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Fleet Services Green Fleet Strategy and Report

PREPARED FOR THE CITY OF HAMILTON

RICHMOND SUSTAINABILITY INITIATIVES – FLEET CHALLENGE

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Terms and Abbreviations

AEC – Annual equivalent cost
B10 – A blend of 10% biodiesel and 90% fossil diesel; in this report, represents an annualized blend of B20 (used during summer months) and B5 (used during winter and shoulder months)
BAU – Business as usual
BEV – Battery-electric vehicle
BET – Battery-electric truck
CAC – Criteria air contaminants; a cause of ground level smog
CAFE – Corporate average fuel economy
Capex – Capital expense
Capital Replacement Ratio - Capital (for vehicle replacements) as a percentage of NPV
CIF – Cost inflation factor
CNG – Compressed natural gas
Controllable operating costs – For this report and benchmarking, operating expenses directly controllable by fleet management, including fuel, cost of capital, repairs & maintenance, inflation, and downtime
CO_2 or CO_2e – Carbon dioxide or carbon dioxide equivalent
CVOR – Commercial Vehicle Operating Registry
Downtime – Period when a vehicle is unavailable for use during prime business hours
E85 – A blend of around 85% ethanol and 15% gasoline
ECM – The electronic control module that manages a vehicle's computerized engine function
ELD – Electronic logging device
EV – Electric vehicle
FAR™ – Fleet Analytics Review™ (Fleet Challenge Excel software tool)
FMIS – Fleet management information system
GHG – Greenhouse gas (expressed in CO_2 equivalent tonnes)
GHG Intensity – A measure of GHGs produced relative to VKT or VMT (see below)
HD or HDV – Heavy-duty vehicle (Classes 7-8)
HEV – Hybrid-electric vehicle
HOS – Hours of service
ICE – Internal combustion engine
KPI – Key performance indicator
LCA – Lifecycle analysis
LD or LDV – Light-duty vehicle
LMHD – Light-, medium-, and heavy-duty vehicle
LPG – Liquid propane gas
LTCP – Long-term capital planning
LOF – Lube, oil, filter
Maintenance Ratio – Ratio of dollars spent on reactive (unplanned) repairs to preventive (planned) maintenance
MD or MDV – Medium-duty vehicle

Terms and Abbreviations (cont'd.)

MHD or MHDV – Medium- and heavy-duty vehicle
MHEV – Mild hybrid-electric vehicle
MT – Metric tonne
NPV – Net present value
OEM – Original equipment manufacturer
OOS – Out of service
Opex – Operating expense
Outlier – Vehicle with operating statistics outside of averages for similar fleet units
PDIC – Professional driver improvement course
PHEV – Plug-in hybrid electric vehicle
PM – Preventative maintenance
PMCVI – Periodic mandatory commercial vehicle inspection
Retention Cycle – The period that a vehicle remains in active service
RNG – Renewable natural gas
ROI – Return-on-investment
Solution – A technology, best management practice, or strategy to reduce fuel use and GHGs
SOP – Standard operating practice
TCO – Total cost of ownership
Uptime – Period when a vehicle is available for use during prime business hours (opposite of downtime)
Vehicle availability – See "Uptime"
VKT or VMT – Vehicle kilometres/miles travelled
WACC – Weighted average cost of capital
ZEV – Zero-emission vehicle

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Foreword

This Green Fleet Strategy and Report has been prepared for the City of Hamilton by Richmond Sustainability Initiatives (RSI) of Toronto, Ontario and its project team Fleet Challenge (FC), collectively referred to as RSI-FC. We have included this foreword because we feel it is important for readers of this report to first have a full understanding of the situation and context.

The report is based on our team's detailed data analysis of one-year of historical data for **1,307 City of Hamilton Fleet Services vehicles and equipment** as submitted by the City. This group of vehicles and equipment includes light-duty vehicles (cars, SUVs, pickup trucks, and vans), medium-duty trucks, heavy-duty trucks, and miscellaneous vehicles and equipment. The City's EMS, Fire, Transit, and Police fleets are excluded from this report.

The RSI-FC team has made considerable effort to make this report as meaningful and relevant as possible to the City of Hamilton in regard to its goals to decommission all diesel vehicles by 2030 and achieve a 100% electric fleet by 2050. We have researched, evaluated, and presented opportunities for fuel-use and GHG reduction that make economic sense and are reasonably attainable in the short to mid-terms.

Our analysis has been aided by using specialized software developed by RSI-FC, which is referred to as the Fleet Analytics Review™ (FAR) tool. Fuel-reduction solutions were analyzed using FAR, designed to efficiently estimate the cost-benefit and GHG emissions reduction potential, in the long-term (a 15-year horizon) of many best management practices (BMPs), low-carbon fuels, and current or emerging technologies that have been proven to be beneficial to commercial and municipal fleets.

This Green Fleet Strategy and Report encapsulates the FAR results, starting from our baseline review of the City of Hamilton's current-day fleet. We present a range of fuel-reduction solutions for the City's consideration. It provides a viable roadmap and a number of options for consideration by the Energy Fleet and Facilities (EFFM) Division of Public Works - solutions that can be implemented immediately and through to 2035.

We have made every effort to ensure that the business assumptions employed in our analysis are as accurate as possible and based on our many years of research into fuel-reduction options for commercial and municipal fleets. All estimates are based on published studies, research, and real data. Sources are noted throughout the document.

Fossil fuel use reduction translates directly to greenhouse gas reduction[1] (hereafter referred to as GHG reduction, carbon reduction, or CO_2 reduction); therefore, all references to fuel savings include the consequential GHG impacts (i.e., increase or decrease).

Prior to reviewing the report readers should be aware of and keep in mind the following:

[1] The terms "greenhouse gas," "GHG," "carbon," CO_2e and "CO_2" are synonymous for the purposes of this report.

Cautious Approach

All solutions explored in this report represent what our team considers to be possible, each with its own set of potentials. However, there are many variations that would modify capital expenses, operating expenses, and GHG emissions projections over time (e.g., switching from fossil fuels to alternate/renewable fuels earlier/later than modelled, phasing in battery-electric vehicles earlier/later than modelled or for segments of the fleet as opposed to fleet-wide implementation, etc.). Therefore, actual fuel/GHG reduction is tied to the *degree of achievement* in implementing each of the solutions and the timing of their implementation.

Challenges to Green Fleet Planning

Regardless of which fuel-switching options recommended in our report are ultimately selected by the City of Hamilton, the reality is that each will require some degree of extra effort; some will require additional cost to implement. For example, although units are capable of using biodiesel blends up to B20 (20% biodiesel and 80% fossil diesel) and/or higher blends of renewable diesel fuels, finding sources for these fuels or attending different retail commercial fuel stations may bring new operational challenges that must be resolved. Other examples are the effort and cost of installing DC fast-charging station(s) should electrification be the top priority in years to come, or the significant expense of compressed natural gas (CNG) or propane (LPG) refuelers.

Emissions Calculation Methods

Internationally, there are two standard reporting methods for vehicle carbon emissions modelling: (1) tailpipe combustion, and (2) fuel lifecycle (sometimes referred to as fuel cycle or well-to-wheel). Modelling of fuel lifecycle GHG emissions of motor fuels is used to assess the overall GHG impacts of the fuel, including each stage of its production and use in addition to the fuel actually used to power a fleet vehicle. Modelling of tailpipe emissions only includes the actual emissions produced by the vehicle itself through combustion. Lifecycle GHG emissions are, therefore, greater than tailpipe emissions.

While lifecycle emissions have been established for most fuel types, lifecycle emissions are extremely difficult to quantify for best management practices and also for electric vehicles because of the different mixes of electricity sources in different jurisdictions (i.e., fossil-fuel based, nuclear, and renewables). For this reason, to assess the potential GHG reduction on an “apples-to-apples” basis for each of the solutions evaluated in this report, we have employed the tailpipe combustion method.

Readers of this report should bear in mind that upstream emissions will diminish the estimated potential GHG reductions of fuel switching and electrification set out in this report to varying degrees. However, the results of our modelling employing the tailpipe combustion method gives a clear indication as to which solutions offer the greatest GHG reduction potential.

Of Further Consideration

In this report, we have calculated the City of Hamilton's fleet baseline and we have modelled go-forward scenarios from baseline to 2035 to provide a roadmap for implementation of fuel-reduction interventions/solutions. The interventions/solutions encompass three groups:

Group One: Lifecycle optimization and best management practices,

Group Two: Low-carbon fuel-switching, and

Group Three: Transition to battery-electric vehicles (BEVs).

We expect that the City of Hamilton may wish to evaluate unique combinations of these solutions different than the scenarios which we data-modelled, based on practicality, availability of models, corporate budgets, vehicle conditions, etc. For this purpose, the FAR software tool will be provided to the City for its own internal use post-project. The tool will be useful for efficiently evaluating any number of other fuel-saving solutions under consideration in the future.

As a backdrop to the objectives of this Green Fleet Strategy Report, our goal is to stimulate the City of Hamilton's interest in continuing to move its fleet towards a low-carbon future. We have made every effort to ensure our analysis is as accurate as possible, but at the time of actual implementation the business assumptions we have employed may have shifted. Therefore, we strongly urge the City to complete thorough cost-benefit analyses at any time in the future when considering implementing the recommended interventions/strategies we've outlined. Further, we suggest that a slow-start, cautious approach be taken which would include pilot testing new technologies in a small control group over at least four seasons of operation, carefully monitoring their performance and assessing the effectiveness of the solutions prior to any plans for wide-scale implementation.

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Executive Summary

Low-carbon transportation is essential to both short-term GHG and fuel-use reduction and long-term decarbonization of the economy. In 2018, the transportation sector accounted for about 25% of greenhouse gas (GHG) emissions in Canada, second only to the oil and gas sector[2]. Municipalities can play a key role in cutting emissions by transitioning their fleets to low-carbon and/or electric vehicles, while saving fuel and maintenance costs.

In May 2020, following a formal, competitive Request for Proposal (RFP) process, the City of Hamilton's Energy Fleet and Facilities (EFFM) Division of Public Works engaged Richmond Sustainability Initiatives – Fleet Challenge (RSI-FC) of Toronto, Ontario, to develop a Fleet Services Green Fleet Strategy and Report.

About Richmond Sustainability Initiatives

Since 2005, RSI-FC has collaborated with fleet managers, technology providers, subject matter experts, and auto manufacturers to find viable solutions, technologies, and best management practices for reducing operating costs and vehicle emissions. From the beginning, we have remained a self-supporting and independently funded program without commercial biases or influences, providing fleet review and consulting services to dozens of leading private and public sector fleets in Canada and the United States.

RSI-FC has employed our innovative, leading-edge data modelling techniques and our proprietary software for the development of the Green Fleet Strategy and Report. Fleet Analytics Review™ (FAR) is a software tool designed and developed by our company specifically for complex green fleet planning. FAR enables our team to develop short- to long-term green fleet plans and strategies by calculating GHG emissions reductions and return-on-investment (ROI) for various best practices and technologies – all driven by actual historical data. In turn, this allows us to evaluate the business case of each solution and provide meaningful recommendations for long-term capital planning. Through the combination of our experience and the use of our software tools, we are delivering an advanced Green Fleet Strategy and Report for the City of Hamilton that is realistic and achievable.

Context

As a proactive response to the City's climate emergency declaration in 2019, a multi-departmental Corporate Climate Change Task Force comprised of City Staff was created. According to the City of Hamilton's Corporate Energy Policy, fleet and transit fuel consumption account for $16 million in operating expenses and 40% of corporate greenhouse gases, highlighting the benefit of implementing green fleet strategies to reduce both fuel-use and GHG emissions. One of the action

[2] Source: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

items for the Task Force is to investigate and identify a plan for all diesel vehicles to be decommissioned by 2030 and all vehicles to be electrified by 2050. This is where the Green Fleet Strategy and Report can play a role in providing recommendations and potential pathways for achieving these goals.

Hamilton's Fleet Profile

The City of Hamilton owns and operates a diverse fleet including cars, pickups, SUVs, medium- and heavy-duty trucks, and equipment. Hamilton's Fleet Services serves the City's population of 747,545[3] residents and its businesses. Some quick facts about Hamilton's fleet[4], are shown below. During the one-year review period (2019):

- All fleet vehicles were owned (not leased or rented) by the City of Hamilton
- The fleet's average age was 7.5 years (includes equipment units)
- All units were either fossil diesel or gasoline-powered, with the exception of ice maintenance vehicles (CNG-powered, one unit propane-powered)
- The original purchase price for the fleet, including vehicles and equipment was $95,158,752
- The current-day estimated replacement cost was $112,153,100
- The estimated market/trade-in value of the fleet was $46,193,264
- Kilometres-travelled was 11,033,700
- Fuel used was 3,701,629 litres
- Total cost of repairs and maintenance, fuel, capital & downtime was $19,911,820
- Average fleet fuel consumption was 36.1 l/100 km
- GHG emissions were 9,371 metric tonnes CO_2e

Green Fleet Strategy and Report – Objective

The primary objective of this Green Fleet Strategy and Report was to analyze the City of Hamilton's in-scope fleet[4] operations data and identify and assess operational improvements and new technologies to reduce GHG emissions from Fleet Services vehicles and equipment. The results presented herein are intended to provide an ambitious roadmap to the City of Hamilton in its quest for go-forward fossil fuel and GHG-reduction solutions to achieve the goals of the Corporate Climate Change Task Force.

Overview of Analysis

With the above-stated objective in mind, after completing our Best Management Practices Review (BMPR) of the City of Hamilton's Fleet Services, RSI-FC conducted lifecycle analysis (LCA) for all vehicle categories, then systematically assessed the impacts of various fuel-reduction solutions on

[3] Census Profile, Canada 2016 Census. Statistics Canada.
[4] Does not include EMS, Fire, Transit, or Police fleets

the City's fleet operations and capital budgeting, and developed recommendations for the Green Fleet Strategy Report. The analysis, using RSI's Fleet Analytics Review™ (FAR) software, included:

- Analysis and preparation of current-day baseline fleet data with data provided by the City
- Completion of lifecycle analysis (LCA) for all vehicle categories and determination of optimized lifecycles based on data provided
- A balancing exercise of fleet capital budgets with LCA-optimized lifecycles through consideration of ROI for units due for replacement, to model a lower-emissions pathway
- Preparation of 36 data models to evaluate the impacts (Opex, Capex, and GHG reductions) of go-forward fuel-reduction solutions relative to the 2019 baseline, over a 15-year budget cycle, which resulted in the completion of several long-term capital planning (LTCP) scenarios
- A review of low-carbon fleet options and recommendations for a structured, phased-in transition to battery-electric vehicles (BEVs) with consideration of LTCP

From our analysis, as we describe within this report, we have made recommendations that have potential for the City of Hamilton to optimize vehicle replacement practices, transition away from fossil fuels, optimize the use of capital towards BEV replacements and charging infrastructure, and ultimately achieve deep GHG reductions while maintaining stability in capital budget planning.

Go-Forward Fuel-Reduction Solutions

RSI-FC completed extensive research into known, credible, proven, and potentially viable fuel-reduction solutions for the City of Hamilton, currently or in the near future. The solutions we assessed include three groups (see below). For every solution in each of the three groups, we assessed the impacts relative to the 2019 operational baseline:

- Group One: Lifecycle optimization and best management practices (BMPs) or "house-in-order" strategies
- Group Two: Fuel switching or "messy middle" – interim, present-day solutions including renewable fuels (E85 ethanol, B10 biodiesel, RNG) and alternate fuels (CNG and LPG)
- Group Three: Battery-electric vehicle (BEV) technology

RSI-FC's proprietary Fleet Analytics Review™ (FAR) software was used to evaluate these options in the context of the existing fleet being reviewed. That is, after optimizing lifecycles, balancing capital budgets, and implementing "house-in-order" strategies, many fuel-saving options were modelled for units due for replacement to estimate operating and capital cost changes as well as GHG emissions reductions over subsequent fiscal years (2020-2035) relative to baseline year 2019. The modelling was intended to demonstrate the potential impacts of implementation after the baseline year. For the purpose of data-modelling, the baseline fleet data provided by the City was for 2019. All scenarios were data-modelled from the 2019 baseline data to evaluate the potential impacts of each low-carbon solution relative to actual data from the in-scope Hamilton fleet at the time of analysis.

As a result of the processes we have employed in the preparation of Hamilton's Green Fleet Strategy and Report, the recommendations we provide herein are based on analysis of the fleet's historical data to forecast long-term impacts (the "past predicts the future"). Our strategies are pragmatic and fiscally-prudent, based on research, data-driven analysis, and sound economic principles and practices.

Preparing for an Electric Vehicle Future

Significant – and potentially contentious – among our recommendations in the following Green Fleet Strategy is a moratorium on replacing Hamilton's end-of-lifecycle internal combustion engine (ICE) vehicles with new ICE units. Vehicle investments are long-term; units purchased today will remain in service for a decade or longer. Globally, numerous jurisdictions have already legislated the end of the ICE – some as soon as 2030. Moreover, OEMs are quickly jumping on the bandwagon of battery-electric vehicle (BEV) production. On January 28, 2021, General Motors pledged to cease building gasoline and diesel cars, vans, and SUVs by 2035. ICE vehicles purchased today for a fleet with a current-day value in the millions of dollars may be nearly worthless when ICEs become obsolete.

ICE-powered vehicles will quickly become outdated as battery-electric vehicles (BEVs) rapidly take over. BEVs have a fraction of the moving parts of an ICE vehicle, cost far less to maintain, offer better performance, and can cost far less to operate. Concurrently, BEV prices are coming down; it is believed that BEVs may reach price-parity with ICEs as soon as 2025. For these reasons, if the condition of currently-owned Hamilton fleet ICE vehicles will allow it, we suggest prolonging their lifecycles until BEV replacements are available.

Today, only light-duty (cars, SUVs), transit buses and a handful of medium- and heavy-duty (MHD) truck BEV models are available. However, by 2022 the types of vehicles that comprise a major portion of the Hamilton fleet, including pickup trucks, will be available as BEVs. And by 2024, BEV MHD truck offerings will be more plentiful. The time is now to **begin preparing for the transition to BEVs** by investing in electric vehicle charging equipment while awaiting suitable BEVs to become readily available.

Summary of Key Results

RSI-FC data-modelled the fleet's 2019 baseline statistics and then assessed 35 low-carbon solutions (scenarios) categorized into three groups, in which we calculated the potential impacts of each relative to the 2019 baseline. These "what-if" scenarios assessed the potential outcomes if each of the low-carbon solutions being modelled were in place for the same types of vehicles, the same number of vehicles, travelling the same number of kilometres as in 2019.

In *Table 1* (below), the two Group One solutions displayed summarize the potential impacts of FAR data models #3 (lifecycle optimization) and #7 (best management practices).

Group One scenarios illustrate the projected capital (Capex) required and annual operating expenses (Opex) increases/decreases relative to the 2019 business-as-usual (BAU) baseline. These best practices are relatively low-cost, high-impact "house-in-order" solutions that we recommend as first steps in a carbon reduction strategy.

In Group Two, the estimated potential impacts over the 2019 baseline are displayed for implementation of each[5] fuel-switching solution data-modelled by our team. Results include, and build on, the benefits from Group One. We refer to this time period as the "messy middle" – the time period we are now in as we await more BEV models to become available – in which fleets must use multiple methods for reducing their environmental impacts.

In Group Three, the cumulative impacts of a multi-year (immediate to 2035) phase-in of battery-electric vehicles (BEVs) are shown. Like Group Two, the results include, and build on, the benefits from Group One.

Our approach and methodology is provided in *Section 3.0*, and details and results of each FAR scenario are provided in *Appendix D*. A summary of key recommendations is shown in *Table 2* (to follow in the Executive Summary). Details on fuel-reduction solutions can be found in *Appendix E*.

The actions and recommendations in this Green Fleet Strategy, if fully implemented, have the potential to reduce the City of Hamilton's fleet GHG emissions by **more than 90% by 2035**.

[5] Results for each Group Two solution include, and build on, the impacts of Group One (best practices). However, each fuel-switching solution is treated independently. That is, other than including Group One solutions as described, they are not cumulative.

Table 1: Key Results of FAR Scenario Analysis

GROUP ONE SOLUTIONS – BEST MANAGEMENT PRACTICES					
FAR Model No.	FAR Scenario	Timing	Vehicle Replacement Capex ($ mil)	Opex Impacts[6] Over 2019 Baseline ($ mil)	GHG Reduction Over 2019 Baseline (t)
3	Balanced Capex and optimized lifecycles	Immediate[7]	13.7	-2.82	-17
7	**Best Management Practices** (light-weighting, lower rolling resistance, driver eco-training, anti-idling policy & technologies, route planning and optimization, trip reduction)	Immediate[7]	13.7	-2.77	-2,928

[6] Opex includes the annual cost of capital for any investments in, and implementation of, fuel-reduction solutions.
[7] For data-modelling purposes, "immediate" means a one-year period immediately following the 2019 baseline for the same types of vehicles, the same number of vehicles, travelling the same number of kilometres as the baseline period.

GROUP TWO SOLUTIONS – FUEL-SWITCHING					
FAR Model No.	FAR Scenario[8]	Timing	Vehicle Replacement Capex ($ mil)	Opex Impacts Over 2019 Baseline ($ mil)	GHG Reduction Over 2019 Baseline (t)
8	**E85** (85% ethanol) fuel (passenger, pickups, vans)	Immediate[9]	0.099[10]	+0.3	-4,691
9	**B10** (10% avg. biodiesel - all diesel on-road units)	Immediate[9]	0.099[10]	-0.11	-3,110
11	**Compressed Natural Gas (CNG)** (LD pickups)	Immediate[9]	0.099[10]	+0.34[11]	-3,204
12	**CNG** (Classes 3-6)	Immediate[9]	0.099[10]	+0.3[11]	-3,266
13	**CNG** (Classes 2-8)	Immediate[9]	0.099[10]	-0.5[11]	-4,402
14	**Renewable Natural Gas (RNG)** (Classes 2-8)	Immediate[9]	0.099[10]	-0.5[11]	-8,177
15	**Liquified Propane Gas (LPG)** (LD units - passenger vehicles, pickups, vans)	Immediate[9]	0.099[10]	-0.072[11]	-3,100
16	**LPG** (LD and Truck Classes 2-8)	Immediate[9]	0.099[10]	-1.6[11]	-3,561

[8] Impacts from fuel-switching and BEV phase-in scenarios include, and build on, Group One scenarios (FAR #7).
[9] For data-modelling purposes, "immediate" is the one-year period immediately following the 2019 baseline if the same types of vehicles, the same number of vehicles, travelling the same number of kilometres as the baseline period, were switched to the low-carbon solution(s) being modelled.
[10] The Capex decrease shown is reflective of a recommended moratorium on purchasing new gas- and diesel-powered internal combustion engine (ICE) vehicles until battery-electric units become available (see report).
[11] For data-modelling purposes, the annual cost of capital for CNG or LPG new vehicle upgrades or conversions of existing vehicles were calculated and treated as annual vehicle operating costs (Opex), and then added to each unit's operating expenses. CNG/LPG fuelling infrastructure investment costs were apportioned and also treated as additional vehicle annual operating costs for all units modelled as CNG or LPG. The fast-fuelling system cost assumptions were $1.68M for CNG and $68k for LPG.

GROUP THREE – BATTERY-ELECTRIC VEHICLE PHASE-IN					
FAR Model No.	FAR Scenario[8]	Timing	Average Vehicle Replacement Capex[12, 13] ($ mil)	Average Opex Impact[12,13,14] Over 2019 Baseline ($ mil)	Total GHG Reduction[13] Over 2019 Baseline (t)
21-22	**BEV phase-in** (passenger vehicles only)	Immediate[9] - 2021	2.7	+.35	-2,943
21-24	**BEV phase-in** (passenger vehicles starting immediately-2022 and pickups in 2022)	Immediate[9] - 2022	5.7	+.47	-3,789
21-36	**BEV phase-in** (passenger vehicles starting immediately, pickups starting in 2022, and medium- and heavy-duty (MHD) trucks starting in 2024)	Immediate[9] - 2035	11.7	+1.2	-8,475

[12] For data modelling purposes, the increased cost of capital due to the higher purchase cost of BEVs was treated as an annual operating expense (Opex) increase for all BEV units modelled. The annual cost of capital for infrastructure investment in Level 2 charging (one Level 2 charger for every two BEVs) was apportioned and allocated to each BEV modelled, also as an increase in Opex.
[13] Capex and Opex impacts are averages for the implementation periods shown. GHG impacts are cumulative.
[14] Includes the impact of compounding inflation for each year of the 15-year period at current rate of inflation.

Summary of Key Recommendations

We summarize our main recommendations for Hamilton's Green Fleet Strategy in *Table 2*. Recommendations are a combination of: (1) potential opportunities for improvement of the City's fleet management practices, or "house-in-order" solutions; interim fuel-switching or "messy-middle" solutions; and (3) go-forward actions in preparation for the transition to battery-electric vehicles (BEVs).

Table 2: Summary of Key Recommendations for Hamilton's Green Fleet Strategy

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[15]/ Next Step
1	2	Asset Management	• Follow a historical data-driven lifecycle cost assessment, which is completed by modelling repair, maintenance, fuel, and cost of capital over the vehicle's entire lifecycle to determine the optimal replacement age of vehicles.	Immediate
2	2	Asset Management	• Consider implementing the green fleet asset management best practices recommended by RSI-FC as illustrated in the process flow chart (Page 25). With these processes the fleet will become green and right-sized.	Immediate
3	2	Vehicle Specifications	• Employ a total cost of ownership (TCO) approach to optimize the use of capital. • Consider TCO in competitive bidding proposal structures instead of the lowest compliant bid approach.	Immediate
4	2	Information Technology	• Create an education piece for idling reduction, operating efficiently, and reducing fuel consumption.	Immediate
5	2	Human Resources	• Add a driver eco-training module to existing Professional Driver Improvement Course (PDIC) safe driver training and consider eco-driver training for all drivers.	Immediate

[15] Immediate = 2021; short-term = 2022-2024; long-term = 2024-2035

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[15]/ Next Step
6	2	Fuel Management	• Measure and track fuel consumption and GHGs at the department and user-group levels to track progress and set tangible goals.	Immediate
7	2	Environment (LEED)	• Modernize and/or retrofit Fleet facilities to obtain LEED certification.	May need additional analysis (outside scope of this report)
8	2	Environment (BEVs)	• Invite frontline employees to take BEV test drives to build an affinity towards electric vehicles.	Immediate & short-term as additional BEV models become available
9	4	Deferred Spending (BEV Transition)	• If possible, avoid buying ICE replacement vehicles until suitable BEVs become available.	Immediate & short-term
10	4	15-Year LTCP Strategy	• Strictly through a lens of fiscal planning, prioritize replacement of units with BEVs *only if they would deliver return-on-investment (ROI)*.	Immediate, short-term & long-term
11	4	15-Year LTCP Strategy	• Allocate capital for charging infrastructure in the near-future to meet the demand in the mid- to long-term.	Immediate & short-term
12	4	Balanced Capex and Optimized Lifecycles	• Consider adopting the RSI-FC recommended lifecycle analysis (LCA) approach to extract maximum value from each vehicle.	Immediate
13	4	Balanced Capex and Optimized Lifecycles	• Consider balancing go-forward capital budgets as part of LTCP by deferring replacement of any units evaluated as being in above average, serviceable condition to later fiscal years.	Immediate
14	4	Balanced Capex and Optimized Lifecycles	• When the fleet's average age and uptime rates are determined to be at acceptable levels, consider re-investing in the fleet at the rate of depreciation.	Short-term

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[15]/ Next Step
15	4	Best Management Practices	• Consider job suitability of vehicles before proceeding with light-weighting enhancements.	Immediate
16	4	Best Management Practices	• In conjunction with driver training, consider route planning software, idling reduction initiatives and maintenance checks by integrating GPS tracking software to monitor driver activity and fuel consumption.	Immediate & short-term
17	4	Best Management Practices	• Consider a fuel-efficient driver incentive program in which drivers are incentivized to improve behaviours or reduce their travel.	Immediate
18	4	Fuel-Switching – Ethanol	• Consider the challenges associated with switching to E85, including supply, any additional infrastructure costs, and whether the potentially greater fuel cost is financially prudent. Should the City proceed with this solution, consider a pilot project with several units switched to E85 to determine the extent of the fuel-efficiency loss; if successful, consider a phased-in approach for other appropriate units.	Immediate & short-term
19	4	Fuel-Switching – Biodiesel	• Use a blend of 5% in winter and 20% in the summer and shoulder months. Consider a pilot project with several units switched to higher-blend biodiesel (B20), and if successful a phased-in approach for other appropriate units.	Immediate & short-term
20	4	Fuel-Switching – Natural Gas (including Renewable Natural Gas)	• If compressed natural gas (CNG) is of interest to the City as an interim solution until BEVs are available, investigate subsidies for CNG upgrades and a CNG vehicle fuelling station. Consider a small-scale pilot project with several high-mileage units switched to CNG, and if successful a phased-in approach for other appropriate units.	Immediate & short-term
21	4	Fuel-Switching – Liquified	• If LPG is of interest for high-mileage City units, as an interim solution until BEVs are available, consider a small-scale pilot	Immediate & short-term

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[15]/ Next Step
		Propane Gas (LPG)	project with several high-mileage units switched to LPG, and if successful a phased-in approach for other appropriate units.	
22	4	BEVs	• Consider a pilot project for several BEVs when they become available (e.g., pickups) to track range capabilities and cost savings and assess the units' performance for all seasons and varying weather conditions. Assuming the pilot project is successful, consider acquiring BEVs in bulk to replace units that would provide the greatest ROI.	Immediate & short-term
23	4	BEVs	• Continue to closely monitor the acquisition costs for BEVs and re-evaluate the business case (cost-benefit) for individual units as prices come down. Also continue to monitor the future availability of electric work/cargo vans, which are currently anticipated to be offered in battery-electric versions in the near future.	Immediate, short-term & long-term
24	4	BEVs (Charging Infrastructure)	• If relying on overnight charging infrastructure, consider supplying power to the charging equipment on two separate feeds from the grid to reduce the risk of local failure taking power away from the whole site.	Immediate, short-term & long-term
25	4	BEVs (Charging Infrastructure)	• Consider high-voltage training for technicians and closely monitor the launch of new BEV training programs.	Immediate, short-term & long-term

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Section 1.0: Introduction and Background

Climate change is an important global issue. The United Nations defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods[16]." The term includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer[17].

Greenhouse gases (GHGs) are gaseous compounds (such as carbon dioxide) that absorb infrared radiation, trap heat in the atmosphere, increasing global temperature and thus contributing to the greenhouse effect[18]. While there are several GHGs[19] to consider, when calculating emissions the most commonly used measure is carbon dioxide equivalent (CO_2e)[20]. This combines the effects of all the major GHGs into a single, comparable measure.

Over the past several decades, scientific evidence of climate change, also referred to as global warming due to the increasing temperatures of the global climate system, has been vast and unequivocal. Thus, the Paris Agreement (the Agreement, the Accord) was established with a goal of keeping global warming below two (2) degrees Celsius compared with preindustrial times. The Agreement entered into force on November 4th 2016. Canada is a signatory and as so has established aggressive carbon-reduction targets and plans.

In addition to climate change, emissions from engine exhausts also contribute to ground-level air pollution and human health risk. Criteria air contaminants (CACs) contribute to smog, poor air quality, and acidic rain. CACs include several gases, particulate matters and volatile organic compounds[21]. In scientific studies, CACs have been linked to increased risks of respiratory and cardiovascular diseases as well as certain cancers. The World Health Organization reports that in 2012 around seven million people died as a result of air pollution exposure; one in eight of total global deaths were linked to air pollution[22]. According to the American Medical Association, globally, an estimated 3.3

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[16] Source: United Nations Framework Convention on Climate Change 1992: https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf
[17] Source: EPA. https://www3.epa.gov/climatechange/glossary.html
[18] Source: https://www.merriam-webster.com/dictionary/greenhouse%20gas
[19] GHGs include, but are not limited to carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), nitrogen triflouride (NF_3), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs).
[20] "Carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential. For example, the global warming potential for methane over 100 years is 21. This means that emissions of one million metric tonnes of methane is equivalent to emissions of 21 million metric tonnes of carbon dioxide." Source: https://stats.oecd.org/glossary/detail.asp?ID=285
[21] CACs include Total Particulate Matter (TPM), Particulate Matter with a diameter less than 10 microns (PM10), Particulate Matter with a diameter less than 2.5 microns (PM2.5), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Sulphur Oxides (SOx), Volatile Organic Compounds (VOC), and Ammonia (NH3).
[22] Source: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

million annual premature deaths (5.86% of global mortality) are attributable to outdoor air pollution[23], although ambient air pollution has been regulated under national laws in many countries.

With this said, socially responsible commercial and municipal fleets can play an important role in reducing GHG emissions and air pollution.

Fleet Sector Impact

Low-carbon transportation is essential to both short-term GHG and fuel-use reduction and long-term decarbonization of the economy. In 2018, the transportation sector accounted for about 25% of greenhouse gas (GHG) emissions in Canada, second only to the oil and gas sector[24]. Municipalities can play a key role in cutting emissions by transitioning their fleets to low-carbon and/or electric vehicles, while saving fuel and maintenance costs.

The transition to battery-electric vehicles (BEVs) of all classes will be a game-changer when these vehicles come to market in the next several years, both in terms of operational cost savings and the deep GHG emission reductions required to curb the most severe impacts of climate change. With significant and growing commitments to integrating BEVs into fleet operations this effect will continue to be a driving force in the transition to BEVs[25]. With continued improvements in range capability and charging infrastructure as the BEV market expands, the electrification of fleets will accelerate.

About Richmond Sustainability Initiatives

Since 2005, Richmond Sustainability Initiatives – Fleet Challenge (RSI-FC) has collaborated with fleet managers, technology providers, subject matter experts, and auto manufacturers to find viable solutions, technologies, and best management practices for reducing operating costs and vehicle emissions. From the beginning, we have remained a self-supporting and independently funded program without commercial biases or influences, providing fleet review, strategies and management consulting services to dozens of leading private and public sector fleets in Canada and the United States.

RSI-FC has employed our innovative, leading-edge data modelling techniques and our proprietary software for the development of this Green Fleet Strategy Report. Fleet Analytics Review™ (FAR) is a software tool designed and developed by our company specifically for complex green fleet planning. It enables our team to develop short- to long-term green fleet plans and strategies by calculating GHG emissions reductions and return-on-investment (ROI) for various best practices and technologies – all driven by actual historical data. In turn, this allows us to evaluate the business case of each solution and provide meaningful recommendations for long-term capital planning (LTCP).

[23] Source: https://jamanetwork.com/journals/jama/article-abstract/2667043
[24] Source: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html
[25] Source: ChargePoint. Trends & Prediction in Fleet Electrification [pdf]. June 2020.

Through the combination of our experience and the use of our FAR software tool, we are delivering an advanced Green Fleet Strategy and Report for the City of Hamilton that is realistic and achievable.

Background

RSI-FC and the City of Hamilton's partnership dates back to 2005. In 2007, the City of Hamilton was publicly recognized by RSI's E3 Fleet Rating program and was officially recognized as Canada's first E3 Green Rated Fleet. Hamilton achieved significant reductions in fuel consumption and GHG emissions and, in doing so, earned a Silver Level E3 Fleet Rating. Since 2007, 14 more Canadian municipal fleets have followed the City of Hamilton's leadership example to become E3 Green Rated Fleets. Municipal fleets, including Hamilton, that have become E3 Green Fleet Rated set a high standard for others, and are a fine example of green fleet leadership.

During the years 2006 through to 2013, the Cities of Hamilton and Toronto partnered with Fleet Challenge (FC) to deliver the annual Green Fleet Expo (GFX). The GFX was a prime leadership opportunity for the City of Hamilton, which influenced hundreds of other municipalities and private sector companies to reducing their fuel consumption. The GFX was conceived, planned, and delivered by fleet management personnel from the Cities of Hamilton and Toronto in a three-way equal partnership with FC. In each of eight consecutive years, GFX attracted as many as 400 fleet managers from across Ontario and beyond to see and test-drive green, fuel-efficient vehicles, learn about advanced fuel-saving technologies, and hear presentations from recognized subject matter experts.

With a history of green fleet leadership and by engaging our team to develop its new Green Fleet Strategy Report, the City will continue to build its profile as a municipal leader in green fleet development and implementation practices.

As a proactive response to the City's climate change emergency declaration in 2019, a multi-departmental Corporate Climate Change Task Force comprised of City Staff was created. According to the City of Hamilton's Corporate Energy Policy, fleet and transit fuel consumption account for $16 million in operating expenses and 40% of corporate greenhouse gases, highlighting the benefit of implementing green fleet strategies to reduce both fuel-use and GHG emissions. One of the action items for the Task Force is to investigate and identify a plan for all diesel vehicles to be decommissioned by 2030 and all vehicles to be electrified by 2050. This Green Fleet Strategy and Report can play a role in providing viable recommendations and pathways for achieving these goals.

Green Fleet Strategy and Report – Objective

The primary objective of this Green Fleet Strategy and Report was to analyze the City of Hamilton's in-scope[26] fleet operations data and identify and assess operational improvements and new technologies to reduce GHG emissions from Fleet Services vehicles and equipment. The results presented herein are intended to provide an ambitious roadmap to the City of Hamilton in its quest for go-forward fuel-reduction solutions to achieve the goals of the Corporate Climate Change Task Force.

[26] This Green Fleet Strategy and Report does not include EMS, Fire, Transit, or Police fleets.

Section 2.0: Current Practices, Survey Results, and Baseline

In this section, we lay the groundwork for the Green Fleet Strategy and Report by providing a snapshot of the current state of Hamilton's in-scope fleet and fleet management practices. We present the results of our signature Best Management Practices Review™ (BMPR), the results of employee participant surveys, and compare Hamilton's baseline fleet data with urban peers from our proprietary municipal fleet database.

Best Management Practices Review

Over the past 15 years, RSI-FC has completed dozens of fleet reviews for Canadian and U.S. corporate and government entities. In doing so, we repeatedly observed many successful and effective Best Management Practices (BMPs) and Standard Operating Practices (SOPs) that are applicable and potentially beneficial to fleets in all business sectors. These practices range from business structure, human resources, safety, and maintenance practices through to operational policies. Our team concluded that proactive fleet managers would value an impartial, third-party, ground-up, and holistic review of their operations to identify gaps and opportunities for improvement. In response to this defined need, that is how BMPR™ (pronounced: bump·er [ˈbəmpər]) evolved. Beginning in 2014, and since that time, numerous fleets have participated in, and benefitted from, the BMPR program.

The in-scope fleets for Hamilton's Green Fleet Strategy and Report include Environmental Services (Forestry, Parks, Cemeteries, Horticulture, Refuse and Recycling), Traffic and Maintenance (including Roads), Water and Wastewater, Enforcement, and Planning and Economic development (By-Law, Building and Licensing). The fleets which are *not* included in this report are EMS, Fire, Transit, and Police.

The comprehensive BMPR process is comprised of the following specific areas of interest, each with its own set of focal points/topics:

1. Asset Management
2. Vehicle Specifications
3. Finance
4. Information Technology
5. Human Resources
6. Preventative Maintenance
7. Fuel Management
8. Environment
9. Communications

Section 2.0 (BMPR) is based on our dialogue with, and exchange of operational information with Hamilton's fleet management staff during in-depth BMPR discussions. In each of the nine sections of Section 2.0, we provide Hamilton fleet staff comments (please see headings shown in green font) from our BMPR discussions. Our team's observations and perspectives (please see headings shown in blue font), in which we identify potential gaps and opportunities for improvement for management's consideration.

1. Asset Management

Asset management has been described as "a systematic process of deploying, operating, maintaining, upgrading, and disposing of assets cost-effectively." Doing so effectively depends on having ready access to operating data, then making wise asset-management decisions based on, and informed by that data. In this area of the BMPR, we reviewed Hamilton's cradle-to-grave handling of its in-scope fleet assets.

Determining Lifecycles, the Decision Process for Vehicle Replacement

- For the Hamilton Fleet, the process starts with the fleet planning group – four subsections - planning, maintenance, parts, and materials and fuel, which occurs annually and involves a review of the reserve fund size and annual capital budget, as well as fleet complement analysis.

- Fleet analysis serves as a "first pass" based on a financing model. It is a review of critical factors including: maintenance cost, fuel consumption, mileage, and other factors to determine which vehicles to replace. The biggest trigger for replacement is maintenance cost; it is considered more important than age of vehicle. For example, for an 8-year lifecycle for an SUV, the first trigger is highest repair costs (excludes PM costs as they are fixed).

- Vehicle replacement decisions are based mostly on annual maintenance dollars by classification of vehicles. For example, the current system would favour replacement of a garbage truck vs 10 SUVs in a particular year.

- Every year, after determining vehicle replacement needs, a meeting takes place with fleet user-group representatives to hear their needs and feedback.

- Vehicle replacement is based on condition-based assessment; there is not a rating scale and assessment. Priorities are based on knowledge of the vehicle condition as opposed to fixed timelines.

- The capital budget is currently around $10 M/year.

Gaps and Opportunities for Improvement

- Green fleet asset management best practices recommended by RSI-FC are illustrated in a process flow chart (*Figure 1*, overleaf); with these processes a fleet will become green and right-sized.

- The issue with monitoring (maintenance) cost spikes of a vehicle as it ages is that when a vehicle that is not fully in use is shown as costing less, in reality it can be a stranded asset if it remains under-utilized until retirement/replacement.

- By following a historical data-driven lifecycle cost assessment, which is completed by modelling repair, maintenance, fuel, and cost of capital over the vehicle's entire lifecycle, the optimal replacement age of vehicles can be determined (such as by using RSI-FC's Lifecycle Analysis (LCA) software).

Reserve Fund Sustainability and Auction Proceeds

- For a number of years, contributions to the reserve fund were 54%, which was not sustainable. In the last seven years, it has gone up to 70% to 100%, and now the fund is able to meet the needs of the department.

- Auction funds from end-of-life vehicles go back into reserve funds, eventually being spent on fleet replacements; however, they do not necessarily go into the capital budget for that year.

Process for User Department Adding a Vehicle to Its Fleet

- Approval by council is required. The user department addresses this with Council through the capital budget process or during the year to prove the need is real, user-groups may be asked to provide data to make their business cases.

Real-Time Tracking of Current Book Values of Vehicle Assets

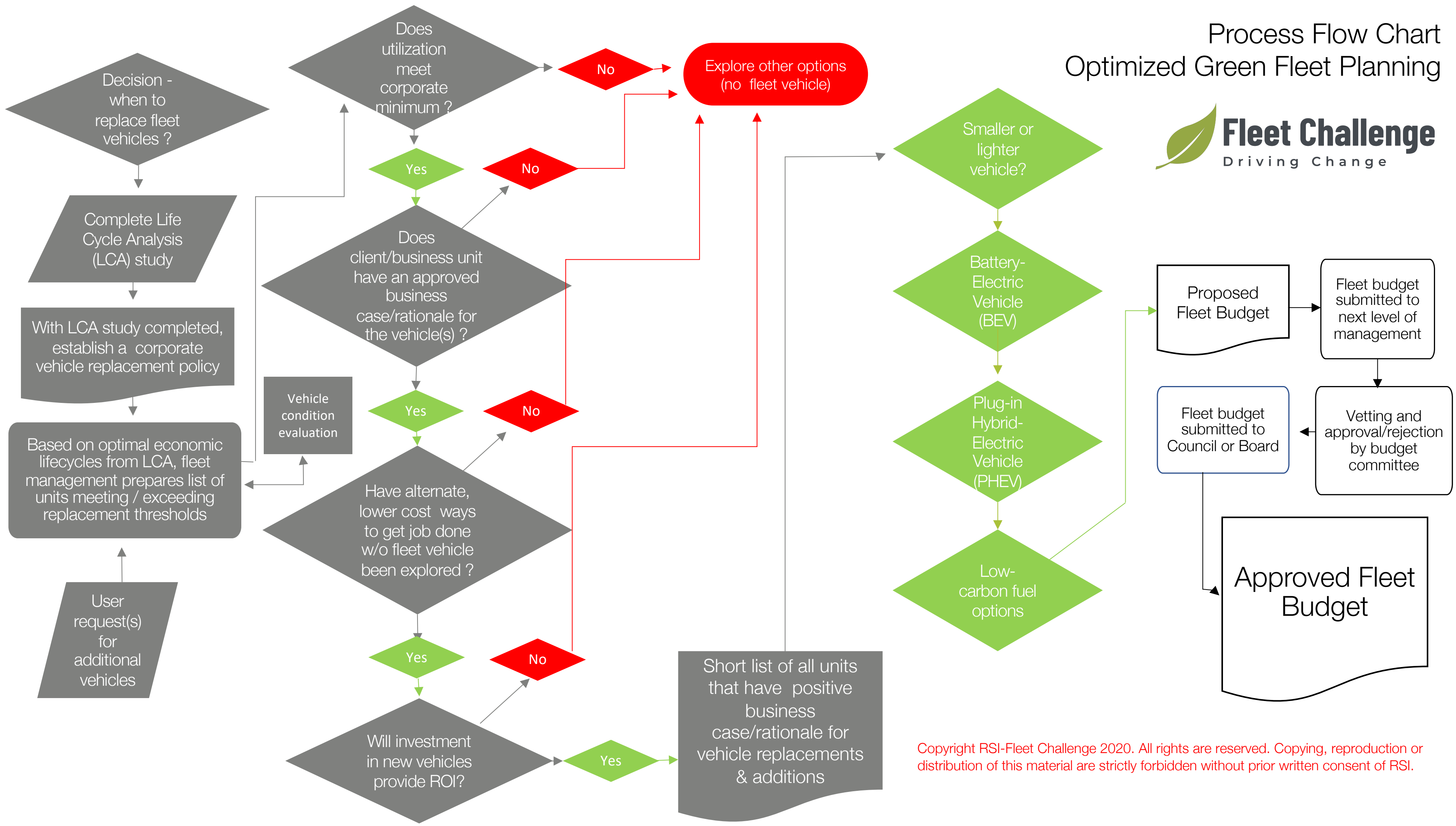
- Hamilton's Finance Department does not keep track of book value of vehicle assets. However, Public Works does have information on the original purchase price and replacement cost of vehicles.

- The Hansen software program that is employed by Hamilton Fleet tracks the original purchase price and the budget replacement cost but not depreciation.

Gaps and Opportunities for Improvement

- Having access to the current book-value of assets would help in determining optimal replacement cycles for different vehicle classes.

Figure 1: Process Flow Chart for Optimized Green Fleet Planning



Vehicle Categorization Protocol

- In Hansen, there are upwards of 500 vehicle classifications to choose from, which have been narrowed down to 200 choices (still a very high number).

