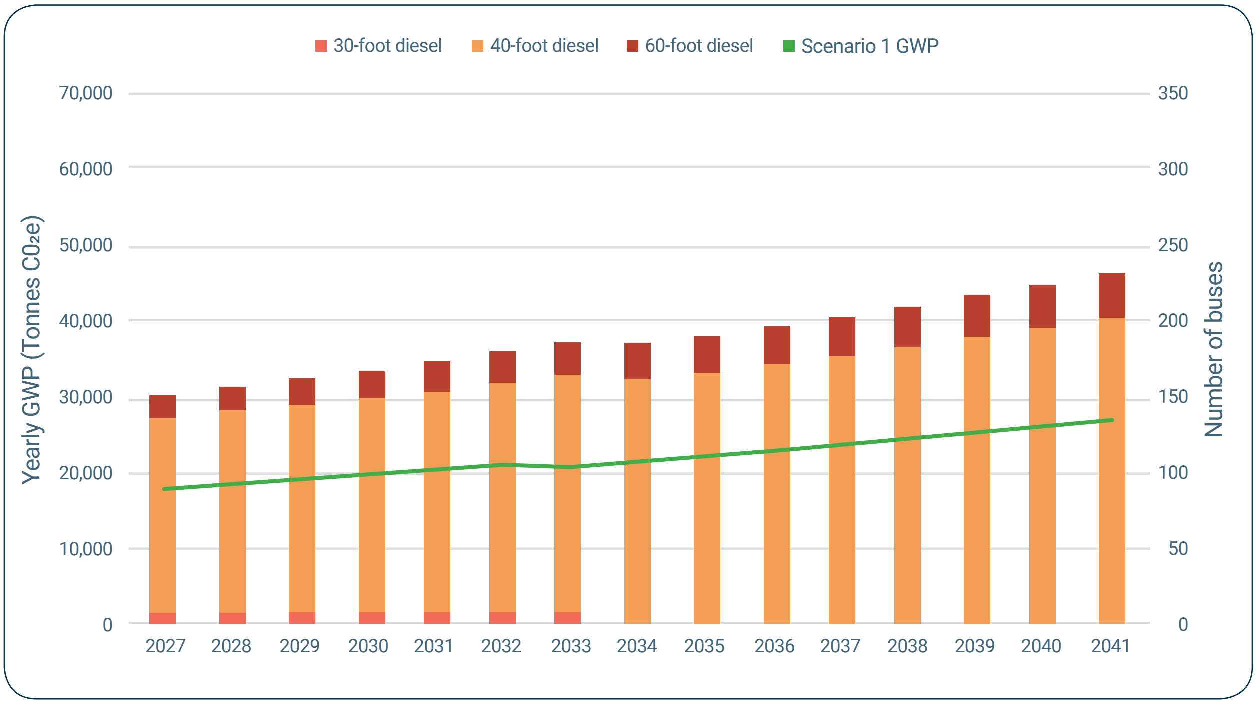


Figure 16. Yearly GHG Emissions for Scenario One (full BEB solution)

