Analysis of Energy Effectiveness Ratios for Light- and Heavy-Duty Vehicles

Potential values for the substitution of gasoline diesel with electricity in British Columbia's Renewable and Low Carbon Fuel Requirement Regulation

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Executive Summary

Background

The British Columbia Ministry of Energy, Mines and Petroleum Resources uses an "Energy Effectiveness Ratio" (“EER”) when calculating the allocation of compliance credits within the Renewable and Low-Carbon Fuel Requirements Regulation (“RLCFRR”). The EER multiplier accounts for the change in vehicle energy efficiency when substituting one fuel for another. For example, an electric vehicle uses much less end-use energy than a vehicle powered by an internal combustion engine while performing the same task (e.g., less kWh required to drive 1 km). The EER accounts for this change in energy efficiency and the resulting change in transportation greenhouse gas (GHG) intensity by allocating more compliance credits to fuel substitutions that increase energy efficiency

EERs are also used by the California Air Resources Board (CARB) and Oregon’s Department of Environmental Quality (DEQ) in their respective fuel GHG intensity regulations: the California Low Carbon Fuel Standard (LCFS) and the Oregon Clean Fuel Program. Although EERs are defined for each fuel substitution identified in these policies, this document focuses on the EERs that apply to the substitution of gasoline and diesel with electricity for light- and heavy-duty vehicles, respectively. Further mention of EERs in the report refer specifically to this substitution.

CARB has proposed updates to the EER values for heavy-duty/diesel vehicles within its fuel GHG intensity regulations and Oregon’s DEQ updated these values in 2017. Both CARB and Oregon’s DEQ have undertaken or acknowledged studies that demonstrate a greater energy efficiency gain when substituting diesel with electricity than each program originally understood. They also acknowledge different EERs amongst different segments of diesel vehicles that perform different tasks: for example, the EER of transit buses can differ from the EER of light rail or trucks. Hence, the CARB and Oregon’s DEQ programs also have segmentation of EER values. Gasoline EERs have remained constant in all policies and no updates are currently proposed.

Research Questions and Goal

The research questions of this study are;

- Why have CARB and Oregon's DEQ acknowledged or implemented different EERs with segmentation amongst different diesel vehicle types?

- Are the energy efficiency and vehicle segments within British Columbia similar to these other two jurisdictions (California and Oregon), indicating that British Columbia RLCFRR should adopt identical values for diesel EERs? If not, what should the diesel EER values be in British Columbia and how robust is the data available for this decision?
- Should EERs be considered for separate segments of vehicles, such as trucks, buses, garbage trucks, marine applications and ground support equipment at airports? If yes, can EERs currently be characterized for these end-uses?
- Is it reasonable to use the same EER for light-duty/gasoline vehicles in British Columbia as in California and Oregon and is there any information indicating that this value should be updated?

The goal of the study is to provide policy recommendations for EER values and segments in British Columbia based on the answers to these questions. The segments in question for the diesel EER are medium and heavy-duty trucks, transit buses, light-rail, garbage trucks, marine applications (propulsion, shore-power, and cargo handling equipment), and airport ground support equipment (GSE). This study also covers light-duty vehicles for the gasoline EER.

Summary of the Research

Diesel/Electric EER

Initially, the same EER was used for the fuel GHG intensity standards implemented by California Air Resourced Board (CARB) and Oregon's Department of Environmental Quality (DEQ), and by the Province of British Columbia. This value of 2.7 was first used in California and was essentially an educated guess made before adequate testing was possible. More recently, CARB and Oregon's DEQ have acknowledged different EER values that imply greater energy efficiency from the electrification of diesel-fuelled vehicles and equipment. Notably, the proposed EER values for buses and other medium- and heavy-duty PEVs in California is 5, based on vehicle test cycle and in-use data and assuming that electric vehicles will primarily travel urban routes (shorter, lower speed routes with more starts/stops). CARB has also conducted tests to determine the EER for shore-power and cargo handling equipment at ports, where these latter tests provide data that can also be used to infer the EER for airport GSE.