Gaps and Opportunities for Improvement

- Implementing a simpler categorization system, such as a high-level application of the Vehicle and Maintenance Repair Standards (VMRS) system developed by the American Trucking Associations (ATA), would make it far easier for narrowing down vehicle replacement options and making cost-comparisons. The VMRS system is an industry-standard benchmarking method employed by thousands of leading North American fleets.

2. Vehicle Specifications

Fleet managers should always prepare detailed specifications for new vehicles with consideration for past performance of similar vehicles (i.e., the past predicts the future). When planning the go-forward procurement of vehicles and vehicle components (such as engines and drivetrains), fleet managers should give preference to units that have demonstrated the lowest historical total cost of ownership (TCO) and highest reliability.

Management should avoid the pitfall of buying vehicles that simply cost the least to acquire and meet only basic requirements. Historical cost information about makes, models, and components should be frequently reviewed. This step enables informed procurement decisions based on TCO concepts, instead of purchasing vehicles based on lowest price.

Specifications for Tenders or RFQ for New Units

- Typically, once the capital budget is approved, Hamilton's Fleet analysts reach out to user groups to undergo needs-based analysis and discuss the viability of down-sizing when appropriate. For example, a one-ton van is replaced with a ½-ton van that meets operation needs.

- Vehicle demonstrations are scheduled for Hamilton's fleet and it's user-groups, vendors are vetted, tenders are issued, and the contract is awarded to the lowest compliant bidder. The tender is publicly issued for one month. The procurement process from start to finish is approximately three to six months depending on complexity.

- Once the contract is awarded, there are: (1) a pre-building meeting (for anything more complex like a sander or garbage truck), (2) pre-delivery inspections, and (3) final compliance inspections.

- The fleet planning group deems whether the unit is compliant and, if yes, hands it off to the user group. There is a 5-10% contingency line for the builder primarily for custom build projects.
- Multi-year contracts are currently in place.

Gaps and Opportunities for Improvement

- A greater level of knowledge transfer between user groups and procurement (e.g., regarding vehicle manufacturers pricing models and model revisions) may make a more seamless procurement process.
- Employing a total cost of ownership (TCO) approach would likely demonstrate where Fleet Services can optimize the use of its capital.
- Procurement should consider TCO in its competitive bidding proposal structures instead of the lowest compliant bid approach.

Practices Around Vehicle Right-Sizing

- Right-sizing is discussed with user groups and is not formal policy. For example, groups were moved from SUVs to EcoSports. The goal is to achieve the best fuel economy and motivate staff to choose the right size.
- User groups currently have the last right (no policy) because the user group is paying for the unit(s) (users can veto Fleet's recommendations). Fleet Services is trying to inform users that it is not about downsizing but more about right-sizing.

Standardization Regarding Vehicle Specs

- Standardization is a goal with benefits on both the procurement side and the user side from an operational and maintenance viewpoint. Fleet Services is moving in a positive way toward standardization. There is currently a five-year snow plow contract with two different styles of plows, but not multiple designs.

Gaps and Opportunities for Improvement

- Standardization, by limiting the number of brands, as in the example of the snow plows, is known to reduce costs and challenges relating to preventive maintenance (PM) and repairs.

3. Finance

A significant concern for fleet managers is fiscal sustainability – ensuring that the fleet operating budget is sufficient to cover annual operational expenses (Opex), and the annual capital (Capex) budget is adequate for actual vehicle replacement costs. A primary goal for a fleet manager is reducing vehicle capital and operating expenses without negatively affecting service levels (uptime). In this section aim to learn about the vehicle Opex and Capex as well as how vehicle costs are recovered.

Vehicle Ownership

- All fleet vehicles are owned (as opposed to being leased). User groups can rent vehicles through rental contract (local supplier); the only cost for these vehicles is fuel. There are options to use extended services instead of renting if vehicles are in good condition.

Vehicle/Equipment Chargeback System

- Users pay a contribution to the reserve fund for vehicle replacement and pay for PM, demand maintenance, and fuel. There is no extended-service vehicle reserve fund (admin. fee only).
- At the start of 2020, the hourly door rate increased to $116.

Gaps and Opportunities for Improvement

- MBN Canada, which keeps statistics for municipalities, can be used as a reference regarding door rates.

At-Fault Accidents/Negligent Damages

- These claims are dealt with by the risk group. The repair cost are paid by risk group – self-insured up to $50k. There is a small degree of impact on user groups; an annual review of department claims results in fees adjusted accordingly.
- In-house compliance officers are responsible for Professional Driver Improvement Course (PDIC) training.

Gaps and Opportunities for Improvement

- An independent safety review consultant contacted by RSI in 2020 recommends driver training sessions should take place regularly, suggesting intervals of three years.

Equipment Training

- User groups provide equipment-specific training (e.g., operating snow plows, lawn equipment, etc.) in a variety of ways using both internal and external training courses.

4. Information Technology

Fleet asset-management decision-making and analysis are best achieved by using dedicated and purpose-designed “best-of-breed” fleet management information systems (FMIS). For maximum management effectiveness and control, accurate and reliable fleet data is essential for managers to make well-informed, data-driven decisions for their fleet asset base. Hamilton Fleet uses the Hansen system at this time.

Regardless of the system used, an FMIS must list and track all vehicles, department/divisional assignments, cost and maintenance histories, manage fuel usage and reconciliation, schedule preventive maintenance events, track spare parts inventories, ensure audit-readiness, produce management and exception reports, prepare cost analyses, evaluate vehicle performance, provide document trail, and much more.

Route Planning

- Skyhawk GPS systems have been integrated into Hamilton Fleet Services for seven years, but the degree to which they are used is up to user groups. Overall, user groups are receptive to Skyhawk.

Corporate Idling Policy

- There is a corporate idling policy, but user groups set their own parameters and adherence. Driver idling is not looked at by Fleet Services, but there have been idling reduction discussions at the corporate level and Fleet, having driver trainers, is positioned well to being the champion.

Gaps and Opportunities for Improvement

- The creation of an education piece for idling reduction, operating efficiently, and reducing fuel consumption would be a welcome addition.

- Fleet Services can champion idling and GHG reduction initiatives with corporate oversight. Fleet can provide the tools, training, and advice but should not be expected to act as the “police” department; this should be dealt with at the corporate level.

5. Human Resources

Human resources pertains not only to Fleet Services personnel but also to the drivers of the fleet's vehicles, as indicated by the following focal points:

Driver Eco-Training

- Currently driver eco-training is not provided by Fleet Services.

Gaps and Opportunities for Improvement

- A driver eco-training module should be added to existing Professional Driver Improvement Course (PDIC) safe driver training.
- Eco-driver training is recommended for all drivers. Natural Resources Canada (NRCan) Smart Driver program is highly recommended by RSI-FC. See: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/greening-freight-programs/smartdriver-training-series/21048#city

Procedures/Components of the Driver Management Program

- Fleet Services has developed procedures for vehicle cleaning; there is a thorough city-wide Level 1 vehicle cleaning process which applies to operators, cab cleaners, and outside contractors.
- Covid-19 presents additional challenges for in-cab driver training. Operators are required to wear a mask and open a window.
- An additional consideration is changing cabin filters for better air quality (reduced exposure to potential infection).
- Fleet Services is considering in-cab cameras (outward facing towards road, inward facing towards driver).
- Driver training is triggered for certain reasons (e.g., a collision, recruitment) but not scheduled at a certain time interval. Professional Driver Improvement Course (PDIC) training is required for all new CVOR operators as part of their onboarding, for any drivers that have been involved in a preventable collision/incident, and as requested by User Groups.
- Safety and compliance driver manuals and procedures do exist; however, it is in the form of a full book (electronic version) as opposed to specific manuals for each vehicle type.

- Currently, driver's pre-trip inspections are on paper – user groups are asked to keep records and defects should be sent to Fleet Services as a work order.

Gaps and Opportunities for Improvement

- Scheduling professional driver improvement course (PDIC) driver refresher training at regular intervals may be a more risk-averse approach to driver management than having remedial training only.

- Creating individual driver manuals for each vehicle type may increase receptiveness of operators through more concise, targeted procedures which are less time-consuming to read through.

- Transitions to electronic logging devices (ELDs) may increase the efficiency of record-keeping on vehicle history.

- Canadian fleets must start transitioning to electronic logging devices (ELDs). The Transport Canada ELD mandate for commercial drivers is aimed at improving road safety and comes into effect in June 2021.

  Under the Ontario regulation[27], a driver is not required to keep a daily log for the day if:

  - On the operator's instructions, a commercial motor vehicle is driven solely within a radius of 160 kilometres of the driver's starting location.
  - The driver returns at the end of the day to the location from which he or she started.

  Log book exemption can create confusion when dealing with municipalities within 160 kilometres of the drivers starting location. Many believe this exempts municipalities from tracking hours of service. However, if a driver is not required to keep a daily log, RSI-FC believes the operator (the City of Hamilton) may be obligated to maintain records for the day.

- RSI-FC recommends expert legal review of the ELD matter prior to the June 2021 deadline.

6. Preventative Maintenance

A prime indicator of fleet management success is a high level of vehicle uptime. There are only two ways fleet managers can achieve increased uptime: (1) acquire newer, younger vehicles; or (2) ensure a highly effective preventive maintenance (PM) program is in place. If sufficient funds are not available

[27] Source: http://www.mto.gov.on.ca/english/trucks/commercial-vehicle-operators-registration.shtml

for purchasing newer vehicles, then fleet management must ramp up PM activities; otherwise, availability and reliability will suffer while operating costs increase. Safety may also be negatively affected as the fleet's vehicles continue to age.

PM Inspections

- For Hamilton, there are three PM levels:
  - PM C – PMCVI, LOF + inspection
  - PM B – LOF + minor PM
  - PM A – inspection only
- The frequency of inspections is based on a time-based system using the Hansen system, which is set up for three times per year for light- and heavy-duty vehicles.
- High-mileage units are identified by the Service Department and more frequent inspections are set up in Hansen.
- Off-road vehicle inspections are tailored more towards manufacturing specs.
- Regular oil is used. Synthetic oil is used only when required as per OEM standards.
- Waste oil is picked up by a vendor and re-sold/recycled.
- Oil filters are collected for recycling along with waste oil.

7. Fuel Management

The cost of fuel is usually one of the largest controllable costs for most fleets. Proactive fleet managers will make it one of their top priorities to ensure their fleet is as fuel-efficient as possible. Reducing fuel use is critical, both fiscally and environmentally.

A best management practice aimed at reducing fuel usage is to monitor the fleet's corporate average fuel efficiency (CAFE). We feel that CAFE is one of the most important key performance indicators (KPIs) for cost-conscious fleet managers to monitor and take actions for improvement.

CAFE is directly reflective of a fleet's footprint. In essence, CAFE is a measure that encompasses many facets of fleet operations ranging from driver behaviours (such as unnecessary idling, harsh driving, unnecessary trips) to right-sizing of vehicles for their assigned tasks (getting the job done with more fuel-efficient vehicles) to the use of alternate and renewable low-carbon fuels. CAFE is also impacted by the fleet's average age since older vehicles are less fuel-efficient than modern units, they burn more fuel and, consequently, cost more to operate and produce more emissions.

Current Alternate/Renewable Fuels Used in Fleet Services

- Zambonis are run by propane and CNG.
- There is no use of B10 or B20 biodiesel in Fleet Services.
- All packers are currently diesel and some are due for replacement. There is a push to replace them with CNG units but this requires large infrastructure costs.

CNG Infrastructure

- There is a natural gas station at Wentworth Street but it is likely to be decommissioned. Another natural gas station is at HSR (city bus facility) and there is discussion of a new bus facility that will have a fuelling station on site for Transit; this will depend on the level of funding. More than half the Transit Fleet is CNG and there are plans of increased commitment to CNG.
- There is discussion of partnering with a private contractor with a natural gas fuelling site and purchasing fuel. Purchasing retail fuel is not a normal practice; all City vehicles typically use City fuelling sites.

Key Performance Indicators

- Fleet Services currently does not have Key Performance Indicators (KPIs) for PM or GHGs, but there is a KPI for corporate average fuel economy (CAFE).

Gaps and Opportunities for Improvement

- A means of measuring and tracking fuel consumption and GHGs at the department and user-group levels may be beneficial for setting goals and making progress.

8. Environment

In Canada and around the world, leading companies and all levels of government have developed Green Fleet Plans to set out their short- and long-term carbon reduction targets; some may also include strategies for air/land/water pollution reduction.

A Green Fleet Plan may also include the fleet's green initiatives for its maintenance or parking garages. For fleets that outsource maintenance, plans may also define eco-standards for contractors, such as third-party suppliers.

Former Green Fleet Plan

- The former Hamilton Green Fleet Plan is from 2009. It has not been revised or reviewed; however, some deliverables and processes are still valid and in place.

Corporate Carbon Reduction Targets for Fleet Services

- Decommission all diesel vehicles by 2030
- Achieve net-zero carbon emissions before 2050
- Achieve 100% electrification for vehicles by 2050

ISO 14001 Standards

- The environmental management system was up to ISO 14001 standards but has not been refreshed.

Gaps and Opportunities for Improvement

- Consider reviewing the environmental management system with regard to current ISO 14001 standards.

LEED Certification of Fleet Facilities

- Fleet facilities are not LEED certified, but there has been progress in other City buildings.

Gaps and Opportunities for Improvement

- Consider modernizing and/or retrofitting Fleet facilities to obtain LEED certification.

Waste Management

- Initiatives were started years ago to reduce waste and separate garbage and recyclables.
- Filter and oil recycling are in place.
- There is proper storage and disposal of chemical cleaners at wash facilities. All wash pads have interceptors.

Gaps and Opportunities for Improvement

- Improvements can be made for recycling paper and cardboard, as well as for managing toxic waste.

Tire Recapping

- Truck tires are recapped for dump trucks, snow plows, and garbage packers.

Hybrid Vehicles

- There are many hybrid Ford Escapes in Fleet Services. The initiative has had tremendous success – some hybrids are 10+ years old and still performing well.

Battery-Electric Vehicles (BEVs)

- Currently, some reluctancy towards BEVs has been encountered. Fleet Services wants to have a comprehensive strategy and standardization to leverage local support and maintenance by buying in volume.
- There are two Kia Soul BEVs currently in service. As mentioned by Fleet staff, there needs to be a strategy before committing fully (to BEVs). Procurement requires three bids, and Kia was able to meet the City's timelines. Policy allows for circumvention of procurement policy, allowing for single bid.
- Two electric Olympia ice resurfacers are on order, as well as electric shop scrubbers/ sweepers.

Gaps and Opportunities for Improvement

- Operator feedback and employee engagement is important. Consider inviting frontline employees to take BEV test drives to build an affinity towards electric vehicles.

BEV Charging Stations

- There have been discussions of installing municipal charging stations in yards as there is insufficient public charging stations for use by municipal vehicles.

Gaps and Opportunities for Improvement

- With BEV options increasing and light-duty trucks (pickups) expected to be on the horizon within two years, as well as medium- and heavy-duty trucks in several years, it is important that the City allocate capital for charging infrastructure in the near-future to meet the demand in the mid- to long-term.

- A charging infrastructure Incentive program was offered by NRCan at the time of this writing but has since lapsed. See: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/zero-emission-vehicle-infrastructure-program/21876. The Government of Canada announced, through Budget 2019, $130 million over five years (2019-2024) to deploy a network of zero-emission vehicle charging (level 2 and higher) and refuelling stations in more localized areas where Canadians live, work, and play. Support is also available for strategic projects for electric vehicle and/or hydrogen infrastructure for corporate fleets, last-mile delivery fleets, and mass transit. This funding will be delivered through cost-sharing contribution agreements for eligible projects that will help meet the growing charging and refuelling demand.

9. Communications

Open communications and interaction are critical in every organization. Most employees like to feel engaged, empowered, and of value to their organization. Moreover, residents of municipalities appreciate hearing success stories. Good news stories about a fleet, whether regarding new cost-saving measures, safety, good deeds by its drivers, or eco-successes, are welcomed by most people. We believe that the Hamilton Fleet Services should, and can easily be a source of pride for the City, its employees, and its residents.

Media Releases Re: Greening Activities

- Currently, there is not a dedicated communications representative for Fleet Services, but there have been existing staff at the corporate level who have taken on additional responsibilities dedicated to climate change. There is interest from the climate change group to start a dialogue with Fleet Services. Fleet Services believes developing a comprehensive strategy for BEVs is part of the equation, which includes driver engagement and feedback.

Green Fleet Survey Results

Our organization recognizes the value of stakeholder engagement and user group participation in any go-forward plans under consideration for our fleet clients. With that focus in mind, RSI-FC set out to gain staff perspectives from the City of Hamilton's Fleet user groups around their currently assigned vehicle types and opinions/views on environmental issues and green fleet initiatives.

In person, face-to-face discussions are, by far, our teams first choice of available options for gathering information, hearing stakeholder feedback and obtaining buy-in. Unfortunately, due to the coronavirus pandemic, in-person meetings were not possible. Knowing that feedback from stakeholders is critical to go-forward planning, as a workaround we opted to instead conduct web-based online surveys of fleet user groups.

RSI-FC understands the importance of hearing the opinions of *all* stakeholders including both management and unionized staff. It was clearly communicated to all survey recipients that their responses were confidential and anonymous; as so, they were encouraged to express their opinions freely.

From experience RSI-FC knows that online surveys are not the ideal method for collecting opinions and gathering information. It is known in the industry that people are often reluctant to provide their personal opinions in this manner; typically, survey response rates are known to only be in the 10 to 15% range. However, in the absence of a better solution, such as face-to-face discussions, there were no other viable options.

The survey was sent to 343 individuals and we received a total of 32 responses, which translates to a response rate of just over 9%, in and around the range of the industry average. We were pleased that the responses we received were high-quality, rich in content, providing us with valuable feedback which we will discuss in this section. We provide a summary of the results below; for complete results with figures, please see *Appendix A*.

Breakdown of Survey Participants

There was a mix of unionized and management employees who participated in the survey (majority from management), and the majority of participants have worked at the City for 10 years or longer.

Most of the survey participants are middle-aged, and generally the male/female ratio of participants is close.

In terms of vehicle type driven, nearly all the survey participants drive light- to medium-duty passenger vehicles (cars, pickups, and SUVs).

Awareness of Environmental Issues

The overwhelming majority of survey participants agree with and/or support Hamilton's climate change emergency declaration, and there is very strong agreement that taking care of our environment should be a top priority. Global warming is ranked at the number one environmental problem by participants, but air and water pollution are a tied as a close second.

In addition to questions on ranking and level of agreement pertaining to environmental issues, survey respondents were given the chance to provide their own comments on the environment and Hamilton's climate change emergency declaration. One comment in particular, shared below, was eloquently written and was, overall, representative of participants' view on the matters:

"I agree that as a leader in our municipality the city needs to walk to talk. Although there are many pillars to climate change and the climate emergency, I agree that we need to look at our fleet and operating equipment to support the direction."

Another response seemed to be reflective of the individuals thoughts on the matter:

"I think climate change has been occurring for a long time - It's not something new and something should have been done about this long time ago"

Views on Pollution Factors and Fuel-Reduction Solutions

We asked participants about their opinions on various pollution factors, fuel-switching options (i.e., alternate/renewable fuel), and battery-electric vehicles (BEVs), to gain a perspective of views and predominant concerns to address in our go-forward Green Fleet Strategy.

Survey participants agree, overall, that all the pollution factors listed (age, fuel type, maintenance, driving habits, right-sizing, and trip planning) have moderate to large impacts on fuel-efficiency and pollution from fleet vehicles. Fuel type is the leading factor among respondents.

In terms of driving habits and behaviours, survey participants generally agree that fuel-efficient, eco-driver training would help them operate Fleet vehicles, as well as personal vehicles, more efficiently.

Regarding natural gas and propane as fossil-fuel alternatives to gasoline and diesel, survey participants generally agree that both natural gas- and propane-powered vehicles are more economical to drive than their conventional fuel counterparts, are reliable, and are safe to drive.

Regarding biodiesel and ethanol as substitutes for standard diesel and gasoline, respectively, survey participants generally agree that biodiesel and ethanol are feasible and safe fossil fuel substitutes; however, there does appear to be a slight knowledge gap/ lack of certainty surrounding these fuels among respondents. Moreover, there appears to be some concern or opposition surrounding the production of plant-based fuels due to the use of food crops.

Overall, there is strong support for and understanding of zero-emissions BEVs from the survey participants, who are confident in their range capabilities, power, heating/cooling, operating cost savings, pollution prevention, and availability now and in the near future.

Survey participants are, overall, very receptive to the wide range of fuel-reduction solutions listed. The highest rating (4.5/5) is for reducing unnecessary engine idling, while the lowest, yet still favourable, ratings are for renewable fuels (biodiesel and ethanol) and alternate fuels (natural gas and propane), with scores of 3.8/5 and 3.9/5, respectively. The switch to battery-only EVs is highly favoured with a rating of 4.3/5.

Synopsis

Participants were given the opportunity to provide their own comments on the various fuel-reduction solutions as well as “freestyle” section that allowed for comments on greening of the City of Hamilton’s fleet at large. There were several common areas of interest and concern which we have outlined below:

- Modernizing fleet units is preferred to extending the use of older units because of lowered emissions and repair costs.
- There is some interest in using renewable natural gas (RNG) from the City’s green bin waste to fuel vehicles and later, when the majority of the fleet transitions to BEVs, to use RNG to heat buildings.
- Regarding BEVs, there were numerous concerns regarding the pollution caused by the production of batteries as well as their disposal and recycling.
- Regarding BEVs, there is some uncertainty pertaining to cost savings vs capital costs.
- Regarding BEVs, there is some concern regarding the non-renewable electricity sources to fuel BEVs and their associated GHG emissions.

Based on the results of this survey and participant comments, it is clear that Fleet's user-group stakeholders are supportive of green fleet initiatives and aware of their benefits, particularly driver training, idling reduction, modernizing the fleet, downsizing/right-sizing, alternate fuels (natural gas and propane), and BEVs. Importantly, there appears to be a high level of willingness to participate in the City of Hamilton's transition to low-carbon vehicles and BEVs.

Baseline KPIs and Peer Fleet Comparison

RSI-FC collected baseline data of Hamilton's in-scope fleet from Fleet staff. The dataset provided to our team included a list of units, makes/models/years, asset values and ages, descriptions, fuel type, fuel cost, repair costs, and maintenance costs for a one-year review period (2019). Downtime data was not available for Hamilton. As a workaround, RSI estimated downtime based on an algorithm that assumes a unit is out of service when being repaired and, thus, repair hours are commensurate with downtime. It should be noted that the 12 peer municipal fleets tally downtime using inconsistent methods; downtime data provided may therefore be unreliable and we have provided it for informational purposes only.

RSI loaded input data into our proprietary software, Fleet Analytics Review™ (FAR), and completed a baseline analysis. In *Tables 3* and *4*, we compare a number of key performance indicators (KPIs) with other urban municipalities from our proprietary municipal fleet database.

Table 3: KPIs for Hamilton's fleet and municipal fleet database

KPI	Metric	Hamilton Fleet Units Included	Hamilton	Benchmark Data – 12 Urban Municipal Fleets
Corporate Average Fuel Economy (CAFE)	L/100 km	Vehicles + equipment	36.1	31.4
Average Downtime	Days/unit	Vehicles + equipment	10.9	7.4
Average PM Cost	$/unit	Vehicles only	$1,085	$1,897
Average Repair Cost	$/unit	Vehicles only	$4,482	$4,513
Average Cost of Capital	$/unit	Vehicles only	$1,337	$1,477
Average Age	Years	Vehicles + equipment	7.5	5.6

KPI	Metric	Hamilton Fleet Units Included	Hamilton	Benchmark Data – 12 Urban Municipal Fleets
Average Vehicle Kilometres - Travelled (VKT)	Km/unit	Vehicles only	13,246	14,889
Cost per Km	$/km	Vehicles only	$1.80	$0.97

Table 4: KPIs for Hamilton's fleet and municipal fleet database, by vehicle category

KPI	Metric	Vehicle Categories	Hamilton	Benchmark Data – 12 Urban Municipal Fleets
Average Age	Years	LD (Class 1, 2)	7.0	4.6
		LD Trucks (Class 3)	7.3	6.6
		MD Trucks (Class 5)	8.8	4.8
		HD Trucks (Class 7, 8)	7.2	7.4
		Equipment	9.5	-
Average VKT	Km/unit	LD (Class 1, 2)	13,625	15,222
		LD Trucks (Class 3)	16,829	13,022
		MD Trucks (Class 5)	11,810	13,683
		HD Trucks (Class 7, 8)	10,665	10,799
		Equipment	-	-
Cost per Km	$/km	LD (Class 1, 2)	$0.34	$0.62
		LD Trucks (Class 3)	$0.81	$0.62
		MD Trucks (Class 5)	$1.12	$3.05
		HD Trucks (Class 7, 8)	$2.45	$3.41
		Equipment	-	-

From the baseline data presented in *Tables 3* and *4*, there are several key points that we would like to outline, including:

- Hamilton's corporate average fuel economy (CAFE) and downtime are both higher than urban peers, potentially because its fleet is older by about two years (older vehicles are less fuel-efficient and often less-reliable).
- The cost per km is likely skewed to the high end in comparison to peers due to the inclusion of equipment in our analysis.
- Light-duty (LD) passenger cars, pickups, vans, and SUVs (Class 1, 2) as well as medium-duty (MD) trucks (Class 5) are considerably older than these same categories in peer fleets; however, the higher age of vehicles does not appear to be reflected in the cost per km for these vehicle categories (significantly lower than peer fleets).
- In comparison to Hamilton's peers, light-duty trucks (Class 3) are slightly older, are driven substantially more, and cost more per km, highlighting a potential area of focus for the City and the opportunity for significant fuel cost savings through acquisition of BEVs.

This preliminary analysis sets the stage for the main purpose of this Green Fleet Strategy and Report – specifically, to inform and model several fuel-reduction solutions for the City of Hamilton Fleet Services vehicles and equipment and provide an ambitious, yet feasible, long-term capital plan to achieve deep GHG emissions reductions.

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Section 3.0: Approach and Methodology

RSI-FC maintains that fuel-reduction plans must be sustainable – both environmentally and financially. For this reason, RSI-FC's approach to developing our recommendations for Hamilton's sustainable fuel-reduction strategy is based on data modelling of the current situation and completing research on a number of go-forward solutions.

To achieve optimal efficiency in completing this type of analysis, our team developed Fleet Analytics Review™ (FAR), a software tool designed specifically for complex green fleet planning and evaluation of short- to long-term fuel-reduction strategies, both in terms of cost savings and GHG reductions.

About Fleet Analytics Review™

Fleet Analytics Review™ (FAR) is a user-friendly, interactive decision support tool designed to aid our team and fleet managers in developing short- to long-term green fleet plans by calculating the impacts of vehicle replacement and fuel-reduction solutions on operating costs, cost of capital, and GHG emissions. Moreover, it is used for long-term capital planning (LTCP) through an approach that works to balance, or smoothen, annual capital budgets and avoid cost spikes if possible. For a detailed FAR description, please see *Appendix B*.

Fuel-use and GHG reduction solutions were analyzed using FAR, designed to efficiently estimate the cost-benefit and GHG emissions reduction potential of many best management practices (BMPs), low-carbon fuels, and current or emerging technologies that have been proven to be beneficial to commercial and municipal fleets. The tool was used to evaluate these options in the context of the existing fleet being reviewed. That is, after optimizing lifecycles and implementing "house-in-order" strategies, fuel-saving options were modelled for units due for replacement to determine if they would deliver operating cost savings over subsequent fiscal years (after baseline to year 2035) and, if so, the potential GHG emissions reductions.

FAR will be licensed in perpetuity to the City of Hamilton for its internal use post-project. The FAR model is dynamic, and users can easily run future scenarios (such as assessing different vehicle types, fuels, or engine/drivetrain combinations) to see how such decisions impact operating expenses – ahead of their implementation, thereby heading off potentially costly errors.

Go-Forward Fuel-Reduction Solutions

Fuel-reduction solutions can generally be grouped into three categories – (1) best management practices (BMPs); (2) fuel switching; and (3) battery-electric – as described below (details on all fuel-reduction solutions researched by RSI-FC can be found in *Appendix E*):

1) **Best Management Practices.** FAR calculated the cost-benefit and GHG reduction, unit-by-unit and fleet-wide, of BMPs or "house-in-order" strategies including operational improvements such as fuel-efficient driver training, route planning, etc., as well as vehicle specifications enhancements such as improved aerodynamics, reduced rolling resistance, light-weighting, and others.

2) **Fuel Switching.** FAR calculated the cost-benefit and GHG reduction, unit-by-unit and fleet-wide, of switching vehicle fuels from fossil-based (e.g., diesel) to alternate ones that are less fossil-based (e.g., natural gas) or to renewable fuels (e.g., biodiesel).

3) **Battery-Electric Vehicles.** FAR calculated the cost-benefit and GHG reduction, unit-by-unit and fleet-wide, of switching to battery-electric vehicles (BEVs). Transitioning to BEVs is the ultimate GHG reduction strategy for a fleet. In this report, we model tailpipe emissions reduction; switching to electric reduces fuel consumption by 100% applying this method. However, in terms of lifecycle GHG emissions, BEVs are "fuelled" by electricity needed to charge the battery(ies), which can indirectly use fossil fuel depending on the source of electricity.

Fuel-reduction solutions will have variable rates of success. For example, if a fleet opts for aerodynamics packages on their trucks it may takes years to phase them in fully, so full fuel-savings results will accrue over a period of time. Similar logic applies to best practices. With driver training, for instance, given that humans all have different rates of learning and information retention, bad driving habits may creep back in over time (or conversely, drivers may improve over time).

The most effective idle-reduction strategy for a fleet often entails a combination of complementary technologies and best practices. For instance, several of the solutions have variable rates of adoption, such as electronic engine parameters, extra cab insulation, and driver training. The right combination will depend on the fleet's routes, fuel costs, climates of operation, maintenance cycles, training methods, driver support, fleet policies, and other factors.

Similarly, regarding fuel switching, fuel-use reduction potential will also be dependent on a multitude of factors, including driver training and habits, climates of operation, and maintenance cycles. For switching to BEVs, which can be regarded as a fuel switch with the source of "fuel" being the power grid, tailpipe emissions are zero and thus there is no range of fuel-reduction potential at the source (i.e., 100% reduction is achieved at the tailpipe). However, the amount of electricity that is needed to power these units will depend on the same aforementioned factors, influencing operation costs and GHG emissions depending on the source of electricity.

Steps to Producing Hamilton's Green Fleet Strategy

RSI-FC employed a multi-step approach in low-carbon, green fleet planning for Hamilton's Green Fleet Strategy. The steps include:

1) **Baseline Analysis.** At the outset, it is crucial to confidently know the current fleet baseline in terms of several key performance metrics ranging from cost, service levels (such as utilization and availability rates), and GHG emissions. For this step, we completed a FAR baseline analysis.

   For Hamilton, we received baseline data of the in-scope fleet from City staff. The dataset provided to our team included a list of units, makes/models/years, asset values and ages, descriptions, fuel type, fuel cost, repair costs, and maintenance costs for a one-year review period (2019). We loaded this input data into FAR and completed a baseline analysis.

2) **Business-as-Usual Review**. Most fleets have in place standard, business-as-usual (BAU) protocol/policies regarding vehicle replacement, capital budgeting, and fleet modernization planning. Fleet management generally employs pre-determined vehicle replacement guidelines (such as vehicles that will be replaced every "x" years or "y"-thousand kilometres travelled). Using FAR, RSI-FC analyzed the long-term outcomes of the fleet's current-day BAU vehicle replacement practices in terms of impacts on annual capital budgets, operating costs, and the GHG impacts of BAU budgeting.

3) **Lifecycle Analysis.** With RSI-FC's proprietary lifecycle analysis (LCA) software tool, our team input the fleet's historical data to calculate the optimal economic lifecycles for each vehicle category in the fleet. Please see more details of LCA practices and specifics for Hamilton later in this section.

4) **Data-Modelling Optimized Lifecycles.** With the fleets optimal economic lifecycles calculated via LCA modelling, we input these vehicle replacement cycles into FAR to data-model the outcomes in terms of long-term capital budgets. For Hamilton, we modeled a 15-year capital budget plan to year 2035 and go-forward operating cost and GHG emission impacts.

5) **Business Case Optimization.** For many of our client's fleets once optimized lifecycles have been modelled in FAR, it becomes very apparent that some vehicles deliver better return-on-investment (ROI) than others. One reason is that some vehicles that due for replacement based on the client's current replacement practices may have had lighter usage than other similar age units. For vehicles in better condition, service life can be extended to optimize the total cost of ownership (TCO). Lower ROI would result if a vehicle, still in good condition, was replaced prematurely; value will be lost.

For Hamilton, the approach used by RSI-FC's data analysts was to *defer* replacement of some vehicles to the ensuing capital budget years to ensure full value is received from each unit. Fleet managers everywhere make tough vehicle replace-or-retain decisions like this each year to optimize the use of available capital. Using RSI-FC's ROI-based approach to deferrals, year-over-year long term capital budgets can be balanced. Ideally, this step should be completed by Fleet staff based on vehicle condition assessments and to balance go-forward annual capital budgets. Without any knowledge of vehicle condition, for this step our team deferred any units which, based on the data provided, were shown to have lower operating costs (including cost of capital) than if replaced. This step allowed us to balance Hamilton's long-term capital budgets based on optimal ROI.

6) **"House-in-Order" Actions.** Before making commitments to fuel-switching or low-carbon technologies, RSI-FC believes it's essential to first get a fleet's "house in order" to save fuel and reduce GHG emissions. By this, we are referring to best management practices (BMPs) that should first be put in place, including:

- **Enhanced Vehicle Specifications**. Low rolling resistance tires, aerodynamic vehicles, light-weighting, idle-reduction technologies, etc.
- **Transportation Demand Management.** Trip reduction/avoidance and route planning/optimization
- **Driver Training and Motivation.** Managing driver behaviours with eco-training and idle-reduction policies
- **Fleet Downsizing.** Reducing the total number of low-utilization vehicles by undertaking a review to determine if some vehicles can be eliminated through early decommissioning
- **Right-Sizing.** Specifying the correctly-sized vehicles for the job at hand

7) **"Messy-Middle" Solutions.** BEVs are undisputedly the optimal solution to GHG reduction and, for higher annual-mileage units, cost savings. However, today, only a limited number of BEV types are available. Battery-electric trucks (BETs) are coming, but in the meantime, many municipalities are seeking to get started with reducing their fleet GHGs right away. For these fleets, including the City of Hamilton, an intermediate answer is fuel-switching – transitioning away from fossil gasoline and diesel to alternate, lower-carbon fuels like propane and natural gas, or renewable fuels like ethanol and biodiesel.

In *Figure 2*, published lifecycle and combustion (tailpipe) emission factors[28] associated with many alternate and renewable fuels as per GHGenius[29] are shown.

Figure 2: Emissions Factors for Various Transportation Fuels

LIFECYCLE Emissions Factors	kg eq Co2 / L	Tonnes eq Co2 / L	lbs. eq Co2 / gallon (US)	Tons eq Co2 / gallon (US)
Gas	3.352	0.00335	27.974	0.01399
Diesel	3.543	0.00354	29.568	0.01478
B2 biodiesel	3.488	0.00349	29.110	0.01456
B5 biodiesel	3.406	0.00341	28.424	0.01421
B10 biodiesel	3.269	0.00327	27.281	0.01364
B20 biodiesel	2.995	0.00300	24.994	0.01250
B50 biodiesel	2.173	0.00217	18.135	0.00907
B100 biodiesel	0.803	0.00080	6.701	0.00335
E10 ethanol	3.138	0.00314	26.188	0.01309
E85 ethanol	1.344	0.00134	11.219	0.00561
CNG	2.939	0.00294	24.528	0.01226
Propane	2.107	0.00211	17.584	0.00879
CNG/gasoline	0.000	0.00000	0.000	0.00000
CNG/E10	0.000	0.00000	0.000	0.00000
Gas/propane	0.000	0.00000	0.000	0.00000
H2	0.000	0.00000	0.000	0.00000

Combustion (Tailpipe) Emissions Factors	kg eq Co2 / L	Tonnes eq Co2 / L	lbs. eq Co2 / gallon (US)	Tons eq Co2 / gallon (US)
Gas	2.216	0.00222	18.493	0.00925
Diesel	2.717	0.00272	22.674	0.01134
B2 biodiesel	2.664	0.00266	22.232	0.01112
B5 biodiesel	2.584	0.00258	21.568	0.01078
B10 biodiesel	2.452	0.00245	20.461	0.01023
B20 biodiesel	2.187	0.00219	18.248	0.00912
B50 biodiesel	1.391	0.00139	11.608	0.00580
B100 biodiesel	0.065	0.00006	0.542	0.00027
E10 ethanol	2.143	0.00214	17.884	0.00894
E85 ethanol	0.369	0.00037	3.079	0.00154
CNG	2.128	0.00213	17.762	0.00888
Propane	1.525	0.00153	12.727	0.00636
CNG/gasoline	0.000	0.00000	0.000	0.00000
CNG/E10	0.000	0.00000	0.000	0.00000
Gas/propane	0.000	0.00000	0.000	0.00000
H2	0.000	0.00000	0.000	0.00000

Source:
GHGenius version 3.11

For biodiesel, the emissions per unit mass/volume decreases as the biodiesel blend increases; however, fuel economy needs to be considered as well. The fuel economy for blends from B5 up to B20 is better than diesel; using blends in this range improves fuel economy and lowers GHG tailpipe emissions on the order of approximately 10 percent (see details in *Section 4.0* and *Appendix E*). To be conservative, we can estimate a tailpipe GHG reduction of at least several percent using biodiesel blends in this range.

For ethanol fuel blends, although both lifecycle and tailpipe measurement methods demonstrate CO_2e reductions on a per liter basis, net GHG reduction is greatly reduced and

[28] Source: GHGenius V 3.11, Natural Resources Canada. https://www.nrcan.gc.ca/energy/efficiency/transportation/7597
[29] GHGenius is a spreadsheet model that calculates the amount of greenhouse gases generated from the time a fuel is extracted or grown to the time that it is converted in a motive energy vehicle to produce power. Whether the fuel is burned in an internal combustion engine or transformed in a fuel cell, GHGenius identifies the amount of greenhouse gases generated by a wide variety of fuels and technologies, the amount of energy used and provided, and the cost effectiveness of the entire lifecycle.

will be more on the order of a few percent. This is because, in order to do the same work as gasoline, a much greater volume of ethanol is required (see details in *Section 4.0* and *Appendix E*). In FAR analysis, RSI-FC compensated for the estimated reduction in fuel-efficiency for ethanol blends.

Similarly, for compressed natural gas (CNG), to compare energy on an apples-to-apples basis, RSI-FC analyzed the amount of natural gas required to obtain the same energy content as a litre of diesel, also known as the diesel-litre equivalent (DLE). Based on the same work performed, a CNG vehicle has tailpipe emissions about 20-30% less than a comparable diesel or gasoline vehicle (see details in *Section 4.0* and *Appendix E*).

8) **Battery-Electric Vehicle Phase-in Planning.** Despite the advantages of BEVs, few, if any fleets would – or could – replace all their internal combustion engine (ICE) units immediately with BEVs given capital budgets constraints and the fact that BEV offerings are quite limited at this time. This means that BEVs must be phased-in over many years. For this reason, in our data-modelling for Hamilton RSI-FC data-modelled the gradual impacts of fleet BEV adaptation on a 15-year phased-in basis.

   We believe that phasing-in of BEVs should occur based on optimized lifecycles to balance long-term budgets based on ROI. In other words, the first units to be replaced with BEVs should be those that have been assessed as the optimal candidate vehicles that will deliver the best ROI. These are typically units with higher utilization and fuel consumption.

   For this purpose, FAR was used by our team to identify the units that will provide ROI if replaced by a BEV-equivalent. In a data-modeling exercise, our team then balanced Hamilton's go-forward capital budgets by making the switches from ICE to BEV units in sync with fiscal years in which the type/categories of BEVs are expected to be available.

   For Hamilton, given that some units did not show ROI when replaced with a BEV, we phased-in BEVs (in accordance with the expected availability of BEV types) until eventually, by 2035, all units with anticipated battery-electric options in the market would be replaced. Our team reasoned that this approach was most appropriate given the objective of this report is to provide a roadmap for deep GHG emissions reduction, despite some lower mileage units being unlikely to deliver ROI if replaced with a BEV based on our modelling.

Lifecycle Analysis

Lifecycle analysis (LCA) is a structured approach to determine the best time to replace vehicles and equipment in terms of age, mileage, or other pertinent factors. LCA provides the empirical justification for replacement policies and facilitates the analysis and communication of future replacement costs.

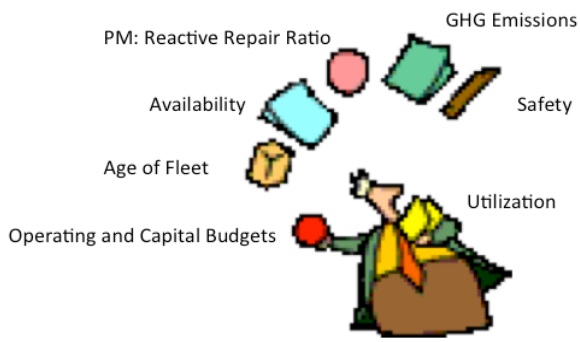
As LCA identifies capital strategies that will optimize vehicle lifecycles and return-on-investment (ROI), it should be the first step in long-term capital budget planning (LTCP).

LCA illustrates the total lifecycle cost of fleet vehicle types/categories. LCA can help determine:

- The age at which units should be considered for replacement.
- When replacement should occur, ideally before costs rise and reliability/safety is reduced, and before significant capital expenditure or refurbishment is necessary.

As shown in *Figure 3*, fleet management is a complex juggling act. Capital investment, operating expenses, depreciation, preventive maintenance levels, fuel consumption, aging of the fleet, availability, utilization, emissions, and inflation are interconnected issues. Making a change to any one of these critical considerations impacts all of them.

Figure 3: Fleet Management Juggling Act

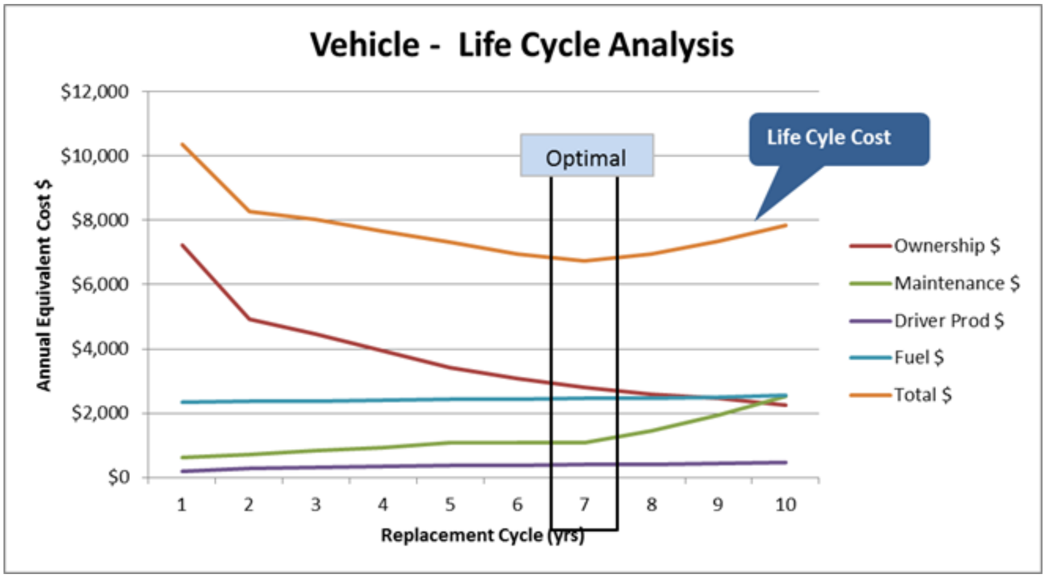


For example, deferred capital spending will result in an aging fleet, in turn resulting in higher reactive repair rates, more downtime, higher fuel consumption, (potentially) increased operating costs, and, ultimately, a larger overall fleet size to allow for more spare vehicles to compensate for the reduced reliability of primary vehicles. Counter to this, if vehicles are replaced too soon, value may be lost.

RSI-FC believes that the key to success is knowing the optimal economic lifecycle for each type of vehicle in a fleet. With that information, fleet managers can balance their go-forward capital spending to align with service level (uptime) and operating expenses (opex), and other essential success measures.

Figure 4 illustrates the concept of LCA. As a vehicle's age at retirement increases, ownership costs decrease and operating costs increase. In this example, the operating costs include maintenance, loss of driver productivity caused by reduced vehicle reliability, and fuel consumption. The sum of operating and ownership costs represents the "lifecycle cost curve." The ideal time to replace vehicles is before the rise in operating expenses begins to outweigh the decline in ownership costs.

Figure 4: Lifecycle Analysis Example



The Lifecycle Cost Curve

The "lifecycle cost curve" and the ideal replacement cycle will be different for various types of vehicles and possibly even for individual vehicles of the same kind. Factors that can cause this variability include differences in vehicle makes/models, model year, equipment design, operating environment, or even operator habits. Recommended replacement cycles for a class of vehicles is an approximation of the optimal time to replace most units within that class based on the category-average cost and performance data, by model year.

Replacement cycles should be considered a guideline only, as some vehicles in poor or unsafe condition may require replacement before the criteria are met. Conversely, some vehicles that exceed the criteria may be in good condition and may not warrant replacement. Fleet managers need to exercise judgment and fleet management principles in either advancing replacement or delaying replacement of individual vehicles case by case.

Lifecycles for vehicles are determined by modelling the expected cash flows for owning and operating the vehicle. The approach involves forecasting a stream of costs over a study horizon (future period) for each type of vehicle and determining the replacement cycle that results in the lowest total cost of ownership (TCO).

For the City of Hamilton, a discounted cash flow analysis was completed for each vehicle class to complete the LCA. Net present value (NPV) was calculated for outgoing cash flows (vehicle purchase cost, maintenance cost, the impact of downtime on driver productivity cost, improved fuel efficiency of a new vehicle compared to the old vehicle) and incoming cash flows (vehicle residual value) to calculate the total lifecycle cost for various vehicle retention periods.

The NPV amounts for cash flows were converted to annual equivalent cost (AEC) to provide a dollar amount, which is easy to relate to and enables comparison of alternative lifecycle costs. AEC is the fixed annual payment that that would be required to pay back the total of capital and operating costs over the study period. The AEC can be viewed as an average annual cost that considers the time value of money for future cash flows.