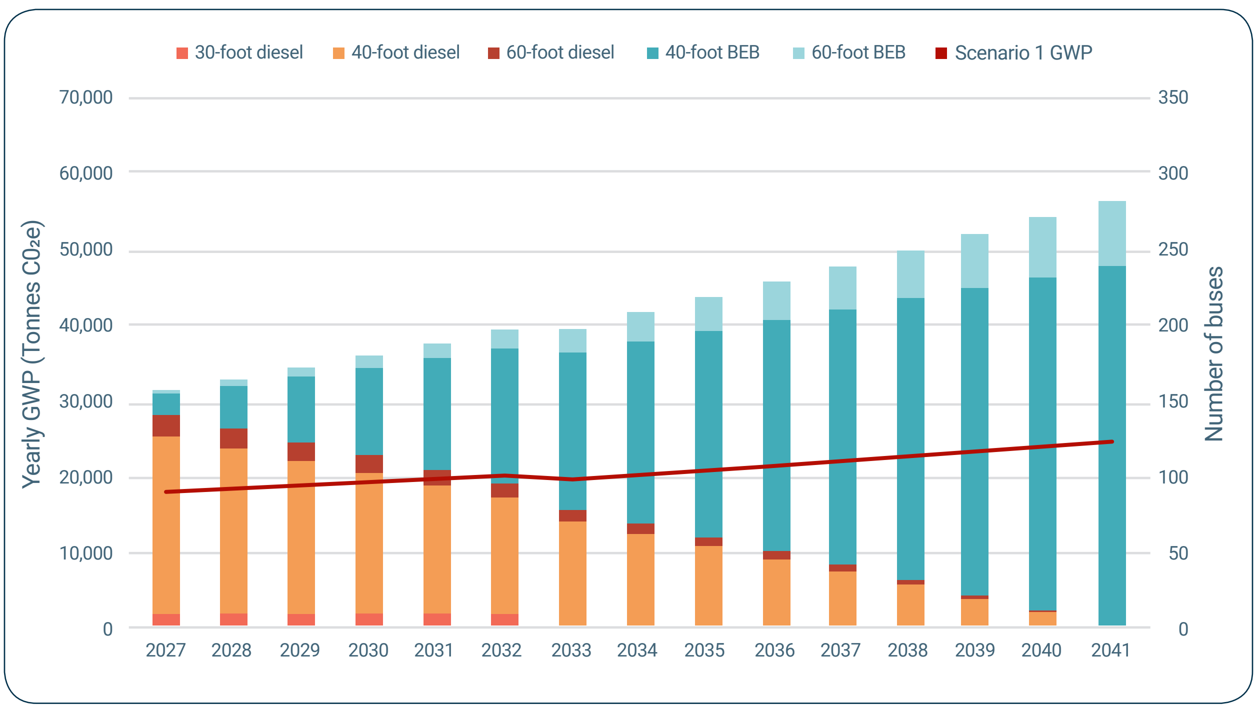


Figure 17. Yearly fleet GHG emissions for Scenario Two (full FCEB solution)