The EER of 2.7 in British Columbia, which applies to all vehicle segments, is based on older and limited data. To inform an update of this value, we reviewed all available evidence for EERs in British Columbia, though the data specific to the province is limited. Helpfully, CARB's analyses of test data reveal a strong relationship between vehicle average speed and EER (or average engine power output and EER). CARB estimated a trend-line for this relationship that can be used to infer EER values for other regions if one knows the average speed of the vehicles in a given segment. The remaining literature is sparse and limited. Furthermore, EERs determined from the literature tend to rely on vehicle simulation data rather than test data. In the case of trucks, simulations produce EERs that are almost always lower for a given average speed than indicated by the CARB test data.

Gasoline/Electric EER

Gasoline/electric EER, which quantifies the fuel substitution that occurs with the adoption of electric light-duty vehicles, is 3.4 in all three regions' policies. This value is based on a comparison of the tested fuel economy of 2011 Nissan Leaf and Versa and the 2011 Chevrolet Volt and Cruze. The electricity used by the PEVs is converted to gasoline equivalents using the lower heating value (LHV) of gasoline, which only accounts for the energy in the fuel that is theoretically available to the engine through combustion. In contrast, fuel economy/efficiency ratings are almost certainly expressed on a higher heating value (HHV) basis (i.e. all combustion energy is included).

To inform a potential updated EER, we extended the comparison of the 2011 Leaf/Versa and Volt/Cruze to include the current vehicle model years and we corrected the EER calculation to use the gasoline HHV. For a broader perspective on this EER, we also calculated the sales weighted energy consumption of PEVs and conventional vehicles within the comparable vehicle classes (e.g. compact car versus mini-van) based on fuel consumption test data. Finally, to understand how the EER may change in the future as a function of efficiency improvements to PEVs and conventional vehicles, we analyzed simulation data that forecasts archetypal vehicle energy consumption to 2050.

Policy Recommendations in Brief

Drawing from our analysis and the uncertainties within in, we provide some general policy recommendations for EERs in the British Columbia RLCFRR, which are followed by recommendations for each transportation segment:

- **The current diesel/electric EER of 2.7 should be updated and is too low for current electrification opportunities:** this initial value was based on limited and largely outdated data used by CARB. This value is too low for all near-term opportunities to electrify diesel vehicles and equipment like buses, drayage and delivery trucks, and garbage trucks.

- **Setting multiple diesel/electric EER values (by segment) is more accurate:** The reviewed research indicates that there are significant differences by segment for the diesel/electric EER, with the EER varying from around 2 to 5.
- **The gasoline/electric EER should be updated as well:** This EER should account for more recent vehicle models and the full range of conventional vehicles that they can displace. As well, the EER should be calculated based on a consistent metric of gasoline energy content (i.e. the higher heating value or HHV).
- **The EERs should be updated over time, but in the meantime the values can based on CARB research:** Periodic review of EERs should be scheduled as technologies change and new data becomes available. In the meantime, research done by CARB for California that finds a statistically significant relationship between vehicle average speeds to EERs can be applied to define these values in British Columbia.

We suggest the following recommendations for an update of BC's EER values, for each of the vehicle segments we've studied:

- **Medium and Heavy-Duty Trucks:** We recommend updating the EER based on slower drayage (intra-urban) routes. British Columbian data for drayage trucks indicate an average speed of 18.7 km/hr. Using CARB's speed-EER trend-line, that corresponds to an EER of 5.0 which is identical to CARB's proposed value.
- **Transit Buses**: Data indicate that transit buses in British Columbia have an average speed of 26 km/hr. Using the CARB relationship between average speed and EER, this corresponds to an EER of 4.5. However, if we assume that electrification for slower urban routes is more likely in the foreseeable future, then harmonizing with CARB's proposed value of 5.0 seems reasonable. In this case, buses and trucks could be in the same segment, which is also harmonized with CARB's proposal.
- **Trolley-buses:** A comparison of new diesel buses to new trolley buses suggests and EER of at least 3.4 given that new diesel buses are often more energy efficient than the older buses that exist in the Translink fleet. Local research and data should be used to confirm this EER if they become available.
- **Light/rail:** Both the CARB EER of 3.3 and the value of 2.7 used in British Columbia are reasonable. If British Columbia were to harmonize with CARB's EERs, the value of 3.3 is just as defensible as 2.7. Local research and data should be used to confirm this EER if they become available.