Fleet Age and Reliability

Most drivers know from personal experience that older vehicles are less reliable, break down more frequently, cost more to repair, and burn more fuel. Multiply that reality many times over as in a commercial fleet, and the impacts can be significant. In general, as commercial vehicle fleets age, higher operating expenses are incurred due to increased reactive repairs (unplanned repairs and breakdowns). Due to decreased reliability, downtime costs for spare/loaner vehicles increase as does the cost of productivity loss for drivers who are dependent on fleet vehicles to perform their daily work routines.

Downtime costs increase exponentially when more than one person is dependent on a single vehicle to complete their work routines. In addition to the cost of less reliable, aging vehicles and the associated increased downtime are the additional expenses of owning, maintaining, licensing, insuring and, parking spare, back-up vehicles.

Even when downtime is minimized through a rigorous preventive maintenance program, downtime costs are unavoidable and can be substantial for a municipality. Ongoing, uninterrupted capital re-investment in modernizing the fleet is critical to any organization that depends on a reliable fleet of vehicles to achieve its objectives and mission, as is the case for all municipalities. The benefits of a newer fleet include better fuel economy, increased vehicle uptime, lower risk of repair, increased safety and, possibly, improved employee morale. Moreover, a more modern and reliable fleet may result in a reduced fleet size since fewer spares will be necessary.

Providing capital to replace units each year with new vehicles is essential in for any organization that relies on its fleet to provide its core services to customers. A guideline for fleet replacement is to invest capital at the rate of depreciation. For example, if vehicles are depreciated over ten years, then 10% of replacement cost would be required each year to maintain the fleet's average age at the desirable level. However, this guideline is only valid if performance indicators such as uptime and fuel-efficiency are satisfactory. If not, a one-time increase in spending would help bring the fleet’s average age and performance up to an acceptable level.

Vehicle Replacement Criteria

Today's vehicles are built better and last longer than ever before. With the right preventive maintenance, operating conditions, and driver behaviours, vehicle service lives can often be extended longer than in the past. The LCA completed for this report optimizes vehicle lifecycle costs based on vehicle age. Vehicle age was determined to be the best replacement criteria for the City of Hamilton, given the relatively low average utilization rates in the fleet. Because annual kms-travelled are low, most vehicles will time-out versus mileage-out at retirement.

For a few vehicle classes in Hamilton's fleet (Class 1 passenger vehicles, pickups, Class 2 vans and utility vans, Class 6 utility vans, and several Class 7 & 8 trucks), we recommend extending lifecycles. That stated, we strongly recommend a cautious approach before doing so. Vehicles approaching their end-of-lifecycles should be assessed case by case with a thorough ground-up and top-down physical assessment of the vehicle's condition, as this would serve to inform and confirm decisions around extending their lifecycles.

For higher annual mileage vehicles in the fleet, it is recommended that the City of Hamilton review the condition of high mileage vehicles at thresholds of 20,000 km/yr for light-duty vehicles (LDVs) and 25,000 km/yr for medium and heavy-duty vehicles (MHDVs) for potential early replacement. This decision should take place on a case-by-case basis as vehicles approach maximum age and km thresholds. The recommended vehicle replacement age can be multiplied by these values to determine mileage thresholds. For example, if the recommended lifecycle is ten years for a vehicle type, the recommended replacement mileage is 10 x 20,000 = 140,000 km.

Vehicle Replacement at the Rate of Depreciation

A guideline for fleet replacement is to invest capital at the rate of depreciation. For example, if new vehicles are amortized over five years, then 1/5th (20%) of the fleet's current NPV would be required each year to maintain the average age of the fleet at the desirable level.

Nb: This guideline is only valid if performance indicators such as uptime and fuel-efficiency are satisfactory – if not, then a one-time increased capital expenditure would help to bring the fleet's average age and performance up to an acceptable level.

Environmental Considerations

LCA is used to evaluate whether the increased costs of capital for newer, more modern, and fuel-efficient vehicles will be offset by lower fuel, repair, and downtime costs. For low-mileage units, the amount of fuel saved may be minimal, often resulting in lifecycle extension being the better financial option. However, aging a fleet to extract full value from each unit will defeat the fleet's progress toward modernization and reduced GHG emissions. For the City of Hamilton, when modelling battery-electric vehicle (BEV) replacement, some units did not show ROI due to increased cost of capital exacerbated by low utilization. Given the objective of this report is to provide a roadmap for deep GHG emissions reduction, we phased-in BEVs (in accordance with the expected availability of BEV types) until by 2035, all units with anticipated battery-electric options in the market are replaced.

Key Parameters and Assumptions

The key LCA parameters and assumptions used for all vehicle classes are listed in *Table 5*.

Table 5: Key LCA Parameters and Assumptions

Parameter	Value	Description
Net Acquisition Cost	Varies by vehicle class	Based on average vehicle acquisition cost provided by the City of Hamilton
Cost of Capital/ Lease Rate	3.95%	Cost of funds for vehicle acquisition (the prime interest rate at the time of the LCA)
Discount Rate for NPV	1.75%	Rate used to discount cash flows
Sales Tax Rate %	1.76%	HST rate - municipalities
Tech. Prod Loss Hrs./Touch	2.5	Average loss in driver productivity each time a fleet technician services a vehicle. Work orders are deemed equivalent to “touches”
Tech. Labour Rate $/Hr.	$116	Estimated/typical hourly labour rate
CIF[30] on Maintenance	1.8%	Cost increase factor or inflation on parts and mechanic labour
CIF on Driver Rate	1.5 %	Cost increase factor or inflation on driver loaded labour rate
CIF on Vehicle	2%	Cost increase factor or inflation on vehicle replacement prices
CIF on Fuel	4%	An assumption based on market trends
Annual Vehicle Efficiency Improvement	2%	Fuel efficiency improvement factor for new vehicles compared to the vehicles being replaced (estimated by Fleet Challenge)
Average Km/Yr.	Varies by vehicle class	Annual distance travelled under the assumption that the new vehicle will travel the same distance as the old vehicle
Cash Flow Horizon (yrs.)	Varies by vehicle class	Discounted cash flow study period, adjusted based on the vehicle class (up to 20 years) and years of available data

[30] CIF = Cost Inflation Factor

LCA is based on average costs and utilization rates for each category of vehicles and provides a credible guideline to optimal vehicle replacement cycles. LCA does have limitations since its outcomes are based on average cost data for each category of vehicles. Some vehicles in poor or unsafe condition may require replacement before the LCA-calculated age criteria are met. Conversely, some vehicles that exceed the criteria may still be in good condition and not warrant replacement due to low usage or recent refurbishment. Therefore, the LCA-recommended replacement criteria should be used as a guideline and not an absolute rule. The physical condition of each unit should then be assessed case-by-case by trained and knowledgeable staff, familiar with the unit's usage and maintenance history before replacement decisions are finalized.

Data Challenges

The discipline of completing fleet LCA is dependent on historical cost data. LCA modelling software was designed and intended to be populated with a fleet's actual historical cost data. Without having cost data and performing LCA, vehicle replacement decisions may be based solely on intuition and personal observations – essentially the sentiments of someone who has a high degree of familiarity with the fleet. Often we have observed that “guesstimates” made by seasoned fleet managers can have a high degree of accuracy. However, today’s business decisions based on “gut” feelings often do not stand up to scrutiny and must be backed up by analytical data.

For the City of Hamilton, our team used an LCA modelling tool developed by RSI-FC in 2013 and refreshed in 2017. Our tool is dependent on actual fleet historical data when available for the model years and vehicle types being studied.

The City provided our team with records and data for its fleet. Despite good record-keeping, data was insufficient for some classes and ages of vehicles. More data means larger sample sizes that are essential for completing LCA. As a workaround, RSI-FC filled gaps in the City’s data with statistics from our proprietary database of Canadian municipal fleets. Our team has collected this data over more than 15 years and represents the results of fleet reviews and analyses we have completed for dozens of Canadian cities, towns, and regions. Being the amalgam of data from almost 50,000 municipal vehicles, our data was determined to be a suitable proxy for the City’s actual information.

For two vehicles/categories, including a Class 6 bus (just one in the fleet) and Class 6 utility vans, the sample sizes were insufficient due to the small number of Hamilton fleet units. Hamilton’s dataset included just one Class 6 bus and eight Class 6 utility vans – much less data than the minimum required for LCA. For these categories, data available from our municipal peer fleet database was used to fill data gaps[31].

[31] Peer municipal fleet data is highlighted in green in the LCA models prepared by our analysts.

LCA was completed for these vehicle categories based on Hamilton's actual historical operational data:

- Class 1 passenger vehicles
- Pickups (Classes 1 & 2)
- Class 2 vans and utility vans
- Class 3 pickups and utility vans
- Class 5 trucks
- Heavy-duty trucks (Classes 7 & 8)

Given the data shortcomings we've described, we also completed LCA by augmenting Hamilton's data with data from our municipal peer fleet database. The following LCAs are based mainly on peer data:

- Class 6 bus (one unit)
- Class 6 utility vans

Lifecycle Analysis Results Summary

LCA was calculated for each in-scope vehicle category in Hamilton's fleet. The LCA findings and recommended lifecycles are based on historical data from Hamilton's fleet, compiled by units and by ages for the review period. For two vehicle categories (Class 6 bus and Class 6 utility vans), LCA was conducted using peer fleet data as there was insufficient data from Hamilton's fleet due to a small number of units.

The LCA took into consideration the cost of downtime (as caused by reduced reliability), the year-to-year "rollup" of weighted average cost of capital (WACC), inflation, worker cost/hour, salvage and market values, inflation, and average kilometres-driven data. The results are summarized in *Table 6*. In *Appendix C*, we have included the LCA charts for each of vehicle category in Hamilton's fleet.

Table 6: Lifecycle Analysis Results Summary

Vehicle Category	Current Planned Lifecycles (years)	*Optimal Lifecycle Calculated through LCA (years)	Lifecycle Applied in FAR (years)	Recommended Change (+ or -) (years)	Data Source/Notes
Passenger (Class 1)	6 to 8	11	11	+3 to +5	Based on Hamilton fleet data[32] Assess each unit case-by-case based on accumulated km and vehicle condition
Pickups (Class 1-2)	8 to 10	7 to 11	Same as original	Unchanged	Based on Hamilton fleet data Assess each unit case-by-case based on accumulated km and vehicle condition
Class 2 vans and utility vans	8 to 10	9 to 10	10	0 to +2	Based on Hamilton fleet data Assess each unit case-by-case based on accumulated km and vehicle condition
Class 3 pickups & utility vans	8 to 10	5 to 6	Pickups same as original, utility vans 6	Pickups unchanged, utility vans -4	Based on Hamilton fleet data The decision to replace early should be based on a unit-by-unit condition assessment
Class 5 trucks	8 to 10	8 to 9	Same as original	Unchanged	Based on Hamilton fleet data
Class 6 buses	20	19 to 20	Same as original	Unchanged	Based on benchmark fleet data from municipal database
Class 6 utility vans	10	16	16	+6	Based on benchmark fleet data from municipal database Assess each unit case-by-case based on accumulated km and vehicle condition

[32] In the FAR input data provided by the City, several Ford Escapes listed as having a 6 year (72 month) lifecycle.

Class 7 trucks	8 to 12	8 to 9	9	-3 to +1	Based on Hamilton fleet data Assess each unit case-by-case based on accumulated km and vehicle condition
Class 8 trucks	7 to 20	9	9	-11 to +2	Based on Hamilton fleet data Assess each unit case-by-case based on accumulated km and vehicle condition

*Based on minimum annual operating costs and minimum rolling 3-year average operating costs

We strongly encourage the City of Hamilton to have Fleet Technicians complete vehicle condition evaluations during every preventive maintenance inspection. In this way, decisions around extending vehicle lifecycles can be founded on data and a solid understanding of each vehicle's actual condition. A simple rating system such as a numerical 1 to 5 indexing where 1 = poor condition and 5 = good condition would greatly assist capital budget planners in determining the highest priority units for replacement, If each vehicle's condition rating (1 to 5) was posted in each vehicle's profile in the Hansen system, it could be easily accessed for capital budget planning.

As we have described, vehicles approaching their end of lifecycle should be assessed case by case. A thorough ground-up and top-down physical assessment of each vehicle's condition, in conjunction with routine shop visits for preventive maintenance inspections, would serve to inform decisions around extending vehicle lifecycles.

Long-Term Capital Planning

After completing lifecycle analysis (LCA), the Fleet Analytics Review™ (FAR) software tool enables methodical, well-informed business decisions for long-term capital planning (LTCP) purposes.

Vehicle data provided by the City of Hamilton for the baseline year (2019) was input into FAR from the fleet's baseline data. The FAR tool calculated capital budgets for the ensuing fifteen years driven by vehicle lifecycles based on fleet management's vehicle retention practices (business as usual or BAU) and the optimized lifecycles that were calculated by RSI-FC's LCAs. On a unit-by-unit basis, FAR calculated (1) whether replacing units due for replacement would save Hamilton operating expenses or cost additional money, and (2) the GHG reduction impacts of vehicle replacements. The tool also calculated and displayed the costs (operating and capital) and GHG impacts of those decisions for the fleet as a whole.

Fleet management does not usually have unlimited capital budgets and so, they must make tough decisions around which vehicles to replace and which to delay replacement. Typically, when a fleet manager uses LTCP for the first time, year one will show a cost spike caused by previously deferred vehicles. Replacement of some of these units can be again delayed because they are still in good serviceable condition, have low mileage, or perhaps have just received a costly refurbishment that will extend the unit's life. Other vehicles may no longer have a purpose in the organization and could potentially be eliminated from the fleet.

For these reasons, each vehicle shown as due for replacement in the LTCP should be reviewed one-by-one and decisions made whether to extend the units life by one (or more) years or eliminate it from the fleet altogether. These decisions can be aided by an LTCP tool by displaying to the user whether a cost-saving is possible by replacing it.

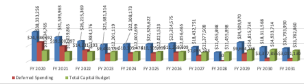
In FAR, replacement of units shown not to provide ROI can be deferred to the following year until replacement yields a net decrease in operating expenses (Opex). Following this method, a fleet manager can balance go-forward annual capital expenses (Capex) and avoid year-over-year cost spikes. This approach can keep the average age of the fleet at an acceptable level, provide the lowest cost and highest uptime, and reduce emissions.

While historical data in FAR will demonstrate whether a business case exists for vehicle replacement, the final step in LTCP depends on fleet management personnel's expertise. *No software tool can supplant this crucial role in capital budget planning.*

For the City of Hamilton, we modelled a 15-year budget cycle (to 2035) for business-as-usual (BAU) vehicle retention practices, optimized lifecycles, balanced Capex and optimized lifecycles (only replacing units with ROI), and a number of fuel-reduction solutions (additional best practices or “house-in-order” actions, fuel-switching or “messy-middle” solutions, and BEV phase-in planning).

A sample screen of the 15-year capital budgeting within FAR is shown in *Figure 5*.

Figure 5: Sample FAR Dashboard



Fiscal Year 2020

Litres of fuel used in period	Operating Expense Increase or Savings (-)	Unit #	Category	Current Fuel Type	Replacement Category	Replacement Fuel	Planned Life Cycle (years)	Planned Capital Budget 2020 (includes existing deferrals)	Enter "DEF" to defer unit to next year or "NIX" to nix unit entirely	Deferred Spending for 2020	Total Capital Budget 2020	Opex Increase or -Reduction from Unit Replacement & Greening Plan	Opex Increase or -Reduction from Vehicle Category Switch with Replacement	Opex Increase or -Reduction from Fuel Switch with Replacement	Net CO_2 Reduction from Unit Replacement & Greening Plan	CO_2 Reduction from Vehicle Category Switch	CO_2 Reduction from Fuel Switch
2,639	$466	560601	Aerial	D	Aerial	D	8	$142,686	DEF	$142,686	$0	$466	$0	$0	0.00	0.00	0.00
6,012	$457	561501	Aerial	D	Aerial	D	8	$0		$0	$0	$457	$0	$0	0.00	0.00	0.00
4,150	$1,115	840501	Aerial	D	Aerial	D	8	$154,926	DEF	$154,926	$0	$1,115	$0	$0	0.00	0.00	0.00
6,695	$702	841701	Aerial	D	Aerial	D	8	$0		$0	$0	$702	$0	$0	0.00	0.00	0.00
3,948	$381	871604	Aerial	D	Aerial	D	8	$0		$0	$0	$381	$0	$0	0.00	0.00	0.00
4,405	$350	107027	Aerial	D	Aerial	D	9	$198,161	DEF	$198,161	$0	$350	$0	$0	0.00	0.00	0.00
4,143	$306	107028	Aerial	D	Aerial	D	9	$158,161	DEF	$158,161	$0	$306	$0	$0	0.00	0.00	0.00
4,881	$1,204	561602	Aerial	D	Aerial	D	9	$0		$0	$0	$1,204	$0	$0	0.00	0.00	0.00
5,971	$691	841101	Aerial	D	Aerial	D	9	$171,592	DEF	$171,592	$0	$691	$0	$0	0.00	0.00	0.00
4,549	$604	841102	Aerial	D	Aerial	D	9	$171,592	DEF	$171,592	$0	$604	$0	$0	0.00	0.00	0.00
4,511	$879	841301	Aerial	D	Aerial	D	9	$0		$0	$0	$879	$0	$0	0.00	0.00	0.00
5,443	$495	841702	Aerial	D	Aerial	D	9	$0		$0	$0	$495	$0	$0	0.00	0.00	0.00
5,614	$350	841703	Aerial	D	Aerial	D	9	$0		$0	$0	$350	$0	$0	0.00	0.00	0.00
7,016	$698	841704	Aerial	D	Aerial	D	9	$0		$0	$0	$698	$0	$0	0.00	0.00	0.00
2,693	$436	140304	Backhoe	D	Backhoe	D	9	$302,971	DEF	$302,971	$0	$436	$0	$0	0.00	0.00	0.00
2,884	$522	430601	Backhoe	D	Backhoe	D	9	$303,520	DEF	$303,520	$0	$522	$0	$0	0.00	0.00	0.00
4,138	$675	901201	Bus	G	Bus	G	20	$0		$0	$0	$675	$0	$0	0.00	0.00	0.00
761	$302	170901	Cement Mixer Truc	D	Cement Mixer Truc	D	8	$178,149	DEF	$178,149	$0	$302	$0	$0	0.00	0.00	0.00
4,899	$560	981003	Chipper Truck	D	Chipper Truck	D	8	$51,776	DEF	$51,776	$0	$560	$0	$0	0.00	0.00	0.00
6,652	-$27,481	981101	Chipper Truck	D	Chipper Truck	D	9	$135,931		$0	$135,931	-$27,481	$0	$0	0.35	0.00	0.00
1,156	$168	851102	Crane Truck	D	Crane Truck	D	8	$260,951	DEF	$260,951	$0	$168	$0	$0	0.00	0.00	0.00
1,249	-$37,371	850905	Dump	D	Dump	D	8	$49,426		$0	$49,426	-$37,371	$0	$0	0.07	0.00	0.00
3,028	$476	850906	Dump	D	Dump	D	8	$49,426	DEF	$49,426	$0	$476	$0	$0	0.00	0.00	0.00
2,622	$294	109251	Dump	D	Dump	D	9	$139,247	DEF	$139,247	$0	$294	$0	$0	0.00	0.00	0.00
3,691	$634	107069	Dump	D	Dump	D	9	$178,292	DEF	$178,292	$0	$634	$0	$0	0.00	0.00	0.00
6,094	-$31,443	160701	Dump	D	Dump	D	9	$202,348		$0	$202,348	-$31,443	$0	$0	0.32	0.00	0.00
5,418	-$53,599	160702	Dump	D	Dump	D	9	$202,542		$0	$202,542	-$53,599	$0	$0	0.29	0.00	0.00
10,143	$1,951	161301	Dump	D	Dump	D	9	$0		$0	$0	$1,951	$0	$0	0.00	0.00	0.00
9,957	$890	161302	Dump	D	Dump	D	9	$0		$0	$0	$890	$0	$0	0.00	0.00	0.00
4,033	$562	171001	Dump	D	Dump	D	9	$86,358	DEF	$86,358	$0	$562	$0	$0	0.00	0.00	0.00
4,133	$644	171002	Dump	D	Dump	D	9	$194,180	DEF	$194,180	$0	$644	$0	$0	0.00	0.00	0.00

Fiscal Year 2021

Unit #	Planned Capital Budget 2021 (includes deferrals from 2020)	Enter "DEF" to defer unit to next year or "NIX" to nix unit entirely	Deferred Spending for 2021	Total Capital Budget 2021	Opex Increase or -Reduction from Unit Replacement & Greening Plan	Opex Increase or -Reduction from Vehicle Category Switch with Replacement	Opex Increase or -Reduction from Fuel Switch with Replacement	Net CO2 Reduction from Vehicle Replacement & Greening Plan	CO2 Reduction from Vehicle Category Switch	CO2 Reduction from Fuel Switch
560601	$156,926	DEF	$156,926	$0	$474	$0	$0	0.00	0.00	0.0
561501	$0		$0	$0	$466	$0	$0	0.00	0.00	0.0
840501	$156,926		$0	$156,926	-$13,550	$0	$0	0.22	0.00	0.0
841701	$0		$0	$0	$715	$0	$0	0.00	0.00	0.0
871604	$0		$0	$0	$388	$0	$0	0.00	0.00	0.0
107027	$196,586	DEF	$196,586	$0	$357	$0	$0	0.00	0.00	0.0
107028	$155,244	DEF	$155,244	$0	$312	$0	$0	0.00	0.00	0.0
561602	$0		$0	$0	$1,227	$0	$0	0.00	0.00	0.0
841101	$247,631	DEF	$247,631	$0	$704	$0	$0	0.00	0.00	0.0
841102	$247,631	DEF	$247,631	$0	$615	$0	$0	0.00	0.00	0.0
841301	$0		$0	$0	$896	$0	$0	0.00	0.00	0.0
841702	$0		$0	$0	$504	$0	$0	0.00	0.00	0.0
841703	$0		$0	$0	$357	$0	$0	0.00	0.00	0.0
841704	$0		$0	$0	$711	$0	$0	0.00	0.00	0.0
140304	$328,118	DEF	$328,118	$0	$444	$0	$0	0.00	0.00	0.0
430601	$328,118	DEF	$328,118	$0	$532	$0	$0	0.00	0.00	0.0
901201	$0		$0	$0	$688	$0	$0	0.00	0.00	0.0
170901	$219,085	DEF	$219,085	$0	$308	$0	$0	0.00	0.00	0.0
981003	$76,425		$0	$76,425	-$4,158	$0	$0	0.26	0.00	0.0
981101	$0		$0	$0	-$28,003	$0	$0	0.35	0.00	0.0
851102	$300,478	DEF	$300,478	$0	$171	$0	$0	0.00	0.00	0.0
850905	$0		$0	$0	-$38,081	$0	$0	0.07	0.00	0.0
850906	$66,235		$0	$66,235	-$4,707	$0	$0	0.16	0.00	0.0
109251	$142,660		$0	$142,660	-$3,986	$0	$0	0.14	0.00	0.0
107069	$168,637	DEF	$168,637	$0	$646	$0	$0	0.00	0.00	0.0
160701	$0		$0	$0	-$32,041	$0	$0	0.32	0.00	0.0
160702	$0		$0	$0	-$54,617	$0	$0	0.29	0.00	0.0
161301	$216,015		$0	$216,015	-$14,111	$0	$0	0.53	0.00	0.0
161302	$216,015		$0	$216,015	-$2,332	$0	$0	0.52	0.00	0.0
171001	$113,204	DEF	$113,204	$0	$573	$0	$0	0.00	0.00	0.0
171002	$216,015	DEF	$216,015	$0	$656	$0	$0	0.00	0.00	0.0

FAR Scenarios

Using optimized lifecycles, we performed a number of scenario analyses to assess the potential impacts of fuel-reduction solutions. For each scenario, FAR calculated annual GHG emissions, operating costs, and capital requirements, which provided a long-term capital planning (LTCP) outlook from baseline to 2035.

In total, RSI-FC data-modelled the fleet's 2019 baseline statistics. We then assessed 35 low-carbon solutions (scenarios) in three groups, and we calculated the potential impacts of each relative to the 2019 baseline. These "what-if" scenarios assessed the potential outcomes if each of the low-carbon solutions were in place for the same vehicles, the same number of vehicles, travelling the same number of kilometres as in 2019.

Details and results for individual scenarios can be found in *Appendix D*. Highlights of FAR scenarios are described below and listed in *Table 7*.

- In FAR #1 (the 2019 baseline), we identified the outliers[33] and tallied the average performance for all categories of vehicles.
- In FAR #2, we assessed the potential impacts (annual GHG emissions, operating costs, and capital required) of optimized vehicle replacement practices based on our LCA study of Hamilton's fleet categories.

[33] For the purposes of this analysis, outliers are defined as vehicles with operating statistics (such as costs, fuel consumption, utilization, availability) 50% lower or higher than average for similar vehicles in the fleet. Outliers are identified within the FAR baseline data model.

- In FAR #3, using optimized lifecycles from FAR #2, going forward from the 2019 baseline, we performed long-term capital budget balancing by "replacing" (hypothetically) only those units which were shown to provide ROI. Our analysis team then data-modelled many low-carbon scenarios starting from after the baseline year to 2035 to evaluate the cost-effectiveness and GHG reduction of each (FAR #4 onward).

- In FAR #4-6, we assessed the potential impacts of several best management practices (BMPs) for the existing fleet that we believe should be addressed at the outset, prior to any more costly upgrades or replacements. FAR #3 essentially became our "new" baseline (new baseline #1). The cumulative impacts of implementing all of these BMPs, or "house-in-order" strategies, are modelled in FAR #7.

- In FAR #8 to 16, we data-modelled several "messy-middle" scenarios involving switching different combinations of vehicle classes to alternate and renewable fuels. The fuels we modeled are proven and mature green fleet, low-carbon solutions that may be possible today while awaiting the commercial availability of suitable BEVs. It is important to note that these scenarios also included replacement of some light-duty ICE units with BEVs in sync with fiscal years in which the type/categories of BEVs are expected to be available. FAR #7 served as a second "new" baseline (new baseline #2) under the assumption that all prior "house-in-order" strategies would be implemented. *Note: FAR #10, calling for a switch from diesel to gas, was not aligned with the main objective of guiding the City to achieve deep GHG emissions reductions from its fleet; therefore, we opted to exclude this scenario from our main analysis.*

- In FAR #21-36, we assessed the potential impacts of a long-term phase-in of BEVs, starting from the FAR #7 baseline (new baseline). We modelled the replacement of units due for replacement with BEVs in the light-duty (LD) category (cars, SUVs) starting immediately and 2021, which are currently the only options currently available. We then modelled the replacement of pickups starting in 2022, and medium- and heavy-duty (MHD) trucks beginning in 2024. Please see *Table 7* (below).

Table 7: City of Hamilton – Low-Carbon Fleet Scenarios

FAR #	Solution Description	Timing of Implementation for FAR Data Modelling
1	Baseline BAU	2019
2	Optimized lifecycles	Immediate
3	Balanced Capex and optimized lifecycles	Immediate
4	Enhanced Specs: light-weighting, LRR	Immediate
5	Driver Behaviours: eco-training & anti-idling policy/technologies	Immediate
6	TDM: route planning/optimization & trip reduction	Immediate
7	All house-in-order strategies (3, 4, 5 & 6)	Immediate
8	Fuel Switch: E85 (passenger, pickups, vans)	Immediate
9	Fuel Switch: B10 (annual blend, annualized – all diesel on-road units)	Immediate
10	Fuel Switch: diesel to gas (LMD)	Immediate
11	Fuel Switch: CNG LD (pickups)	Immediate
12	Fuel Switch: CNG MHD (Classes 3 to 6)	Immediate
13	Fuel Switch: CNG LMHD (Classes 2 to 8)	Immediate
14	Fuel Switch: RNG LMHD (Classes 2 to 8)	Immediate
15	Fuel Switch: LPG LD (passenger, pickups, vans)	Immediate
16	Fuel Switch: LPG LMHD (LD & Truck Classes 2 to 8)	Immediate
21, 22	BEV: LD (passenger)	Immediate
23, 24	BEV: LD passenger & pickups, bus	Immediate and onward (LD passenger) 2022 onwards (LD pickups)
25-36	BEV: LD passenger & pickups, bus, MHD trucks	Immediate and onward (LD passenger) 2022 onwards (LD pickups) 2024 onwards (MHD trucks)

Section 4.0: Hamilton's Low-Carbon and BEV Transition Plan

The primary objective of this Green Fleet Strategy was to analyze the City of Hamilton's in-scope fleet operations data and identify and assess operational improvements and new technologies to reduce GHG emissions from Fleet Services vehicles and equipment. Note that this Green Fleet Strategy does not include EMS, Fire, Transit, or Police fleets.

This baseline included data on service levels (uptime and utilization), operating costs, fuel consumption, and GHG emissions during the review period (2019). From the baseline, we modelled the impacts on go-forward 15-year budget cycles (to 2035) for business-as-usual (BAU) vehicle retention practices, optimized lifecycles, balanced Capex and optimized lifecycles (only replacing units with ROI), and a number of fuel-reduction solutions (additional best practices or "house-in-order" actions, fuel-switching or "messy-middle" solutions, and BEV phase-in planning). Details and results for individual scenarios can be found in *Appendix D*.

In this section, for simplicity and effectiveness, we encapsulated the FAR scenario results as one single 15-year long-term capital planning (LTCP) strategy, providing a roadmap for the Energy Fleet and Facilities (EFFM) Division of Public Works to implement the various solutions to year 2035.

The emphasis of our roadmap to 2035 is on BEV phase-in, as this is the most effective long-term GHG reduction strategy for a fleet as battery-electric technology continues to advance. Our team reasoned that this approach was most appropriate given the objective of this report is to assist Hamilton's Fleet Services to achieve deep GHG emissions reduction, despite some lower mileage units being unlikely to deliver ROI if replaced with a BEV based on our modelling.

Deferred Spending Recommended

The most impactful and perhaps controversial recommendation in our 15-year plan is to avoid and defer replacement – if at all possible - of any internal combustion engine (ICE) units that are due for replacement until BEV replacements are available for purchase.

We realize the difficulties of carrying out such a recommendation. However, it is widely known and accepted by automotive experts everywhere, including RSI-FC, that the world is clearly moving away from ICEs for BEVs. There is little – if any – remaining doubt about this reality.

BEV replacements are coming – pickups are expected to be available in 2022 and at least two manufacturers are already accepting orders for new pickups. Medium- and heavy-duty trucks are expected to be available by 2024 (or sooner).

Fleet vehicles are long-term investments with lifecycles of 10 years or longer. With that in mind, we assert that it would not be wise for Hamilton to invest capital in dying-technology ICE vehicles when BEVs, with all their known advantages, including potentially lower costs, less maintenance, etc., are just around the corner. An ICE vehicle purchased today will be an anachronism in just a few years and as so, a poor investment. Examples from the recent past include cassette tapes versus CDs, celluloid film versus digital media, and so on. In hindsight, few would choose to invest in these examples of past-tense technologies knowing they would soon become obsolete.

RSI-FC's position and our recommendation for Hamilton is to, if at all possible, avoid buying ICE replacement vehicles until suitable BEV units are available.

We acknowledge that deferring vehicle replacements until BEVs are available will be challenging. Extending the life of currently in-service ICE vehicles will require creative solutions – short-term rentals, open-ended leasing, vehicle refreshes or repairs may all form part of the range of answers to extending the lives of the Hamilton fleet's current ICE units until suitable BEV replacements are available. Each unit would need to be evaluated on a case-by-case basis.

FAR Scenario Results – 15-Year LTCP Strategy

Table 8 (overleaf) shows the year-by-year impacts of many possible low-carbon solutions that we evaluated in RSI-FC's 15-year low-carbon and BEV transition plan (15-year LTCP strategy). We present these as possible low-carbon solutions for the City of Hamilton's in-scope fleet vehicles, in terms of year of implementation, GHG emissions, changes in controllable operating costs (relative to the baseline year), and capital required for each option. *Figure 6* (overleaf) displays the same results but in graphical form.

Our team began by establishing the fleet's 2019 baseline (FAR #1). We then data-modeled optimized vehicle replacement practices (FAR #2), and then we balanced Capex year-over-year by replacing only those units which were shown to provide ROI (FAR #3).

Starting from FAR #3, we next data-modelled several additional best management practices (BMPs) in FAR #4-6 (Group One), which included:

- Enhanced vehicle specifications, including light-weighting and low-rolling resistance (LRR) tires (FAR #4);
- Driver eco-training and anti-idling policy and technologies (FAR #5); and
- Transportation demand management (TDM), including route planning/optimization and trip reduction (FAR #6).

The cumulative impacts of these best management practices (BMPs), or "house-in-order" strategies, are modelled in FAR #7.

Starting from FAR #7, which served as a new baseline under the assumption that all prior "house-in-order" strategies would be implemented, we data-modelled several "messy-middle" scenarios (Group Two) involving switching different combinations of vehicle classes to alternate and renewable fuels (FAR #8-16), which included:

- Ethanol-85 (E85) for flex-fuel capable passenger vehicles, pickups, and vans (FAR #8);
- B10 biodiesel (annualized blend, with B20 used in summer months and B5 used in winter and shoulder months) for all diesel on-road units (FAR #9);
- Compressed natural gas (CNG) for light-, medium-, and heavy-duty (LMHD) vehicles (three scenarios, FAR #11-13);
- Renewable natural gas (RNG) for LMHD vehicles (FAR #14); and
- Liquid propane gas (LPG) for LMHD vehicles (two scenarios, FAR #15-16).

These "messy-middle" solutions are proven and mature green fleet, low-carbon solutions that may be possible today while awaiting the commercial availability of suitable BEVs.

Starting from FAR #7 (new baseline #2), we assessed the potential impacts of a long-term phase-in of BEVs (Group Three) to 2035 for units due for replacement (FAR #21 to #36), including:

- Replacement of light-duty (LD) passenger vehicles (cars, SUVs) starting immediately-2021, which are the only options currently available (FAR #21, 22);
- Replacement of pickups starting in 2022 (FAR #23, 24); and
- Replacement of medium- and heavy-duty (MHD) trucks beginning in 2024 (FAR #25-36).

Although some units did not show ROI when replaced with a BEV due to increased cost of capital, we phased-in BEVs until eventually, by 2035, all units with anticipated battery-electric options in the market would be replaced. Strictly through a lens of fiscal planning our recommendation to the City of Hamilton is to prioritize replacement of units with BEVs *only if they would deliver ROI*.

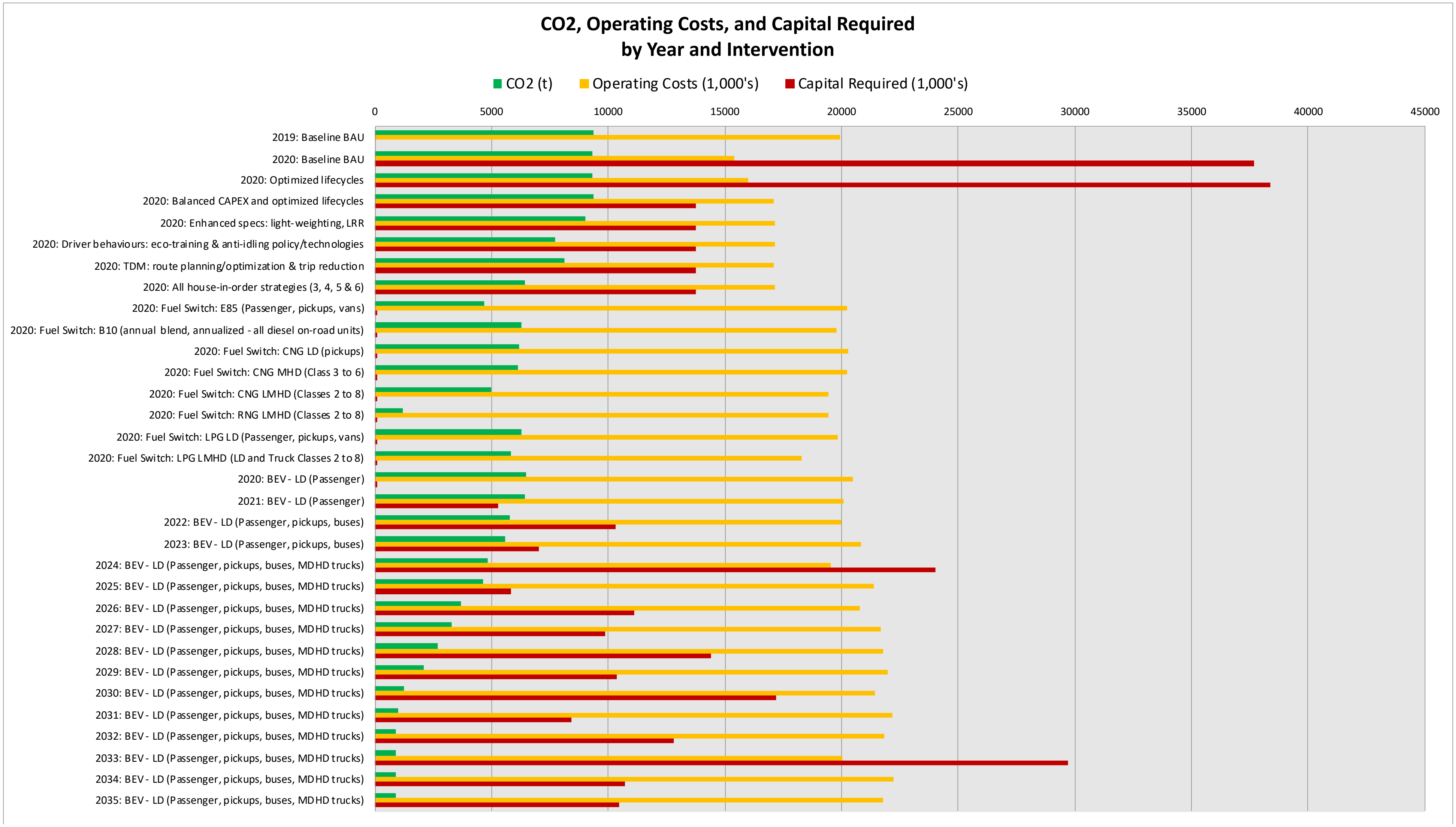
Table 8: Low-Carbon and BEV Transition Plan for City of Hamilton

FAR #	Solution	Timing of Data Modelling	CO_2 (t)	Projected Operating Costs (1,000's)	Projected Capital Required (1,000's)
1	Baseline BAU (current lifecycles)	2019	9,371	$19,912	$37,660
2	Optimized lifecycles	Immediate	9,308	$15,971	$38,333
3	Balanced Capex and optimized lifecycles	Immediate	9,354	$17,097	$13,735
4	Enhanced Specs: light-weighting, LRR	Immediate	9,010	$17,118	$13,735
5	Driver Behaviours: eco-training & anti-idling policy/technologies	Immediate	7,702	$17,116	$13,735
6	TDM: route planning/optimization & trip reduction	Immediate	8,094	$17,103	$13,735
7	All house-in-order strategies (3, 4, 5 & 6)	Immediate	6,443	$17,143	$13,735
Moratorium on buying new ICE vehicles until BEVs become available					
8	Fuel Switch: E85 (passenger, pickups, vans)	Immediate	4,680	$20,208[34]	$99
9	Fuel Switch: B10 (annual blend, annualized – all diesel on-road units)	Immediate	6,261	$19,800	$99
11	Fuel Switch: CNG[35] LD (pickups)	Immediate	6,167	$20,253	$99
12	Fuel Switch: CNG MHD (Classes 3 to 6)	Immediate	6,105	$20,209	$99
13	Fuel Switch: CNG LMHD (Classes 2 to 8)	Immediate	4,969	$19,408	$99
14	Fuel Switch: RNG LMHD (Classes 2 to 8)	Immediate	1,194	$19,408	$99
15	Fuel Switch: LPG LD (passenger, pickups, vans)	Immediate	6,271	$19,840	$99
16	Fuel Switch: LPG LMHD (LD & Truck Classes 2 to 8)	Immediate	5,810	$18,291	$99
21	BEV: LD (passenger)	Immediate	6,454	$20,466	$99
22	BEV: LD (passenger)	2021	6,428	$20,052	$5,286
23	BEV: passenger, pickups, bus	2022	5,789	$19,966	$10,328
24	BEV: passenger, pickups, bus	2023	5,582	$20,800	$7,033

[34] Operating expenses were shown to increase with E85 due to reduced fuel-efficiency plus minor additional fuel-handling expenses.
[35] To data-model the additional capital costs for CNG and LPG, including both the conversion costs for LMD vehicles (or upgrades to CNG for new class 8 HD units), and the cost of one (1) CNG fast-fill station ($1.68m) or one (1) LPG station ($68k), we apportioned these costs across all units selected for CNG or LPG assessment. The cost of capital was applied to each unit selected for CNG or LPG modelling as an additional annual operating expense.

FAR #	Solution	Timing of Data Modelling	CO_2 (t)	Projected Operating Costs (1,000's)	Projected Capital Required (1,000's)
25	BEV: passenger, pickups, bus, MDHD trucks	2024	4,813	$19,528	$24,035
26	BEV: passenger, pickups, bus, MDHD trucks	2025	4,609	$21,357	$5,822
27	BEV: passenger, pickups, buses, MDHD trucks	2026	3,679	$20,781	$11,086
28	BEV: passenger, pickups, buses, MDHD trucks	2027	3,305	$21,660	$9,875
29	BEV: passenger, pickups, buses, MDHD trucks	2028	2,677	$21,771	$14,398
30	BEV: passenger, pickups, buses, MDHD trucks	2029	2,097	$21,987	$10,362
31	BEV: passenger, pickups, buses, MDHD trucks	2030	1,259	$21,408	$17,176
32	BEV: passenger, pickups, buses, MDHD trucks	2031	1,005	$22,180	$8,419
33	BEV: passenger, pickups, buses, MDHD trucks	2032	897	$21,827	$12,823
34	BEV: passenger, pickups, buses, MDHD trucks	2033	896	$20,044	$29,707
35	BEV: passenger, pickups, buses, MDHD trucks	2034	896	$22,205	$10,700
36	BEV: passenger, pickups, buses, MDHD trucks	2035	896	$21,755	$10,462

Figure 6: Low-Carbon and BEV Transition Plan for City of Hamilton



Synopsis – 15-Year LTCP Strategy

In *Table 8* and *Figure 6* (above), we are recommending a plan to the City of Hamilton that calls for a moratorium on purchasing new ICE vehicles for the short term (two years for pickups, four years for MHDVs), while waiting for battery-electric counterparts to become available. The exception, of course, is for LD passenger BEVs which are currently available, such as the Kia Souls being acquired by the City, as well as other comparable options such as the Chevrolet Bolt. Our position is that fleets should re-consider buying fossil-fuelled units because internal combustion engine (ICE) vehicles are quickly becoming an outdated and archaic technology, and BEV replacements will soon be available. The purchase of new ICE vehicles now, whether gasoline or diesel, means that a fleet, like the City of Hamilton's Fleet, will commit to using new fossil-fuelled vehicles for approximately the next decade when zero-emissions BEVs, which are often more economical than their fossil-fuel counterparts, are just around the corner.

If Hamilton decides to proceed with a plan that is similar to the one RSI-FC is suggesting and have a moratorium on purchasing new (otherwise fossil-fuelled) vehicles, we recommend, in the interim, to allocate capital towards charging infrastructure required for the transition to BEVs for all vehicle categories. While both the transition to CNG and BEVs requires large infrastructure investments, as will be outlined in the next section (*Section 4.0)*, the cost of a fast-filling CNG station (well in excess of $1m CAD) is far greater than that of a DC fast charger ($50-200k[36] CAD).

In *Figure 6* (above), we can see that while CO_2e emissions decrease sharply over the next 15 years according to the plan we have proposed, there is a slightly increasing trend in operating costs, which may be counterintuitive given the enormous fuel savings potential for BEVs. This occurs for two reasons: (1) the cost of capital is currently greater for BEVs and we have assumed this to be the case going forward; and (2) we have included compound inflation in our analysis at a rate of 2.2%.

Fuel cost savings, for some units, are not great enough to offset the increased cost of capital due to relatively low mileage. Of course, the higher the kilometres travelled, the stronger the business case for BEVs becomes. For the City of Hamilton, the relatively high usage of Class 3 trucks potentially makes these vehicle very suitable candidates for BEV replacement. There is the likelihood that the acquisition cost of BEVs will decline with time as both supply and demand increase, and as battery technology continues to improve. However, we did not want to make this assumption based on speculation; rather, our FAR analysis uses current, real data as much as possible and limits assumptions.

In terms of capital costs, from *Figure 6* (above) the average annual capital required for each year of RSI-FC's BEV phase-in plan is about $11.7m. This is reasonable considering that the current replacement cost of the entire in-scope fleet, from our baseline analysis, is about $112m. Estimating

[36] Source: https://www.toronto.ca/wp-content/uploads/2020/02/8c46-City-of-Toronto-Electric-Vehicle-Strategy.pdf

an average lifecycle to be 10 years, the annual capital required in our suggested LTCP is, roughly, on pace with the rate of depreciation ($112m divided by $11.7/year is roughly equal to 10 years).

Although some units did not show ROI when replaced with a BEV due to increased cost of capital, we phased-in BEVs until eventually, by 2035, all units with anticipated battery-electric options in the market would be replaced. Strictly through a lens of fiscal planning, our recommendation to the City of Hamilton is to replace units with BEVs *only if they would deliver ROI*. As mentioned, the relatively high-mileage Class 3 trucks potentially makes these vehicles very suitable candidates.

Solutions – Overview, Impacts, Feasibility, and Recommendations

Next, we provide details on all fuel-reduction solutions proposed in our 15-year low-carbon and BEV transition plan for the City of Hamilton. More details on all solutions that have been researched by RSI-FC, including the ones presented to the City, can be found in *Appendix E*.

Balanced Capex and Optimized Lifecycles

Overview

Once optimized lifecycles were modelled, it became apparent that some vehicles deliver better return-on-investment (ROI) than others. Some vehicles in the fleet may have received lighter usage than other similar age units, which may have been worked harder. For vehicles in better condition, their service life can be extended to optimize their lifetime total cost of ownership (TCO). Lower ROI would result if a vehicle, still in good condition, was replaced prematurely; value will be lost.

For Hamilton, the approach used by RSI-FC was to defer some vehicles to ensuing capital budget years to ensure full value is received from each unit. In data-modeling, without knowledge of the physical condition of units due for replacement based on vehicle ages, our analysts instead deferred vehicles showing low/no ROI to following budget years in order to balance annual year-over-year capital budgets. This step was intended to be an example of balancing long-term budgets using optimized lifecycles and ROI – in reality, fleet managers make similar decisions each year based on vehicle condition assessments and other information, such as maintenance history.