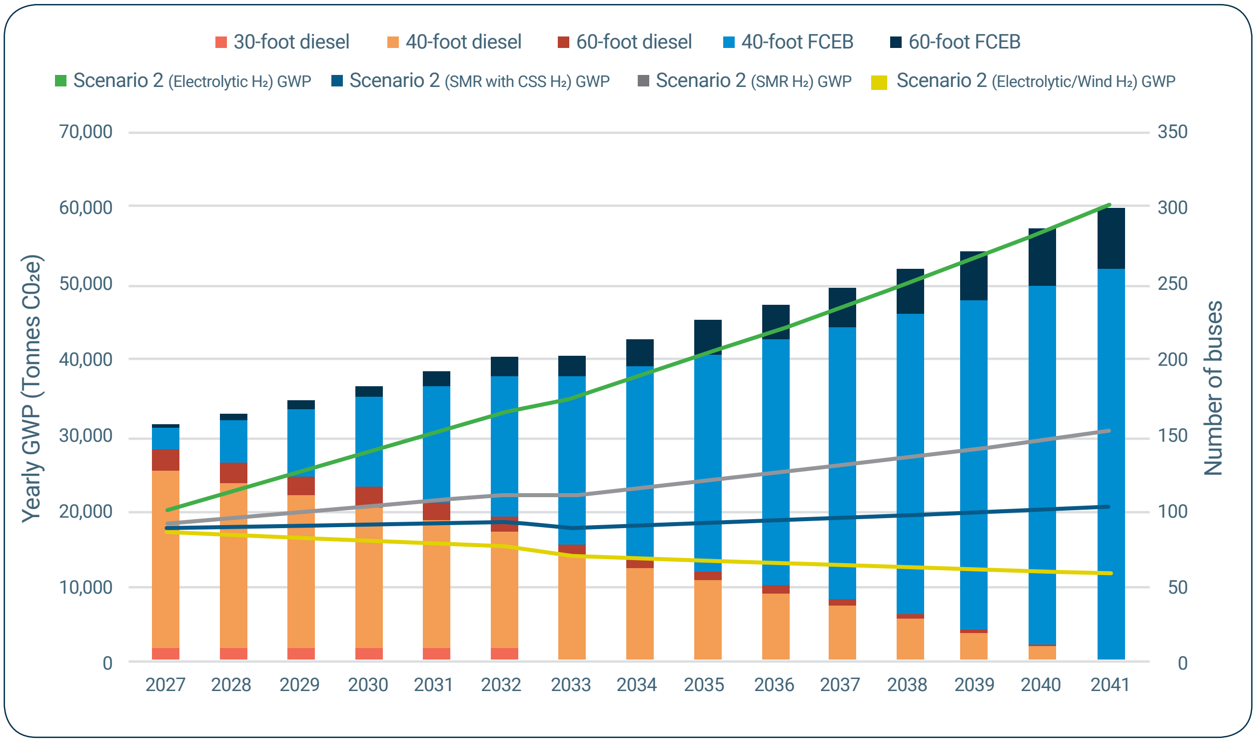
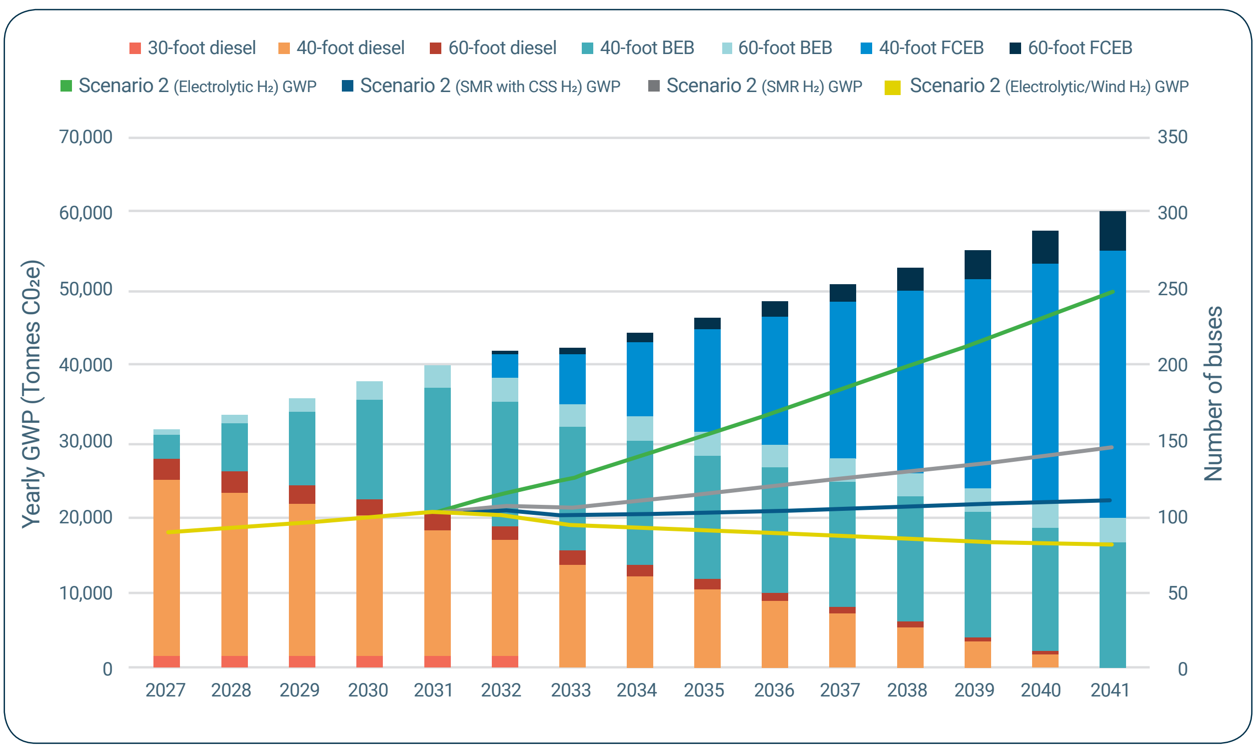


Figure 18. Yearly fleet GHG emissions for Scenario Three (mixed green fleet)