- **Garbage trucks:** Very little data exists for garbage trucks. Based on typical average speeds recorded in the US, garbage trucks could be put into the same segments as other trucks and buses with an EER of 5.

- **Marine propulsion:** There is very little data describing the EER of marine propulsion. The EER from a single simulated example ranges from 2.6 to 3.6. A specific segment probably is not needed at present, since no electrification of marine propulsion is expected soon in British Columbia.

- **Shore power and marine cargo handling:** Although we found no data sources specific to British Columbia, CARB has conducted substantial research on the topic that indicates an EER of 2.6 or 2.7 is reasonable.

- **Airport ground support Equipment (GSE):** Though data is limited, the analysis indicates that an EER of roughly 4 should apply to GSE. However, this EER is the least certain of all the segments analysed in this report.

- **Light-duty vehicles:** The EER should be updated to account for the sales-weighted average of the vehicles in question using the HHV of gasoline to compare electric energy consumption and volumetric fuel consumption. When using the sales weighted method with the gasoline HHV for 2017/2018 model year vehicles, the EER is 4.1 rather than 3.4. Finally, this EER calculation should be updated periodically to account for improvements in vehicle fuel consumption testing and changes in vehicle offerings, vehicle efficiency, and sales.

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1. Introduction

1.1. Energy Effectiveness Ratios (EERs)

The British Columbia Ministry of Energy, Mines and Petroleum Resources uses an "Energy Effectiveness Ratio" ("EER") when calculating the allocation of compliance credits within the Renewable and Low-Carbon Fuel Requirements Regulation ("RLCFRR"). The EER multiplier accounts for the change in vehicle energy efficiency when substituting one fuel for another. For example, an electric vehicle uses much less end-use energy than a vehicle powered by an internal combustion engine while performing the same task (e.g., less kWh required to drive 1 km). The EER accounts for this change in energy efficiency and the resulting change in transportation greenhouse gas (GHG) intensity by allocating more compliance credits to fuel substitutions that increase energy efficiency.

EERs are defined in the RLCFRR for each fuel substitution identified in that policy, for example, with one EER for the substitution of diesel with electricity, and another EER for the substitution of gasoline with electricity. EERs are also used by the California Air Resources Board (CARB) and Oregon's Department of Environmental Quality (DEQ) in their respective fuel GHG intensity regulations: the California Low Carbon Fuel Standard (LCFS) and the Oregon Clean Fuel Program.

These EERs are dimensionless numbers that are calculated by comparing the energy consumed when powering two equivalent vehicles with different fuels. In this report we consider several approaches to these calculations:

1. "Test cycle data": an EER could be calculated by dividing the energy per kilometer consumed by a diesel- or gasoline-powered vehicle versus a battery electric vehicle when operating under the same conditions in a controlled test. For equipment and vehicles where distance travelled is not relevant, some other metric of activity, like operating hours, can be used.
2. "In-use data": in practice, EERs can also be calculated by comparing the energy consumption data of similar vehicles as they are used for real-world transportation.
3. "Simulation data": EERs can also be inferred from the energy consumption estimated by vehicle simulation models. These models have vehicle specification inputs (e.g. mass, size, drivetrain etc.) and "drive cycle" inputs (i.e. defining distance, grade, speed and acceleration over time). With this information, the model simulates vehicle energy consumption.

4. “Literature-based”: finally, this approach constructs reasonable estimates based on some combination of the previous three types of data or based on the EER used in another policy or jurisdiction.