Impacts

In *Table 9*, we show the estimated impacts of optimized lifecycles, as determined by LCA, and balancing of long-term capital budgets as we have described. This scenario depicts “like-for-like” vehicle replacements (i.e., replacing gas-powered units with similar new gas-powered units) and prior to any new green fleet interventions.

Table 9: FAR Results for Balanced Capex & Optimized Lifecycles (FAR #3)

FAR Model No.	FAR Scenario	Timing	Vehicle Replacement Capex ($ mil)	Opex Impacts Over 2019 Baseline ($ mil)	GHG Reduction Over 2019 Baseline (t)
3	Balanced Capex and optimized lifecycles	*Immediate	13.7	-2.8	-17

* For data-modelling purposes, "immediate" is the one-year period immediately following the 2019 baseline.

Recommendations

- Consider adopting the RSI-FC recommended lifecycle analysis (LCA) approach to extract maximum value from each vehicle.
- Consider balancing go-forward capital budgets as part of long-term capital planning (LTCP) by deferring replacement of any units evaluated as being in above average, serviceable condition to later fiscal years.
- When the fleet's average age and uptime rates are determined to be at acceptable levels, consider re-investing in the fleet at the rate of depreciation.

Best Management Practices

Overview

Light-Weighting

Lighter vehicles consume less fuel, produce less emissions, and can carry larger payload. However, light-weighting may overstress some vehicles, increasing maintenance demand and lifecycle cost; therefore, fleet must exercise caution before choosing which vehicles to proceed with a light-weighting enhancement.

Low-Rolling Resistance Tires

Rolling resistance is the energy lost from drag and friction of a tire rolling over a surface[37]. The phenomenon is complex, and nearly all operating conditions can affect the final outcome. For heavy trucks, an estimated 15%–30% of fuel consumption is used to overcome rolling resistance.

[37] Source: https://afdc.energy.gov/conserve/fuel_economy_tires_light.html

A 5% reduction in rolling resistance would improve fuel economy by approximately 1.5% for light and heavy-duty vehicles. Installing LRR tires can help fleets reduce fuel costs. It's also important to ensure proper tire inflation (see section below).

Tires and fuel economy represent a significant cost in a fleet's portfolio. In Class 8 trucks, approximately one-third of fuel efficiency comes from the rolling resistance of the tire. The opportunity for fuel savings from low rolling resistance tires in these and other vehicle applications is substantial.

According to a North American Council for Freight Efficiency (NACFE) report, the use of low rolling resistance tires, in either a dual or a wide-base configuration, is a good investment for managing fuel economy. Generally, the fuel savings pay for the additional cost of the low rolling resistance tires. In addition, advancements in tire tread life and traction will reduce the frequency of low rolling resistance tire replacement.

Anti-Idling Policy and Technologies

An idling-reduction policy is a way to motivate fleet drivers to limit unnecessary idling. However, for an idling-reduction policy to be successful continuous enforcement such as spot-checks and fuel use tracking must be present. An idling-reduction policy could be used as an overarching commitment to idling reduction that is carried out though driver training and motivation sessions, rather than an initiative on its own.

There are several idling-reduction technologies available that can aid in idle reduction, including auxiliary power units (APU), stop/start devices, auxiliary cab heaters, battery backup systems, and block heaters/ engine preheaters. Their functionality, potential, and costs vary considerably and are described in *Appendix E* (FAR models a cost of $5,000 for all vehicle categories). To reap the most benefits any idling-reduction technology, installation should always be accompanied by behavioural solutions of driver training and motivation.

Driver Eco-Training

Driver training to modify driver behaviours and ongoing motivation to continue good behaviours are crucial components of successful idling-reduction programs. While most drivers understand the vehicle idling issue, many continue their inefficient practice of excessive idling due to lack of knowledge and/or motivation.

Driver training can be used to optimize the use of idle reduction technologies. The technologies can reduce idling but the drivers have the ability to override the technologies. Proper training can aid in utilizing the technologies to their full potential.

Further, driver training can promote good practices while on the road including progressive shifting, anticipating traffic flow, and coasting where possible.

Route Planning/Optimization and Trip Reduction

In addition to enhanced vehicles specifications and improved driver behaviours, fuel consumption and exhaust emissions can be further reduced through route planning/optimization and trip reduction.

Route planning software can be used optimize multi-stop trips. It can also be used for idling reduction initiatives by integrating GPS tracking software to monitor driver activity in real-time. Moreover, reporting and analytics features within route planning software can help with identifying when a fleet vehicle requires maintenance to ensure optimal fuel efficiency and thus minimize cost and emissions.[38]

Impacts

Each of the best management practices (BMPs) we analyzed have associated implementation costs which diminish the potential savings that can be attained. Regardless, each BMP we data-modelled was shown to potentially deliver Opex savings, as shown in *Table 10* (below). GHG reduction for each ranged from 361 to 1,669 tonnes. If all BMPs were fully and successfully implemented, we estimate that GHGs could be reduced by up to 2,928 tonnes with a net cost savings of almost $2.8m based on fuel cost reduction over the 2019 baseline. Again, this is based on a fleet configured as it is today at Hamilton with ICE vehicles only.

Table 10: FAR Results for Best Management Practices (BMPs) (FAR #4-7)

FAR Model No.	FAR Scenario	Timing	Vehicle Replacement Capex[39] ($ mil)	Opex Impacts Over 2019 Baseline ($ mil)	GHG Reduction Over 2019 Baseline (t)
4	Enhanced specs: light-weighting & LRR	Immediate[40]	13.7	-2.794	-361
5	Driver behaviours: driver eco-training & anti-idling policy/ technologies	Immediate[40]	13.7	-2.796	-1,669

[38] Source: https://blog.route4me.com/2020/05/carbon-emissions-reduction-route-optimization-helps-cut-tons-carbon-emissions/
[39] Based on Capex derived from optimized lifecycles from LCA and long-term Capex balancing
[40] For data-modelling purposes, "immediate" is the one-year period immediately following the 2019 baseline if the same vehicles, the same number of vehicles, travelling the same number of kilometres as the baseline period, were switched to the low-carbon solution(s) being modelled.

FAR Model No.	FAR Scenario	Timing	Vehicle Replacement Capex[39] ($ mil)	Opex Impacts Over 2019 Baseline ($ mil)	GHG Reduction Over 2019 Baseline (t)
6	TDM - route planning/optimization & trip reduction	Immediate[40]	13.7	-2.809	-1,277
7	FAR 7: All above "house-in-order" strategies	Immediate[40]	13.7	-2.769	-2,928

Recommendations

- Consider job suitability of vehicles before proceeding with light-weighting enhancements.
- In conjunction with driver training, consider route planning software, idling reduction initiatives and maintenance checks by integrating GPS tracking software to monitor driver activity and fuel consumption.
- Consider a fuel-efficient driver incentive program, such as through a green card initiative similar to one at the Lake Simcoe Region Conservation Authority in which drivers are incentivized to improve behaviours or reduce their travel through card stamping and prize draws[41].

Fuel Switching

Overview

Ethanol

Ethanol is a renewable fuel made from various plant materials known as biomass or feedstocks. Corn and wheat are most commonly used to produce ethanol. In most North American jurisdictions, renewable fuel standards require all gasoline sold to be a 5-10% ethanol blend (E5-10). Ethanol burns cleaner and more completely than gasoline or diesel fuel; blending ethanol with gasoline increases oxygen content in the fuel, thereby reducing air pollution[42].

[41] Source: ClimateWise Business Network. ClimateWise Member Spotlight: Lake Simcoe Region Conservation Authority
[42] Source: https://afdc.energy.gov/fuels/ethanol_fuel_basics.html

A higher blend of ethanol, known as E85 (85% ethanol, 15% gas) can lead to significant GHG reductions. The 15% gasoline is needed to assist in engine starting because pure ethanol is difficult to ignite in cold weather[43]. This fuel must be used in dedicated "flex-fuel" vehicles (FFVs), which can run on any combination of gasoline and ethanol blends (up to 85%).

In terms of tailpipe emissions, E85 has a GHG emissions reduction potential of about 30% when compared to the same volume of gasoline[44]. However, E85 contains about 27% less energy than gasoline per unit volume[45]. Given this energy loss, about 37% more E85 is required to achieve the same amount of work as gasoline. Therefore, the emissions reduction for the same work performed is actually about only 4% when compared to the energy equivalent of gasoline (i.e., for the same distance travelled the emissions for a vehicle running on E85 are 96% of those of a gasoline vehicle, which is 70% multiplied by 1.37 accounting for the additional volume required to achieve the same work).

Given the significant energy losses per unit volume as compared to gasoline, the cheaper cost of E85 per unit volume compared to gasoline does not offset the higher volume required to achieve the same distance travelled, likely making E85 more expensive than gasoline. Based on April 2020 fuel prices in the US, and accounting for energy equivalence (i.e., same distance travelled), E85 is about 16% costlier than gasoline[46].

If E85 is to be considered by Hamilton, it may be available at some retail fuel stations and can also potentially be delivered direct-to-vehicle. Alternatively, it could be stored and dispensed in bulk from an onsite fuelling station, but this would incur additional implementation costs. Ethanol tanks require a water monitoring system. In addition, a 10-micron filter, signage, and other upgrades are required to ensure the system is compliant. A pilot-test program is recommended to learn, with certainty, the efficiency impacts of using E85.

Biodiesel

Biodiesel is a renewable fuel made from vegetable oil and waste cooking oil, animal fats such as beef tallow and fish oil, and even algae oil[47]. Biodiesel is often referred to as fatty acid methyl ester or FAME[48].

Biodiesel can be blended in a variety of ratios with conventional fossil diesel. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix (e.g., B2 indicates

[43] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/ethanol/3493
[44] Source: http://www.patagoniaalliance.org/wp-content/uploads/2014/08/How-much-carbon-dioxide-is-produced-by-burning-gasoline-and-diesel-fuel-FAQ-U.S.-Energy-Information-Administration-EIA.pdf
[45] Source: https://afdc.energy.gov/fuels/ethanol_benefits.html
[46] Source: https://afdc.energy.gov/fuels/prices.html
[47] Source: https://www.nrcan.gc.ca/energy/alternative-fuels/resources/nrddi/3669
[48] Source: https://www.neste.com/what-difference-between-renewable-diesel-and-traditional-biodiesel-if-any

2% biodiesel and 98% fossil diesel). Biodiesel blends include: B2, B5, B10, B20, blends greater than B20, and B100 (100% biodiesel, also known as "neat" biodiesel).[49]

Canadian regulations require fuel producers and importers to have an average renewable fuel content of at least 2% based on the volume of diesel fuel and heating distillate oil that they produce or import into Canada.

Tailpipe GHG emissions reductions are dependent on the biodiesel blend used; for a given unit mass or volume, the higher the blend, the lower the GHG emissions. B20, in particular, reduces CO_2 by 15% in comparison to conventional diesel per unit mass/volume[50]. However, actual tailpipe emissions reduction potential for the same distance travelled is dependent on both GHG emissions per unit mass/volume and fuel economy. B5 has been shown to improve fuel economy by as much as 10% in comparison to conventional diesel[51], whereas fuel economy can be 2% lower for B20 and as much as 10% lower for B100 (pure or "neat" biodiesel)[52]. Therefore, there may be a "sweet spot" for optimizing fuel economy and GHG emissions reduction using blends from B5 to approaching B20. Using blends in this range improves fuel economy and lowers GHG tailpipe emissions on the order of approximately 10 percent. Using biodiesel can also reduce several other tailpipe emissions including particulates and unburned hydrocarbons[53]. Moreover, the lifecycle CO_2 emissions can be significantly lower for biodiesel than for conventional diesel[54].

Natural Gas

Natural gas (NG), a fossil fuel composed of mostly methane, is one of the cleanest burning alternative fuels. It is also considered safer than traditional fuels since, in the event of a spill, NG is lighter than air and thus disperses quickly when released. NG can be used in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) to fuel cars, buses, and trucks. Vehicles that use NG in either form are called natural gas vehicles (or NGVs).

NG is found in abundance in porous rock formations and above oil deposits. After NG is extracted from the ground, it is processed to remove impurities and compressed to be stored and transported by pipeline. CNG is used in traditional gasoline internal combustion engine vehicles that have been modified, or in vehicles which were manufactured for CNG use, either alone (dedicated), with a segregated gasoline system to extend range (dual-fuel), or in conjunction with another fuel such as

[49] Source: https://www3.epa.gov/region9/waste/biodiesel/questions.html
[50] Source: https://www.fueleconomy.gov/feg/biodiesel.shtml
[51] Source: https://www.consumerreports.org/cro/2012/05/diesel-vs-biodiesel-vs-vegetable-oil/index.htm
[52] Source: https://www.fueleconomy.gov/feg/biodiesel.shtml
[53] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/biodiesel/3509
[54] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/biodiesel/3509

diesel (bi-fuel). CNG is most commonly used in fleet vehicles like buses and heavy-duty trucks because it requires a larger fuel tank than gasoline and diesel fuel[55].

CNG has a higher energy content per unit mass than diesel but requires more storage space because it is less dense[56]. Unlike diesel, which is stored in liquid form, CNG is stored as a gas under high pressure. For this reason, the energy density and cost of natural gas is usually provided per unit mass (kg) instead of per unit volume (litres).

To compare energy on an apples-to-apples basis, we must look at the amount of natural gas required to obtain the same energy content as a litre of diesel, also known as the diesel-litre equivalent (DLE). The DLE of one kilogram of natural gas is 1.462 litres[57]. We can also understand this concept through the inverse relationship – 0.684 kg of natural gas are required to get the same energy content as one litre of diesel. However, a natural gas engine uses about 12% more natural gas than a comparably-sized diesel engine[58]. Therefore, the actual amount of natural gas required to obtain the same energy content as one litre of diesel is an estimated 0.77 kg.

Based on the same work performed and confirmed through the above analysis, a CNG vehicle has tailpipe emissions about 20-30% less than a comparable diesel or gasoline vehicle[59,60]. NGVs also emit up to 95% less nitrogen oxides (NO_x) compared to diesel and gasoline vehicles[61]. Furthermore, CNG vehicles do not emit particulate matter (PM10), a main cause of air pollution[62].

Renewable Natural Gas

RNG, or biomethane, is a fully renewable energy source that is fully interchangeable with conventional natural gas. Like conventional natural gas, RNG can be used as a transportation fuel in the form of CNG or LNG.

RNG production has become an important priority thanks to its environmental benefits. RNG production is usually based on capturing and purifying the gas from collected organic waste — anything from crop residues and animal manures to municipal organic wastes and food processing by-products.

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[55] Source: https://consumerenergyalliance.org/2019/04/energy-explorer-cng-vs-lng/#:~:text=The%20reason%20you%20see%20CNG,requires%20a%20larger%20fuel%20tank.&text=Like%20CNG%2C%20LNG%20is%20compressed,state%20into%20a%20liquid%20state.
[56] Source: https://www.eia.gov/todayinenergy/detail.php?id=9991
[57] Source: http://cngva.org/wp-content/uploads/2017/12/Energy-Content-Factsheet-FINAL-EN.pdf
[58] Source: http://cngva.org/wp-content/uploads/2017/12/Energy-Content-Factsheet-FINAL-EN.pdf
[59] Source: https://brc.it/en/categorie_faq/cng/
[60] Source: https://envoyenergy.ca/cng-benefits/#:~:text=Commercial%20fleets%20all%20over%20the,solution%20for%20fuelling%20their%20fleets.
[61] Source: Northwest Gas Association – Natural Gas Facts
[62] Source: https://brc.it/en/categorie_faq/cng/

The use of RNG is a natural progression from the use of fossil-based CNG. While use of natural gas as fuel requires large infrastructure investments, RNG has a very high emissions reduction potential; different sources estimate the lifecycle emissions reduction to be between 75% and 90% compared to diesel. The carbon dioxide that is generated during the production and combustion of RNG is used in the regeneration of new biomass, representing a closed-loop cycle for carbon dioxide that is released[63].

Liquified Petroleum Gas

Propane, otherwise known as liquefied petroleum gas (LPG), is produced as part of natural gas processing and crude oil refining. In natural gas processing, the heavier hydrocarbons that naturally accompany natural gas, such as LPG, butane, ethane, and pentane, are removed before the natural gas enters the pipeline distribution system. In crude oil refining, LPG is the first product that results in the refining process.

Propane is a gas that can be turned into a liquid at a moderate pressure (160 pounds per square inch). It is stored in pressure tanks at about 200 psi and 100 degrees Fahrenheit. When propane is drawn from a tank, it changes to a gas before it is burned in an engine.

Propane has been used as a transportation fuel since 1912 and is the third most commonly used fuel in the United States, behind gasoline and diesel. More than four million vehicles fuelled by propane are in use around the world in light-, medium- and heavy-duty applications. Propane holds approximately 86% of the energy of gasoline and so requires more storage volume to drive a range equivalent to gasoline, but it is usually price-competitive on a cents-per-km-driven basis.

In terms of tailpipe emissions, propane has a GHG emissions reduction potential of about 31% when compared to the same volume of gasoline based on GHGenius version 3.11. However, as mentioned, propane contains about 14% less energy than gasoline per unit volume. Given this energy loss, about 16% more fuel is required to achieve the same amount of work as gasoline. Therefore, the emissions reduction for the same work performed is actually around 20% when compared to the energy equivalent of gasoline (i.e., for the same distance travelled the emissions for a vehicle running on propane are about 80% of those of a gasoline vehicle, which is 69% multiplied by 1.16 accounting for the additional volume required to achieve the same work).

Feasibility Considerations

Ethanol

- E85 can be used in flex-fuel ready gasoline vehicles with no further modifications.

[63] Source: Closing the Loop. Canadian Biogas Association. 2015.

- There are no infrastructure costs associated with E85 use if a fuelling station is attended or if E85 is delivered direct-to-vehicle.

- Alternatively, E85 could be stored and dispensed in bulk from an onsite fuelling station, but this would incur additional implementation costs.

- E85 is a cleaner burning fuel than gasoline, thereby reducing air pollution. This can result in cleaner intake valves and fuel injectors, and reduced knocking and pinging[64].

- E85 can improve vehicle performance (acceleration) because of its higher octane content[65].

- Given the significant energy losses per unit volume as compared to gasoline, the cheaper cost of E85 per unit volume compared to gasoline does not offset the higher volume required to achieve the same distance travelled, likely making this solution cost-prohibitive. In-fleet pilot testing is recommended.

- E85 cannot be used in small equipment such as most portable generators and other small engines, so a dedicated fuel tank would be required for exclusive use by flex-fuel capable vehicles only.

Biodiesel

- Blends of B20 and lower can be used in diesel equipment with no modifications, although certain manufacturers do not extend warranty coverage if equipment is damaged by poor quality fuel in these blends (see details in *Appendix D*).

- Since there are no vehicle conversion or infrastructure costs associated with biodiesel use, biodiesel could be immediately introduced to begin reducing fuel-use and emissions.

- Keeping biodiesel to a lower blend (i.e., B5 or B10) will have better cold weather operability properties than a higher blend (i.e., B20 +) due to thickening at low temperatures.

- Although production is abundant, there are a limited number of biodiesel vendors and distributors.

- Due to thickening at low temperatures, it may be prudent to store biodiesel fuel in a heated building or storage tank, as well as heat the fuel system's fuel lines, filters, and tanks.

- Biodiesel is as safe in handling and storage as petroleum-based diesel fuel.

[64] Source: https://driving.ca/chevrolet/auto-news/news/western-canadas-first-e85-ethanol-gas-station-ready-to-pump
[65] Source: https://www.canadianmanufacturing.com/regulation/ethanol-market-chasing-us-canadas-fueling-options-flatline-142054/

Natural Gas

- New NGVs for Class 5-8 vehicles may cost up to $50,000 ($45,000 modelled in FAR) more than their conventional diesel counterparts; therefore, the payback period may be substantial for lower mileage units.

- New NGVs for light-duty vehicles (LDVs) may cost up to $10,000 ($7,500 modelled in FAR) more than their conventional gasoline counterparts. In this case, depending on kilometres-travelled, the payback period may still be substantial.

- CNG fast-filling station infrastructure costs could run to $1m CAD or much more, ($1.68m modelled in FAR) depending on capacities and complexity, and this may be a conservative estimate. Slow-fill refuellers may be an option, but caution must be exercised to ensure protracted filling time does not create operational challenges.

- An operational concern is that in certain situations, such as a long-duration electrical power interruption, CNG compressor or other fuel system failure, etc., dedicated CNG vehicles (i.e., vehicles powered solely by CNG) would be sidelined, and this is a risk that must be managed.

- Unless subsidies were available to offset the cost, a major investment in an NG fueling system would need to be a long-term capital investment for it to be financially viable.

- CNG is still a non-renewable fossil fuel (albeit a clean-burning one).

- CNG may be a viable short-term solution for GHG reduction while awaiting suitable BEVs to become available. However, a ***long-term investment*** in very costly CNG fuelling infrastructure to support a ***short-term GHG reduction solution*** does not seem to be a prudent choice.

Renewable Natural Gas

- Without the commercial availability of RNG, there must be investment in an anaerobic digester to make RNG, adding to the already large cost of $1m or much more to build a CNG fuelling station and the significant additional cost of vehicle retrofits and/or new vehicle upgrades to CNG. Moreover, the quality of the RNG must be ensured to be of high enough standard to be used in natural gas-powered vehicles.

- Unlike CNG which would likely offer fuel cost savings, compressed RNG is approximately equal in price to diesel and gasoline in terms of diesel litre equivalent (DLE)[66]. Therefore, in many situations the use of RNG may not be a financially viable option. In our FAR modelling

[66] Source: https://www.canadianmanufacturing.com/regulation/ethanol-market-chasing-us-canadas-fueling-options-flatline-142054/

we assumed RNG price parity with fossil NG since no published market prices were available for RNG.

Liquified Propane Gas

- Propane vehicle conversions and fueling systems generally cost much less than natural gas systems, modelled at $6,000 and $68,000, respectively, in FAR. Depending on kilometres-travelled, the payback – and the payback period – may still be substantial.

Recommendations

Ethanol

- Consider the challenges associated with switching to E85, including supply, any additional infrastructure costs, and whether the potentially greater fuel cost is financially prudent. Should the City proceed with this solution, consider a pilot project with several units switched to E85 to determine the fuel-efficiency loss; if successful, consider a phased-in approach for other appropriate units.

Biodiesel

- Some precautions must be taken before making the switch to biodiesel, including using a lower blend due to viscosity issues at cold temperatures. We recommend using a blend of 5% in winter and 20% in the summer and shoulder months.

- Consider a pilot project with several units switched to biodiesel, and if successful a phased-in approach for other appropriate units.

Natural Gas (including Renewable Natural Gas)

- If CNG is of interest to the City, we recommend investigating subsidies for CNG upgrades and a CNG vehicle fuelling station.

- Consider a small-scale pilot project with several high-mileage units switched to CNG, and if successful a phased-in approach for other appropriate units.

Liquified Propane Gas

- If a strong business case for LPG can be shown for high-mileage units, consider a small-scale pilot project with several high-mileage units switched to CNG, and if successful a phased-in approach for other appropriate units.

Impacts

The potential impacts of the above-described fuel switching solutions are shown in *Table 10* (below). In reviewing *Table 11*, it is important to note the major reduction in Capex which is reflective of our recommendation to have a temporary moratorium on replacing end-of-lifecycle ICE vehicles with new ICEs.

Table 11: FAR Results for Fuel-Switching Scenarios (FAR #8-16)

GROUP TWO SOLUTIONS – FUEL-SWITCHING					
FAR Model No.	FAR Scenario[67]	Timing	Vehicle Replacement Capex ($ mil)	Opex Impacts Over 2019 Baseline ($ mil)	GHG Reduction Potential Over 2019 Baseline (t)
8	**E85** (85% ethanol) fuel (passenger, pickups, vans)	Immediate[68]	0.099[69]	+0.3	-4,691
9	**B10** (10% avg. biodiesel - all diesel on-road units)	Immediate[68]	0.099[69]	-0.11	-3,110
11	**Compressed Natural Gas (CNG)** (LD pickups)	Immediate[68]	0.099[69]	+0.34[70]	-3,204
12	**CNG** (Classes 3-6)	Immediate[68]	0.099[69]	+0.3[70]	-3,266
13	**CNG** (Classes 2-8)	Immediate[68]	0.099[69]	-0.5[70]	-4,402
14	**Renewable Natural Gas (RNG)** (Classes 2-8)	Immediate[68]	0.099[69]	-0.5[70]	-8,177

[67] Impacts from fuel-switching and BEV phase-in scenarios include, and build on, Group One scenarios (FAR #7).
[68] For data-modelling purposes, "immediate" is the one-year period immediately following the 2019 baseline if the same types of vehicles, the same number of vehicles, travelling the same number of kilometres as the baseline period, were switched to the low-carbon solution(s) being modelled.
[69] The Capex decrease shown is reflective of a recommended moratorium on purchasing new gas- and diesel-powered internal combustion engine (ICE) vehicles until battery-electric units become available (see report).
[70] For data-modelling purposes, the annual cost of capital for CNG or LPG new vehicle upgrades or conversions of existing vehicles were calculated and treated as annual vehicle operating costs (Opex), and then added to each unit's operating expenses. CNG/LPG fuelling infrastructure investment costs were apportioned and also treated as additional vehicle annual operating costs for all units modelled as CNG or LPG. The fast-fuelling system cost assumptions were $1.68M for CNG and $68k for LPG.

GROUP TWO SOLUTIONS – FUEL-SWITCHING					
FAR Model No.	FAR Scenario[67]	Timing	Vehicle Replacement Capex ($ mil)	Opex Impacts Over 2019 Baseline ($ mil)	GHG Reduction Potential Over 2019 Baseline (t)
15	**Liquified Propane Gas (LPG)** (LD units - passenger vehicles, pickups, vans)	Immediate[68]	0.099[69]	-0.072[70]	-3,100
16	**LPG** (LD and Truck Classes 2-8)	Immediate[68]	0.099[69]	-1.6[70]	-3,561

Battery-Electric Vehicles

Overview

Globally, vehicles are steadily moving away from the internal combustion engine toward zero-emission battery-electric vehicles (BEVs) and, eventually, hydrogen fuel cells.

Air quality is a growing concern in many urban environments and has direct health impacts for residents. Tailpipe emissions from internal combustion engines are one of the major sources of harmful pollutants, such as nitrogen oxides and particulates. Diesel engines in particular have very high nitrogen oxide emissions and yet these make up the majority of the global fleet. As the world's urban population continues to grow, identifying sustainable, cost-effective transport options is becoming more critical. Battery-electric vehicles (BEVs) are one of the most promising ways of reducing harmful emissions and improving overall air quality in cities.

Fleet managers who operate BEVs will see savings in maintenance and fuel costs. BEVs have considerably fewer parts than internal combustion engine (ICE) vehicles. A drivetrain in an ICE vehicle contains more than 2,000 moving parts, compared to about 20 parts in an BEV drivetrain. This 99% reduction in moving parts creates far fewer points of failure, which limits and, in some cases, eliminates traditional vehicle repairs and maintenance requirements, creating immense savings for fleet managers. BEVs do not require oil changes or tune-ups, do not require diesel exhaust fluid (DEF), and their brake lining life is greatly extended over standard vehicles due to regenerative braking. Though each fleet's electrification journey will be different, the transition to electricity offers significant cost reductions over the long term.

There has also been significant expansion in charging infrastructure through publicly available charging stations. As of early 2020, there were nearly 5,000 charging outlets across Canada, and

Natural Resources Canada is investing $130 million from 2019-2024 to further expand the country's charging network, making range anxiety even less of a barrier to BEV ownership.

Upstream Emissions

From a broader perspective, to have almost none or zero well-to-wheel emissions, the electricity used to recharge the batteries must be generated from renewable or clean sources such as wind, solar, hydroelectric, or nuclear power. In other words, if BEVs are recharged from electricity generated by fossil fuel plants, they cannot truly be considered as zero emission vehicles (ZEVs). Upstream emissions should be considered when evaluating the effectiveness of ZEVs in reducing emissions. Generally, when considering upstream emissions from electricity supply, BEVs still emit more than 50% less GHG emissions than their gasoline or diesel counterparts[71], and in some cases emit more than 80% less in a grid composed of mostly renewable electricity[72]. This level of emissions reduction is what cities need in order to collectively achieve the "deep decarbonization" necessary to mitigate the most serious impacts of climate change.

Battery-Electric Trucks

A new study[73] quantified what commercial EV-makers have been saying for years: electric trucks are a triple win. They save money for fleet operators, and reduce both local air pollution and GHG emissions. The study, which was commissioned by the National Resources Defense Council (NRDC) and the California Electric Transportation Coalition, and conducted by the international research firm ICF, looked at the value proposition for fleet operators of battery-electric trucks and buses (and apparently invented a new acronym: BETs).

Today, BETs have a significant upfront price premium compared to legacy diesel trucks and buses. However, the costs of battery packs and other components are rapidly falling, and the study found that, by 2030 or earlier, electric vehicles will offer a lower total cost of ownership (TCO) for nearly all truck and bus classes, even without incentives.

Medium- and heavy-duty battery-electric trucks are quickly being developed by many manufacturers. BETs offer a multitude of benefits, including:

- Less noise pollution
- Zero tailpipe GHG emissions
- Oil-free operation with very few moving parts

[71] Source: https://www.eei.org/issuesandpolicy/electrictransportation/Pages/default.aspx
[72] Source: https://blog.ucsusa.org/rachael-nealer/gasoline-vs-electric-global-warming-emissions-953
[73] Source: Posted January 2, 2020 by Charles Morris (https://chargedevs.com/author/charles-morris/) & filed under Newswire (https://chargedevs.com/category/newswire/), The Vehicles (https://chargedevs.com/category/newswire/the-vehicles/)

- Simple, low-maintenance electric powertrain with few components
- Longer lasting brakes due to regenerative braking system
- Potential to significantly extend range due to high regenerative braking from carrying heavy loads[74]. The heavier the truck load, the greater the energy produced from regenerative braking.
- Overnight recharging when the vehicle is not in operation and when demand for electricity is lower, which reduces energy costs
- Massive savings potential in total energy costs and service costs
- Competitive lifecycle costs over a 10-year operating life and are better suited over gasoline, diesel, or CNG when accounting for future economic trends

Electric Refuse Trucks

There is an existing and growing market for electric refuse trucks. Several manufacturers have battery-electric refuse trucks on the market (e.g., Volvo, Mack, BYD, Lion Electric), while other companies have converted existing refuse trucks to battery-electric (e.g., Motiv, Emoss). In additional to the benefits previously listed for battery-electric trucks at large, battery-electric refuse trucks offer:

- Range up to and exceeding 200 km[75] for a full day of operation (1,200 homes) on a charge
- Optimal visibility and turning radius
- No hydraulic pumps, valves, tubing, hoses, and fluid
- Arm and body movements powered by battery that drives electric motors for each function
- Savings of up to 80% on total energy costs and up to 60% on service costs

Diesel and CNG refuse trucks require much more input energy to achieve the required outcome relative to electric refuse trucks. Diesel and CNG refuse trucks are approximately 5 and 5.8 times less efficient than battery-electric refuse trucks, respectively, while hydrogen fuel cell electric trucks are approximately 1.8 times less efficient. This is because:

- Internal combustion engines (ICEs) are much less efficient than electric motors in converting input energy to output motion.

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[74] Source: https://www.firstpost.com/tech/science/worlds-largest-electric-vehicle-is-a-110-tonne-dump-truck-that-needs-no-charging-7190131.html
[75] Source: https://electrek.co/2018/05/09/volvo-all-electric-garbage-truck/

- ICEs use energy when the truck is idling, coasting or braking. Electric motors not only don't use energy during these operations, they can act as a generator when coasting or braking, generating energy in a process known as regenerative braking.

- The heavier the refuse truck load, the greater the energy produced from regenerative braking. Depending on the topography of the collection zone, an optimized route can be analysed to further increase the energy efficiency of electric refuse trucks.

Impacts

The potential impacts of BEV phase-in solutions are shown in *Table 12*. It is important to note that Capex and Opex are average values over the implementation periods shown and GHG reduction potential values are cumulative impacts over the implementation periods shown.

Table 12: FAR Results for BEV Phase-in Scenarios (FAR #21-36)

GROUP THREE – BATTERY-ELECTRIC VEHICLE PHASE-IN					
FAR Model No.	FAR Scenario[76]	Timing	Average Vehicle Replacement Capex[77] ($ mil)	Average Opex Impact[77,78,79] Over 2019 Baseline ($ mil)	Total GHG Reduction[77] Over 2019 Baseline (t)
21-22	BEV phase-in (passenger vehicles only)	Immediate[80] - 2021	2.7	+.35	-2,943
21-24	BEV phase-in (passenger vehicles starting immediately-2022 and pickups in 2022)	Immediate[80] - 2022	5.7	+.47	-3,789

[76] Impacts from fuel-switching and BEV phase-in scenarios include, and build on, Group One scenarios (FAR #7).
[77] For data modelling purposes, the increased cost of capital for the additional purchase cost of BEVs were treated as annual operating expense increases for all BEV units modelled. The annual cost of capital for infrastructure investment in Level 2 charging (one Level 2 charger for every two BEVs) was apportioned and allocated to each BEV modelled, also as an increase in Opex.
[78] Capex and Opex impacts are averages for the implementation periods shown. GHG impacts are cumulative.
[79] Includes the impact of compounding inflation for each year of the 15-year period at current rate of inflation
[80] For data-modelling purposes, "immediate" is the one-year period immediately following the 2019 baseline if the same vehicles, the same number of vehicles, travelling the same number of kilometres as the baseline period, were switched to the low-carbon solution(s) being modelled.

GROUP THREE – BATTERY-ELECTRIC VEHICLE PHASE-IN					
FAR Model No.	FAR Scenario[76]	Timing	Average Vehicle Replacement Capex[77] ($ mil)	Average Opex Impact[77,78,79] Over 2019 Baseline ($ mil)	Total GHG Reduction[77] Over 2019 Baseline (t)
21-36	**BEV phase-in** (passenger vehicles starting immediately, pickups starting in 2022, and medium- and heavy-duty (MHD) trucks starting in 2024)	Immediate[80] - 2035	11.7	+1.2	-8,475

BEV Feasibility Considerations

- DC fast charging installation requires a commercial electrician[81] and costs an estimated $50,000 - $200,000 for equipment and installation[82].
- Overnight charging infrastructure may be more feasible than in-route charging infrastructure if there is limited service amperage[83].
- Heavy-duty trucks charged in a garage between 50 and 100 kW (equivalent to DC fast charging) would potentially take several hours to charge[84]. Caution must be exercised to ensure longer charging times do not create operational challenges.
- Extreme cold temperatures can significantly reduce range in BEVs due to heating of the cabin and heating of the battery itself[85]. Therefore, it is important account for this when purchasing BEVs to ensure sufficient range is provided to cover a day's worth of routes in the heart of winter.

[81] Source: https://calevip.org/electric-vehicle-charging-101
[82] Source: https://www.toronto.ca/wp-content/uploads/2020/02/8c46-City-of-Toronto-Electric-Vehicle-Strategy.pdf
[83] Source: https://www.masstransitmag.com/home/article/12291796/bus-electrification-choosing-the-right-charging-method
[84] Source: https://www.plugincanada.ca/electric-bus-faq/
[85] Source: https://www.geotab.com/blog/ev-range/

- Power grid failure or local failure at a garage could pose a significant risk to operations. To mitigate this risk, backup generators can deal with short power outages. For longer outages, larger generators would be needed, but this would come at a very expensive cost. [86]

Recommendations

- Consider a pilot project for several BEVs when they become available (e.g., pickups) to track range capabilities and cost savings and assess the units' performance for all seasons and varying weather conditions.

- Assuming the pilot project is successful, consider acquiring BEVs in bulk to replace units that would provide the greatest ROI.

- Continue to closely monitor the acquisition costs for BEVs and re-evaluate the business case (cost-benefit) for individual units as prices come down. Also continue to monitor the future availability of electric work/cargo vans, which are currently not anticipated to be offered in battery-electric versions in the near future.

- If relying on overnight charging infrastructure, consider supplying power to the garage on two separate feeds from the grid to reduce the risk of local failure taking power away from the whole site[87].

- Consider high-voltage training for technicians and closely monitor the launch of new BEV training programs. A pilot for a new EV Maintenance Training Program for automotive technicians was successfully completed at BCIT and will be available to the public soon[88]. There is also an Electric Vehicle Technology Certificate Program offered by SkillCommons, managed by the California State University and its MERLOT program, which offers free and open learning materials electric vehicle development, maintenance, alternative/renewable energy, and energy storage[89].

Additional Considerations

B100 Biodiesel

In early 2020, a breakthrough technology allowed high-use dump trucks to run on 100% biodiesel (B100) in Ames, Iowa, a city that experiences extreme winters with blizzards and temperatures below -20°C. The following outlines how the system works[90]:

[86] Source: https://www.plugincanada.ca/electric-bus-faq/
[87] Source: https://www.plugincanada.ca/electric-bus-faq/
[88] Source: https://commons.bcit.ca/news/2019/12/ev-maintenance-training/
[89] Source: http://support.skillscommons.org/showcases/open-courseware/energy/e-vehicle-tech-cert/
[90] Source: Renewable Energy Group (REG). Getting Aggressive on Sustainability [pdf]. 2020.

- The fuel delivery system has a split tank – one for petroleum diesel and the other one for biodiesel installed on the truck.
- In cold weather, diesel is used on start-up. The system warms the biodiesel and automatically switches to B100.
- At shut-off, the truck idles for a couple minutes while the B100 is purged from the lines.

There have been no operational concerns from operators or service technicians, and B100 has proven to be an easy and extremely effective way for the City of Ames to have an immediate impact on its fleet GHG emissions. This potentially can be an additional and highly effective interim solution considered by the City of Hamilton.

NRCan Zero Emission Vehicle Infrastructure Program

The Government of Canada is committed to helping accelerate the decarbonization and electrification of our transportation sector, and charging infrastructure is a key component to achieving this. As mentioned earlier, Natural Resources Canada (NRCan) is investing $130 million from 2019-2024 to further expand the country's charging network, particularly level 2 and higher stations.

The funding will be delivered through cost-sharing contribution agreements for eligible projects, including:

- BEV charging infrastructure in parking areas intended for public use (e.g., service stations, restaurants, libraries, etc.);
- On-street charging infrastructure;
- Workplace charging infrastructure;
- On-road light-duty vehicle fleet (including municipal fleets);
- On-road medium- or heavy-duty vehicle fleets (including refuse trucks and public utility vehicles);
- Charging infrastructure for multi-unit residential buildings (MURBs); and
- Public transit charging infrastructure.

The City of Hamilton would be eligible for funding based on the project criteria listed above, however the funding window has since closed. NRCan's contribution through this program will be limited to

50% of total project costs, and the maximum funding and approximate costs for each type of charging infrastructure is shown in *Table 13* (directly taken from NRCan's website[91] with costs and charging rates from the City of Toronto's Electric Vehicle Strategy Report[92]):

Table 13: Specifications for NRCan's Zero Emission Vehicle Infrastructure Program, plus Approximate Total Costs and Charging Rates

Type of Infrastructure	Output	Maximum NRCan Funding	Total Costs (Equipment + Installation)	Approximate Charge Rate Per Hour
AC Level 2 (208/240V) Connectors	3.3 kW - 19.2kW	Up to 50% of total project cost, to a maximum of $5,000 per connector*	$5,000 - $10,000	40 km
DC Fast Charger	20 kW - 49 kW	Up to 50% of total project cost, to a maximum of $15,000 per fast charger	-	-
DC Fast Charger	50 kW and above	Up to 50% of total project cost, to a maximum of $50,000 per fast charger	$50,000 - $200,000	300+km

* To calculate the funding for level 2 chargers, each connector can count as a unit towards the minimum of 20 chargers if each connector can charge a vehicle at the same time.

Battery Replacement and Energy Storage

Most, if not all, BEV manufacturers have an eight-year or 100,000 mile (160,000 km) warranty on their batteries – whichever one (i.e., vehicle age or distance travelled) comes first[93]. However, the current prediction is that an EV battery will last from 10-20 years, depending on usage, before it needs to be replaced[94]. Consumer Reports estimates the average EV battery pack's lifespan to be at around 200,000 miles (320,000 km), which is nearly 17 years of use if driven 12,000 miles (19,200 km) per year. Therefore, in most cases, the vehicle will reach its end-of-life before there is a need for battery replacement.

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[91] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/zero-emission-vehicle-infrastructure-program/21876
[92] Source: https://www.toronto.ca/wp-content/uploads/2020/02/8c46-City-of-Toronto-Electric-Vehicle-Strategy.pdf
[93] Source: https://www.myev.com/research/ev-101/how-long-should-an-electric-cars-battery-last
[94] Source: https://www.edfenergy.com/electric-cars/batteries

When battery capacity falls below 80%, drivers may start to see a noticeable decline in range[95] – which would most likely occur at or after the typical vehicle replacement age because battery degradation is a very gradual process[96]. Once the EV battery capacity becomes undesirable for powering a vehicle, it can be used to power a building by contributing to a battery storage system, which stores energy from a battery that can be used at a later time[97]. For example, if a building is powered by renewable energy such as wind or solar, an “old” EV battery can be used to store energy produced while the wind is blowing or the sun is shining, and then release the stored energy during low-wind periods or at night. This method of generating electricity has multiple benefits, including:

- An effective way of continuing the life of an old EV battery;
- Reducing energy used from the grid, thereby reducing energy costs; and
- Increasing energy security when using renewables, which have variable energy outputs, by releasing stored energy during off-peak times.

When batteries do reach the end of their working life, they can be recycled, which typically involves separating out valuable materials such as cobalt and lithium salts, stainless steel, copper, aluminium, and plastic. Currently, about half of the materials in an EV battery pack are recycled, but with EVs expected to undergo an explosion in popularity over the next decade or so, car manufacturers are looking to improve this.[98]

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[95] Source: https://www.edfenergy.com/electric-cars/batteries
[96] Source: https://www.myev.com/research/ev-101/how-long-should-an-electric-cars-battery-last
[97] Source: https://www.edfenergy.com/electric-cars/batteries
[98] Source: https://www.edfenergy.com/electric-cars/batteries

Section 5.0: Summary of Key Recommendations

In this section, we summarize our main recommendations for Hamilton's Green Fleet Strategy (*Table 14*). Recommendations are from *Section 2.0*, in which we identified potential opportunities for improvement of the City's fleet management practices, as well as from *Section 4.0*, in which we presented a 15-year long-term capital planning (LTCP) strategy and detailed fuel-reduction solutions for the City's consideration.

Table 14: Summary of Key Recommendations for Hamilton's Green Fleet Strategy

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[99]/ Next Step
1	2	Asset Management	• Follow a historical data-driven lifecycle cost assessment, which is completed by modelling repair, maintenance, fuel, and cost of capital over the vehicle's entire lifecycle to determine the optimal replacement age of vehicles.	Immediate
2	2	Asset Management	• Consider implementing the green fleet asset management best practices recommended by RSI-FC as illustrated in the process flow chart (Page 25). With these processes the fleet will become green and right-sized.	Immediate
3	2	Vehicle Specifications	• Employ a total cost of ownership (TCO) approach to optimize the use of capital. • Consider TCO in competitive bidding proposal structures instead of the lowest compliant bid approach.	Immediate
4	2	Information Technology	• Create an education piece for idling reduction, operating efficiently, and reducing fuel consumption.	Immediate
5	2	Human Resources	• Add a driver eco-training module to existing Professional Driver Improvement Course (PDIC) safe driver training and consider eco-driver training for all drivers.	Immediate

[99] Immediate = 2021; short-term = 2022-2024; long-term = 2024-2035

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[99]/ Next Step
6	2	Fuel Management	• Measure and track fuel consumption and GHGs at the department and user-group levels to track progress and set tangible goals.	Immediate
7	2	Environment (LEED)	• Modernize and/or retrofit Fleet facilities to obtain LEED certification.	May need additional analysis (outside scope of this report)
8	2	Environment (BEVs)	• Invite frontline employees to take BEV test drives to build an affinity towards electric vehicles.	Immediate & short-term as additional BEV models become available
9	4	Deferred Spending (BEV Transition)	• If possible, avoid buying ICE replacement vehicles until suitable BEVs become available.	Immediate & short-term
10	4	15-Year LTCP Strategy	• Strictly through a lens of fiscal planning, prioritize replacement of units with BEVs *only if they would deliver return-on-investment (ROI)*.	Immediate, short-term & long-term
11	4	15-Year LTCP Strategy	• Allocate capital for charging infrastructure in the near-future to meet the demand in the mid- to long-term.	Immediate & short-term
12	4	Balanced Capex and Optimized Lifecycles	• Consider adopting the RSI-FC recommended lifecycle analysis (LCA) approach to extract maximum value from each vehicle.	Immediate
13	4	Balanced Capex and Optimized Lifecycles	• Consider balancing go-forward capital budgets as part of LTCP by deferring replacement of any units evaluated as being in above average, serviceable condition to later fiscal years.	Immediate
14	4	Balanced Capex and Optimized Lifecycles	• When the fleet's average age and uptime rates are determined to be at acceptable levels, consider re-investing in the fleet at the rate of depreciation.	Short-term

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[99]/ Next Step
15	4	Best Management Practices	• Consider job suitability of vehicles before proceeding with light-weighting enhancements.	Immediate
16	4	Best Management Practices	• In conjunction with driver training, consider route planning software, idling reduction initiatives and maintenance checks by integrating GPS tracking software to monitor driver activity and fuel consumption.	Immediate & short-term
17	4	Best Management Practices	• Consider a fuel-efficient driver incentive program in which drivers are incentivized to improve behaviours or reduce their travel.	Immediate
18	4	Fuel-Switching – Ethanol	• Consider the challenges associated with switching to E85, including supply, any additional infrastructure costs, and whether the potentially greater fuel cost is financially prudent. Should the City proceed with this solution, consider a pilot project with several units switched to E85 to determine the extent of the fuel-efficiency loss; if successful, consider a phased-in approach for other appropriate units.	Immediate & short-term
19	4	Fuel-Switching – Biodiesel	• Use a blend of 5% in winter and 20% in the summer and shoulder months. Consider a pilot project with several units switched to higher-blend biodiesel (B20), and if successful a phased-in approach for other appropriate units.	Immediate & short-term
20	4	Fuel-Switching – Natural Gas (including Renewable Natural Gas)	• If compressed natural gas (CNG) is of interest to the City as an interim solution until BEVs are available, investigate subsidies for CNG upgrades and a CNG vehicle fuelling station. Consider a small-scale pilot project with several high-mileage units switched to CNG, and if successful a phased-in approach for other appropriate units.	Immediate & short-term
21	4	Fuel-Switching – Liquified	• If LPG is of interest for high-mileage City units, as an interim solution until BEVs are available, consider a small-scale pilot	Immediate & short-term

No.	Section	Area/ Topic	Recommendation(s)	Implementation Timing[99]/ Next Step
		Propane Gas (LPG)	project with several high-mileage units switched to LPG, and if successful a phased-in approach for other appropriate units.	
22	4	BEVs	• Consider a pilot project for several BEVs when they become available (e.g., pickups) to track range capabilities and cost savings and assess the units' performance for all seasons and varying weather conditions. Assuming the pilot project is successful, consider acquiring BEVs in bulk to replace units that would provide the greatest ROI.	Immediate & short-term
23	4	BEVs	• Continue to closely monitor the acquisition costs for BEVs and re-evaluate the business case (cost-benefit) for individual units as prices come down. Also continue to monitor the future availability of electric work/cargo vans, which are currently anticipated to be offered in battery-electric versions in the near future.	Immediate, short-term & long-term
24	4	BEVs (Charging Infrastructure)	• If relying on overnight charging infrastructure, consider supplying power to the charging equipment on two separate feeds from the grid to reduce the risk of local failure taking power away from the whole site.	Immediate, short-term & long-term
25	4	BEVs (Charging Infrastructure)	• Consider high-voltage training for technicians and closely monitor the launch of new BEV training programs.	Immediate, short-term & long-term

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Section 6.0: Green Fleet Strategy Discussion and Implementation

The results presented in this Green Fleet Strategy and Report are, as mentioned, intended to provide an ambitious roadmap to the City of Hamilton in its quest for go-forward fuel-reduction solutions to achieve the goals of the Corporate Climate Change Task Force.