Air pollutant quantities

Figure 19. Yearly tailpipe emissions for Base Case Scenario

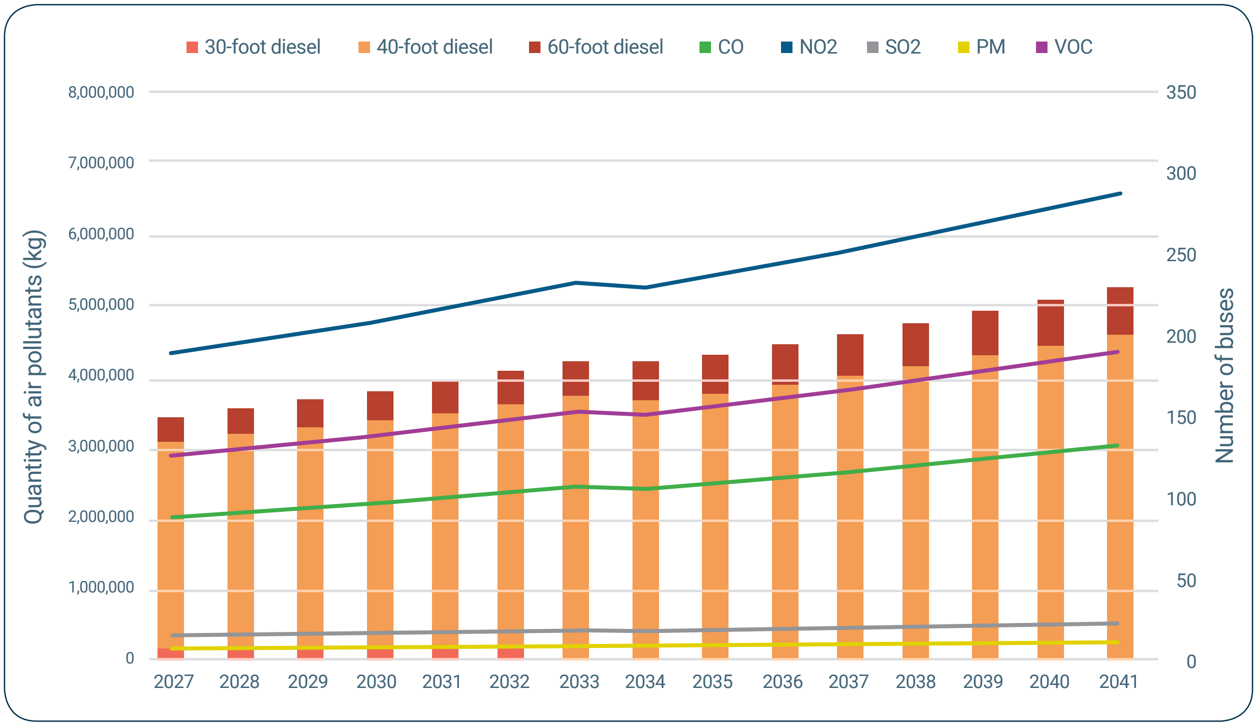


Figure 20. Yearly tailpipe for Scenario One (full BEB solution)

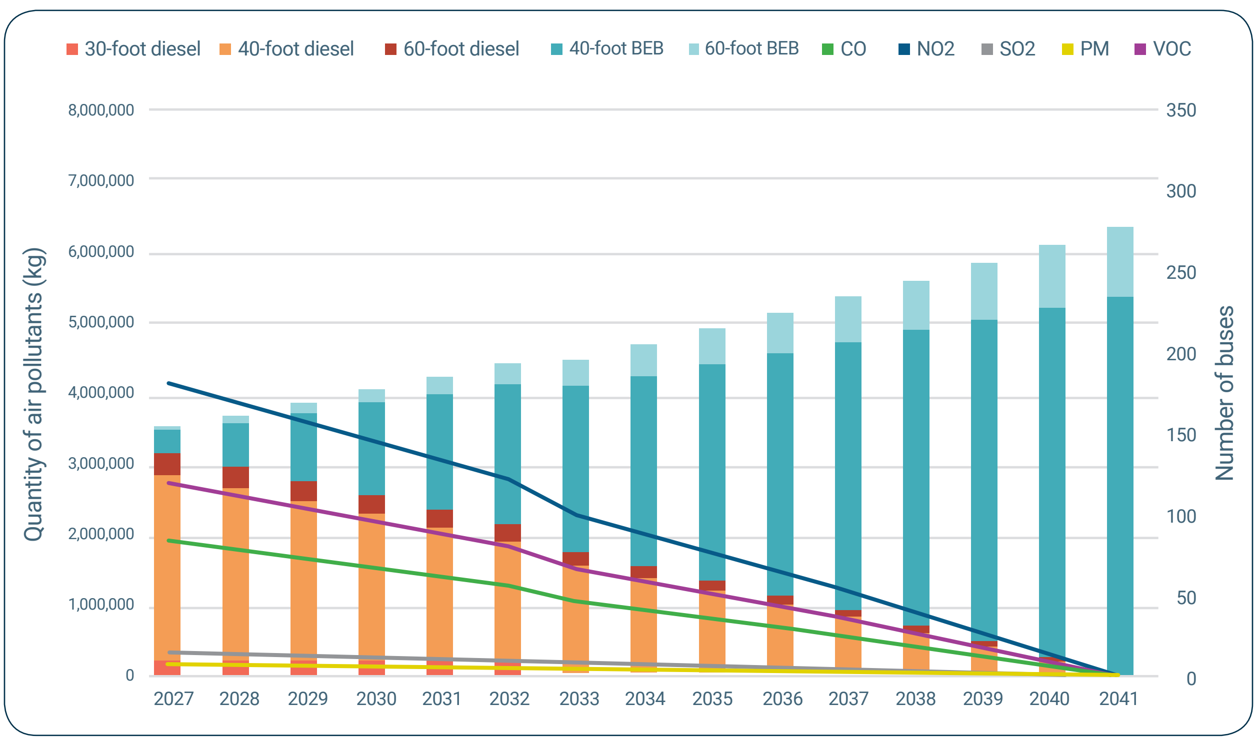


Figure 21. Yearly tailpipe emissions for Scenario Two (full FCEB solution)

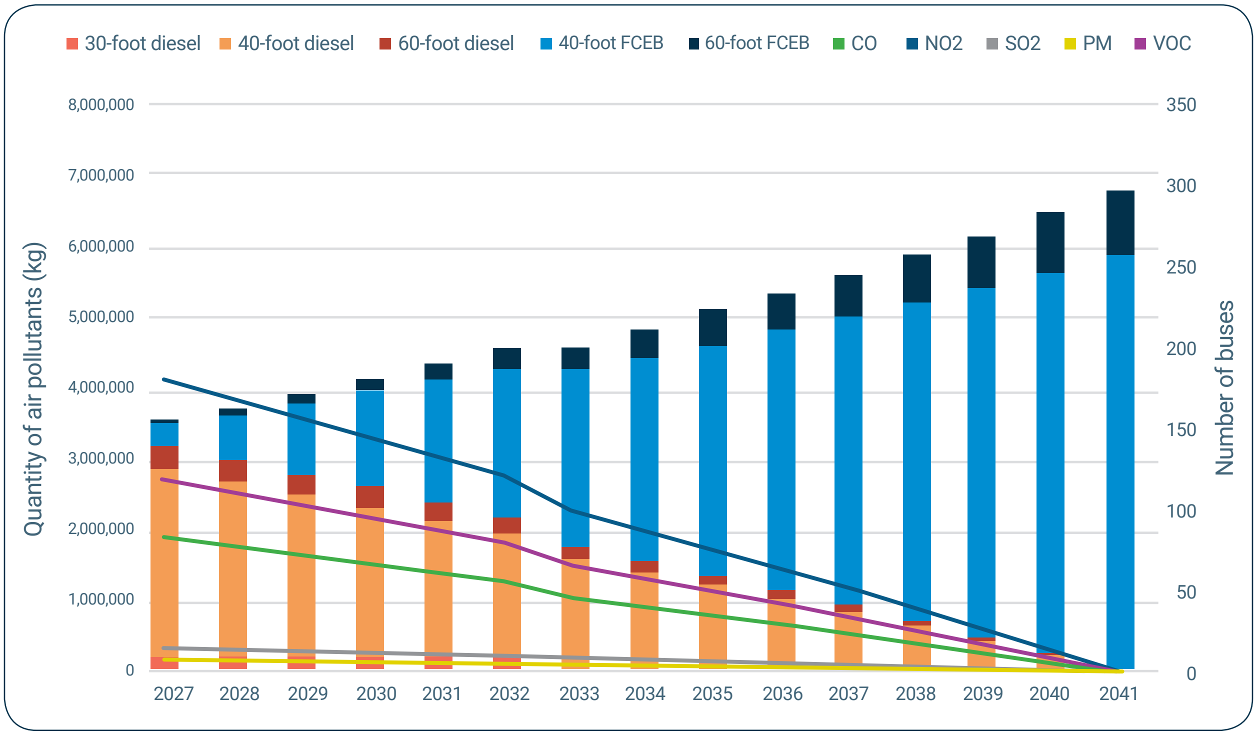
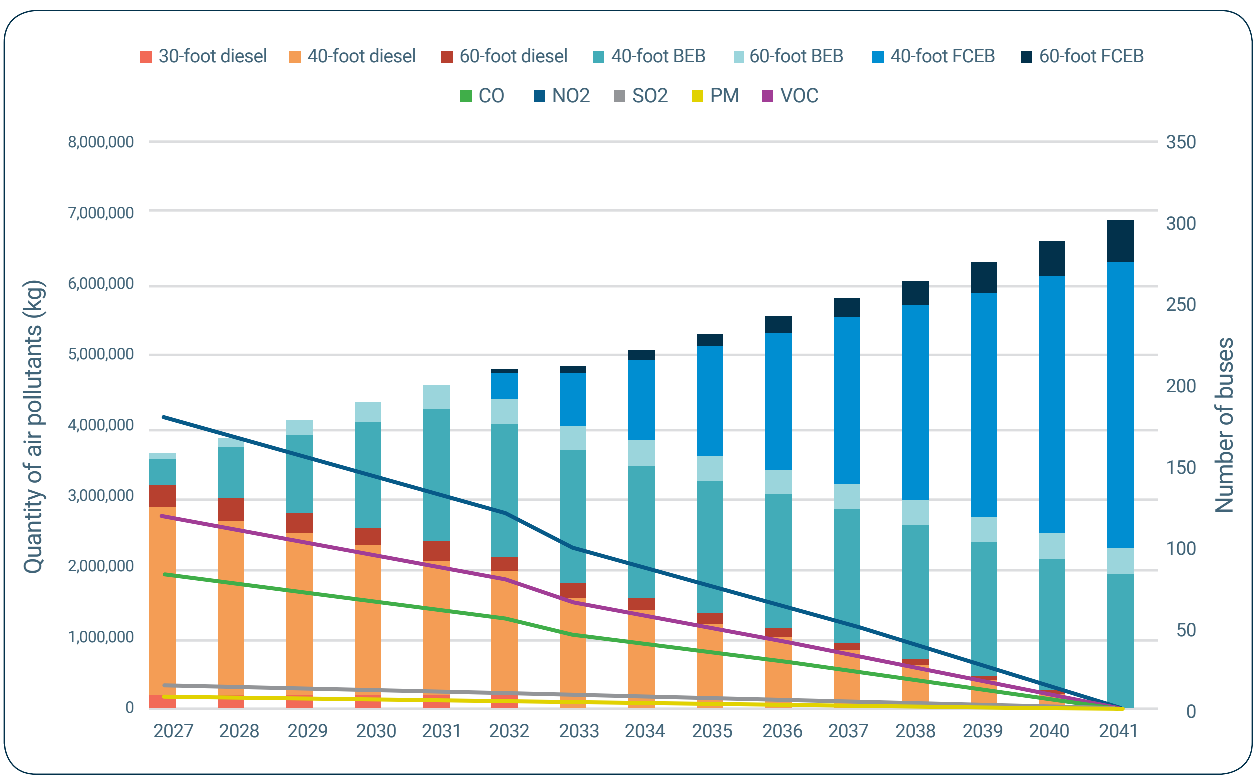