Main Takeaways from FAR Scenario Analysis

In *Section 4.0*, we proposed a 15-year long-term capital planning (LTCP) strategy for the City to implement various fuel-reduction solutions to 2035. The emphasis is on BEV phase-in, as this, we believe, is the most effective long-term GHG reduction strategy for a fleet as battery-electric technology continues to advance. Our approach was to model "house-in-order" solutions first, then add the potential of fuel-switching interim solutions which we term the "messy middle," and, finally, phase-in BEVs as they become available in the near future for all vehicle classes. The GHG reduction impact of modelling these three steps together was an estimated 90% over the baseline (2019 review period) by 2035, which fulfils the deep GHG emissions reduction required to achieve the goals of the Corporate Climate Change Task Force.

In addition to presenting a condensed 15-year LTCP strategy with the various solutions being implemented as logical steps in time, we also modelled the solutions individually or in groups (e.g., best practices) to analyze their relative impacts. Note that all fuel-switching and BEV phase-in scenarios included (i.e., were in addition to) balanced Capex and optimized replacement cycles, as well as best management practices (BMPs). Here are the main takeaways for the City of Hamilton's consideration:

- Based on our modelling, optimized lifecycles and balanced Capex (replacing only those units which were shown to provide ROI) was shown to decrease annual Opex by around $2.8 m (average value) over the 2019 baseline. However, this intervention alone would only result in a ~ 1% decrease in GHG emissions over the baseline. Therefore, more solutions would have to be implemented to achieve deep GHG emissions reductions goals.

- Based on our modelling, implementing additional BMPs offers significant Opex reduction potential (average of $2.8m/year over the baseline) and GHG reduction potential (more than 31% over the baseline). In particular, implementing only driver eco-training and anti-idling policy/technologies would decrease emissions by an estimated 18% over the baseline, while implementing only route planning/optimization and trip reduction would lead to an estimated 14% reduction. This demonstrates the potentially significant impacts of "getting the house in order" before implementing any fuel-switching or battery-electric solutions.

- Based on our modelling, a BEV phase-in for passenger vehicles and pickups netted a GHG reduction of about 40% over the baseline. This demonstrates that passenger vehicles and pickups contribute a significant amount to the total Hamilton Fleet emissions, highlighting a potential area of focus for the City ahead of the transition of medium- and heavy-duty (MHD) trucks to electric.

It is important to note that the scenarios are meant to provide guidance and stimulate thought regarding each individual solution, and not serve as an accounting-accurate evaluation. In reality, the City of Hamilton may consider multiple fuel-switching options in conjunction with one another, depending on unit age, vehicle condition, and kilometres-travelled.

BEV Transition

BEVs have a very high potential for achieving significant fuel cost savings and GHG emissions reductions for the City of Hamilton. With zero tailpipe emissions, transitioning the fleet to electric is the ultimate fuel-reduction solution. We are essentially suggesting a temporary moratorium on purchasing new ICE vehicles for the short term (two years for pickups, four years for MHDVs), while waiting for battery-electric counterparts to become available. The exception, of course, is for LD passenger BEVs which are currently available, such as the Kia Souls ordered by the City, as well as other comparable options such as the Chevrolet Bolt. Moreover, BEV refuse/recycling trucks and transit buses (the latter outside the scope of this report) are also available for purchase now.

Our position is that fleets should avoid buying fossil-fuelled units because internal combustion engine (ICE) vehicles are quickly becoming an outdated and archaic technology. The purchase of a new ICE vehicles now, whether gasoline or diesel, means that a fleet, like the City of Hamilton's Fleet, will commit to using new fossil-fuelled vehicles for approximately the next decade when zero-emissions BEVs, which are often more economical than their fossil-fuel counterparts, are just around the corner.

For municipalities, the "workhorse" of the fleet is the pickup truck. Of all the fleet vehicles in RSI-FC's 50,000 vehicle Canadian municipal fleet database, 46% are pickup trucks. In Hamilton's in-scope fleet, pickups comprise about 25% of the fleet based on the data provided (324 pickups out of a total of 1,307 units). At this time, there are at no BEV pickups available for purchase, but at least seven manufacturers are preparing BEV pickups to hit the market starting in the year 2022.

We expect that battery-electric models for Class 5-8 trucks will come to market in the near future – almost all truck manufacturers have announced plans to launch battery-electric trucks in these classes soon, likely by 2024. Several are taking orders now, including Lion Electric, Tesla, Nikola, and others.

CNG conversion is a solution that can potentially deliver significant fuel cost savings and GHG reductions; however, the cost of installing a fast fuelling system in far greater than installing a DC fast charger for BEVs. Moreover, if BEVs come down in price over time, the business case will continue to improve and potentially more units would demonstrate a positive ROI. Given that MHDVs are likely moving away from the internal combustion engine toward battery-electric zero-emission units, a fleet-wide commitment to CNG may not be a prudent choice for the future.

For fiscal responsibility reasons, a phased-in approach is recommended for Hamilton to transition to a BEV fleet. The reality is that, since only LD BEVs are available now, and pickups are expected to be available in two years, followed by MHD trucks in about four years, a phase-in is the only option for the first few years. Municipal replacement cycles are long-term – up to 10 or 12 years – or more for some vehicles. Therefore, a BEV phase-in plan in the long term is needed for a balanced approach to capital spending.

Next Steps

Our Green Fleet Strategy describes the analysis we have completed to evaluate and determine viable fuel-reduction solutions that are available to the City of Hamilton, now and in the near future. We have presented the strengths, weaknesses, and cost-benefit analysis to help inform fleet management in decision-making around which solutions are effective interim solutions and which help to achieve longer-term goals. Such decisions should be made with consideration for budgets and cash flow planning, current and expected future business climate, and the level of ambition in achieving deep reductions in GHG emissions (and at the same time, potentially significant cost savings).

From our work in developing fuel-reduction strategies for more than a 15 years, we have observed that certain elements lead to the highest rates of successful implementation. These include:

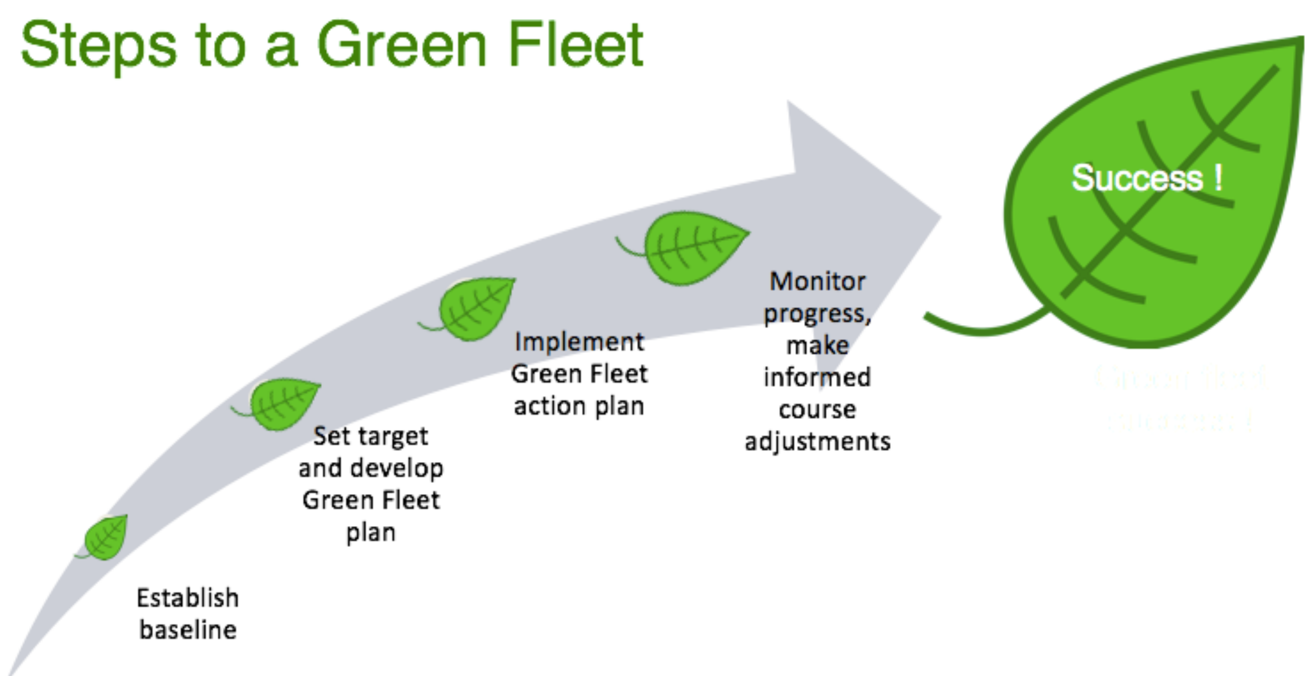
- A corporate culture that encourages environmental leadership;
- An internal “champion”;
- Commitment to greening the fleet – from the ground floor operational level up to the most senior level of the organization;
- Carefully managed risk and a willingness to experiment;
- A strong green fleet commitment stated in policy, clearly defined timelines, and responsibilities;
- Procurement policies that take into consideration lifecycle costs of vehicles;
- Carefully prepared green fleet plans that are based in reality and practicality;
- Reliable and consistent fleet operating data;

- Measurable, measured, and achievable goals – with a degree of stretch; and
- A strong communications team to share successes.

Figure 7 is a simple but effective visualization of the steps for achieving a successful green fleet. The first step (establishing baseline) has been achieved using the data provided by the City of Hamilton to inform the baseline analysis, and step two (setting target and developing green fleet plan) is well underway through RSI-FC's FAR analysis and recommendations presented in this report.

Our software tool, FAR, will be provided to the City of Hamilton for its own internal use post-project. The tool can be useful for both steps 3 and 4 (implementation and monitoring) to precisely evaluate any number and combination of fuel-saving solutions for specific units (implementation) as well as to re-evaluate solutions as progress is made (monitoring).

Figure 7: Steps to a Green Fleet



Appendix A: Green Fleet Survey Results

Figure 8: Breakdown of survey participants by employment status

What is your employment status with the City of Hamilton?

Answer	0% — 100%	Number of Response(s)	Response Ratio
Full-time, unionized employee		9	28.1 %
Full-time, management employee		23	71.8 %
Part-time		0	0.0 %
Student or Intern		0	0.0 %
Retiree		0	0.0 %
Other		0	0.0 %
No Response(s)		0	0.0 %
	Totals	32	100%

Figure 9: Breakdown of survey participants by employment length

***How long have you been employed by the City of Hamilton?**

Answer	0% — 100%	Number of Response(s)	Response Ratio
Less than 6 months		0	0.0 %
6 months to less than 1 year		3	9.3 %
1 year to less than 10 years		12	37.5 %
10 years to less than 25 years		13	40.6 %
25 years or more		3	9.3 %
Other		1	3.1 %
No Response(s)		0	0.0 %
	Totals	32	100%

Figure 10: Breakdown of survey participants by age

Which is your age category? (optional question)

Answer	Number of Response(s)	Response Ratio
Younger than 18	0	0.0 %
18 - 24	0	0.0 %
25 - 34	2	6.2 %
35 - 44	9	28.1 %
45 - 54	12	37.5 %
55 - 64	7	21.8 %
65 or older	0	0.0 %
Prefer not to answer	2	6.2 %
No Response(s)	0	0.0 %
Totals	32	100%

Figure 11: Breakdown of survey participants by gender

What is your gender? (optional question)

Answer	Number of Response(s)	Response Ratio
Male	17	53.1 %
Female	12	37.5 %
Prefer not to answer	3	9.3 %
No Response(s)	0	0.0 %
Totals	32	100%

Figure 12: Breakdown of survey participants by vehicle type

*What type of vehicle do you drive at work to perform your job responsibilities?

Answer	Number of Response(s)	Response Ratio
No vehicle	7	21.8 %
Car	7	21.8 %
Pickup	7	21.8 %
Van	0	0.0 %
SUV	9	28.1 %
Medium-duty single-axle truck	0	0.0 %
Heavy-duty tandem axle truck (snow plow, dump, refuse trucks etc.)	0	0.0 %
Other	2	6.2 %
No Response(s)	0	0.0 %
Totals	32	100%

Figure 13: Respondents' view on Hamilton's climate change emergency declaration

* In March 2019, the City of Hamilton declared a climate change emergency. Since that time the Government of Canada and more than 400 other Canadian municipalities have done the same. Most of these organizations are implementing programs to reduce their carbon emissions. Please share your thoughts on the following:

Answer	Number of Response(s)	Response Ratio
I agree there is a climate change emergency	11	34.3 %
I support Hamilton's climate change emergency declaration	19	59.3 %
I do not agree there is a climate emergency	1	3.1 %
I do not support Hamilton's climate emergency declaration	0	0.0 %
I need more information about Hamilton's climate emergency declaration	1	3.1 %
I am undecided about this matter	0	0.0 %
This issue does not matter to me	0	0.0 %
Other	0	0.0 %
No Response(s)	0	0.0 %
Totals	32	100%

Figure 14: Respondents' level of environment concern

* Please tell us your thoughts about our environment. Do you feel our environment is (pick one below):

Answer	Number of Response(s)	Response Ratio
In good shape	1	3.1 %
In some trouble but can be saved with a little effort	9	28.1 %
In bad shape but a lot of effort might save it	22	68.7 %
In such bad shape little can be done about it	0	0.0 %
Other	0	0.0 %
No Response(s)	0	0.0 %
Totals	32	100%

Figure 15: Respondents' level of agreement on the environment as a priority

There is a lot of attention to the environment these days. Do you agree the current level of concern is justified? (Do you agree it is really as bad as some people say it is?)
1 = Strongly disagree, 2 = Disagree, 3 = Undecided, 4 = Somewhat agree, 5 = Strongly agree

	Number of Response(s)	Rating Score*
	32	4.7

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Figure 16: Ranking of environmental problems by survey participants

*Which of the following do you feel are the biggest problems facing our environment? Please rate the following from 1 (smallest) to 5 (biggest):

1 = Smallest

Answer	Number of Response(s)	Ranking Score*
Toxic waste	31	2.7
Water pollution	31	3.3
Air pollution (ground level smog)	31	3.3
Global warming caused by greenhouse gas emissions	31	3.4
Other (please explain in the box below)	31	2.3

*The Ranking Score is the weighted average calculated by dividing the sum of all weighted rankings by the number of total responses.

Figure 17: Respondents' view on impacts of various pollution factors

*Thinking of pollution caused by vehicles, what are your thoughts on the impacts of each of the following (low to high impact)

1 = Very low impact, 2 = Low impact, 3 = Unsure/undecided, 4 = Has an impact, 5 = Has a big impact

Answer	Number of Response(s)	Rating Score*
The age of the fleet vehicles	32	4.2
The types of fuel used	32	4.4
Maintenance of the fleet vehicles	32	4.1
The driving habits of the vehicle operators	32	3.8
Vehicle that are over-sized for our job requirements	32	4.0
Unnecessary trips in vehicles	32	4.0
Routes that are not planned in a way to reduce distance	32	3.7

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Figure 18: Respondents' level of agreement on efficacy of eco-driver training

*This question is about driving habits and behaviors, and ways to help Hamilton's fleet vehicle drivers operate vehicles in the most fuel-efficient manner.Please provide your responses below.

1 = Disagree, 2 = Undecided/unsure, 3 = Agree

Answer	Number of Response(s)	Rating Score*
I would like to receive fuel-efficient, eco-driver training from the City of Hamilton	32	2.3
Learning eco-driving habits would benefit me in my personal life by saving me money on fuel	32	2.5
I am an excellent driver and eco-driver training would not benefit me in any way	32	1.6

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Figure 19: Respondents' level of agreement on fuel economy, reliability, and safety of natural gas- and propane-powered vehicles

* Natural gas and propane are gaseous vehicle fuels that produce less GHG emissions than gasoline and diesel. With your present knowledge of vehicles powered by these fuels, please rate the following statements about natural gas and propane powered vehicles.

1 = Strongly disagree, 2 = Disagree, 3 = Unsure/undecided, 4 = Agree, 5 = Strongly agree

Answer	Number of Response(s)	Rating Score*
I am not familiar with natural gas powered vehicles and prefer not to answer	32	2.6
I am not familiar with propane powered vehicles and prefer not to answer	32	2.7
Natural gas powered vehicles are more economical to drive	32	3.5
Propane powered vehicles are more economical to drive	32	3.3
Natural gas powered vehicles are reliable	32	3.5
Propane powered vehicles are reliable	32	3.3
Natural gas powered vehicles are safe to drive	32	3.7
Propane powered vehicles are safe to drive	32	3.5

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Figure 20: Respondents' level of confidence and agreement on biodiesel and ethanol as fossil fuel substitutes

* Biodiesel is a clean, renewable substitute for standard diesel fuel that is made from plant matter (like soybeans) and also waste vegetable oils. Biodiesel can be used in various blends with standard diesel to reduce emissions. Ethanol is a clean, renewable fuel made from plant matter (such as corn). It is blended up to 85% with gasoline (for some vehicles) to reduce emissions.Based on your present knowledge, or what you have heard about these fuels, please rate the following statements.

1 = Strongly disagree, 2 = Disagree, 3 = Unsure/undecided, 4 = Agree, 5 = Strongly agree

Answer	Number of Response(s)	Rating Score*
I do not know enough about biodiesel and prefer not to provide my opinion	32	3.1
I do not know enough about ethanol and prefer not to provide my opinion	32	3.1
Biodiesel is a direct replacement for standard diesel fuel	32	3.2
Ethanol fuel can be used in most modern vehicles	32	3.4
Biodiesel is a safe fuel for use in vehicles	32	3.4
Ethanol is a safe fuel for use in vehicles	32	3.5
Biodiesel makes engines last longer because it provides better lubrication	32	3.1
I oppose plant-based fuels because they are sometimes made from food crops	32	2.6

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Figure 21: Respondents' level of confidence and agreement on BEVs

There has a been a lot of news lately about zero-emission battery-electric vehicles. Light-duty electric vehicles (such as cars and SUVs) are available now; medium- and heavy-duty electric trucks and buses are coming very soon. With what you know now, or have heard about electric vehicles, please provide your opinions on the following statements about electric vehicles.

1 = Strongly disagree, 2 = Disagree, 3 = Unsure/undecided, 4 = Agree, 5 = Strongly agree

Answer	Number of Response(s)	Rating Score*
Electric vehicles can travel far enough to meet my daily needs in doing my job	32	4.0
Electric vehicles are powerful enough for my needs in doing my job	32	4.2
Electric vehicles are sufficiently warm in the winter and cool in the summer for comfort	32	4.1
Electric vehicles are safe	32	4.4
Electric vehicles cost less to operate and will save money for the City of Hamilton	32	3.8
Electric vehicles cause less pollution than standard gas or diesel vehicles	32	4.4
Electric vehicles of the type the City of Hamilton needs for our work are available now or in the near future	32	3.9

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Figure 22: Respondents' opinions on actions to reducing fleet GHG emissions

25% of Canada's greenhouse gas (GHG) emissions are from the transportation sector. GHGs are responsible for global warming, extreme weather and climate change.Vehicle fleets everywhere, including the City of Hamilton, are taking action to reduce their emissions. How do you feel about the following options for Hamilton?We invite your ideas and comments or explanations about your responses in the text box below.

1 = Really bad idea, 2 = Bad idea, 3 = Unsure/undecided, 4 = Good idea!, 5 = Really good idea!

Answer	Number of Response(s)	Rating Score*
Having a 'younger', more modern and fuel-efficient fleet	32	4.4
Improve work planning to require less, or no driving	32	4.4
Reduce unnecessary engine idling	32	4.5
Switch some vehicles to natural gas or propane fuels	32	3.9
Switch vehicles to renewable fuels (biodiesel and ethanol)	32	3.8
Switch some vehicles to hybrid (gas/electric)	32	4.2
Switch some vehicles to all-electric (battery power only)	32	4.3
Use of GPS devices to reduce trip distances	32	4.1
Use of virtual meetings and video methods to avoid vehicle trips	32	4.4
Downsize vehicles to the minimum required for the job	32	4.2

*The Rating Score is the weighted average calculated by dividing the sum of all weighted ratings by the number of total responses.

Appendix B: Fleet Analytics Review™

Fleet Analytics Review™ (FAR) is a user-friendly, interactive decision support tool designed to aid our team and fleet managers in developing short- to long-term green fleet plans by calculating the impacts of vehicle replacement and fuel-reduction solutions on operating costs, cost of capital, and GHG emissions. Moreover, it is used for long-term capital planning (LTCP) through an approach that works to balance, or smoothen, annual capital budgets and avoid cost spikes if possible.

FAR is a complex, sophisticated MS Excel software developed by the RSI-FC team in 2016. Since its inception, FAR has been used by our team as the foundational analysis platform for our work in helping fleets with green fleet planning and the transition to low-carbon fuels/technologies.

Clients to date for which reports were completed using FAR include:

- City of Kawartha Lakes (2020)
- Durham Region (2020)
- Town of Gander (2020)
- Town of Whitby (2020)
- Town of Aurora (2019)
- NW Natural Gas Distribution, Portland, OR, USA (2018)
- The County of Middlesex Centre (2017)
- The Region of Peel (2017)
- The Town of Enfield, CT, USA (2017)
- Toronto-Hydro Electric (2017)
- Winnipeg Airport Authority (2017)
- Greater Toronto Airport Authority (2016)
- Oxford County (2016)
- The City of Vaughan (2016 - 2018)

Purpose

The core functionality of the FAR software is to calculate the financial and GHG reduction impacts of vehicle replacements, operational improvements, and low-carbon fuels/technologies for a fleet.

In the context of assessing fleet modernization, FAR is especially useful in calculating the operating expense (opex) impacts of vehicles being retained in the fleet beyond their viable age and with diminishing salvage values. Aged, older-technology vehicles consume more fuel, produce more GHGs, usually cost more to operate, are less reliable, and may also present a safety risk. FAR automatically calculates and quantifies these impacts in a defensible business case format.

For fuel-reduction solutions under consideration by fleet management as a means of saving fuel costs and avoiding GHGs, including best management practices (BMPs), alternate or renewable fuels (natural gas, propane, biodiesel, etc.), and EVs (battery-electric, plug-in hybrid, or hybrid), FAR calculates the cost-benefit of the investment in vehicle upgrades, vehicle conversion costs, fuelling infrastructure, or EV charging infrastructure, i.e., whether these solutions would yield a net operating cost reduction, unit-by-unit and fleet-wide.

Approach

The FAR software tool employs a holistic approach – all relevant factors and controllable expenses are considered in its analysis. The data points in our approach include energy equivalency factors of each alternative fuel type (compared to a fossil diesel fuel baseline), vehicle upgrade costs, alternately-fuelled vehicle acquisition (or vehicle retrofit) capital costs, vehicle maintenance considerations (higher or lower maintenance demand), fuel system/charging infrastructure capital costs, and any additional expenses for storage, handling & dispensing the fuel(s). All of these factors are modelled within the context of planned vehicle lifecycles – a total cost of ownership (TCO) approach.

The FAR process uses historical cost metrics and vehicle operating data (i.e., miles/km-driven, fuel usage, repair and maintenance costs, unit age, cost of capital, downtime, residual value, etc.) to establish not only the fleet's fuel usage and GHG emissions baseline, but also financial and service levels (i.e., utilization, availability/uptime) performance.

FAR highlights "exception" units, vehicles that are performing in a sub-standard way in terms of cost and performance, thus potentially enabling management to identify the reason(s) and take appropriate action(s).

Go-Forward Fuel-Reduction Solutions

With the FAR baseline established, the software is used to analyze go-forward fuel-reduction solutions. FAR takes into consideration the Opex implications and determines whether Opex reductions will offset any capital expenses (Capex) including vehicle upgrades, vehicle conversions, "up-charges" for premium vehicles (e.g., EVs), and investment in infrastructure.

The FAR analysis includes, but is not limited to:

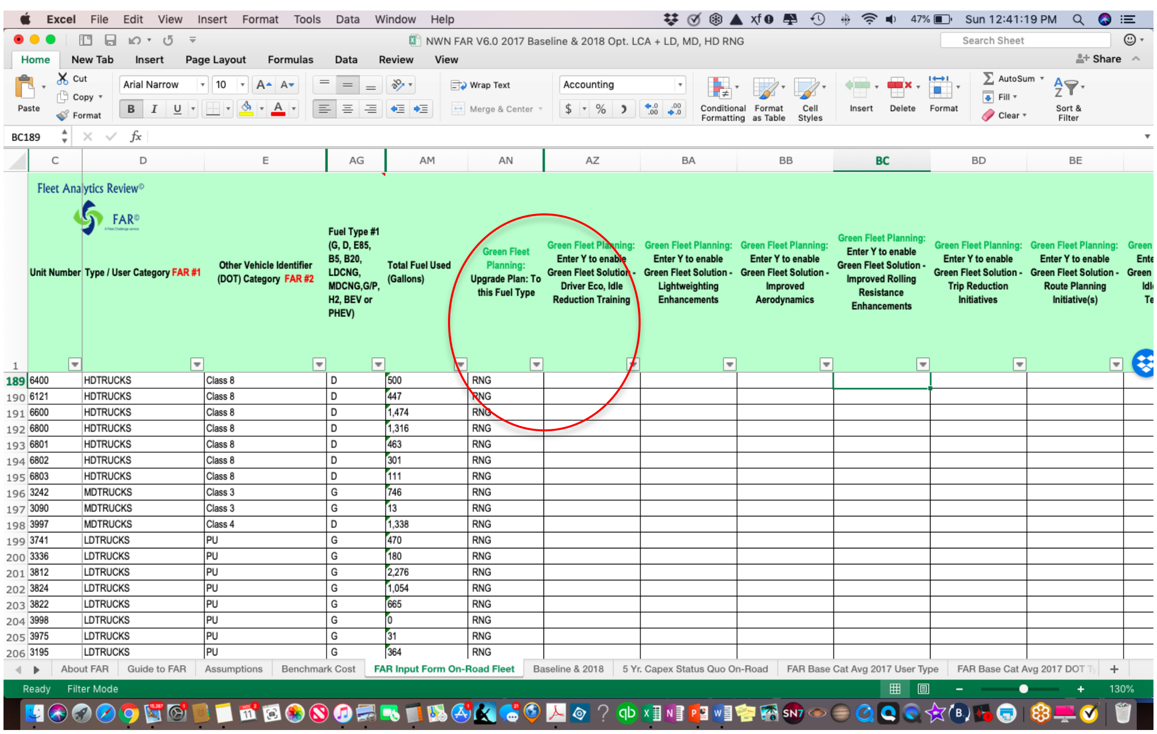
- The fuel usage and cost differential (+ or -) for the fuel type selected vs the current type (if applicable)
- The energy-efficiency difference

- The unit cost of upgrade for the fuel-saving technology
- The unit cost of conversion to the selected fuel type
- The cost of fueling infrastructure for the selected fuel type apportioned evenly to the chosen vehicles for the fuel-switch
- The cost of charging infrastructure for EVs apportioned evenly to the chosen vehicles to be replaced
- The cost of capital for vehicle replacement for the selected fuel type

FAR then calculates whether a cost-savings or return-on-investment (ROI) would result within the remaining lifecycle for each of the vehicles selected for the vehicle upgrade or fuel switch.

Figure 23 shows a screen capture from FAR demonstrating the FAR fuel-switching capabilities. In this example, the user is switching several light-, medium-, and heavy-duty trucks from their current fuel source to renewable natural gas (RNG), and this is accomplished simply by selecting the vehicle(s) to be evaluated and then choosing (in this example) RNG from a drop-down list.

Figure 23: Screen Capture of FAR Showing Fuel-Switching Options



Row	Unit Number	Type / User Category FAR #1	Other Vehicle Identifier (DOT) Category FAR #2	Fuel Type #1 (G, D, E85, B5, B20, LDCNG, MDCNG,G/P, H2, BEV or PHEV)	Total Fuel Used (Gallons)	Green Fleet Planning: Upgrade Plan: To this Fuel Type
189	6400	HDTRUCKS	Class 8	D	500	RNG
190	6121	HDTRUCKS	Class 8	D	447	RNG
191	6600	HDTRUCKS	Class 8	D	1,474	RNG
192	6800	HDTRUCKS	Class 8	D	1,316	RNG
193	6801	HDTRUCKS	Class 8	D	463	RNG
194	6802	HDTRUCKS	Class 8	D	301	RNG
195	6803	HDTRUCKS	Class 8	D	111	RNG
196	3242	MDTRUCKS	Class 3	G	746	RNG
197	3090	MDTRUCKS	Class 3	G	13	RNG
198	3997	MDTRUCKS	Class 4	D	1,338	RNG
199	3741	LDTRUCKS	PU	G	470	RNG
200	3336	LDTRUCKS	PU	G	180	RNG
201	3812	LDTRUCKS	PU	G	2,276	RNG
202	3824	LDTRUCKS	PU	G	1,054	RNG
203	3822	LDTRUCKS	PU	G	665	RNG
204	3998	LDTRUCKS	PU	G	0	RNG
205	3975	LDTRUCKS	PU	G	31	RNG
206	3195	LDTRUCKS	PU	G	364	RNG

FAR is user-friendly and intuitive; it is based on standard off-the-shelf MS Excel. It is dynamic, and users can run future scenarios (such as assessing different vehicle types, fuels, or engine/drivetrain combinations) to see how such decisions impact Opex ahead of their implementation, thereby mitigating risk and heading off potentially costly errors.

Recent Enhancements and Upgrades to FAR™

FAR V30.5 (beta) features upgrades and enhancements to the functionalities of the FAR tool. These include:

Fuel-Efficient Green Fleet Planning Tools – Fuel-Switching. FAR now includes several powerful "Green Fleet Planning" tools. One of these tools is used to estimate the financial and GHG impacts of switching vehicle fuels from fossil-based (gas or diesel) to alternate or renewable fuels or BEVs.

In the Input Form, FAR analysts may make choices as to fuel-switching (for example, changing all gas or diesel-powered vehicles in specific categories to E85, B5-B100 biodiesel, hybrid, plug-in hybrid, battery-electric, CNG, or even hydrogen fuel cells). FAR calculates the net cost and GHG reduction of the fuel-switch being considered, taking into consideration not just the fuel/electricity costs, but the change in fuel efficiency, as well infrastructure costs such as installing a CNG fueling station, electric vehicle chargers, etc.

Enhanced Vehicle Replacement Cost-Benefit Analysis. Comparisons and analysis regarding either (a) aging a vehicle (or vehicles) that are now due for replacement for another year or (b) going ahead and replacing the vehicle(s) is now based on the actual average historical peer fleet cost data from our proprietary municipal fleet database.

In FAR, when a vehicle is due for replacement, it calculates the annual cost for a new replacement vehicle (including the capital, fuel, repairs, PM, and downtime) and then compares that amount to the actual average cost for a similar vehicle —that is one-year older (from our peer fleet database). FAR now displays the cost-benefit of replacing each unit that is due for replacement in the 5+ yr Capex plan tab – in blue font each vehicle that will save Opex if it is replaced, and red font if it will incur more opex. This marks a significant change in FAR and eliminates all guesswork or sketchy assumptions and supplants it with real peer fleet operating cost data by model year and vehicle categories we have collected since 2006.

Fuel-Usage and GHG Reduction for New Vehicles. For each vehicle that is due for replacement, FAR now shows the potential fuel-usage and GHG reduction.

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Appendix C: Lifecycle Analysis Charts

Table 15: LCA for passenger vehicles (Class 1) using Hamilton fleet data

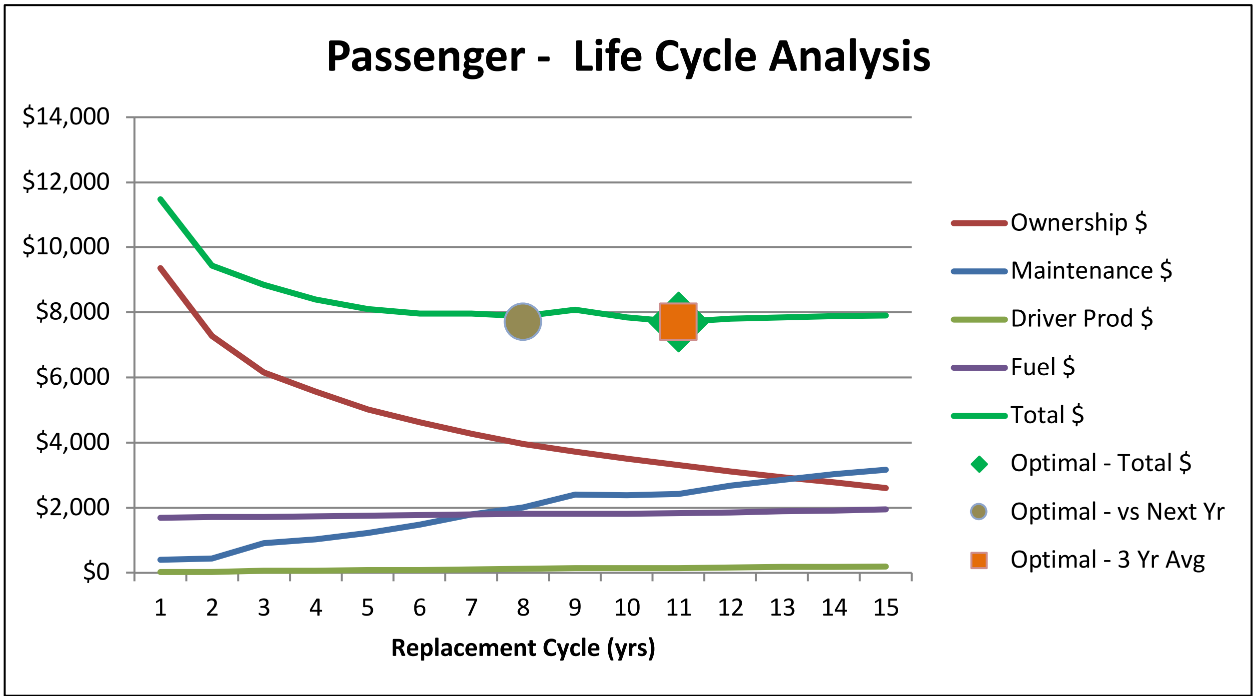


Table 16: LCA for pickups (Classes 1 & 2) using Hamilton fleet data

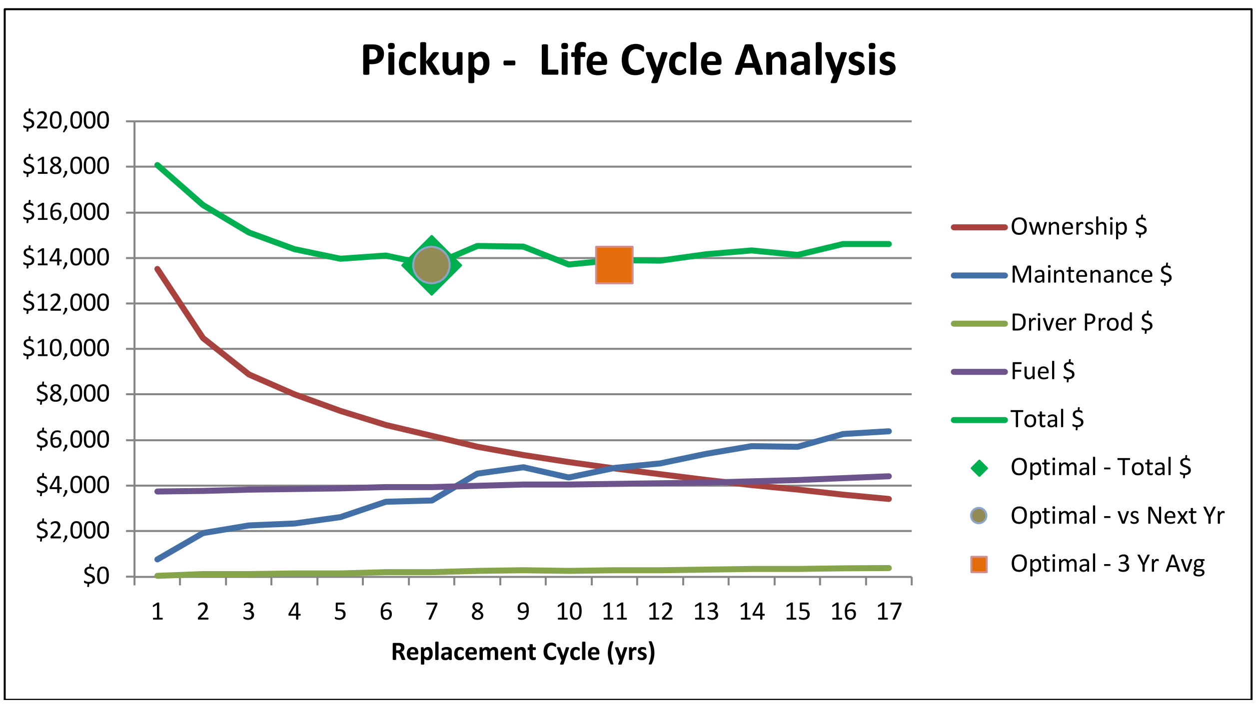


Table 17: LCA for Class 2 vans and utility vans using Hamilton fleet data

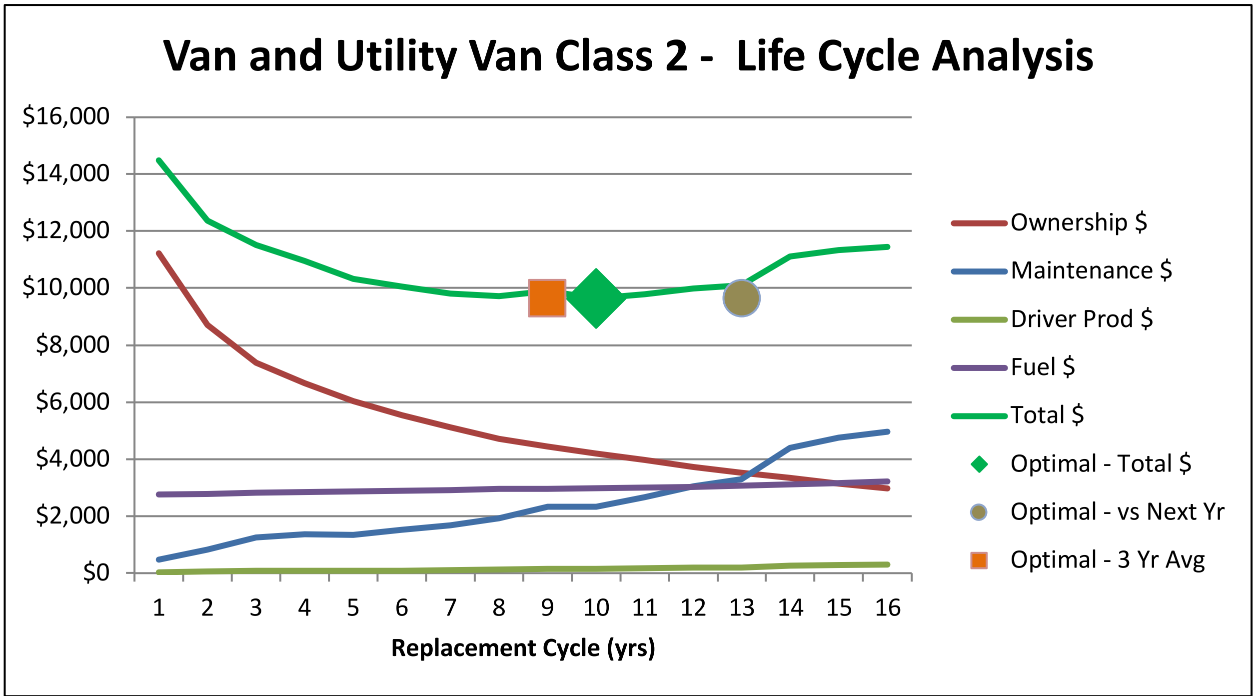


Table 18: LCA for Class 3 pickup trucks and utility vans using Hamilton fleet data

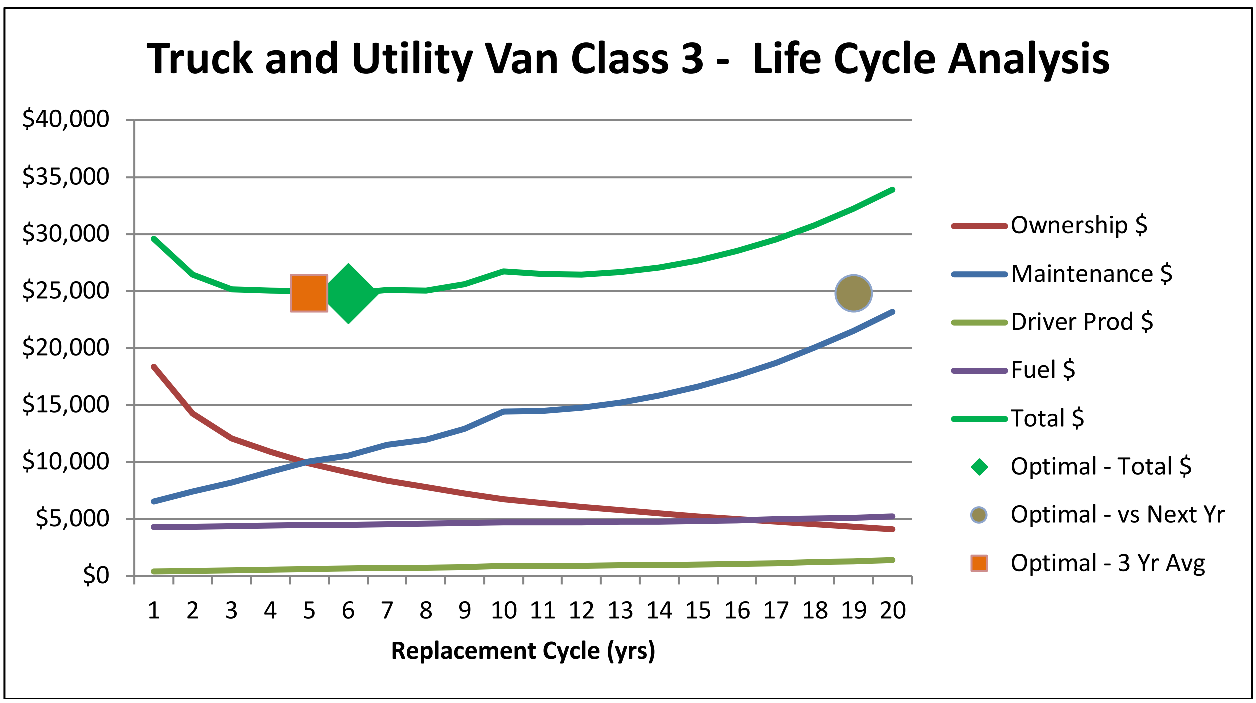


Table 19: LCA for Class 5 trucks using Hamilton fleet data

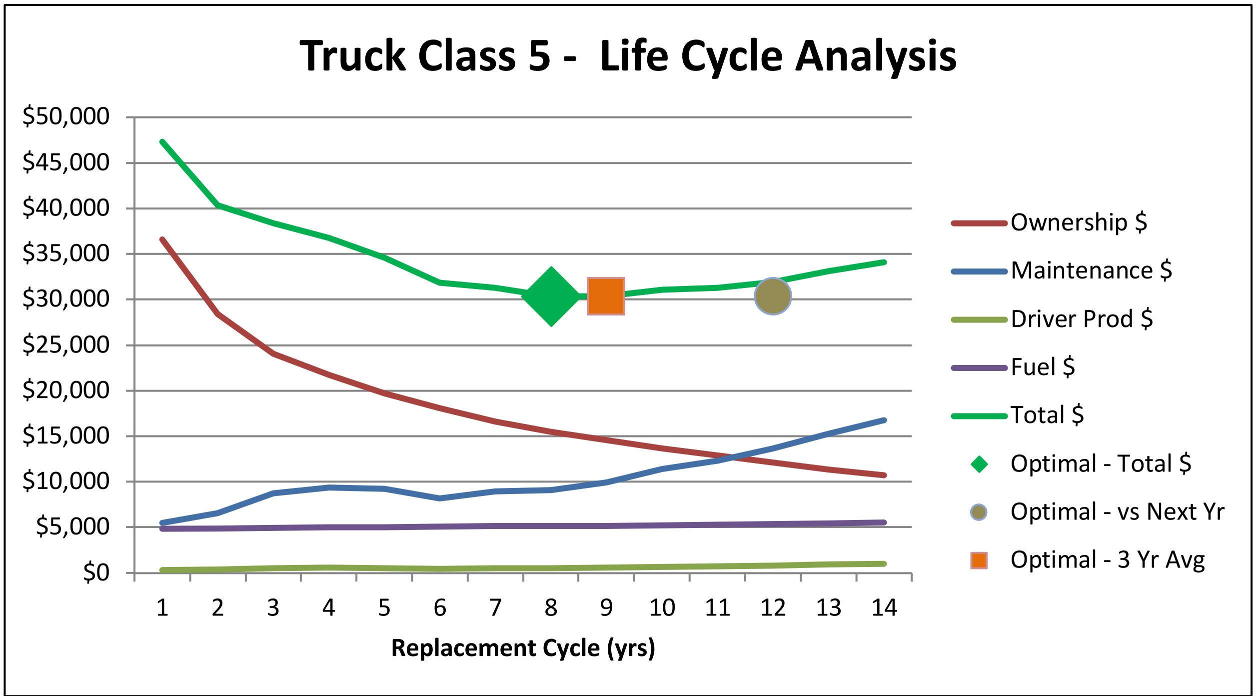


Table 20: : LCA for Class 6 utility vans using benchmark fleet data from municipal database