Figure 22. Yearly tailpipe for Scenario Three (mixed green fleet)



Social Analysis

To examine the transition through a social impact perspective, CUTRIC has identified socio-economically disadvantaged areas that could benefit from introducing ZEBs.

Seven types of disadvantaged areas have been identified:

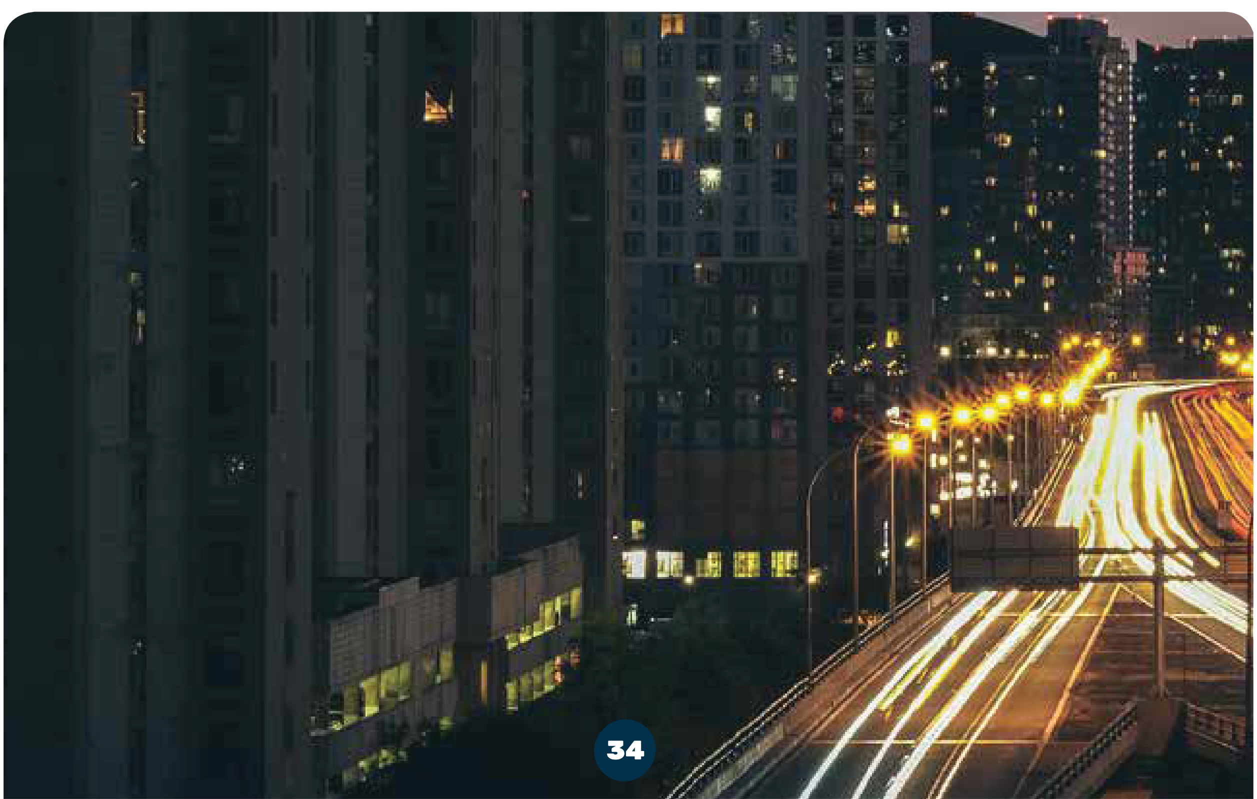
- Noise-sensitive areas
- Communities that are inhabited and exposed to high levels of air pollution and contamination
- Communities that are inhabited by low-income or economically disadvantaged population
- Communities that are inhabited by a high elderly population
- Communities that are inhabited by a population with limited formal education
- Communities that are exposed to high levels of air pollution (PM2.5)
- Lastly, communities that spend more than 30 per cent of their income on housing

Thirteen routes were identified as being a high priority, shown in Table 4, with a priority score of 3 or greater. Routes that were identified as high ridership, or serving the University of Saskatchewan were also prioritized within each ranking.

Highest priority routes for electrification from social standpoint

Table 4. Highest scoring Saskatoon Transit routes for electrification scores from a social standpoint

Route Name	Route Number	Priority Score	Additional Criteria
Meadowgreen / City Centre	2	4.5	High Ridership / Frequency
City Centre / Confederation	5	4.5	
Eastview / City Centre	16	4	High Ridership / Frequency
City Centre / Hudson Bay Park	3	4	
City Centre	4	3.5	Service the University of Saskatchewan High Ridership / Frequency
Cumberland / Centre Mall	81	3.5	High Ridership / Frequency
City Centre / Centre Mall	19	3.5	
Rosewood / Centre Mall	86	3.5	
Dundonald / City Centre	7	3	High Ridership / Frequency
College Park / University	18	3	Service the University of Saskatchewan
City Centre / Confederation	60	3	High Ridership / Frequency
City Centre / Kensington	65	3	High Ridership / Frequency
Main Street / Centre Mall	82	3	High Ridership / Frequency



Conclusions

Base Case Scenario (diesel fleet)

2041 Fleet GHG emissions
26,981 tCO_2e

Number of Diesel Buses in 2041 fleet
231

Total operations and maintenance costs (15 years):
$181.1 million

Total life cycle cost (15 years):
$261.9 million

Scenario One (full BEB solution)

2041 Fleet GHG emissions reduction
-10.1%

Number of Diesel Buses in 2041 fleet
0

Number of BEBs in 2041 fleet
278

Total life cycle cost (15 years):
$479.2 million

Total operations and maintenance costs (15 years):
$221.4 million

Diesel Bus to BEB ratio
1:1.26

Scenario Two (full FCEB solution)

2041 Fleet GHG emissions

+123.0% Electrolytic

+12.4% SMR

-24.5% SMR with CSS

-57.7% Electrolytic from wind sources

Number of FCEBs in 2041 fleet

298

Number of Diesel Buses in 2041 fleet

0

Total operations and maintenance costs (15 years):

$637.6 million

Total life cycle cost (15 years):

$1,105.1 million

Diesel Bus to BEB ratio

1:1.38

Scenario Three (mixed green fleet)

2041 Fleet GHG emissions reduction

- **+84.2%** Electrolytic
- **+8.4%** SMR
- **-16.8%** SMR with CSS
- **-39.6%** Electrolytic from wind sources