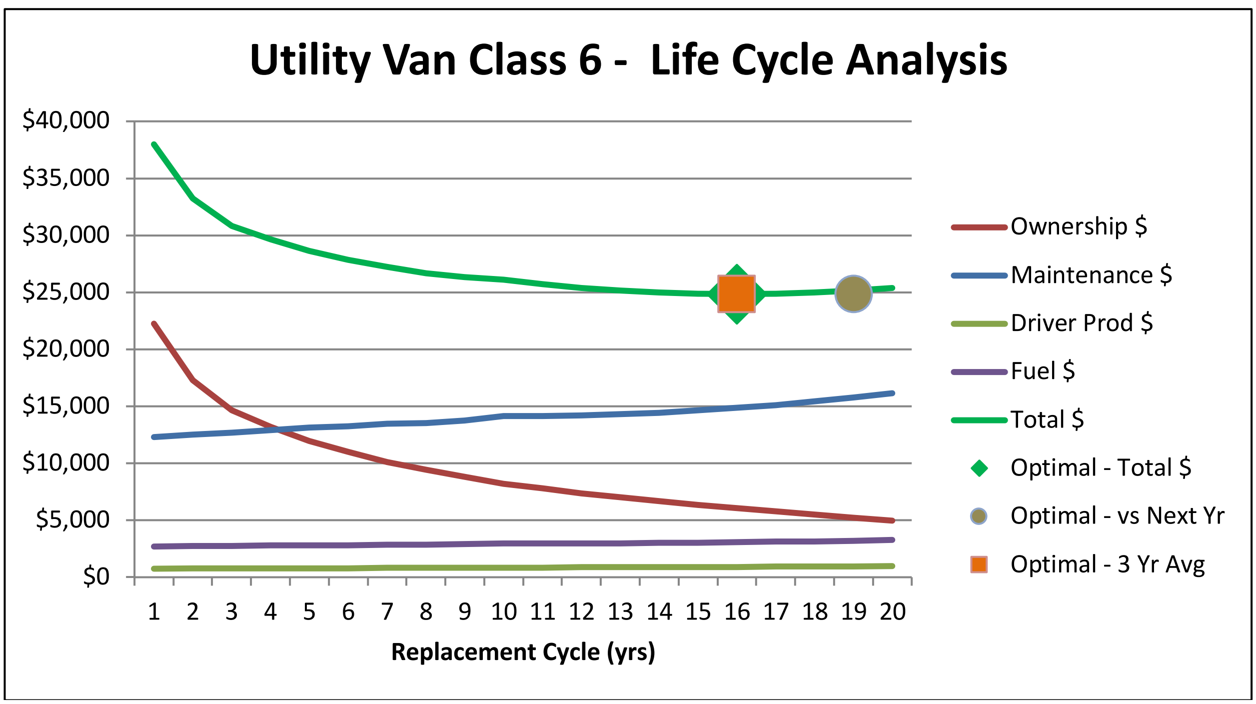


Table 21: LCA for Class 7 trucks using Hamilton fleet data

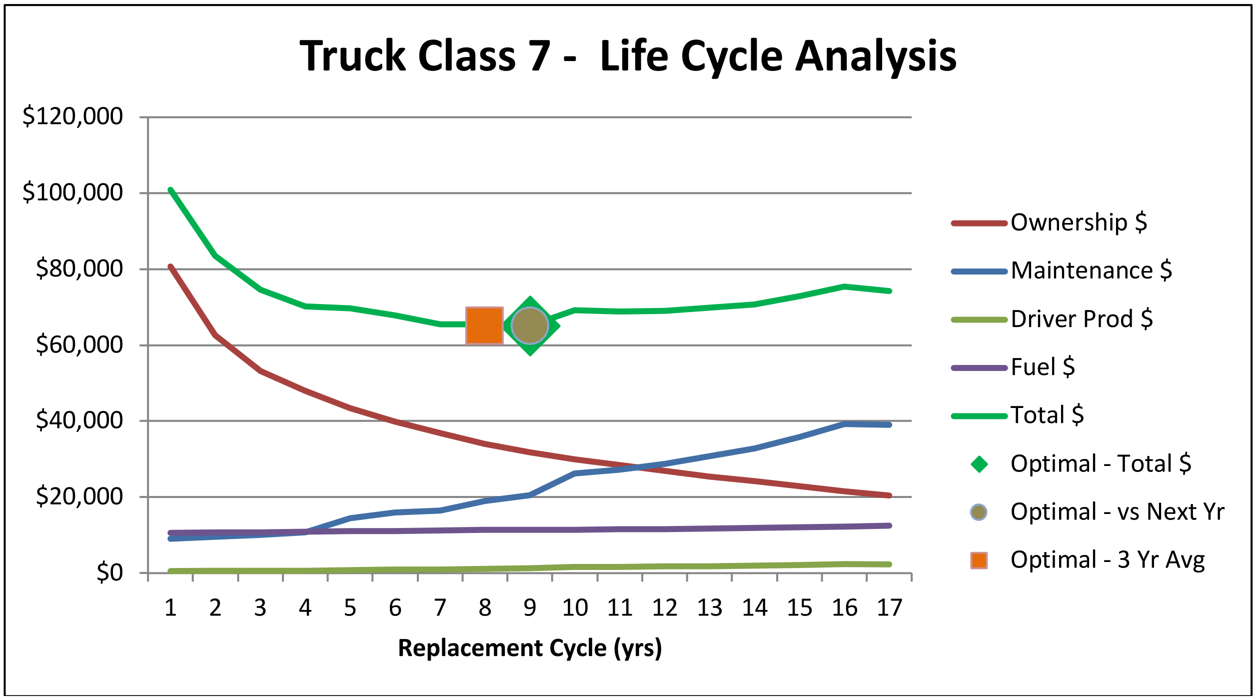
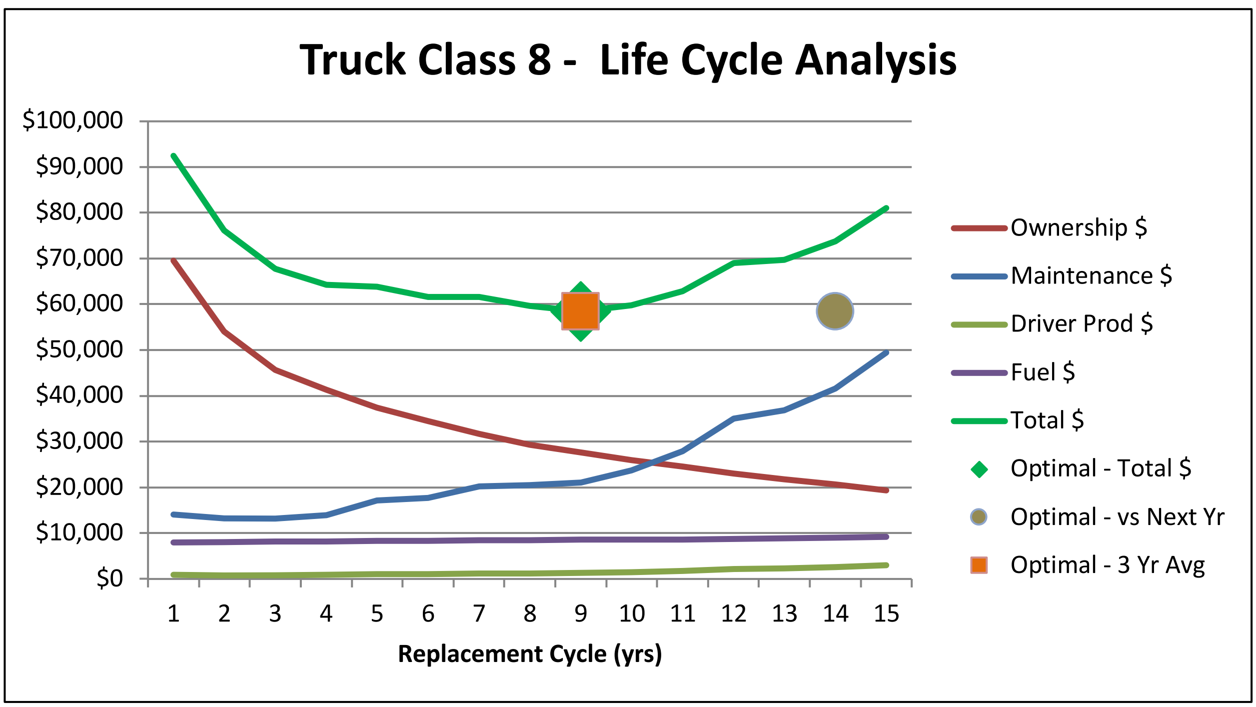


Table 22: LCA for Class 8 trucks using Hamilton fleet data



Appendix D: FAR Scenario Details and Results

RSI-FC's long-term capital planning (LTCP) begins with a baseline review. The FAR software tool was used to plot Hamilton's current-day baseline relative to the fleet's age and operating statistics in a one-year review period (2019). This baseline included data on service levels (uptime and utilization), operating costs, fuel consumption, and GHG emissions.

From the baseline, we modelled 15-year budget cycles (to 2035) for business-as-usual (BAU) vehicle retention practices, optimized lifecycles, balanced Capex and optimized lifecycles (only replacing units with ROI), and a number of fuel-reduction solutions (additional best practices or "house-in-order" actions, fuel-switching or "messy-middle" solutions, and BEV phase-in planning). Details and results for each individual scenario are presented below.

Business-as-Usual

FAR Scenario One modelled go-forward outcomes based on Hamilton's present-day vehicle and equipment replacement practices. These business-as-usual (BAU) outcomes included the impacts of current vehicle replacement cycles on operating expenses (opex), vehicle/equipment replacement capital requirements, and GHG emissions over a fifteen-year horizon.

Based on present-day replacement practices, it was estimated that $ 37.6 million would be required to replace all due or past-due units with new like-for-like vehicles (not EVs at this stage). It should be noted that numerous vehicles in the Hamilton fleet are beyond the current planned age for replacement – significant "catch-up" is required to modernize the fleet. In ensuing years, far fewer vehicles require replacement, bringing down capital spending to between $5 and 8 million in the following three fiscal years (2021-2023). However, there is an uneven capital spend projected in following years.

In the unlikely event that all vehicles due for replacement in 2020 were indeed replaced, operating expenses are forecasted to decrease by about $ 4.5 million and GHG emissions are estimated to decrease by over 60 tonnes CO_2e due to the increased fuel efficiency of newer vehicles.

The annual capital budget requirements, Opex, and GHG emissions to the year 2035 based on Hamilton's present-day BAU replacement practices are shown in *Table 23*.

Table 23: FAR #1 – 15-Year Capital Budget with BAU Vehicle Replacements

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 37,660,280	$ -	$ 37,660,280	-4.54	62.6
FY 2021	$ 7,999,083	$ -	$ 7,999,083	-4.98	74.2
FY 2022	$ 5,468,466	$ -	$ 5,468,466	-4.73	88.3
FY 2023	$ 5,346,491	$ -	$ 5,346,491	-4.55	97.5
FY 2024	$ 13,756,710	$ -	$ 13,756,710	-4.97	128.3
FY 2025	$ 8,220,390	$ -	$ 8,220,390	-4.51	136.3
FY 2026	$ 12,941,829	$ -	$ 12,941,829	-4.58	155.4
FY 2027	$ 13,420,845	$ -	$ 13,420,845	-4.13	183.1
FY 2028	$ 18,074,300	$ -	$ 18,074,300	-4.04	216.1
FY 2029	$ 6,462,137	$ -	$ 6,462,137	-4.40	217.3
FY 2030	$ 26,987,138	$ -	$ 26,987,138	-4.23	244.4
FY 2031	$ 11,056,060	$ -	$ 11,056,060	-4.82	244.4
FY 2032	$ 11,327,444	$ -	$ 11,327,444	-4.33	246.9
FY 2033	$ 6,463,354	$ -	$ 6,463,354	-4.59	247.0
FY 2034	$ 20,564,502	$ -	$ 20,564,502	-5.24	247.9
FY 2035	$ 7,297,240	$ -	$ 7,297,240	-4.57	248.3

Optimized Lifecycles

FAR Scenario Two calculated the impacts of optimized vehicle replacement cycles on operating expenses, vehicle/equipment replacement capital requirements, and GHG emissions over a fifteen-year horizon.

Based on optimized lifecycles, it was estimated that $ 38.3 million would be required to replace all due or past-due units with new like-for-like vehicles (not EVs at this stage), which is slightly greater than present-day replacement practices. Operating expenses are forecasted to decrease by about $ 3.9 million and GHG emissions are estimated to decrease by about 53 tonnes CO_2e over the baseline. Like BAU, there is an uneven capital spend projected in following years.

The impacts of optimized lifecycles determined through LCA modelling are shown in *Table 24*.

Table 24: FAR #2 – 15-Year Capital Budget with Optimized Lifecycles

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ -	$ 38,333,256	-3.94	53.1
FY 2021	$ 4,287,415	$ -	$ 4,287,415	-4.14	59.4
FY 2022	$ 6,344,770	$ -	$ 6,344,770	-4.56	75.5
FY 2023	$ 7,179,728	$ -	$ 7,179,728	-4.19	87.5
FY 2024	$ 12,647,854	$ -	$ 12,647,854	-4.35	116.9
FY 2025	$ 11,825,345	$ -	$ 11,825,345	-4.23	133.8
FY 2026	$ 13,167,300	$ -	$ 13,167,300	-3.79	154.8
FY 2027	$ 6,728,124	$ -	$ 6,728,124	-3.38	167.9
FY 2028	$ 12,784,565	$ -	$ 12,784,565	-3.35	196.3
FY 2029	$ 29,126,900	$ -	$ 29,126,900	-3.37	219.2
FY 2030	$ 13,360,939	$ -	$ 13,360,939	-3.57	236.3
FY 2031	$ 9,120,495	$ -	$ 9,120,495	-4.26	238.0
FY 2032	$ 11,122,230	$ -	$ 11,122,230	-4.09	238.1
FY 2033	$ 12,336,224	$ -	$ 12,336,224	-4.32	238.2
FY 2034	$ 16,125,922	$ -	$ 16,125,922	-4.43	239.1
FY 2035	$ 13,090,186	$ -	$ 13,090,186	-4.12	239.1

Balanced Capex and Optimized Lifecycles

Because a large number of fleet units are due for replacement under both current replacement practices and optimized lifecycles, in FAR Scenario Three we modelled a reduction of the first-year capital spend to a more reasonable, manageable amount as well as a more balanced capital year-to-year capital budget.

The long-term capital budgets shown in FAR Scenarios One and Two are clearly very unbalanced year-over-year. Seldom are fleet managers provided unlimited capital budgets to replace all units requiring replacement based on their assessments. For this reason, re-balancing long-term capital budgets is standard practice for fleet managers everywhere. Decisions must be made by management each year to defer the purchase of some units until later years to balance annual budgets going forward.

The “science” of making decisions around which vehicles should be deferred, and which must be replaced, is knowing, with confidence: (1) whether a vehicle’s replacement will deliver a return-on-investment (ROI), and (2) the physical condition of each unit. The former, (1), is what FAR was designed to do, while (2) is based on the skilled evaluations made by the fleet manager and his/her team. FAR calculates the potential ROI for each fleet vehicle due for replacement. This determination is made by comparing the cost of similar one-year older vehicles (using model-year and vehicle type data from RSI-FC's peer fleet database) to the projected operating costs of new, replacement vehicles.

For FAR Scenario 3, to demonstrate our recommended process for balancing year-over-year long-term budgets and reducing the overall capital required in fiscal year one (2020), we deferred any units that showed little or no ROI to the following year. The same process was repeated by our team for each fiscal year from 2020 to 2035, taking into consideration vehicle age and mileage. *Note that RSI-FC did this for demonstration purposes only – it should be based on vehicle condition assessments.*

Readers of this report must understand that, to undertake this step, anyone making final determinations as to which vehicles ultimately should be replaced and which should be deferred to another year must confidently know each unit's condition. With this knowledge, units in good condition can be deferred to subsequent years to balance long-term budgets. As third-party consultants, RSI-FC does not have access to this information, and to reduce and apportion the required capital over a more extended period, we opted to defer instead:

1. Units with low/no ROI
2. Units that have most recently became due for replacement (to ensure past-due units get higher priority for replacement)
3. Lower-mileage units (to ensure that higher-mileage units are replaced first)

By selectively and strategically deferring the purchase of some units to later years using this prioritization protocol (above), the capital budget requirement was more balanced over the 15-year capital plan than FAR Scenarios One and Two with increasing capital spending towards the end of the period due to compounding inflation.

Table 25 shows the impacts of a balanced long-term budget, in consideration of ROI, vehicle age, and total kms-travelled.

Table 25: FAR #3 – 15-Year Balanced Capital Budget (for demonstration purposes only)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.81	16.5
FY 2021	$ 31,539,963	$ 19,500,097	$ 12,039,865	-3.75	36.2
FY 2022	$ 26,215,369	$ 14,231,193	$ 11,984,176	-3.25	61.2
FY 2023	$ 21,681,314	$ 9,480,195	$ 12,201,119	-2.46	80.6
FY 2024	$ 22,308,173	$ 10,305,474	$ 12,002,699	-2.46	109.1
FY 2025	$ 22,326,622	$ 10,305,099	$ 12,021,523	-2.31	126.4
FY 2026	$ 23,314,575	$ 11,258,109	$ 12,056,465	-1.84	146.7

FY 2027	$	18,432,751	$	7,055,243	$	11,377,508	-1.36	164.4
FY 2028	$	11,455,898	$	-	$	11,455,898	-1.05	182.1
FY 2029	$	24,509,970	$	9,694,236	$	14,815,734	-0.78	195.0
FY 2030	$	18,311,568	$	3,377,855	$	14,933,714	-1.83	199.9
FY 2031	$	16,793,990	$	3,011,130	$	13,782,860	-2.29	202.0
FY 2032	$	13,398,036	$	-	$	13,398,036	-1.63	203.1
FY 2033	$	15,579,686	$	-	$	15,579,686	-1.88	203.2
FY 2034	$	16,284,071	$	389,422	$	15,894,649	-1.77	203.2
FY 2035	$	15,887,190	$	-	$	15,887,190	-1.48	203.2

Important Note Regarding FAR Scenario Three:

FAR Scenario Three was prepared *for demonstration purposes only.* RSI-FC prepared this scenario without any degree of knowledge regarding the mechanical condition of Hamilton's vehicles. In preparing Scenario 3 in FAR, our analysts deferred replacement of vehicles where the business case for replacement was low or did not exist. In the next pass at balancing the budgets we deferred units that most recently became due for replacement and we deferred units with lower mileage. Therefore, the amount of capital required for vehicle replacement in Scenario Three is reflective of vehicles due (or past-due) for replacement for which the investment in replacement vehicles were calculated to potentially provide optimal ROI.

LCA is not a guarantee of performance. It is only an averaging of operational costs by model year for groups of like vehicles within a fleet, to enable fleet managers to assess average annual economic costs by vehicle age. Within a fleet, some vehicles may have had lighter usage than average; other units may have recently been refurbished – either of these situations may enable extending lifecycles beyond the optimal life calculated by LCA.

For this reason, we recommend that long-term vehicle replacement planning should be a two-step process. It should begin with determining an initial list of units due/past-due for replacement via LCA-optimized lifecycles. Then, the actual condition of each vehicle due for replacement should be assessed case-by-case by fleet personnel who are knowledgeable and familiar with the condition of each unit. This process may allow safely extending vehicle lifecycles by deferring replacement of some units to ensuing years, thereby enabling the balancing of long-term capital plans.

Best Management Practices

Starting from FAR Scenario Three, we modelled the adaptation of what we have termed “house-in-order” strategies, which are best management practices (BMPs) we believe should be addressed at the outset, prior to any more costly upgrades or replacements. These Group One solutions focus on fuel-use reductions and include: (1) enhanced vehicle specifications, (2) driver eco-training, and (3) route planning and trip reduction.

In FAR Scenario Four (*Table 26*, below), we applied light-weighting and low rolling resistance (LRR) to appropriate units in Hamilton’s in-scope fleet. In FAR Scenario Five (*Table #27*, below), we modelled the impacts of driver eco-training and anti-idling policy and technologies. In FAR Scenario Six (*Table #28*, below), we modelled the fuel-use reduction impacts of route planning/optimization and trip reduction.

In FAR Scenario Seven (*Table 29*, below), we assessed the impacts of all these house-in-order strategies combined. The result was a further decrease in operating expenses by about $40,000-60,000 every year for the fleet compared to FAR Scenario Three. Moreover, GHG emissions are modelled to decrease by, on average, over 3,000 tonnes CO_2e every year over the baseline and FAR Scenario Three – a significant reduction demonstrating the impact of house-in-order strategies alone, particularly from improved driver behaviours and route planning and trip reduction.

Table 26: FAR #4 - 15-Year Balanced Capital Budget with Light-Weighting and LRR

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.79	360.8
FY 2021	$ 31,539,963	$ 19,500,097	$ 12,039,865	-3.73	379.8
FY 2022	$ 26,215,369	$ 14,231,193	$ 11,984,176	-3.23	403.9
FY 2023	$ 21,681,314	$ 9,480,195	$ 12,201,119	-2.44	422.5
FY 2024	$ 22,308,173	$ 10,305,474	$ 12,002,699	-2.43	450.0
FY 2025	$ 22,326,622	$ 10,305,099	$ 12,021,523	-2.29	466.7
FY 2026	$ 23,314,575	$ 11,258,109	$ 12,056,465	-1.82	486.2
FY 2027	$ 18,432,751	$ 7,055,243	$ 11,377,508	-1.33	503.2
FY 2028	$ 11,455,898	$ -	$ 11,455,898	-1.02	520.2
FY 2029	$ 24,509,970	$ 9,694,236	$ 14,815,734	-0.76	532.6
FY 2030	$ 18,311,568	$ 3,377,855	$ 14,933,714	-1.81	537.4
FY 2031	$ 16,793,990	$ 3,011,130	$ 13,782,860	-2.26	539.5
FY 2032	$ 13,398,036	$ -	$ 13,398,036	-1.60	540.5
FY 2033	$ 15,579,686	$ -	$ 15,579,686	-1.85	540.6
FY 2034	$ 16,284,071	$ 389,422	$ 15,894,649	-1.74	540.7
FY 2035	$ 15,887,190	$ -	$ 15,887,190	-1.45	540.7

Table 27: FAR #5 - 15-Year Balanced Capital Budget with Driver Eco-Training and Idling Reduction Policy/Technologies

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.80	1668.4
FY 2021	$ 31,539,963	$ 19,500,097	$ 12,039,865	-3.73	1684.9
FY 2022	$ 26,215,369	$ 14,231,193	$ 11,984,176	-3.23	1705.4
FY 2023	$ 21,681,314	$ 9,480,195	$ 12,201,119	-2.44	1721.3
FY 2024	$ 22,308,173	$ 10,305,474	$ 12,002,699	-2.44	1744.5
FY 2025	$ 22,326,622	$ 10,305,099	$ 12,021,523	-2.29	1759.1
FY 2026	$ 23,314,575	$ 11,258,109	$ 12,056,465	-1.82	1775.7
FY 2027	$ 18,432,751	$ 7,055,243	$ 11,377,508	-1.33	1790.1
FY 2028	$ 11,455,898	$ -	$ 11,455,898	-1.03	1804.6
FY 2029	$ 24,509,970	$ 9,694,236	$ 14,815,734	-0.76	1815.1
FY 2030	$ 18,311,568	$ 3,377,855	$ 14,933,714	-1.81	1819.4
FY 2031	$ 16,793,990	$ 3,011,130	$ 13,782,860	-2.26	1821.1
FY 2032	$ 13,398,036	$ -	$ 13,398,036	-1.60	1822.0
FY 2033	$ 15,579,686	$ -	$ 15,579,686	-1.86	1822.1
FY 2034	$ 16,284,071	$ 389,422	$ 15,894,649	-1.74	1822.1
FY 2035	$ 15,887,190	$ -	$ 15,887,190	-1.45	1822.1

Table 28: FAR #6 - 15-Year Balanced Capital Budget with Route Planning/Optimization and Trip Reduction

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.81	1277.2
FY 2021	$ 31,539,963	$ 19,500,097	$ 12,039,865	-3.74	1294.4
FY 2022	$ 26,215,369	$ 14,231,193	$ 11,984,176	-3.24	1316.0
FY 2023	$ 21,681,314	$ 9,480,195	$ 12,201,119	-2.45	1332.7
FY 2024	$ 22,308,173	$ 10,305,474	$ 12,002,699	-2.45	1357.2
FY 2025	$ 22,326,622	$ 10,305,099	$ 12,021,523	-2.30	1372.4
FY 2026	$ 23,314,575	$ 11,258,109	$ 12,056,465	-1.83	1389.9
FY 2027	$ 18,432,751	$ 7,055,243	$ 11,377,508	-1.35	1405.1
FY 2028	$ 11,455,898	$ -	$ 11,455,898	-1.04	1420.3
FY 2029	$ 24,509,970	$ 9,694,236	$ 14,815,734	-0.78	1431.4
FY 2030	$ 18,311,568	$ 3,377,855	$ 14,933,714	-1.83	1435.8
FY 2031	$ 16,793,990	$ 3,011,130	$ 13,782,860	-2.28	1437.6
FY 2032	$ 13,398,036	$ -	$ 13,398,036	-1.62	1438.6
FY 2033	$ 15,579,686	$ -	$ 15,579,686	-1.87	1438.7
FY 2034	$ 16,284,071	$ 389,422	$ 15,894,649	-1.76	1438.7
FY 2035	$ 15,887,190	$ -	$ 15,887,190	-1.47	1438.7

Table 29: FAR #7 – 15-Year Balanced Capital Budget with All "House-in-Order" Strategies

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.77	2928.0
FY 2021	$ 31,539,963	$ 19,500,097	$ 12,039,865	-3.70	2942.1
FY 2022	$ 26,215,369	$ 14,231,193	$ 11,984,176	-3.20	2959.0
FY 2023	$ 21,681,314	$ 9,480,195	$ 12,201,119	-2.41	2972.3
FY 2024	$ 22,308,173	$ 10,305,474	$ 12,002,699	-2.41	2991.5
FY 2025	$ 22,326,622	$ 10,305,099	$ 12,021,523	-2.26	3004.0
FY 2026	$ 23,314,575	$ 11,258,109	$ 12,056,465	-1.79	3017.8
FY 2027	$ 18,432,751	$ 7,055,243	$ 11,377,508	-1.30	3029.8
FY 2028	$ 11,455,898	$ -	$ 11,455,898	-0.99	3041.8
FY 2029	$ 24,509,970	$ 9,694,236	$ 14,815,734	-0.73	3050.4
FY 2030	$ 18,311,568	$ 3,377,855	$ 14,933,714	-1.78	3054.3
FY 2031	$ 16,793,990	$ 3,011,130	$ 13,782,860	-2.23	3055.7
FY 2032	$ 13,398,036	$ -	$ 13,398,036	-1.57	3056.4
FY 2033	$ 15,579,686	$ -	$ 15,579,686	-1.82	3056.5
FY 2034	$ 16,284,071	$ 389,422	$ 15,894,649	-1.71	3056.6
FY 2035	$ 15,887,190	$ -	$ 15,887,190	-1.42	3056.6

Fuel Switching and BEV Phase-in

Starting from FAR Scenario Seven, we modelled the impacts of alternate and renewable fuels in conjunction with BEV phase-in, as well as BEV phase-in only, on the City of Hamilton's in-scope fleet. Group Two FAR Scenarios 8-16 involved switching different combinations of vehicle classes to alternate/renewable fuels, described below:

- FAR Scenario Eight: Ethanol-85 (E85) for passenger vehicles, pickups, and vans
- FAR Scenario Nine: B10 biodiesel (annualized blend, with B20 in summer months and B5 in winter and shoulder months) for all diesel on-road units
- FAR Scenarios 11-13: Compressed natural gas (CNG) for light-, medium-, and heavy-duty (LMHD) vehicles – pickups only for FAR #11, Class 3-6 for FAR #12, and Class 2-8 for FAR #13
- FAR Scenario 14: Renewable natural gas (RNG) for Class 2-8 vehicles
- FAR Scenarios 15-16: Liquid propane gas (LPG) for LMHD vehicles – LD only for FAR #15, and LD plus Truck Classes 2-8 for FAR #16

These “messy-middle” solutions are proven and mature green fleet, low-carbon solutions that may be possible today while awaiting the commercial availability of suitable BEVs. It is important to note that these scenarios also involved replacing ICE units with BEVs in sync with fiscal years in which the type/categories of BEVs are expected to be available. FAR Scenarios 21, 23, and 25 involved BEV phase-in only, as described below:

- FAR Scenarios 21: BEV replacement for passenger vehicles only
- FAR Scenarios 23: BEV replacement for passenger vehicles, pickups, and bus
- FAR Scenarios 25: BEV replacement for passenger vehicles, pickups, bus, and MDHD trucks

Tables 30-40 show the impacts for fuel-switching and BEV scenarios, with FAR Scenario Seven – balanced capital budgets (optimized lifecycles with consideration of ROI) and all “house-in-order” strategies – serving as the starting point.

Table 30: FAR #8 – E85 (passenger, pickups, vans) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 38,233,825	$ 99,431	0.30	4691.1
FY 2021	$ 46,167,545	$ 40,881,378	$ 5,286,167	-0.12	4699.0
FY 2022	$ 43,541,522	$ 33,213,503	$ 10,328,018	-0.18	5109.7
FY 2023	$ 36,510,293	$ 29,477,697	$ 7,032,596	0.67	5176.3
FY 2024	$ 32,613,383	$ 8,578,586	$ 24,034,797	-0.59	5862.9
FY 2025	$ 14,440,705	$ 8,618,404	$ 5,822,302	1.25	5947.7
FY 2026	$ 20,075,097	$ 8,989,582	$ 11,085,515	0.72	6556.5
FY 2027	$ 15,543,126	$ 5,667,997	$ 9,875,129	1.61	6838.0
FY 2028	$ 14,398,082	$ -	$ 14,398,082	1.72	7401.1
FY 2029	$ 14,304,323	$ 3,942,583	$ 10,361,741	1.95	7867.9
FY 2030	$ 20,216,346	$ 3,040,601	$ 17,175,745	1.41	8421.8
FY 2031	$ 10,533,943	$ 2,114,526	$ 8,419,416	2.19	8625.0
FY 2032	$ 12,823,022	$ -	$ 12,823,022	1.84	8715.7
FY 2033	$ 29,707,380	$ -	$ 29,707,380	0.06	8715.8
FY 2034	$ 11,089,632	$ 389,422	$ 10,700,210	2.21	8715.8
FY 2035	$ 10,462,129	$ -	$ 10,462,129	1.76	8715.8

Table 31: FAR #9 – B10 (all on-road diesel units) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 38,233,825	$ 99,431	-0.11	3110.2
FY 2021	$ 46,167,545	$ 40,881,378	$ 5,286,167	-0.54	3136.1
FY 2022	$ 43,541,522	$ 33,213,503	$ 10,328,018	-0.57	3755.5
FY 2023	$ 36,510,293	$ 29,477,697	$ 7,032,596	0.26	3961.3
FY 2024	$ 32,613,383	$ 8,578,586	$ 24,034,797	-0.90	4694.0
FY 2025	$ 14,440,705	$ 8,618,404	$ 5,822,302	0.93	4894.5
FY 2026	$ 20,075,097	$ 8,989,582	$ 11,085,515	0.44	5796.3
FY 2027	$ 15,543,126	$ 5,667,997	$ 9,875,129	1.36	6157.1
FY 2028	$ 14,398,082	$ -	$ 14,398,082	1.57	6754.9
FY 2029	$ 14,304,323	$ 3,942,583	$ 10,361,741	1.86	7312.4
FY 2030	$ 20,216,346	$ 3,040,601	$ 17,175,745	1.37	8123.8
FY 2031	$ 10,533,943	$ 2,114,526	$ 8,419,416	2.17	8368.0
FY 2032	$ 12,823,022	$ -	$ 12,823,022	1.84	8471.3
FY 2033	$ 29,707,380	$ -	$ 29,707,380	0.06	8471.4
FY 2034	$ 11,089,632	$ 389,422	$ 10,700,210	2.21	8471.4
FY 2035	$ 10,462,129	$ -	$ 10,462,129	1.76	8471.4

Table 32: FAR #11 – CNG (LD pickups) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	0.34	3203.9
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	-0.07	3229.8
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	-0.02	3789.1
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	0.89	3948.2
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	0.09	4705.2
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	1.99	4870.6
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	1.61	5770.6
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	2.64	6135.7
FY 2028	$ 19,646,775	$ -	$ 19,646,775	3.00	6739.4
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	3.49	7270.8
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	3.16	8108.4
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	4.07	8363.1
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.79	8471.1
FY 2033	$ 42,326,275	$ -	$ 42,326,275	2.04	8471.2
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	4.20	8477.9
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.82	8477.9

Table 33: FAR #12 – CNG (Class 3-6) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	0.30	3266.4
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	-0.12	3292.3
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	-0.05	3833.9
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	0.82	4034.2
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	0.02	4786.2
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	1.91	4982.0
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	1.57	5830.0
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	2.61	6190.4
FY 2028	$ 19,646,775	$ -	$ 19,646,775	2.95	6805.8
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	3.42	7363.1
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	3.19	8109.0
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	4.08	8363.6
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.81	8471.6
FY 2033	$ 42,326,275	$ -	$ 42,326,275	2.06	8471.7
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	4.22	8476.7
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.83	8476.7

Table 34: FAR #13 – CNG (Class 2-8) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	-0.50	4402.3
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	-0.94	4428.1
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	-0.83	4896.9
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	0.06	5051.2
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	-0.62	5631.5
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	1.28	5787.9
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	1.05	6485.1
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	2.12	6778.6
FY 2028	$ 19,646,775	$ -	$ 19,646,775	2.58	7237.2
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	3.15	7652.5
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	3.01	8274.3
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	3.94	8479.6
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.68	8565.2
FY 2033	$ 42,326,275	$ -	$ 42,326,275	1.93	8565.3
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	4.08	8570.2
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.69	8570.2

Table 35: FAR #14 – RNG (Class 2-8) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	-0.50	8177.0
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	-0.94	8202.8
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	-0.83	8268.9
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	0.06	8322.1
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	-0.62	8377.9
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	1.28	8430.0
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	1.05	8506.6
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	2.12	8582.7
FY 2028	$ 19,646,775	$ -	$ 19,646,775	2.58	8589.2
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	3.15	8591.7
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	3.01	8612.5
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	3.94	8678.4
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.68	8700.7
FY 2033	$ 42,326,275	$ -	$ 42,326,275	1.93	8700.8
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	4.08	8700.8
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.69	8700.8

Table 36: FAR #15 – LPG (passenger, pickups, vans) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	-0.07	3100.0
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	-0.49	3123.3
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	-0.39	3731.0
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	0.54	3917.6
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	-0.24	4678.4
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	1.68	4867.5
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	1.33	5779.8
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	2.39	6142.3
FY 2028	$ 19,646,775	$ -	$ 19,646,775	2.75	6761.9
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	3.25	7326.1
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	2.92	8161.9
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	3.86	8409.0
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.58	8514.5
FY 2033	$ 42,326,275	$ -	$ 42,326,275	1.83	8514.6
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	3.99	8521.3
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.60	8521.3

Table 37: FAR #16 – LPG (LD, Truck Classes 2-8) & BEV Phase-in (passenger, pickups, buses, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	-1.62	3561.3
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	-2.06	3584.6
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	-1.86	4151.9
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	-0.95	4335.5
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	-1.51	5022.8
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	0.41	5203.3
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	0.34	6030.1
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	1.48	6362.9
FY 2028	$ 19,646,775	$ -	$ 19,646,775	2.03	6922.4
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	2.68	7438.1
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	2.68	8182.5
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	3.66	8409.1
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.42	8505.2
FY 2033	$ 42,326,275	$ -	$ 42,326,275	1.67	8505.3
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	3.80	8512.1
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.42	8512.1

Table 38: FAR #21 – BEV Phase-in (passenger vehicles only)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.77	2928.0
FY 2021	$ 31,539,963	$ 19,500,097	$ 12,039,865	-3.71	2964.4
FY 2022	$ 26,215,369	$ 14,231,193	$ 11,984,176	-3.22	3024.7
FY 2023	$ 21,681,314	$ 9,480,195	$ 12,201,119	-2.44	3080.9
FY 2024	$ 22,308,173	$ 10,305,474	$ 12,002,699	-2.45	3151.0
FY 2025	$ 22,326,622	$ 10,305,099	$ 12,021,523	-2.31	3179.1
FY 2026	$ 23,314,575	$ 11,258,109	$ 12,056,465	-1.85	3263.2
FY 2027	$ 18,432,751	$ 7,055,243	$ 11,377,508	-1.39	3347.9
FY 2028	$ 11,455,898	$ -	$ 11,455,898	-1.08	3363.0
FY 2029	$ 24,509,970	$ 9,694,236	$ 14,815,734	-0.82	3371.6
FY 2030	$ 18,311,568	$ 3,377,855	$ 14,933,714	-1.87	3390.7
FY 2031	$ 16,793,990	$ 3,011,130	$ 13,782,860	-2.34	3455.8
FY 2032	$ 13,398,036	$ -	$ 13,398,036	-1.69	3477.9
FY 2033	$ 15,579,686	$ -	$ 15,579,686	-1.94	3478.0
FY 2034	$ 16,284,071	$ 389,422	$ 15,894,649	-1.83	3478.1
FY 2035	$ 15,887,190	$ -	$ 15,887,190	-1.55	3478.1

Table 39: FAR #23 – BEV Phase-in (passenger, pickups, bus)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 38,333,256	$ 24,598,492	$ 13,734,765	-2.77	2928.0
FY 2021	$ 30,499,253	$ 22,298,674	$ 8,200,579	-3.35	2956.2
FY 2022	$ 28,907,604	$ 13,613,263	$ 15,294,341	-3.84	3604.7
FY 2023	$ 20,344,001	$ 9,251,110	$ 11,092,891	-2.63	3816.3
FY 2024	$ 19,108,430	$ 9,939,929	$ 9,168,501	-2.52	3931.4
FY 2025	$ 23,072,790	$ 10,005,612	$ 13,067,178	-2.68	4092.6
FY 2026	$ 25,786,798	$ 10,866,937	$ 14,919,860	-2.43	4571.6
FY 2027	$ 16,932,741	$ 7,055,243	$ 9,877,498	-1.75	4707.0
FY 2028	$ 10,410,190	$ -	$ 10,410,190	-1.42	4793.1
FY 2029	$ 24,978,625	$ 8,601,122	$ 16,377,504	-1.27	4944.7
FY 2030	$ 18,611,265	$ 3,040,601	$ 15,570,664	-2.33	5307.4
FY 2031	$ 12,554,392	$ 2,114,526	$ 10,439,866	-2.49	5372.5
FY 2032	$ 15,175,457	$ -	$ 15,175,457	-2.66	5394.7
FY 2033	$ 16,801,175	$ -	$ 16,801,175	-2.59	5394.8
FY 2034	$ 14,198,391	$ 389,422	$ 13,808,968	-2.16	5394.8
FY 2035	$ 14,796,142	$ -	$ 14,796,142	-2.11	5394.8

Table 40: FAR #25 – BEV Phase-in (passenger, pickups, bus, MDHD trucks)

Budget Year	Planned Capital Budget	Deferred Spending	Total Capital Budget	Total Opex vs Baseline ($mil)	Total GHG Reduction vs Baseline (tonnes CO2e)
FY 2020	$ 54,600,756	$ 54,501,325	$ 99,431	0.55	2917.2
FY 2021	$ 62,965,760	$ 57,603,168	$ 5,362,592	0.14	2943.1
FY 2022	$ 60,674,478	$ 48,098,408	$ 12,576,070	0.15	3581.7
FY 2023	$ 51,831,435	$ 43,923,269	$ 7,908,166	1.02	3789.1
FY 2024	$ 47,632,619	$ 11,123,123	$ 36,509,496	0.21	4560.6
FY 2025	$ 17,975,706	$ 11,192,060	$ 6,783,646	2.09	4763.9
FY 2026	$ 26,753,238	$ 11,612,138	$ 15,141,100	1.68	5694.5
FY 2027	$ 20,745,291	$ 7,521,838	$ 13,223,452	2.71	6068.8
FY 2028	$ 19,646,775	$ -	$ 19,646,775	3.05	6696.7
FY 2029	$ 20,147,308	$ 4,253,537	$ 15,893,771	3.51	7276.6
FY 2030	$ 26,680,346	$ 3,490,244	$ 23,190,101	3.18	8114.2
FY 2031	$ 13,888,852	$ 2,458,935	$ 11,429,917	4.08	8368.8
FY 2032	$ 16,345,081	$ -	$ 16,345,081	3.81	8476.8
FY 2033	$ 42,326,275	$ -	$ 42,326,275	2.05	8476.9
FY 2034	$ 15,111,215	$ 477,272	$ 14,633,943	4.21	8483.6
FY 2035	$ 14,304,827	$ -	$ 14,304,827	3.83	8483.6

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Appendix E: Details on Fuel-Reduction Solutions

This appendix of our report provides further detailed information on many of the 20+ fuel-reduction solutions modelled in FAR, which have been researched by RSI-FC – some of which have already been implemented by the City of Hamilton, and many of which are considered as potential new, go-forward strategies.

Best Management Practices

Best management practices – Group One - include: (1) enhanced vehicle specifications – vehicle choice and/or vehicle upgrades – which lower fuel consumption, lower GHG emissions, and improve overall performance; (2) proper maintenance procedures including tire inflation systems; and (3) fleet operational improvements including:

- Idling reduction initiatives
- Driver training to educate drivers on efficient driving practices
- Ongoing feedback and motivation to maintain good driving habits
- Route planning and optimization, including trip reduction, minimization, or elimination

Enhanced Vehicle Specifications at a Glance

There are a number of vehicle specifications that can aid in fuel-use and emissions reductions. *Table 41* lists sample vehicle specifications and their respective impacts.

Table 41: Strengths and Weaknesses of Enhanced Vehicle Specifications

Specification	Strengths	Weaknesses
Smaller Vehicles	Consume less fuel and thus have reduced emissions	Might not always be suitable for the job
Lighter Vehicles	Consume less fuel, produce less emissions, and can carry larger payload (e.g., if a truck is lighter by “x” pounds/kg, it can carry a commensurately increased payload), which increases efficiency	Light weighting may overstress some vehicles, increasing maintenance demand and lifecycle cost
Aerodynamically Designed Vehicles	Reduces fuel consumption and emissions	Minimal effectiveness in urban setting, high cost, increased maintenance

Specification	Strengths	Weaknesses
		demand for some solutions
Low Rolling Resistance (LRR) Tires and Wide-base Tires	Reduces fuel consumption and emissions, reduce frequency of tire replacement	Potential for on-road service issues, axle loading restrictions in some jurisdictions with wide-base tires
Electronically Controlled, Programmable Diesel Engines	Allow tailoring/minimizing power and torque needs, road speed, and idle time limits therefore reducing fuel consumption and emissions	Seldom give problems, however when they do, often require specialized and costly diagnostic skills (might need to be outsourced) with potentially protracted downtime
Idling-Reduction Devices	Reduces idle time and therefore lowers fuel use and emissions	Actual idling reduction benefits are dependent on the use of technologies by drivers, some who resent intervention by such devices; some may feel devices could cause a safety concern

Fleet Downsizing

Getting a fleet's "house in order" should include shedding any under-utilized vehicles, so that stranded capital tied up in low-usage units can be re-applied to fleet modernization and new electric vehicles (EVs). When exception data demonstrates that a vehicle's usage has been less than the organization's acceptable minimum threshold, the vehicle is incurring cost without serving a purpose. Hence, the vehicle is a liability, unless it has some redeeming value, i.e., a special-purpose or backup vehicle for emergencies, or a unit reserved for peak periods.

Low-usage units should be routinely and regularly reviewed to determine if there are more cost-effective ways of accomplishing the corporate end-goal. If a specific vehicle is used infrequently, management should consider creative solutions for a less costly travel mode, i.e., an interdepartmental vehicle sharing arrangement, a 3rd party service-provider, video conferencing, use of employee's vehicles, etc.

A fleet's first step in cost reduction is to reduce the total number of low-utilization vehicles. Management should undertake a review to determine if some vehicles can be eliminated through early decommissioning.

Right-Sizing

In days past, some fleet managers subscribed to the adage "identify the size of truck you really need for the job — and then buy one bigger." Today, we know this is anachronistic thinking that led to fleets with oversized vehicles, poorer fuel economy, and higher operating costs and GHG emissions.

Instead, savvy fleet managers are leaving the old approach behind and employing the correct and most efficient approach, which is to right-size fleet vehicles – that is, correctly specify the size of vehicle for the job at hand, which leads to lower overall operating costs.

Job Suitability

The types of vehicles and the equipment staff members are fitted should be aligned with the vocational and load requirements. For example, a passenger sedan would be completely unsuitable for plowing snow or carrying loads of anything other than people. Rather, fleet vehicles types are matched specifically to the tasks at hand; in this case, a light-duty truck would be required for snow removal in, for example, parking lots.

Choose the Size Down When Appropriate

Acquiring light-duty (class 2a) vans and pick-ups as opposed to heavier-duty units (2b), which have higher acquisition and maintenance costs, is a recommended best management practice which results in a lower total cost of ownership.

A further example is with heavy-duty units; selecting a single-axle plow-dump unit, which has inherently lower operating costs than a tandem-axle unit, is recommended when appropriate (i.e., when the specific task at hand, or job suitability, is fulfilled by either unit).

Accounting for Limited Space

Limited space for roads, as a result of urban development and densification, may lead to an increased number of traffic roundabouts. Roundabouts pose unique problems for snowplows as well as refuse and recycling trucks because of tight turning movements and lack of adequate space to maneuver. Single axle units are shorter in overall length and, therefore, turn in a smaller radius than tandem or tridem axle units. They also cost less to acquire and maintain. The disadvantages are that single axle trucks may have less traction/control in slippery conditions and have less load-carrying capacities, such as salt/sand or waste (less productivity). However, in urban, low-speed, traffic-congested environments with limited space, such as roundabouts, single axle plows or refuse/recycling trucks will have an advantage over multi-axle units. In this example, it is important to weigh the pros and cons for different sized vehicles; when space is tight, it is often recommended to go smaller when it is safe (i.e., at low speeds) and productivity is acceptable.

Right-Sizing Summary

In summary, it is important for a fleet to consider the following in regard to right-sizing:

- Ensure that fleet vehicles are matched specifically to the tasks at hand (i.e., are job suitable) in terms of both vocation and load requirements.
- When multiple sized units fulfil a task equally well, choose the size down.
- When space is limited, it is often best to choose smaller units, given that it is safe to do so and that the productivity level is acceptable.

Low Rolling Resistance (LRR) Tires

Rolling resistance is the energy lost from drag and friction of a tire rolling over a surface[100]. The phenomenon is complex, and nearly all operating conditions can affect the final outcome. With the exception of all-electric vehicles, it is estimated that 4%–11% of light-duty vehicle fuel consumption is used to overcome rolling resistance. All-electric passenger vehicles can use approximately 23% of their energy for this purpose. For heavy trucks, this can be as high as 15%–30%.

A 5% reduction in rolling resistance would improve fuel economy by approximately 1.5% for light and heavy-duty vehicles. Installing low rolling resistance tires can help fleets reduce fuel costs. It's also important to ensure proper tire inflation (see sections below).

Tires and fuel economy represent a significant cost in a fleet's portfolio. In Class 8 trucks, approximately one-third of fuel efficiency comes from the rolling resistance of the tire. The opportunity for fuel savings from low rolling resistance tires in these and other vehicle applications is substantial.

According to a North American Council for Freight Efficiency (NACFE) report, the use of low rolling resistance tires, in either a dual or a wide-base configuration, is a good investment for managing fuel economy. Generally, the fuel savings pay for the additional cost of the low rolling resistance tires. In addition, advancements in tire tread life and traction will reduce the frequency of low rolling resistance tire replacement.

[100] Source: https://afdc.energy.gov/conserve/fuel_economy_tires_light.html

Automatic Tire Inflation Systems (ATIS)

Proper tire inflation pressure is critical to the optimal operation of a commercial vehicle. Underinflated tires result in decreased fuel efficiency and increased tire wear[101]. A 0.5-1.0% increase in fuel consumption is seen in vehicles running with tires underinflated by 10 psi. Appropriate pressure reduces tire wear, increases fuel efficiency, and leads to fewer roadside breakdowns due to tire failures. An example of an automatic tire inflation system is shown in *Figure 24*.

Figure 24: Automatic Tire Inflation System (courtesy NACFE)

In the U.S., a large truckload carrier with 5,000 tractors and 15,000 trailers averaging 124,000 miles a year on tractors and 41,000 miles on trailers, conducted a fuel economy test with 60 trucks pulling trailers without tire inflation systems and 75 trucks matched with trailers with the systems installed. The results of the test showed a 1.5% improvement in fuel consumption for trucks with ATIS.

Tire Inflation with Nitrogen

Nitrogen is said to permeate tire walls up to four times slower than air. Tires will lose one to two psi over one month versus the six months it takes a nitrogen-filled tire to lose that same amount of pressure. As a result, the time spent adjusting the tire pressure is reduced.

Supporters of nitrogen for tire inflation claim better tire pressure retention. This is believed to result in:

- A smoother ride
- Improved steering and braking
- Reduced risk of blowouts by as much as 50 percent[102]
- Increased tires tread life by up to 30 percent, improving the tire's life and its grip to the road[103]
- Reduced fuel consumption by up to 6%[104]

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[101] Source: https://nacfe.org
[102] Source: http://www.gonitrotire.com
[103] Source: http://www.gonitrotire.com
[104] The fuel consumption reduction estimates vary considerably. Enviro-fleets, A guide to helpful resources, June 2010, report an improvement of up to 10%, but the industry standard is between 3% and 6%.

It must be noted that it is not the nitrogen itself that improves the fuel efficiency, but rather the enhanced retention of inflation pressure over time[105]. Reduced tire pressure leads to increased fuel consumption. Therefore, if vehicle tire pressure is well monitored, there might not be a fuel consumption benefit of using nitrogen.

Idling Reduction

Idling reduction is an important concern for all leading fleets that are looking to optimize costs and reduce the environmental impact. Municipal fleet vehicles left idling for no apparent reason are seen by the public as being wasteful and polluting. These negative messages are potentially damaging to the reputation of any municipality.

Fuel consumption from idling of heavy-duty vehicles is significant. While we acknowledge there are times when idling is simply unavoidable, the U.S. Department of Energy estimates that unnecessarily idling heavy-duty vehicles wastes from half to one U.S. gallon (1.89 to 3.79 liters) or more per hour. Some fleets idle 30 to 50% or more of their operating time[106]. These are several main approaches to idling reduction, including:

- Idling-reduction policy
- Driver training and motivation
- Idling-reduction awareness and fact-based training
- Incentive programs
- Ongoing driver education
- The use of idling reduction devices, including:
  - Auxiliary power units (APU)
  - Stop/start devices
  - Auxiliary cab heaters
  - Battery backup systems
  - Block heaters / engine preheaters

Idling-Reduction Policy

An idling-reduction policy is a way to motivate fleet drivers to limit unnecessary idling. However, for an idling-reduction policy to be successful continuous enforcement such as spot-checks and fuel use tracking must be present. An idling-reduction policy could be used as an overarching commitment to idling reduction that is carried out though driver training and motivation sessions, rather than an initiative on its own.

[105] Source: NHTSA Report, 2009: https://one.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/.../2009/811094.pdf
[106] Source: FC Best Practices Manual 2008

When Engine Idling is Unavoidable

There are times when idling is unavoidable. These include:

- Cab heating/ventilation and air conditioning (HVAC)
- Power for critical equipment (such as the use of a PTO for ancillary equipment)
- Maintaining brake air pressure (MD and HD trucks)

It is important to differentiate between *unnecessary* idling and idling that is *unavoidable* due to operational requirements. The focus of all idling-reduction initiatives should be to reduce and, ideally, eliminate *unnecessary* idling and to explore alternatives of how to limit idling for operational purposes with solutions that do not impede with operations, but offer environmental and economic benefits.

Idling Reduction Devices

There are several idling-reduction technologies available that can aid in idle reduction. Their functionality, potential, and costs vary considerably and are described in *Table 42.* To reap the most benefits any idling-reduction technology, installation should always be accompanied by behavioural solutions of driver training and motivation.

Table 42: Idling Reduction Devices and Their Associated Costs

Technology	Description	Cost Estimates
Auxiliary Power Units (APU)	An APU consists of a small engine that provides power to heat and cool the cab, as well as to power accessories, heat the engine, and charge the start battery. DC-powered APU systems are also available.	APUs can cost anywhere from ~$8,500 to ~$10,000. Annual maintenance cost is estimated as high as $500.
Stop/Start Devices (Idle-Stop systems)	A stop/start system automatically shuts down and restarts the internal combustion engine to reduce the amount of time the engine spends idling. This technology is particularly useful for vehicles that spend significant amounts of time waiting at traffic lights or frequently come to a stop in traffic jams.	Stop/start devices typically are part of OEM hybrid vehicle systems, but more recently has also been introduced in regular combustion engine vehicles to reduce fuel consumption. Such devices can also be purchased separately (offered by companies like Bosch that also manufacturers OEM devices) and their costs average at about $300-$350.

Technology	Description	Cost Estimates
Auxiliary Cab Heaters	There are two types: 1) Gas- or diesel-fired auxiliary air heater: In most cases, it is fitted in the cab, drawing in cab air through a blower and heating it. 2) Gas- or diesel-fired auxiliary coolant heater: It is installed in a vehicle's engine compartment and enables the vehicle's own coolant circuit to work without the use of the entire engine. Such water-based auxiliary heaters use small amounts of fuel to heat up the liquid in the air-exchange system and provide warm air in the cabin. Compared to air-based auxiliary heaters, the advantage of water-based auxiliary heaters is that they also warm the engine in the process (similarly to block heaters), thus enhancing starting performance. Auxiliary coolant heaters are manufactured by companies like Webasto and Espar.	~$1,250 +
Battery Backup Systems	A battery backup system powers electric devices (emergency lights, etc.) without drawing power from the primary battery. The system consists of adding an isolator and an additional battery to a vehicle's electric system. When the vehicle is off, the isolator prevents power being drawn from the primary battery and instead uses the alternate battery to power any electronic systems. When the vehicle is running, both batteries are recharged; charging to the start battery is prioritized and it is charged first.	The system costs between $400-$600 plus the price of a battery which varies based on the required capacity.
Block Heater / Engine Preheater	Engine block heaters use power from electrical outlets in corporate facilities, where vehicles are parked overnight to heat the engine block. The block heater on	Block heaters cost between $70 and $150 and have a negligible annual maintenance cost.

Technology	Description	Cost Estimates
	timer can be set to switch-on a few hours before the vehicle is used to warm up the engine block. This decreases required warm-up idling time. This is a very low-cost option, and a necessity in Canadian winters; however, it is limited to reducing warm-up idling only.	

Emissions Reduction Potential

Despite the wide selection of idling reduction solutions, when it comes to internal combustion engines, there is no technology that completely eliminates CO_2 and other emissions. Only battery-electric and hydrogen fuel cell vehicle technologies can eliminate tailpipe emissions. Idling-reduction initiatives can be helpful in reducing unnecessary idling in the short and medium term, and as a segue to gradual transition to electric trucks and hydrogen fuel cells in the long-run.

Driver Training and Motivation

Idling-Reduction Training and Incentives

Driver training to modify driver behaviours and ongoing motivation to continue good behaviours are crucial components of successful idling-reduction programs. While most drivers understand the vehicle idling issue, many continue their inefficient practice of excessive idling due to lack of knowledge and/or motivation.

Driver training can be used to optimize the use of idle reduction technologies. The technologies can reduce idling but the drivers have the ability to override the technologies. Proper training can aid in utilizing the technologies to their full potential.

In addition to establishing corporate idling reduction policies, behaviour-based approaches for idling reduction include:

- Idling-reduction training for drivers; and
- Incentive programs to encourage drivers to limit idling.

For best results, these approaches should be used in conjunction. Regardless of the approach, the greatest impact pledges of idling-reduction should be made in a public forum. Moreover, idling-reduction targets should be customized as various fleet vehicles may have different operating requirements and will benefit from targets that accurately reflect their work environment. Beginning from a measured starting point, progress should be evaluated at regular intervals to modify and adapt the approach if progress is not occurring.

Driver Eco-Training

Driver eco-training should be fact-based and aimed at increased awareness and promotion of good practices. Typically, eco-training courses address the following areas:

- Progressive shifting (or use of automated transmissions)
- Starting out in a gear that doesn't require using the throttle when releasing the clutch
- Shifting up at very low RPM
- Block shifting where possible (e.g., shifting from third to fifth gear)
- Maintaining a steady speed while driving
- Using cruise control where appropriate
- Anticipating traffic flow
- Coasting where possible
- Braking and accelerating smoothly and gradually
- Avoiding unnecessary idling

Driver eco-training programs vary considerably. They can be organized as short (typically an hour long) information sessions/workshops or can be considerably longer and involve more hands-on activities. Extended training can vary in length from a half to a full day, or can also be scheduled into shorter sessions over a period of time.

Online Training

Online training courses are gaining popularity thanks to their flexibility. This trend has accelerated due to the Covid-19 pandemic and the need for social distancing measures. It is strongly recommended that discussion sessions among the drivers be organized to review training topics to deepen their understanding and provide a forum for questions and concerns. The individual responsible for the idling reduction incentives program could facilitate such sessions.

In-Person Training

In-person driver eco-training courses vary greatly in length, depth, and format. These courses offer a more personalized approach, facilitate immediate discussion, and typically allow for practical application. For best results, eco-training could be combined with professional driver improvement training.

NRCan SmartDriver Training Series

SmartDriver provides free, practical training to help Canada's commercial and institutional fleets lower their fuel consumption, operating costs, and harmful vehicle emissions. Fleet energy-management training that helps truckers, transit operators, school bus driver, and other professional drivers is claimed by NRCan to improve fuel efficiency by up to 35 percent. RSI-FC highly recommends NRCan's SmartDriver training: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/greening-freight-programs/smartdriver-training-series/21048

Continuous Motivation

Studies have demonstrated that driver training benefits, although significant, are likely to diminish over time. Ongoing feedback and motivation is recommended as a preventive measure. This can include:

(1) Tracking Idling to Provide Feedback to Drivers

- Monitoring the progress of any initiative is crucial not only to determine the impact, but to also provide feedback to the drivers to provide them the opportunity to modify their behaviour.
- Practices that track and report fuel consumption establish a valuable monitoring basis. Knowledge and comprehensive factual information can help build a stronger business case and "buy-in" for idling reduction.
- Telematics technologies help managers and drivers track idling and provide measurable data to manage goals. Such technologies, however, can be expensive as they typically use GPS systems and OBD monitoring devices.

(2) Implementing a Corporate Idling Reduction Policy

- It is our opinion that in most cases drivers want to "do the right things." By ramping up communications about excessive idling and instituting a clear idling policy, a reduction of unnecessary idling will likely result.

(3) Ongoing Information Campaigns and Reminders

- In general, information campaigns are low-cost, easy to manage, and lead to a more knowledgeable and receptive public. To raise awareness of the issues these can be initiated even before driver training commences. Numerous resources that address idling awareness issues are available free of charge and ready to implement.

(4) Non-Monetary Incentives Programs

- There are a few approaches that can aid in motivating drivers to continue to apply the skills gained during eco-training. Competition among departments/teams to reduce idling can be an effective approach. Periodic recognition of high-performers can be either public or private. An example of a non-monetary reward might be the donation to a charity in the amount of the lowest idling department's fuel cost savings.

Summary and Potential Impact

Driver training is an initiative that attempts to change an individual's behaviour and thus the results are hard to predict and the variance is large. A multitude of aspects, such as the current level of driver education and driving practices, the level of idling, corporate culture and policy, and individual receptiveness and willingness to change will influence results. It is estimated that driver training has a potential to reduce vehicle fuel consumption by anywhere from 3% to 35%, with the typical results between 5% and 10%.

Route Planning and Optimization

In addition to vehicle upgrades, proper maintenance, driver training, and continuous motivation to maintain good driving habits, a fleet can further minimize fuel consumption and exhaust emissions through route planning and optimization. Route planning software can be used optimize multi-stop trips. There are different software available for categories in both public and private fleets (e.g., service dispatch software, courier software, trucking software, etc.) [107].

Route planning software used for delivery services ensures the minimum driving time for multi-stop trips by using advanced algorithms to arrive at the optimal route that provides the highest collective reduction in total driving time and, consequently, fuel consumption. This can also mean fewer vehicles and less traffic on the road at one time.[108]

Route planning software can also be used for idling reduction initiatives by integrating GPS tracking software to monitor driver activity in real-time. Moreover, reporting and analytics features within route planning software can help with identifying when a fleet vehicle requires maintenance to ensure optimal fuel efficiency and thus minimize cost and emissions.[109]

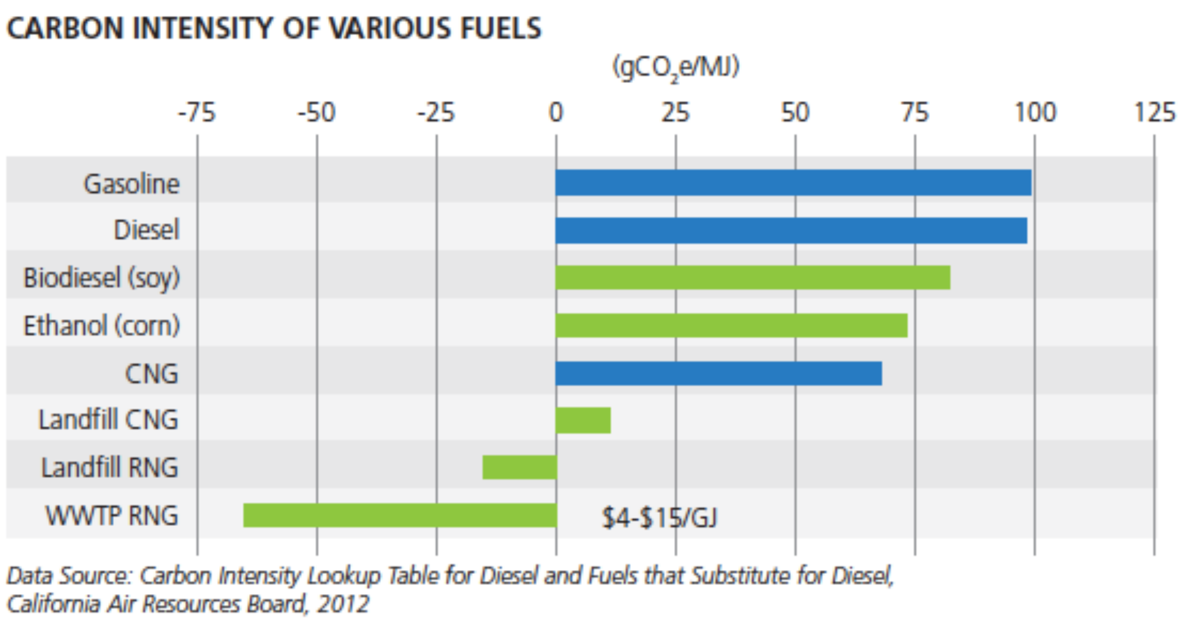
[107] Source: https://www.capterra.com/route-planning-software/
[108] Source: https://blog.route4me.com/2020/05/carbon-emissions-reduction-route-optimization-helps-cut-tons-carbon-emissions/
[109] Source: https://blog.route4me.com/2020/05/carbon-emissions-reduction-route-optimization-helps-cut-tons-carbon-emissions/

Low-Carbon Fuel Switching

Of all current-day fuel-reduction solutions, fuel switching is often the most expedient way to reduce emissions in the short term. As awareness of climate change issues amplify, the use of low-carbon fuels is gaining increased domestic and global interest. Fuel switching is a process of diverting a fleet's fuel consumption away from traditional fossil-based sources to either alternate or renewable energy sources.

Figure 25 shows the carbon intensity of various fuels relative to baselines for traditional fossil gasoline and diesel.

Figure 25: Carbon Intensity of Various Fuels

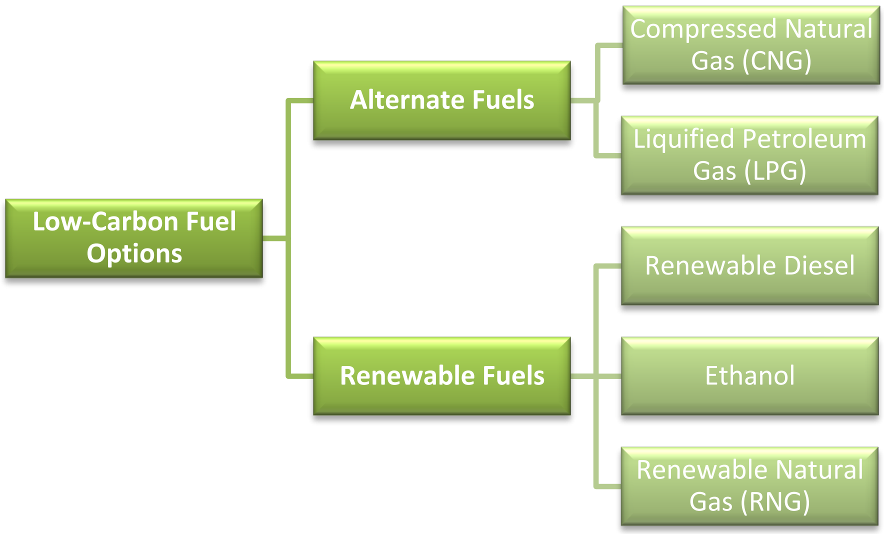


No Pain, No Gain!

Unfortunately, regardless of which fuel-switching options are selected, the reality is that each will require some degree of effort to implement. For example, although transit buses are capable of using biodiesel and/or renewable diesel, obtaining the fuels would likely bring new operational challenges such as switching bulk suppliers and/or requiring extra efforts from vehicle drivers to attend different retail fuel stations instead of those they are accustomed to frequenting. Adding B10 biodiesel to the in-house fuelling supply system will require minor modifications, extra work routines, and procedures for staff to follow.

Figure 26 provides an overview of the low-carbon fuel alternatives now available to reduce a fleet's fuel consumption and GHG emissions.

Figure 26: Low-Carbon Fuel Options



An alternate route to changing the fuel used to power an internal combustion engine is to introduce a complete change such as battery-electric or hydrogen fuel cell vehicles. Some jurisdictions have already legislated elimination of the internal combustion engine in coming years. How successful that will be remains to be seen, but in response to the need to and regulation supporting the transition away from fossil fuels, zero-emission electric and fuel cell trucks are already planned for production. These technologies will be explained in later sections of this Appendix. First, we will explore low-carbon fuel options, also known as the “messy middle.”

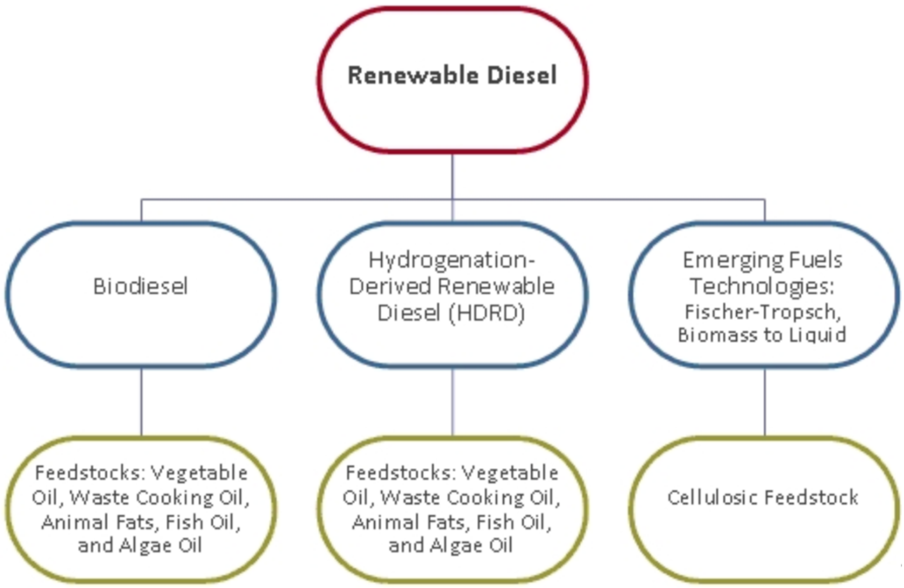
Renewable Diesel

Renewable diesel is a fossil diesel fuel substitute currently made from plant and animal oils and fats as well as from cellulosic feedstock consisting of agriculture and forest biomass[110].”

There are two main renewable diesels – biodiesel and hydrogenation-derived renewable diesel (HDRD), explained below – and other technologies to convert biomass into renewable diesel are being developed (outlined in *Figure 27)*[111]. All diesel fuel sold in Canada contains a percentage of renewable diesel owing to a renewable fuels standard.

[110] Source: https://www.nrcan.gc.ca/energy/alternative-fuels/resources/nrddi/3669
[111] Source: https://www.nrcan.gc.ca/energy/alternative-fuels/resources/nrddi/3669

Figure 27: Renewable Diesel Types and Feedstocks



Biodiesel Overview

Biodiesel is a renewable fuel made from vegetable oil and waste cooking oil, animal fats such as beef tallow and fish oil, and even algae oil[112]. In technical terms, biodiesel is a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters made by chemically reacting lipids (e.g., vegetable oil, soybean oil, animal fat) with alcohol-producing fatty acid esters. Biodiesel is often referred to as fatty acid methyl ester or FAME[113].

Biodiesel can be blended in a variety of ratios with conventional fossil diesel. Much of the world uses a system known as the "B" factor to state the amount of biodiesel in any fuel mix (e.g., B2 indicates 2% biodiesel and 98% fossil diesel). Biodiesel blends include: B2, B5, B10, B20, blends greater than B20, and B100 (100% biodiesel, also known as "neat" biodiesel).[114]

Canadian regulations require fuel producers and importers to have an average renewable fuel content of at least 2% based on the volume of diesel fuel and heating distillate oil that they produce or import into Canada. The regulations include provisions that govern the creation of compliance

112 Source: https://www.nrcan.gc.ca/energy/alternative-fuels/resources/nrddi/3669
113 Source: https://www.neste.com/what-difference-between-renewable-diesel-and-traditional-biodiesel-if-any
114 Source: https://www3.epa.gov/region9/waste/biodiesel/questions.html

units, allow trading of these units among participants and also require record-keeping and reporting to ensure compliance[115].

Blends of 20% biodiesel and lower can be used in diesel equipment with no or only minor modifications, although certain manufacturers do not extend warranty coverage if equipment is damaged by poor quality fuel in these blends.

Biodiesel used in its pure form (B100) may require certain engine modifications to avoid maintenance and performance problems. A new system recently emerged involving the use of a heated fuel storage tank in which the engine starts on standard diesel, and then after warm-up of the fuel tank, switches over to B100. The system is said to allow the use of B100 year-round in cold, winter conditions.

Hydrogenation-Derived Renewable Diesel vs Traditional Biodiesel

Hydrogenation-derived renewable diesel (HDRD) is made from animal fats or vegetable oils – alone or blended with petroleum – refined by a process called hydro treating. HDRD and traditional biodiesel (also known as fatty acid methyl ester or FAME, as stated earlier) are often confused; however, they are distinctly different products, even though both are made from organic biomasses. The differences can be found in their production process, cleanliness, and quality.

Unlike biodiesel, HDRD is made primarily from waste and residues and impurities are removed during the hydro treating process at a high temperature[116]. The outcome is a colorless and odorless fuel of an even quality that has an identical chemical composition to fossil diesel. It is also often called an "advanced biofuel" or "second-generation biofuel."

Traditional, first-generation FAME-type biodiesel, on the other hand, is produced by esterifying vegetable oils or fats. The esterification process restricts the use of poor quality or impure raw materials, such as waste and residues. The quality of traditional biodiesel also varies in other respects based on the raw materials used.

HDRD is cleaner and has a lower carbon footprint than petroleum-based diesel, and it can also operate at colder temperatures than fossil diesel and biodiesel. Therefore, HDRD can be used in higher concentrations than biodiesel and even as a standalone product in diesel engines. However, it generally cost significantly more than traditional biodiesel; biodiesel has been on average 60% cheaper than HDRD from 2010-2017[117].

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[115] Source: https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/renewable.html
[116] Source: https://www.neste.com/what-difference-between-renewable-diesel-and-traditional-biodiesel-if-any
[117] Source: https://www.naviusresearch.com/wp-content/uploads/2019/05/Biofuels-in-Canada-2019-2019-04-25-final.pdf

Biodiesel At a Glance

Table 43: Strengths and Weaknesses of Biodiesel

Strengths	Weaknesses
1. Safe and non-toxic 2. Proven, mature technology in North America and Europe 3. No conversion costs to vehicles 4. Minor costs to convert fuelling infrastructure (tanks and pumps) 5. Warranty approved by most engine manufacturers[118,119,120] 6. Increases lubricity and therefore is known to extend engine life (Note: Today's ultra-low sulfur diesel suffers from reduced lubricity and biodiesel is commonly used to counteract this issue.) 7. Can reduce GHG emissions, depending on blend used and source of biodiesel	1. Although production is abundant, there are a limited number of vendors and distributors; locating vendors/suppliers may be challenging 2. Viscosity issues related to the higher-blends (B5 or higher) in cold weather conditions that require special attention 3. Possible perception that "food" production is sacrificed for fuel production 4. Potential of higher fuel cost, depending on blend and market conditions (Note: Prior to the recent market situation for oil, B20-B50 was approximately the same price or less than fossil diesel.) 5. Marginal level of reduced energy efficiency, which varies from 1% in the case of B20 reaching 7.5% in the case of B100

Biodiesel Emissions Reduction Potential

Tailpipe GHG emissions reductions are dependent on the biodiesel blend used; for a given unit mass or volume, the higher the blend, the lower the GHG emissions. B20, in particular, reduces CO_2 by 15% in comparison to conventional diesel per unit mass/volume[121]. However, actual tailpipe emissions reduction potential for the same distance travelled is dependent on both GHG emissions per unit mass/volume and fuel economy. B5 has been shown to improve fuel economy by as much as 10% in comparison to conventional diesel[122], whereas fuel economy can be 2% lower for B20

[118] Source: www.neste.com. Neste is a producer of renewable diesel. The company describes itself as the global leader in the renewable diesel market and wants to develop significant business from non-traffic renewable product markets by the end of the decade.
[119] Source: http://biodiesel.org/using-biodiesel/oem-information
[120] Source: https://www.afdc.energy.gov/fuels/biodiesel_blends.html
[121] Source: https://www.fueleconomy.gov/feg/biodiesel.shtml
[122] Source: https://www.consumerreports.org/cro/2012/05/diesel-vs-biodiesel-vs-vegetable-oil/index.htm

and as much as 10% lower for B100 (pure or "neat" biodiesel)[123]. Therefore, there may be a "sweet spot" for optimizing fuel economy and GHG emissions reduction using blends from B5 to approaching B20. Using blends in this range improves fuel economy and lowers GHG tailpipe emissions on the order of approximately 10 percent. Using biodiesel can also reduce several other tailpipe emissions including particulates and unburned hydrocarbons[124]. Moreover, the lifecycle CO_2 emissions can be significantly lower for biodiesel than for conventional diesel[125].

Biodiesel – Ease of Implementation

There are no vehicle conversion or infrastructure costs associated with biodiesel use. Therefore, either biodiesel or HDRD could be immediately introduced without delay to begin reducing emissions for a fleet following research into the optimal blends for operational needs and cold-weather considerations.

Biodiesel Production in Canada

In 2016, Canadian biodiesel production increased due to new production capacity coming on-line. Canada's biodiesel production was estimated to reach 400 million liters in 2016 and forecast to reach 550 million liters in 2017, but is still below the level needed to meet the federal mandate. The balance will continue to be met by imports.

Primary feedstocks remain canola, animal fat, and recycled oils. Canola feedstock was expected to account for nearly 29 percent of Canadian biodiesel production by the end of 2016 and in 2017. Cooking oil was forecast to account for 49 percent of the feedstock in 2016 and 46 percent on 2017. Soybean oil was expected to increase to 20 percent by 2017.

Biodiesel Gelling

Biodiesel is essentially oil; therefore, it solidifies in cold temperatures (commonly referred to as gelling). If the fuel begins to gel, it can clog engine filters and eventually thicken enough to prevent flow from the fuel tank to the engine. The temperature at which crystals begin to form is called the cloud point. The cloud point varies considerably from one biodiesel source to another. Due to Canadian climate conditions, the flow properties of biodiesel are an important consideration. It must be noted that even petroleum diesel can gel, thus additives are often used during wintertime as a preventative. In the case of biodiesel blends, such additives can aid in reducing the cloud point during winter months.

[123] Source: https://www.fueleconomy.gov/feg/biodiesel.shtml
[124] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/biodiesel/3509
[125] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/biodiesel/3509

According to the U.S. Department of Energy, the temperature at which B100 starts to gel will vary with the feedstock and can range from 0°C to 15°C. Soy is the most common source of biodiesel, and has a cloud point of 0°C.

Biodiesel blending aids in reducing the cloud point temperature, as conventional diesel has a considerably lower cloud point temperature. The goal for users is to ensure that the fuel's cloud point temperature is appropriate for weather conditions. The U.S. Department of Energy sought to obtain a biodiesel blend with cloud point safe for use in cold weather. They used a specially formulated cold weather conventional diesel fuel that has a cloud point of -38°C. This diesel was mixed with soy biodiesel to make a B20 blend. As a result, the cloud point of that B20 blend was -20°C. [126]

Generally speaking, keeping the biodiesel and diesel fuel to a lower blend (e.g., B10) will have better cold weather operability properties than a higher blend (e.g., B20 +).

Operational Considerations when Choosing Higher Biodiesel Blends

To minimize risk, a higher blend (B20 or higher, depending on the cloud point of a particular biodiesel) could be used in the warmest months of the year and B5 could be used during the rest of the year. Many Canadian and U.S. fleets using biodiesel follow this practice.

To maximize the overall impact of the biodiesel's usefulness in reducing GHGs it is recommended that the highest possible biodiesel blend be used during the summer months. For example, if diesel consumption remains relatively constant month-to-month, then using B20 during cold months (winter) and shoulder seasons (some of spring and fall) and B5 the rest of the year may be approximately equal to using an average annual blend of B10. However, for deeper emissions reduction, if B60 were used from June to August, and B5 during colder months, the yearly average equivalent would increase to B18.75.

Future Technologies to Support B100 Use

Emerging technologies are looking to address the cloud point issues via fuel heating systems. One such provider is *Optimus Technologies*[127] that offers heated fuel system solutions. This could prove to be a cost-effective way to use pure B100 biodiesel to maximize emissions reduction potential.

Given that these technologies are relatively new and results of further testing in real-world applications are limited, as well as the associated risks involved, RSI-FC does not recommend considering this solution for widespread implementation at this time. Nevertheless, a fleet should

[126] Source: https://www.afdc.energy.gov/uploads/publication/biodiesel_handling_use_guide.pdf
[127] Source: https://www.optimustec.com

periodically evaluate this and other technological advancements for potential application, with a openness to pilot-testing any technologies under review.

ASTM Standards

The American Society for Testing and Materials (ASTM) sets out standards for biodiesel, diesel, and heating oil. Four ASTM standards have relevance to consumer use of biodiesel and biodiesel blends, which are[128]:

ASTM D6751 - Biodiesel Blend Stock Specification B100
ASTM D975 - Diesel Fuel Specification
ASTM D7467 - 17 Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)
ASTM D6468 - Standard Test Method for High Temperature Stability of Middle Distillate

Most commonly, manufacturers that support B20 usage will require the biodiesel to conform to ASTM specifications. B100 must conform to ASTM D6751 prior to blending, and the finished B20 blend must conform to ASTM D7467. Any product marketed as biodiesel must meet the standard set by the ASTM D6751.

BQ9000

Customers should purchase the biodiesel blend from a BQ9000 Certified Marketer. The B100 fuel used in the blend should be sourced from a BQ9000 Accredited Producer. BQ9000 Certified Marketers and Accredited Producers can be found at www.bq-9000.org.

Biodiesel fuel should meet ASTM D6751 or ASTM D7467 standards and fuel should be used within 6 months of production.

Storage and Handling

Biodiesel fuels have shown poor oxidation stability, which can result in long-term storage problems. When biodiesel fuels are used at low ambient temperatures, filters may plug and the fuel in the tank may thicken to the point where it will not flow sufficiently for proper engine operation. Therefore, it may be prudent to store biodiesel fuel in a heated building or storage tank, as well as heat the fuel system's fuel lines, filters, and tanks.

Additives also may be needed to improve storage conditions and allow for the use of biodiesel fuel in a wider range of ambient temperatures. To demonstrate their stability under normal storage and use conditions, biodiesel fuels tested using ASTM D6468 should have a minimum of 80% reflectance after

[128] Source: Fleet Challenge publication – Fleet Managers Comprehensive Guide to Use and Storage of Biodiesel

aging for 180 minutes at a temperature of 150°C. The test is intended to predict the resistance of fuel to degradation at normal engine operating temperatures and provides an indication of overall fuel stability.

Biodiesel fuel is an excellent medium for microbial growth. Since water accelerates microbial growth and is naturally more prevalent in biodiesel fuels than in petroleum-based diesel fuels, care must be taken to remove water from fuel tanks. The effectiveness of using conventional anti-microbial additives in biodiesel is unknown. The presence of microbes may cause operational problems, fuel system corrosion, premature filter plugging, and sediment build-up in fuel systems.

Health and Safety

Pure biodiesel fuels have been tested and found to be nontoxic in animal studies. Emissions from engines using biodiesel fuel have undergone health effects testing in accordance with EPA Tier II requirements for fuel and fuel additive registration.

Tier II test results indicate no biologically significant short-term effects on the animals studied other than minor effects on lung tissue at high exposure levels. Biodiesel fuels are biodegradable, which may promote their use in applications where biodegradability is desired (e.g., marine or farm applications). Biodiesel is as safe in handling and storage as petroleum-based diesel fuel.

Vehicle Warranties

Back in 2003, the Engine Manufacturers Association issued a technical statement indicating biodiesel use up to B5 should not cause engine or fuel systems problems[129]. Most North American engine manufacturers now offer full support using biodiesel blends up to a B20 with no vehicle modifications required[130].

Heavy-Duty Vehicle Warranties

Detroit Diesel, Caterpillar, Volvo and Cummins are the big four manufacturers of HD truck diesels. They all support the use of B20 in most of their modern engines. Older engines were produced with rubber which is eroded by biodiesel, instead of Viton injections system seals. In general, most modern engines are suited for biodiesel of up to 20% and ASTM standard biodiesel is required (almost all commercially produced biodiesel is ASTM standard).

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[129]http://www.truckandenginemanufacturers.org/file.asp?A=Y&F=7036%2Epdf&N=7036%2Epdf&C=documents
[130] http://biodiesel.org/news/news-display/2017/01/17/automakers-fuel-the-u.s.-market-with-more-biodiesel-capable-diesel-vehicle-models

Caterpillar

B20 is approved for the majority of engine models. B20 is approved for Tier 4 Interim/Stage III B and beyond engines with after-treatment devices.

Cummins

Cummins approves the use of B20 biodiesel blends in the following engine models:

On-Highway: ISX, ISM, ISL, ISC and ISB engines certified to EPA '02 and later emissions standards, ISL, ISC and ISB engines certified to Euro 3.

Off-Highway: QSX, QSM, QSL, QSC, QSB6.7, QSB4.5 and QSB3.3 engines certified to Tier 3/Stage IIIA, QSM Marine, QSM G-Drive.

High Horsepower Off-Highway built after January 1, 2008: QSK78, QSK60, QSK50, K2000E, K50, QSK45, QSK38, K1500E, K38, QST30, QSK23, QSK19 and K19. Also, Marine QSK60, QSK50, K50 QSK45, QSK38, K38 QSK19, K19.

Cummins has approved B20 for the high horsepower engines listed above with the following fuel systems: Pressure Timed, High-Pressure Injection, Modular Common Rail Fuel Injection System and BOSCH Pump-Line-Nozzle.

Freightliner truck models equipped with Cummins engines are approved for use with B20 biodiesel blends. Custom Chassis Corporation (FCCC) is a division of Daimler Trucks North America (DTNA). Freightliner Custom Chassis manufactures premium vehicle chassis for walk-in cabs, motor homes, school buses and commercial buses. All FCCC vehicles are equipped with Cummins engines. Therefore, Freightliner and DTNA support the Cummins position of approval for the use of B20 biodiesel blends in all Freightliner Custom Chassis vehicles.

Volvo

Volvo Trucks affirms that the use of biodiesel up to a maximum B20 will not affect the manufacturer's mechanical warranty as to engine and emissions system related components, provided the biofuel used in the blend conforms to ASTM D6751, B1 to B5 blends conform to ASTM D975, and B6 to B20 blends conform to ASTM D7467.

Detroit Diesel

Detroit Diesel is a division of Daimler Trucks North America. Detroit Diesel Series 60 Engines manufactured after 2004 are compatible with biodiesel blends up to B20. It is not recommended to run blends higher than 5% biodiesel on Series 60 engines manufactured prior to 2004, as they may contain materials that are not compatible with biodiesel. Biodiesel blends must meet the specifications listed in the Detroit Biodiesel Policy.

Hino

Hino's complete product line of class 4 and 5 cab over, and class 6 and 7 conventional trucks, are now approved for up to B20 biodiesel usage.

All 2011 and 2012 model year cab over and conventional trucks powered exclusively with Hino's proprietary J-Series engines are approved to use B20 biodiesel blends that contain biofuel blend stock (B100) compliant to ASTM D6751, and blended fuel compliant to ASTM D975. B20 biodiesel meeting these standards is also approved for use in Hino's new 2012 diesel-electric hybrid COE truck.

Hino trucks built prior to the 2011 model year are approved to use B5 biodiesel. All biodiesel fuels used in Hino trucks must be purchased from a fuel handler licensed under BQ9000.

John Deere

All John Deere engines can use biodiesel blends. B5 blends are preferred, but up to B20 can be used providing the biodiesel used in the fuel blend meets the standards set by the ASTM D6751 or European Standard (EN) 14214.

John Deere engines without exhaust filters can operate on biodiesel blends below and above B20 (up to B100). For these engines, John Deere-approved fuel conditioners containing detergent/dispersant additives are required when using biodiesel blends of B20 or higher, and recommended when using lower biodiesel blends.

John Deere engines with exhaust filters should not use biodiesel blends above B20. For these engines, John Deere-approved fuel conditioners containing detergent/dispersant additives are required when using B20, and recommended when using lower biodiesel blends.

Mack

Mack Trucks states that the use of biodiesel up to a maximum B20 will not affect the manufacturer's mechanical warranty as to engine and emissions system related components, provided the biofuel used in the blend conforms to ASTM D6751, B1 to B5 blends conform to ASTM D975, and B6 to B20 blends conform to ASTM D7467.

Navistar

Navistar unconditionally warrants use of biodiesel blends up to and including B5 blends meeting the ASTM D975-08a standard. Use of B6-B20 blends in International® MaxxForce™ Diesel Engines 2007-up is at the discretion of the customer/operator and will not automatically void an engine warranty. However, if engine component failure can be directly attributable to use of a B6-B20 blend not provided by a BQ9000 certified fuel supplier, Navistar may, at its option, deny warranty on the affected engine or engine component.

Renewable Diesel Summary

Should supply be readily available, and the price point competitive with fossil diesel, renewable diesel may have good potential for a fleet due to the following:

- Implementation is straightforward and can be done without significant change management.
- No vehicle modifications are required.
- Minimal to no price increase for biodiesel, and possibly a decrease in price depending on prevailing market conditions as compared to conventional diesel fuel.
- Biodiesel blends higher than B2 and lower than B20 may provide substantially better fuel economy than conventional biodiesel, B2, and B100, thereby reducing fuel cost and CO_2 emissions.

Ethanol

Ethanol is a renewable fuel made from various plant materials known as biomass or feedstocks. Corn and wheat are most commonly used to produce ethanol. In most North American jurisdictions, renewable fuel standards require all gasoline sold to be a 5-10% ethanol blend (E5-10). Ethanol burns cleaner and more completely than gasoline or diesel fuel; blending ethanol with gasoline increases oxygen content in the fuel, thereby reducing air pollution[131].

[131] Source: https://afdc.energy.gov/fuels/ethanol_fuel_basics.html

A higher blend of ethanol, known as E85 (85% ethanol, 15% gas), is available in some areas and can lead to significant GHG reductions. The 15% gasoline is needed to assist in engine starting because pure ethanol is difficult to ignite in cold weather[132]. This fuel must be used in dedicated “flex-fuel” vehicles (FFVs), which can run on any combination of gasoline and ethanol blends (up to 85%). However, in some jurisdictions, it may be challenging to find a local supplier of E85 as it is only available through specialized providers.

Production of Ethanol

In chemical terms, ethanol production involves the fermentation of sugars or starches contained in grains or other feedstocks. Ethanol fuel is then distilled and dehydrated to create a high-octane, water-free alcohol[133].

Several steps are involved in making ethanol available as a vehicle fuel. First, biomass feedstocks are grown, collected, and transported to an ethanol production facility. Then, ethanol is made from these feedstocks at the production facility along with by-products such as animal feed and corn oil. Next, the fuel is transported to a blender/fuel supplier. Finally, ethanol is mixed with gasoline by the blender/fuel supplier at the desired blend (up to 85%) and distributed by truck to fueling stations.[134]

Feedstock Sources and Environmental Considerations

Corn and wheat are the most common feedstocks used to produce ethanol, requiring arable land to be grown. As a result, there are environmental considerations, including:

- Using food crops to produce fuel (i.e., the perception of food used as fuel)
- Using arable land to produce fuel reduces the available land to produce food, which potentially leads to increased food prices
- Use of fertilizers and pesticides to grow food-grade crops
- Upstream lifecycle emissions associated with land use, fertilizer production, crop growth, crop harvesting, crop transportation, and ethanol production

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[132] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/ethanol/3493
[133] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/ethanol/3493
[134] Source: https://afdc.energy.gov/fuels/ethanol_fuel_basics.html

As biofuel technologies develop, the focus is turning towards feedstocks that take up less space and land, require less fertilizer and pesticide, and are more energy efficient. These include "cellulosic" feedstock or energy crops, namely tall grasses like switchgrass and miscanthus as well as fast-growing trees like hybrid poplar and willow. Energy crops are attractive because they produce energy efficiently, require only modest amounts of fertilizer and pesticides, and require less fertile soil than is needed for other crops. Technologies are also currently being developed to produce ethanol from wood and algae. It is expected that non-edible plant materials will become sources of ethanol in the future. Cellulosic materials cannot be used as food, so concerns for food production and pricing issues, as is the case with corn and wheat, would be avoided.

Emissions Reduction Potential

Emissions reductions from using ethanol as fuel instead of pure gasoline varies according to biomass used and percentage blend. Although the production and burning of ethanol produce emissions, the absorption of carbon dioxide from the growing of feedstocks can result in the net effect being a large reduction of GHG emissions compared to fossil fuels such as gasoline. The higher the ethanol blend, the greater the GHG reductions. [135]

In terms of lifecycle GHG emissions, E10 made from corn produces 3-4% less GHG emissions compared to gasoline, and E10 made from wood or agricultural cellulosic materials produces 6-8% less emissions compared to gasoline[136]. Corn-based E85 is estimated to reduce lifecycle GHG emissions by 25-50% compared to gasoline[137]. If cellulosic feedstocks are used, ethanol can have lifecycle GHG emissions reductions ranging from 88 – 108% compared to refined petroleum, meaning that potentially more carbon dioxide is captured when the feedstock crops are grown than released by a vehicle when ethanol is burned[138].

In terms of tailpipe emissions, E85 has a GHG emissions reduction potential of about 30% when compared to the same volume of gasoline[139]. However, E85 contains about 27% less energy than gasoline per unit volume[140]. Given this energy loss, about 37% more E85 is required to achieve the same amount of work as gasoline. Therefore, the emissions reduction for the same work performed is actually about only 4.1% when compared to the energy equivalent of gasoline (i.e., for the same distance travelled the emissions for a vehicle running on E85 are 95.9% of those of a gasoline vehicle,

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[135] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/ethanol/3493
[136] Source: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-transportation/alternative-fuels/biofuels/ethanol/3493
[137] Source: https://www.tandfonline.com/doi/pdf/10.3155/1047-3289.59.8.912
[138] Source: https://afdc.energy.gov/fuels/ethanol_benefits.html
[139] Source: http://www.patagoniaalliance.org/wp-content/uploads/2014/08/How-much-carbon-dioxide-is-produced-by-burning-gasoline-and-diesel-fuel-FAQ-U.S.-Energy-Information-Administration-EIA.pdf
[140] Source: https://afdc.energy.gov/fuels/ethanol_benefits.html

which is 70% multiplied by 1.37 accounting for the additional volume required to achieve the same work).