Number of BEBs in 2041 fleet
98

Number of Diesel Buses in 2041 fleet
0

Number of FCEBs in 2041 fleet
203

Total life cycle cost (15 years):
$588.7 million

Total operations and maintenance costs (15 years):
$318.4 million

Diesel Bus to BEB ratio
1:1.39

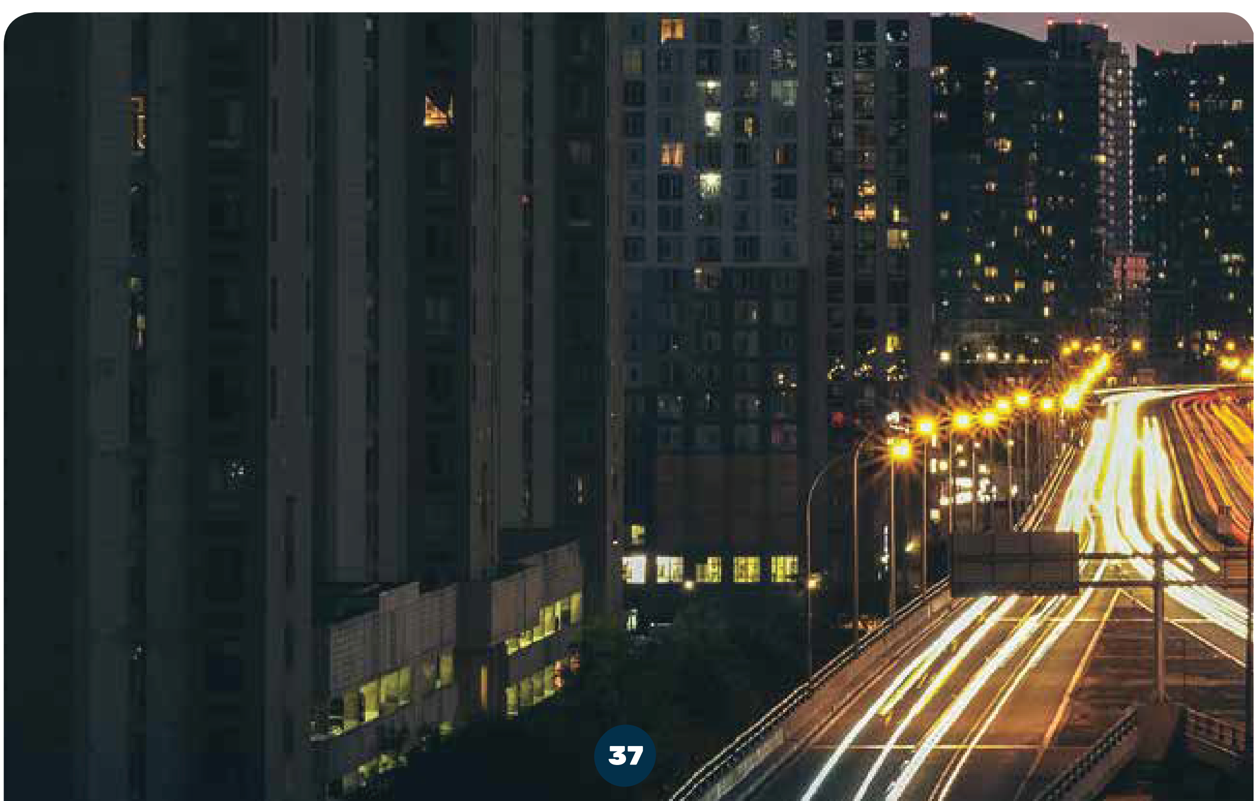


Table 5. Base case scenario/electrification scenario comparison

	Base case scenario (diesel fleet)	Scenario One (full BEB solution)	Scenario Two (full FCEB solution)	Scenario Three (Mixed green fleet)
2048 fleet GHG emissions	26,981 tCO_2e	-	-	-
2048 fleet GHG emissions reduction	-	-10.1 per cent	-57.7 to +123.0 per cent	-39.6 to +84.2 per cent
Number of diesel buses in 2048 fleet	231	-	-	-
Number of BEBs in 2048 fleet	-	278	-	98
Number of FCEBs in 2048 fleet	-	-	298	203
Total life cycle cost (15 years)	$261.9 million	$479.2 million	$1,105.1 million	$588.7 million
Total operation and maintenance cost (15 years)	$181.1 million	$221.4 million	$637.6 million	$318.4 million
Diesel bus to ZEB ratio	-	1:1.26	1:1.38	1:1.39

In conclusion, until the Saskatoon energy grid becomes greener, this study shows only marginal GHG reductions are achievable through substantial financial investment. Based on the multi-criteria decision-making analysis in the final report, the Base Case Scenario is the data-driven recommended pathway forward for Saskatoon Transit. Although, this may change in time if ZEB technology and related costs improve and sustainable sources become the foundation of the City's grid electricity.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