Ethanol Cost

Given the significant energy losses per unit volume as compared to gasoline, the cheaper cost of E85 per unit volume compared to gasoline does not offset the higher volume required to achieve the same distance travelled, likely making E85 more expensive than gasoline. Based on April 2020 fuel prices in the US, and accounting for energy equivalence (i.e., same distance travelled), E85 is about 16% costlier than gasoline[141].

Flex-Fuel Vehicles

E85 cannot be used in a conventional, gasoline-only engine. Vehicles must be specially designed to run on E85. These flex-fuel vehicles can run on E85, gasoline, or any blend of the two. These vehicles feature specially designed fuel systems and other components that allow a vehicle to operate on a mixture of gasoline and ethanol, with mixtures varying from 0 percent to 85% ethanol. Also, given that ethanol is not as energy-efficient as gasoline and thus more fuel is required, the fuel tank in a flex-fuel vehicle must be larger than a conventional vehicle. These cars and trucks have the same power, acceleration, payload, and cruise speed as conventionally fueled vehicles and are priced similarly to gasoline-only vehicles.

Ethanol Supply and Storage

E85 is available at some retail fuel stations and can also potentially be delivered direct-to-vehicle. Alternatively, it could be stored and dispensed in bulk from an onsite fuel station. Ethanol tanks require a water monitoring system. In addition, a 10-micron filter, signage, and other upgrades are required to ensure the system is compliant.

Ethanol Summary

E85 has an excellent emissions reduction potential for a fleet, particularly when the fleet is already E85 capable (i.e., has flex-fuel vehicles). If electric vehicles are not a viable option, new light-duty vehicles purchases should be flex-fuel capable to further enhance the GHG reduction potential for a fleet.

The implementation of E85 vehicles can be expedient if there are only minimal costs and effort required to prepare the infrastructure for E85 storage. In addition, the availability of E85 supply in a particular jurisdiction must be confirmed to proceed with this alternative fuel option. The downfall is

[141] Source: https://afdc.energy.gov/fuels/prices.html

that there are significant energy losses per unit volume as compared to gasoline, which may make E85 more expensive because more is required to achieve the same distance travelled.

Natural Gas

Natural gas (NG), a fossil fuel composed of mostly methane, is one of the cleanest burning alternative fuels. It is also thought to be safer than traditional fuels since, in the event of a spill, NG is lighter than air and thus disperses quickly when released. NG can be used in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) to fuel cars and trucks. Vehicles that use NG in either form are called natural gas vehicles (or NGVs).

NG is found in abundance in porous rock formations and above oil deposits. After NG is extracted from the ground, it is processed to remove impurities and compressed to be stored and transported by pipeline. CNG is used in traditional gasoline internal combustion engine vehicles that have been modified, or in vehicles which were manufactured for CNG use, either alone (dedicated), with a segregated gasoline system to extend range (dual-fuel), or in conjunction with another fuel such as diesel (bi-fuel). CNG is most commonly used in fleet vehicles like buses and heavy-duty trucks because it requires a larger fuel tank than gasoline and diesel fuel[142].

In Canada, business case modelling[143] demonstrated that the use of natural gas (NG) by medium and heavy-duty truck applications provides substantial economic and environmental benefits. The cost and placement of fuel storage tanks is the major barrier to wider and quicker adoption of CNG as a fuel. However, CNG offers many advantages for fleets, and although there are major upfront capital costs ($1m or far more), savings may ensue.

According to the Canadian Urban Transit Association (CUTA) more Canadian cities are transitioning their public transportation fleets away from diesel-powered buses and opting for transit vehicles fueled by NG[144], a trend that is gaining momentum across North America and worldwide. This is due in part to government regulations that mandate a reduction in nitrogen oxide and greenhouse gas emissions that harm air quality, as well as a heightened sense of awareness about the health threats caused by local and toxic diesel particulate emissions.

[142] Source: https://consumerenergyalliance.org/2019/04/energy-explorer-cng-vs-lng/#:~:text=The%20reason%20you%20see%20CNG,requires%20a%20larger%20fuel%20tank.&text=Like%20CNG%2C%20LNG%20is%20compressed,state%20into%20a%20liquid%20state.
[143] Source: Natural Gas Use in the Medium and Heavy-Duty Vehicle Transportation Sectorin Roadmap 2.0 June 2019
[144] Source: https://cutaactu.ca/en/news-media/natural-gas-buses-cost-operational-and-environmental-alternative

CNG at a Glance

Table 44: Strengths and Weaknesses of CNG

Strengths	Weaknesses
1. Lower fuel cost than gasoline or diesel on an energy-equivalent basis 2. Can be used in heavy-duty truck applications 3. A CNG-powered vehicle gets approximately the same fuel economy as a conventional gasoline vehicle on a diesel-gallon-equivalent basis 4. Potentially reduces GHG emissions by more than 20% compared to a diesel vehicle[145,146] 5. Lower CACs compared to other fuels 6. Low safety risk 7. Piping directly to fuelling sites reduces upstream emissions resulting from delivery	1. Vehicle conversion costs are significant but payback is typically in 3-10 years depending on the application and usage 2. An in-house CNG fuelling system carries *significant* capital costs 3. Additional electricity costs for CNG refuellers 4. Potentially increased fueling time: if slow refuellers are employed, fuelling will take overnight; with fast refuellers, fuelling will take approximately the same time as traditional gas/diesel vehicles 5. Scarcity of refuelling centres in Canada

Safety

According to the U.S. Department of Energy's Alternative Fuels Data Center, NGVs are safer than vehicles powered by gasoline or diesel and the industry is highly regulated to address any additional safety concerns. There are an estimated 11 million NGVs[147] in use in over 30 countries globally. Codes, standards and regulations ensure that CNG vehicles are safe and that CNG refueling stations have been installed according to industry standards.

Compressed natural gas (CNG) has several inherent properties that make it safer than diesel or gasoline, including the following:

- It has a higher ignition temperature than gasoline (about 1022°F, compared to about 482°F for gasoline).

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[145] Source: https://brc.it/en/categorie_faq/cng/
[146] Source: https://envoyenergy.ca/cng-benefits/#:~:text=Commercial%20fleets%20all%20over%20the,solution%20for%20fuelling%20their%20fleets.
[147] Source: Closing the Loop. Canadian Biogas Association. 2015.

- Natural gas burns only if the concentration in air is within specific limits, which is between 5 and 15 percent; this property along with a high ignition temperature make combustion of CNG very unlikely.
- It is lighter than air, thus in the unlikely event of a leak it dissipates quickly into the atmosphere.

In addition, the CNG industry is highly regulated and there are a series of safety measures in place, including the following:

- Natural gas is odourless; however, for safety reasons it is odorized to enable easy leak detection. According to a safety article in the *Natural Gas Vehicle Knowledge Base*, the average person can detect odorized natural gas at concentrations as low as 0.3 percent.
- Fuel cylinders are significantly stronger than diesel tanks and fuel tanks are up to a half-inch thick and are made of steel, or a composite designed to be stronger than steel.
- Cylinders and tanks are fitted with valves to handle high pressure, prevent leakage and eliminate risks of explosion.

In the U.S., the Federal Transit Administration followed 8,331 natural gas utility, school, municipal, and business fleet NGVs that traveled 178.3 million miles on CNG. They found that the NGV fleet vehicle injury rate was 37% lower than the gasoline fleet vehicle rate. Furthermore, the examined fleet was involved in seven fire incidents, only one of which was directly attributable to failure of the natural gas fuel system. Finally, there were no fatalities compared with 1.28 deaths per 100 million miles for gasoline fleet vehicles.

Emissions Reduction Potential

Based on the same work performed, a CNG vehicle has tailpipe GHG emissions about 20-30% less than a comparable diesel vehicle[148,149]. NGVs also emit up to 95% less nitrogen oxides (NO_x) compared to diesel and gasoline vehicles[150]. Furthermore, CNG vehicles do not emit particulate matter (PM10), a main cause of air pollution[151].

148 Source: https://brc.it/en/categorie_faq/cng/
149 Source: https://envoyenergy.ca/cng-benefits/#:~:text=Commercial%20fleets%20all%20over%20the,solution%20for%20fuelling%20their%20fleets.
150 Source: Northwest Gas Association – Natural Gas Facts
151 Source: https://brc.it/en/categorie_faq/cng/

Feasibility Considerations

The business case for natural gas is, in most cases, made on the differential in price between diesel fuel and natural gas – the higher initial investment costs for NGVs are typically offset by the fuel savings by using CNG over diesel. New NGVs for fleets may cost up to $50,000 more than conventional diesel fleet vehicles (based on truck Classes 7, 8 and 9)[152,153]. New CNG buses can cost $120,000 more than conventional diesel buses[154,155], likely making the payback period longer than for trucks, depending on kilometres-driven.

For Class 5 to 7 medium-duty trucks in the fleet that are currently powered by gasoline, CNG conversions are available. Conversion costs range from $6k to $10k CAD. CNG powered trucks could be re-fueled with overnight slow-fill systems which cost much less than fast-fill systems. Trucks being considered for conversion to CNG must have ample available frame space for CNG tanks and often this is not possible due to the types of add-on equipment and bodies mounted on the trucks. CNG conversions may present operational challenges if their range was less than fossil-fuelled units. In the event of a power interruption, such as during a severe weather event or some other cause, overnight slow re-fuellers would cease to function and CNG powered vehicles would be sidelined, which could negatively affect the City's emergency preparedness plans.

An operational concern is that in certain situations, such as an electrical power interruption, CNG compressor or other fuel system failure, etc., dedicated CNG vehicles (i.e., vehicles powered solely by CNG) would be sidelined, and this is a significant risk that must be managed.

Infrastructure Costs

CNG filling station infrastructure costs could run to $1m or much more, depending on capacities and complexities, and this is a conservative estimate. A CNG station would consist of the following elements:

- Compressor
- Storage
- Dispenser
- Slow and fast fill positions
- Engineering and permitting
- Site prep and gas service

[152] Source: Closing the Loop. Canadian Biogas Association. 2015.
[153] Source: Consultations with Change Energy
[154] This value represents the additional cost, in CAD, of a CNG transit bus over a traditional diesel bus.
[155] Source: Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO_2. Bloomberg Finance L.P. 2018.

Types of Filling Infrastructure

There are three main types of CNG fuelling stations:

(1) Slow-fill refuellers: use a compressor only; fuelling typically takes place overnight
(2) Fast-fill refuellers: storage capacity is required; fuelling time is 8 minutes per vehicle
(3) Hybrid refuellers: have both slow and fast-fill-up

Thinking Ahead

Despite the increased capital costs for NGVs and their fuelling systems, many fleets have embraced the technology and apparently achieved success from their investments. We emphasize that NG is a fossil fuel – albeit a clean burning one – and it is important to keep in mind the global shift away from internal combustion engines and non-renewable fossil fuels. Some jurisdictions have already legislated the end of the internal combustion engine.

Zero-emission battery-electric vehicle options are available “here and now” in the case of transit buses and fully electric Class 5 to 8 trucks are not far off in the future. Experts agrees that the world is transitioning to electric vehicles and, ultimately, hydrogen fuel cells. With that reality, the use of NG as a vehicle fuel may be considered as an interim solution for organizations wishing to achieve immediate carbon reductions in the short-term while awaiting the availability of EVs. Unless subsidies were available to offset the cost, a major investment in an NG fuelling system would need to be a long-term capital investment for it to be cost-effective. Few would disagree that a large capital investment with a protracted payback period would not be a prudent decision for what may be an interim, short-term solution with a marginal business case.

Natural Gas Summary

Should the goal be for a NG fuelling system to be a long-term capital investment, NG may have good potential for a fleet due to the following:

- A CNG vehicle saves fuel costs and has significantly reduced tailpipe CO_2 emissions compared to a diesel vehicle.
- NGVs nearly eliminate the emissions of nitrogen oxides (NO_x), and do not emit particulate matter (PM10).
- NG is considered safer than traditional fuels since, in the event of a spill, NG is lighter than air and thus disperses quickly when released.

Renewable Natural Gas

An alternative to fossil sources is renewable natural gas (RNG), which is a methane biogas – a gaseous product of the decomposition of organic matter obtained through biochemical process such as anaerobic digestion. It is recovered from landfills, wastewater treatment plants, anaerobic digesters at dairies, food processing plants, or waste processing facilities that are cleaned to meet natural gas pipeline standards.[156]

RNG, or biomethane, is a fully renewable energy source that is fully interchangeable with conventional natural gas. Like conventional natural gas, RNG can be used as a transportation fuel in the form of compressed natural gas (CNG) or liquefied natural gas (LNG).

RNG production has become an important priority thanks to its environmental benefits. RNG production is usually based on capturing and purifying the gas from collected organic waste — anything from crop residues and animal manures to municipal organic wastes and food processing by-products.

RNG at a Glance

Table 45: Strengths and Weaknesses of RNG

Strengths	Weaknesses
1. Interchangeable with fossil natural gas 2. Can be used to power natural gas vehicles without conversion 3. Very low GHG emissions 4. RNG can be produced year-round without intermittency	1. Costs for an anaerobic digester are considerable and depend on the required size and capacity

Production

In general, the feedstocks for RNG systems can be grouped into five broad categories, based on the primary source of the organic material:

- Agricultural organics
- Residential source separated organics (SSO)
- Commercial SSOs
- Landfill gas

[156] Source: https://www.mjbradley.com/sites/default/files/MJB%26A_RNG_Final.pdf

- Wastewater treatment residuals

Anaerobic digestion is a process during which the waste (from landfills or waste water treatment plants) is converted into methane and carbon dioxide in a digester or holding tank. The gas produced is then cleaned or purified to meet utility pipeline specifications. The digesters can be located at waste water treatment plants, landfills, or at green bin waste facilities.

Emissions Reduction Potential

When RNG is used to fuel fleet vehicles, GHG emissions reductions are significant; different sources estimate the lifecycle reduction to be between 75% and 90% compared to diesel. The carbon dioxide that is generated during the production and combustion of RNG is used in the regeneration of new biomass, representing a closed-loop cycle for carbon dioxide that is released[157].

Feasibility Considerations

Without the commercial availability of RNG in a fleet's jurisdiction, a fleet would need to invest in an anaerobic digester to make their own RNG. This would add to the already large cost of $1m or much more to build a CNG fuelling station. Also, unlike CNG which would likely offer fuel cost savings, compressed RNG is approximately equal in price to diesel and gasoline in terms of diesel litre equivalent (DLE)[158]. Therefore, in many situations the use of RNG is not a financially viable option. However, with GHG reduction potential of up to 90% compared to diesel, a fleet manager may still want to consider RNG as an option.

RNG Summary

The use of RNG is a natural progression from the use of fossil-based CNG. While use of natural gas as fuel requires large infrastructure investments, RNG has a very high emissions reduction potential.

RNG is thus an important fuel to consider for use in medium and heavy-duty vehicles. Nevertheless, the technology of producing RNG is still under development and it is expected to become more widespread in the near future.

Liquified Petroleum Gas

Propane, otherwise known as liquefied petroleum gas (LPG), is produced as part of natural gas processing and crude oil refining. In natural gas processing, the heavier hydrocarbons that naturally accompany natural gas, such as LPG, butane, ethane, and pentane, are removed before the natural

[157] Source: Closing the Loop. Canadian Biogas Association. 2015.
[158] Source: Closing the Loop. Canadian Biogas Association. 2015.

gas enters the pipeline distribution system. In crude oil refining, LPG is the first product that results in the refining process.

Propane is a gas that can be turned into a liquid at a moderate pressure (160 pounds per square inch). It is stored in pressure tanks at about 200 psi and 100 degrees Fahrenheit. When propane is drawn from a tank, it changes to a gas before it is burned in an engine.

Application

Propane has been used as a transportation fuel since 1912 and is the third most commonly used fuel in the United States, behind gasoline and diesel. More than four million vehicles fuelled by propane are in use around the world in light-, medium- and heavy-duty applications. Propane holds approximately 86 percent of the energy of gasoline and so requires more storage volume to drive a range equivalent to gasoline, but it is usually price-competitive on a cents-per-km-driven basis.

Propane vehicle conversions and fueling systems generally cost much less than natural gas systems.

Emissions Reduction Potential

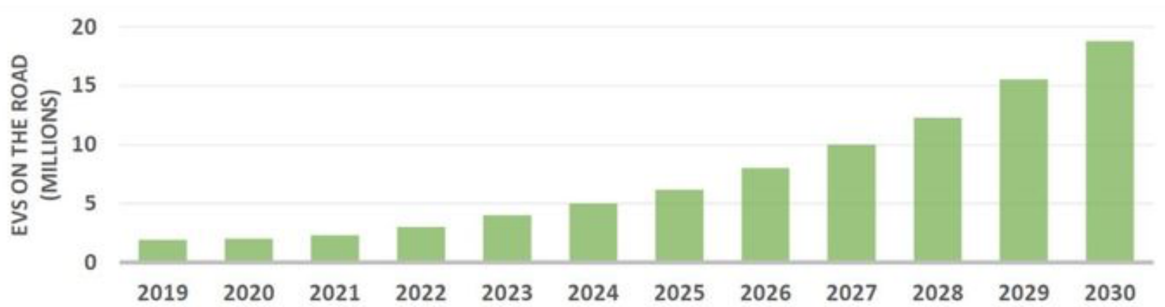
In terms of tailpipe emissions, propane has a GHG emissions reduction potential of about 31% when compared to the same volume of gasoline based on GHGenius version 3.11. However, as mentioned, propane contains about 14% less energy than gasoline per unit volume. Given this energy loss, about 16% more fuel is required to achieve the same amount of work as gasoline. Therefore, the emissions reduction for the same work performed is actually around 20% when compared to the energy equivalent of gasoline (i.e., for the same distance travelled the emissions for a vehicle running on propane are about 80% of those of a gasoline vehicle, which is 69% multiplied by 1.16 accounting for the additional volume required to achieve the same work).

Electric Vehicle Technologies

Over the past decade, electric transportation technologies including hybrid-electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery-electric vehicles (BEVs), have been rapidly developing and quickly gaining popularity in the market. Electric vehicle (EV) technologies offer significantly reduced or no tailpipe emissions and vastly improved energy efficiency.

Today, EVs have reached their tipping point and sales are booming while the public vehicle charging infrastructure rapidly grows. Demand for EVs accelerated during the 2010s and is expected to continue accelerating during the 2020s, as shown in *Figure 28* for the United States.

Figure 28: Forecasted EV Growth in US (Source: Edison Electric Institute)



For fleet managers looking to reduce their annual fuel budget and corporate emissions, battery-electric, hybrids, and plug-in hybrids are a good option. Savvy fleet managers will seek applications where the type of vehicle used will deliver sufficient fuel cost savings to offset their additional cost of capital and, after the vehicles are fully depreciated (usually ~5 years), deliver net cost savings until the end of their economic lifecycle (often ~10 years).

There are a number of light-duty electric vehicle technologies currently available in the market. They include:

- **Mild Hybrid Electric Vehicles (MHEVs)**, which are equipped with internal combustion engines (ICEs) and a motor-generator in a parallel combination allowing the engine to be turned off whenever the vehicle is coasting, braking, or stopped and which restart quickly. MHEVs use a smaller battery than full hybrid electric vehicles (HEVs, see below) and do not have an exclusively electric mode of propulsion; rather, the motor-generator has the ability to both create electricity and boost the gas engine's output, resulting in better performance and reduced fuel use. Examples of MHEVs are the Honda Insight and the 2019 Ram 1500. [159]

- **Hybrid Electric Vehicles (HEVs)**, which use two or more distinct types of power, such as an ICE and a battery-powered electric motor as the modes of propulsion, albeit with very limited range when in electric mode. When an HEV accelerates using the ICE, a built-in generator creates power which is stored in the battery and used to run the electric motor at other times. This reduces the overall workload of the ICE, significantly reducing fuel consumption and extending range. Examples of HEVs include the Toyota Prius and Ford Fusion Hybrid. [160]

- **Plug-In Hybrid Electric Vehicles (PHEVs)**, which use rechargeable batteries, or another energy storage device, that can be recharged by plugging into an external source of electric power. PHEVs can travel considerable distances in electric-only mode, typically more than

[159] Source: https://www.autotrader.ca/newsfeatures/20180410/types-of-electric-vehicles-explained/
[160] Source: https://www.autotrader.ca/newsfeatures/20180410/types-of-electric-vehicles-explained/

25 km and up to 80 km for some models, due to their much higher battery capacity than hybrids. When the battery power is low (usually ~80% depleted), the gasoline ICE turns on and the vehicle functions as a conventional hybrid. Such vehicles typically have the same range as their gasoline counterparts. Examples of PHEVs include the Chevrolet Volt and Toyota Prius Prime.[161]

- **Battery-Electric Vehicles (BEVs)**, or all-electric vehicles, which are propelled by one or more electric motors using electrical energy stored in rechargeable batteries. BEVs are quieter than ICE vehicles and have no tailpipe emissions. In recent years, BEV range has been considerably extended, thereby providing much wider BEV applications and reducing range anxiety. Today, many BEV models have ranges exceeding 400 km, which provide much greater reliability when travelling longer distances. Recharging a BEV can take significantly longer than refuelling a conventional vehicle, with the difference depending on the level of charging speed; a full battery charge using a level 2 charger takes several hours, but charging from a nearly depleted battery to 70% at a fast (level 3) charge station can take 30 minutes[162]. Examples of BEVs include the Nissan Leaf, Chevrolet Bolt, and Tesla Model 3.

While commercial hybrid (HEV and PHEV) and full battery-electric (BEV) pickups, trucks and vans are still limited, options are quickly becoming available. Medium and heavy-duty battery-electric trucks are quickly being developed by many manufacturers. Demand for those offered by Tesla, Volvo, Freightliner, and others exceeds current supply and will soon be available for fleet purchase. Battery-electric buses are currently available for purchase.

Almost daily, manufacturers are announcing new electric cars, pickups, vans, buses and trucks of all gross vehicle weight ratings. There is no question that BEVs are taking over for traditional internal combustion engine (ICE) vehicles in a big way. Some jurisdictions have already legislated the end of ICEs. If they haven't done so already, fleet managers should start making plans for BEVs now.

While their upfront costs will be higher, BEVs have increasingly proven to be a viable solution to rising fuel costs and emissions. Since BEVs have few moving parts, tune-ups or oil changes are never required, and they seldom, if ever, require brake relining due to regenerative braking. And best of all, they burn zero fuel.

Plug-in hybrid electric vehicles would be an excellent solution for a low-mileage, return to base fleet. PHEVs have a much larger all-electric range as compared to conventional first-generation hybrid vehicles, and they eliminate any range anxiety that may be associated with all-electric vehicles, because the combustion engine works as a backup when the batteries have become depleted.

[161] Source: https://www.autotrader.ca/newsfeatures/20180410/types-of-electric-vehicles-explained/
[162] Source: https://www.autotrader.ca/newsfeatures/20180410/types-of-electric-vehicles-explained/

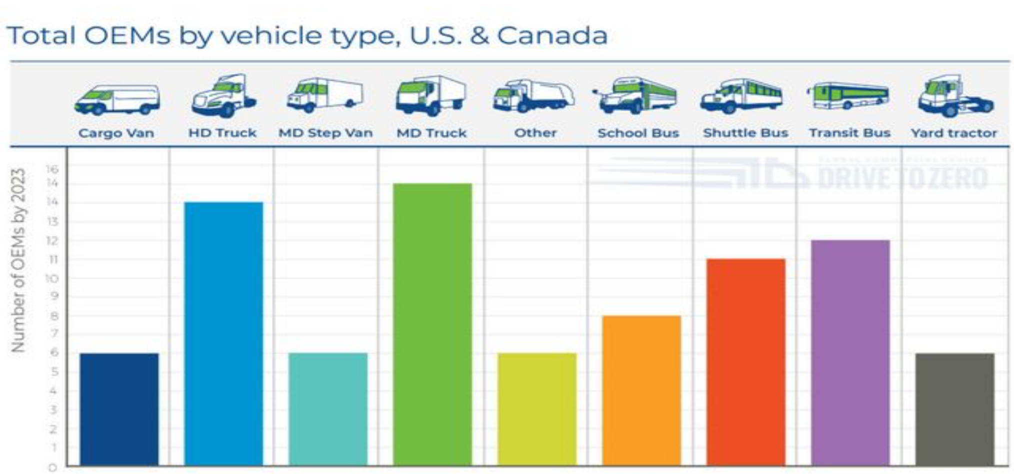
Zero Emission Battery-Electric Vehicles

Since the release of the first mass-produced BEV, the Nissan Leaf, which debuted in 2010 with an EPA range estimated at only 73 mi or 117 km[163], there has been a surge in lithium-ion battery production leading to a drastic decline in prices. Today, several more affordable BEV models have ranges exceeding 400 km, which provide much greater reliability when travelling longer distances. For example, the 2020 Tesla Model 3 Standard Plus has an EPA-estimated range of 402 km[164], while the 2020 Chevrolet Bolt has an EPA-estimated range of 417 km[165].

There has also been significant expansion in charging infrastructure through publicly available charging stations. As of early 2020, there were nearly 5,000 charging outlets across Canada, and Natural Resources Canada is investing $130 million from 2019-2024 to further expand the country's charging network, making range anxiety even less of a barrier to BEV ownership.

In addition to battery-electric pickups that are soon to emerge, emerging battery-electric buses and medium and heavy-duty trucks such as those planned by Tesla, Volvo, Freightliner, and other manufacturers are attracting considerable interest because of their the elimination of tailpipe GHG and CAC emissions, in addition to the potential for significant maintenance and fuel cost savings. In *Figure 29*, we see that the OEMs are quickly ramping up with other types of commercial EV trucks (medium- and heavy-duty truck categories) that are suited for municipal work environments.

Figure 29: Total EV OEMs by 2023 (Source: Calstart)



Fleet managers who operate battery-electric trucks and buses can see massive savings in maintenance and fuel costs. BEVs have considerably fewer parts than internal combustion engine

[163] Source: https://www.mrmoneymustache.com/the-nissan-leaf-experiment/
[164] Source: https://www.tesla.com/en_ca/model3
[165] Source: https://www.chevrolet.com/electric/bolt-ev

(ICE) vehicles. A drivetrain in an ICE vehicle contains more than 2,000 moving parts, compared to about 20 parts in an BEV drivetrain. This 99% reduction in moving parts creates far fewer points of failure, which limits and, in some cases, eliminates traditional vehicle repairs and maintenance requirements, creating immense savings for fleet managers. BEVs do not require oil changes or tune-ups, have no diesel exhaust fluid (DEF), and their brake lining life is greatly extended over standard vehicles due to regenerative braking. Though each fleet's electrification journey will be different, the transition to electricity offers significant cost reductions over the long term.

A new study[166] quantified what commercial EV-makers have been saying for years: electric trucks and buses are a triple win. They save money for fleet operators, and reduce both local air pollution and GHG emissions. The study, which was commissioned by the National Resources Defense Council (NRDC) and the California Electric Transportation Coalition, and conducted by the international research firm ICF, looked at the value proposition for fleet operators of battery-electric trucks and buses (and apparently invented a new acronym: BETs).

Today, BETs have an upfront price premium compared to legacy diesel trucks and buses. However, the costs of battery packs and other components are rapidly falling, and the study found that, by 2030 or earlier, electric vehicles will offer a lower total cost of ownership (TCO) for nearly all truck and bus classes, even without incentives.

Battery-Electric Vehicles at a Glance

Table 46: Strengths and Weaknesses of BEVs

Strengths	Weaknesses
- Well-designed, no noise, few moving parts, long warranties - Little/no maintenance - Government grants and incentives may be available - Effectively eliminates need for idling-reduction initiatives - Very positive driver feedback - Very positive public opinions - Potential for significant lifecycle GHG emissions, depending on electricity source	- High capital cost for battery-electric trucks/buses and chargers - Limited availability of new battery-electric trucks - For faster charging, 240V (Level 2) or 480V (DCFC) charging equipment required at extra cost - Existing electrical capacity at facilities may require significant upgrades to power charging stations for multiple vehicles - Potential driver range anxiety - Potential for costly battery replacements in aged BEVs

[166] Source: Posted January 2, 2020 by Charles Morris (https://chargedevs.com/author/charles-morris/) & filed under Newswire (https://chargedevs.com/category/newswire/), The Vehicles (https://chargedevs.com/category/newswire/the-vehicles/)

Air Quality and Upstream Emissions

Air quality is a growing concern in many urban environments and has direct health impacts for residents. Tailpipe emissions from internal combustion engines are one of the major sources of harmful pollutants, such as nitrogen oxides and particulates. Diesel engines in particular have very high nitrogen oxide emissions and yet these make up the majority of the global bus fleet. As the world's urban population continues to grow, identifying sustainable, cost-effective transport options is becoming more critical.

Battery-electric vehicles (BEVs) require electricity to recharge the batteries; therefore, electricity is effectively a "fuel" in these types of vehicles. Battery-electric vehicles (BEVs) may be defined as zero emissions vehicles (ZEVs) since the California Air Resources Board (CARB) defines a ZEV as a vehicle that emits no exhaust gas from the onboard source of power[167]. However, CARB's definition accounts for pollutants emitted at the point of the vehicle operation and the clean air benefits are usually local. Depending on the source of the electricity used to recharge the batteries, air pollutant emissions are shifted to the location of the electricity generation plants. For example, if electricity used for charging vehicles comes primarily from "dirty" sources such as coal, lifecycle vehicle emissions will result.

From a broader perspective, to have almost none or zero well-to-wheel emissions, the electricity used to recharge the batteries must be generated from renewable or clean sources such as wind, solar, hydroelectric, or nuclear power. In other words, if BEVs are recharged from electricity generated by fossil fuel plants, they cannot truly be considered as ZEVs. Upstream emissions should be considered when evaluating the effectiveness of ZEVs in reducing emissions. Generally, when considering upstream emissions from electricity supply, BEVs still emit more than 50% less GHG emissions than their gasoline or diesel counterparts[168], and in some cases emit over 80% less in a grid composed of mostly renewable electricity[169]. This level of emissions reduction is what cities need in order to collectively achieve the "deep decarbonization" necessary to mitigate the most serious impacts of climate change.

Charging Technologies

The time it takes to fully charge a BEV is dependent on the type (level) of charger used, the vehicle's technology (i.e., the maximum amount of current allowed by the vehicle, in amps), and range (i.e., battery capacity). Charging speed is expressed in kilometers/miles of range per hour of charging. BEVs can be charged by varying levels of chargers ranging from level 1-3 with the following general characteristics shown in *Table 47*[170]:

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[167] Source: California Air Resources Board (2009-03-09). "Glossary of Air Pollution Terms: ZEV"
[168] Source: https://www.eei.org/issuesandpolicy/electrictransportation/Pages/default.aspx
[169] Source: https://blog.ucsusa.org/rachael-nealer/gasoline-vs-electric-global-warming-emissions-953
[170] Source: https://calevip.org/electric-vehicle-charging-101

Table 47: Characteristics of BEV Charging Levels

BEV Charging Levels	Outlet Voltage	Amperage	Added Range Per Hour
Level I	120V	12-16 amps	5-10 km
Level II	240V	16-40 amps	22-56 km
Level III	480+V	100+ amps	>250 km

Level 1 chargers can be plugged right into a standard outlet. They are the most economical option for private owners; however, at such a low charging rate it is usually not practical to use level 1 chargers exclusively. For example, it would take about 40 hours to fully charge a light-duty BEV with a range of 400 km starting at 20% battery (80 km range remaining).

Level 2 chargers are common in private households as well as public spaces such as mall parking lots. They incur an installation cost but are similar to common 240V installations such as the outlets that power clothes dryers. For a light-duty BEV with a range of 400 km and at 20% battery (80 km range remaining), it would take about eight hours to fully charge. Level 2, 240-volt chargers typically range in cost from around $1.5-5k, depending on electrical system requirements. Each Level 2 charger can serve two vehicles at any time of day; usually, charging is done overnight during the off-peak period. The vast majority of the time, BEV owners only need a level II charger; the exception is when travelling longer distances. During these times, much faster charging rates are required through level 3 charging.

Level 3, or Direct Current Fast Chargers (DCFCs), requiring inputs of 480+ volts and 100+ amps (50-60 kW)[171], are specialized systems designed to quickly charge vehicles and provide flexibility to owners travelling longer distances or in need to partial quick charge. For a light-duty BEV with a range of 400 km and at 20% battery (80 km range remaining), it would typically take less than one hour to fully charge. Installations of DCFCs require a commercial electrician due to the electrical load and wiring requirements[172]. The costs for installing a Level 3 DCFC vary greatly. Costs for a fast-charging station are dependent on the electrical supply available at the chosen charging site, site preparation costs including trenching, cable runs and many other installation considerations. Equipment and installation costs for DC fast charging stations can range from $50,000 to $200,000[173].

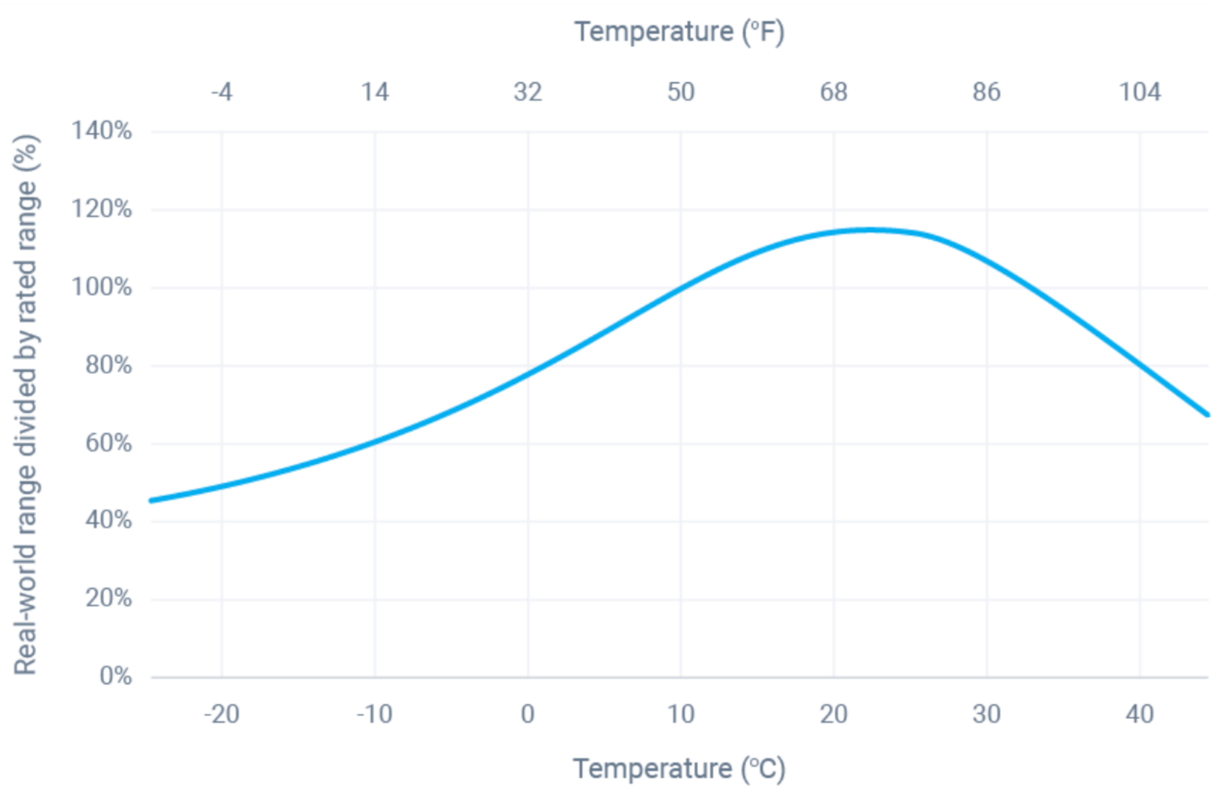
Impact of Temperature on Battery Performance

Canadians enjoy the ebbs and flows of seasonality and extreme temperatures. BEV range is adversely affected by cold and hot temperatures because of auxiliary heating and cooling – that is,

[171] Source: https://calevip.org/electric-vehicle-charging-101
[172] Source: https://calevip.org/electric-vehicle-charging-101
[173] Source: https://www.toronto.ca/wp-content/uploads/2020/02/8c46-City-of-Toronto-Electric-Vehicle-Strategy.pdf

heating/cooling the vehicle cabin, and heating/cooling the battery itself to maintain optimal performance. Batteries are susceptible to temperature fluctuations which hinder, but in some cases helps, range. For example, on a typical winter day in central Canada with a temperature at -15°C, range can drop by over 50% of the EPA estimated range, meaning that a BEV with a range of 400 km will only get 200 km (*Figure 30*, below). Conversely, at temperatures in the low-twenties, range can significantly exceed the EPA-estimated range given that other conditions are optimal (e.g., starting temperature, terrain, and driver habits). With some preparation and knowledge, owners and operators of BEVs can mitigate the effects of temperature on performance by pre-conditioning their vehicle (i.e., warming up or cooling down before use) as well as keeping their vehicle plugged in when temperatures are extreme; this allows the system to maintain battery temperature controls and also prolongs battery life.[174]

Figure 30: The Effects of Temperature on BEV Range



[174] Source: https://www.geotab.com/blog/ev-range/

Training Options and Recommendations

While there is a paucity of BEV technician training in Canada, due to the rapid onset of electric mobility we suspect that reality will soon change. A pilot for a new EV Maintenance Training Program for automotive technicians was successfully completed at BCIT and will be available to the public soon[175].

There is an Electric Vehicle Technology Certificate Program offered by SkillCommons, managed by the California State University and its MERLOT program, which offers free and open learning materials electric vehicle development, maintenance, alternative/renewable energy, and energy storage[176]. There is also a Hybrid and Electric Vehicles course offered at Centennial College in Toronto, which appears to focus more on hybrid systems than fully electric vehicles[177].

Before BEVs are deployed in a fleet to any great extent, we recommend high-voltage training for technicians. Published high-voltage guidelines specific to vehicle technicians servicing BEVs are not readily available through traditional sources. However, we suggest that anyone working with high voltage in any format, including BEVs, should be provided guidance on applying Occupational Health & Safety Management System fundamentals. This includes a “plan, do, check, and act” philosophy while working with energized electrical equipment[178]. Such training is available for non-electrical workers from Lineman’s Testing Laboratories (LTL) of Weston, Ontario. LTL offers an awareness-level course for non-electrical workers which is claimed by the company to provide a basic-level understanding of workplace electrical safety.

Aside from awareness training, fleet technicians should also have access to, and be trained on the use of, electrical-specific personal protective equipment (PPE). Such PPE would include tested and certified non-conductive gloves as well as non-conductive tools and equipment as a last line of defence, ensuring all such gear is appropriately used and maintained. Protective gloves and other PPE, as well as non-conductive tools, must be re-tested periodically to ensure safety.

BEV Summary

For light-duty vehicles and buses, and soon for medium- to heavy-duty trucks, BEVs have excellent potential for a fleet due to the following:

- Significant lifecycle GHG emissions reductions

[175] Source: https://commons.bcit.ca/news/2019/12/ev-maintenance-training/
[176] Source: http://support.skillscommons.org/showcases/open-courseware/energy/e-vehicle-tech-cert/
[177] Source: https://db2.centennialcollege.ca/ce/coursedetail.php?CourseCode=CESD-945
[178] Source: https://training-ltl.ca/

- Significant reduction in operational costs due to elimination of fuel consumption, low costs for electricity, and minimal maintenance costs

- Relatively low charging infrastructure costs in comparison to infrastructure costs for other fuel-reduction / emission-reducing technologies such as CNG

If BEVs were to be considered by a fleet, it would be prudent to consider installing a direct current fast charger (DCFC). Such a fast charger would enable fleet management staff to quickly charge their light-duty vehicles in situations where plugging in for overnight charging may not been possible or for emergency situations. For heavy-duty BEVs such as transit buses, it is important to consider that, depending on available amperage, a full charge may take several hours even with DCFCs.

Evaluation of the fleet to identify vehicles that have a potential for a replacement with a BEV should be completed. Furthermore, change management is recommended to be part of the transition process to help drivers accept and adapt to BEVs and overcome any lingering range anxiety.

Hydrogen Fuel Cells

Hydrogen fuel cells are able to produce electricity for motive power with zero emissions and therefore offer enormous environmental and sustainable energy benefits. Fuel cells are flexible in size, power density, and application. Industry experts are in general agreement that in the next phase zero-emission vehicle (ZEV) batteries will be recharged with onboard hydrogen fuel cells.

Although fuel cell technology has been around since 1960 (GM introduced the first fuel cell vehicle, the Electrovan, in 1966), adaptation of the technology has been slow. Only in recent years, supported by the focus on zero-emissions technologies, has the hydrogen fuel cell regained momentum. Leading (light-duty) vehicle manufacturers including Honda, Toyota and Hyundai have launched their first mass-production hydrogen-powered vehicles.

Sources of Hydrogen and Emissions

Hydrogen is the most abundant element in the universe. It can be produced from several sources including:

- Fossil sources include natural gas, coal, and oil

- Renewable energy sources such as wind, solar, geothermal, and hydroelectric power

Hydrogen also has a potential to be made locally at large central plants or in small distributed units at or near the point of use.

Although hydrogen vehicles have no tailpipe emissions, currently most hydrogen is produced from fossil sources. As a result, presently there are no emissions benefits to switching to a hydrogen powered vehicle – the lifetime emissions may be the same, or even higher, than those of conventional fuels.

At the same time, this technology has a high potential to be very clean through use of renewable sources, which would effectively eliminate all fuel-related emissions. Alas, due to low demand this technology is still too expensive to be commercially viable.

Currently, much work is taking place around the world toward "green" hydrogen from renewable sources. The hydrogen fuel cell trucks, shown in *Figure* 31, will be refueled with green hydrogen made from hydropower in Switzerland, as opposed to "grey" hydrogen made from methane with very high CO_2 emissions, which is the case in most countries.

Figure 31: Hydrogen Fuel Cell Trucks Bound for Switzerland

Fuel Cell Technology for Transportation

Hydrogen fuel cell vehicles (FCVs) are like electric vehicles in that they use an electric motor to power the drive wheels and have no smog-related or greenhouse gas tailpipe emissions. Rather than being plugged in to charge a battery, these vehicles use onboard fuel cells to generate electricity.

In a fuel cell, hydrogen from the fuel tank (filled similarly to gasoline/diesel) is combined with oxygen from the air to electrochemically generate electricity. Water is also produced in this process[179]. The electricity generated is used to power the vehicle. A fuel cell is two to three times more energy efficient than traditional gasoline or diesel engines.

[179] Source: https://www.epa.gov/greenvehicles/hydrogen-fuel-cell-vehicles

In the zero-emissions transportation area, fuel cells have particular benefits over electric vehicle technology, namely they can easily meet the extended range requirements and offer rapid refuelling to satisfy driver and consumer interests.

Technological Advancement

One of the main issues with the development of hydrogen transportation has been the shortage of hydrogen fuelling stations. Manufacturers are not willing to produce vehicles that customers cannot fuel, while developers are reluctant to build hydrogen stations (costing $2,000,000 and more) due to lack of demand.

A critical mass must be reached for most transportation technologies to develop and expand, typically done through governmental leadership and financial support, as with the evolution of electric vehicles.

California has made significant investments to develop the fuelling station network to support hydrogen fuelled vehicles. As of Spring 2017, there were thirty-six hydrogen fuelling stations in the U.S.; all but three were in California. There are currently about 2,000 hydrogen vehicles on California roads.

There are several medium and heavy-duty hydrogen vehicles being developed[180]:

California-based US Hybrid Inc., a company that has been building fuel cell engines for transit buses, step vans, and military vehicles for several years, recently unveiled its first Class 8 fuel cell port drayage truck featuring its proton-exchange membrane (PEM) fuel cell engine that will run at the Ports of Los Angeles and Long Beach. The fuel cell truck is estimated to have a driving range of 200 miles under normal drayage operation and can be fully refueled in less than nine minutes.

Salt Lake City start-up Nikola Motor Co. announced they are beginning to build their Nikola One, a hydrogen fuel cell semi-truck that produces 1,000 horsepower, can generate 2,000 pound-feet of torque, and travel 800 miles or more between fillings. The company has also announced plans to help move the industry one step further by constructing a fueling network of over 350 hydrogen stations in the U.S.

Toyota Motor Corp. has unveiled their “Project Portal” venture, a Class 8 truck powered by a hydrogen fuel cell. Toyota will begin testing the concept vehicle in real-world use shuttling shipping

[180] Source: http://www.gladstein.org/hydrogen-fuel-cell-trucks/?elqTrackId=6a5315625a44431c811600250fbe96e3&elq=f9398669248a444fa236415f8ae2dde6&elqaid=1302&elqat=1&elqCampaignId=700

containers between the ports of Los Angeles and Long Beach and various freight depots up to 70 miles away.

Kenworth Truck Co. was the first major heavy-duty truck maker to join the fuel cell race and recently announced they are developing a hydrogen fuel cell tractor to haul freight from the Southern California ports to nearby warehouses. The tractor uses lithium-ion batteries to power an electric motor.

UPS unveiled an extended range Class 6 fuel cell vehicle that it will deploy in its "Rolling Laboratory" fleet of alternative fuel and advanced technology vehicles.

Fuel Cell Powered Public Transit

In British Columbia, 20 fuel cell buses were operated in its transit fleet between 2010 and 2014. At the time, it was the largest fleet of its kind in the world, providing regular revenue transit service to residents in the community of Whistler, British Columbia[181]. In late 2014, the program was discontinued. It was estimated that the cost of Whistler's hydrogen buses were $1.34 per kilometre to maintain, versus 65 cents per kilometre for diesel-powered buses.

In the short-term, hydrogen vehicle technology is infeasible. Nevertheless, based on current trends future changes are expected as the market develops. Although progress on FCVs development has picked up speed, the technology has not yet been fully commercialized. Thus, it is extremely difficult to make projections of vehicle classes available in the future and their related costs.

Hydrogen Fuel Cell Summary

Fuel cell technology has a very high potential for future applications for vehicles in all classes. Nevertheless, the technology currently is still very expensive, lifecycle emissions are high, and FCVs as well as fuelling stations are not yet available. As a result, any projections of fuel cell application in the future must be approached with caution and understanding of the inherent limitations. Therefore, it is recommended that a fleet monitor the development and availability of fuel cell technology for future applications in fleet operations.

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[181] Source: http://www.chFC.ca/say-h2i/cars-and-buses/cars-and-buses