1.2. Updates and Segmentation for Diesel and Gasoline to Electricity EER Values

CARB has proposed updates to the electricity to diesel EER value within its fuel GHG intensity regulations and Oregon’s DEQ updated these values in 2017. Both CARB and Oregon’s DEQ have undertaken or acknowledged studies that demonstrate a greater energy efficiency gain when substituting diesel with electricity than each program originally understood (summarized in Section 2.1). They also acknowledge different EERs amongst different segments of diesel vehicles that perform different tasks: for example, the EER of transit buses can differ from the EER of light rail or trucks. Hence, the CARB and Oregon’s DEQ programs also have segmentation of EER values.

The diesel/electric EER in the British Columbian RLCFRR has not been updated since the policy was implemented in 2010 and the EER is currently lower than the EER values now acknowledged by the California and Oregon policies. Furthermore, there is no segmentation in the British Columbian diesel/electric EER values. However, market participants within the British Columbian RLCFRR have requested that the Ministry of Energy, Mines and Petroleum Resources consider CARB and the Oregon DEQ’s research into Diesel/Electric EER’s (both the values and segmentation) in its upcoming Compliance Pathways Assessment Discussion.

Gasoline EERs have remained constant in all policies and no updates are currently proposed, but there is similar interest in understanding whether the values should be updated in general or to better reflect the fuel substitution in British Columbia.

1.3. Scope, Goals and Research Questions

To support this request, Navius is providing an analysis and evaluation of diesel/electric EERs (simply referred to as EERs for the rest of the report), with the aim of understanding whether British Columbia should use EERs and segmentation like what has been proposed or adopted by CARB and Oregon's DEQ. Likewise, Navius is also providing an analysis of gasoline/electric EERs.

For the diesel/electric EER, this analysis considers research and data for trucks, transit buses, transit rail, garbage trucks, marine applications (at port and on the water) and airport ground support equipment. For the gasoline/electric EERS, this analysis considers fuel economy test-data for light-duty vehicles.

The analysis explores EERs or energy consumption for gasoline and diesel vehicles/equipment as compared to plug-in electric vehicles (PEVs) with batteries or vehicles/equipment that are powered when connected to the electricity grid (e.g. trolley buses). PEVs include battery electric vehicles (BEVs), powered only by electricity, and plug-in hybrid vehicles (PHEVs), are powered with electricity or an on-board generator or engine that consumes diesel fuel to extend the vehicles range. In this study and in EER calculations, BEVs and PHEVs are treated identically because while consuming grid-supplied energy, they displace the same amount of gasoline or diesel.

The research questions of this study are;

- Why have CARB and Oregon's DEQ acknowledged or implemented different EERs with segmentation amongst different diesel vehicle types?
- Are the energy efficiency and vehicle segments within British Columbia similar to these other two jurisdictions (California and Oregon), indicating that British Columbia RLCFRR should adopt identical values? If not, what should the EER values be in British Columbia and how robust is the data available for this decision?
- Should EERs be considered for separate segments of vehicles, such as trucks, buses, garbage trucks, marine applications and ground support equipment at airports? If yes, can EERs currently be characterized for these end-uses?
- Is it reasonable to use the same EER for light-duty/gasoline vehicles in British Columbia as in California and Oregon and is there any information indicating that this value should be updated?

The goal of the study is to provide policy recommendations for EER values and segments in British Columbia based on the answers to these questions.

1.4. Outline

This report begins with a summary of EERs and EER segments in the Californian, Oregonian and British Columbia fuel GHG intensity regulations. This is followed by an explanation of the basis for the EERs used in each region with a focus on CARB's research supporting the proposed updated EERs for trucks and buses in California. We then present EER and energy consumption data relevant to each segment (i.e. trucks, buses, rail, marine, ground equipment, light-duty vehicles etc.), focusing on information from British Columbia where available. This is followed by a summary and discussion of the research that includes the policy recommendations for EER values in British Columbia.

2. Basis of Gasoline and Diesel/Electric EERs

2.1. EERs by Jurisdiction

The diesel/heavy-duty EER values in the California LCFS and the Oregon Clean Fuels Program noted by BC Hydro in their comment on the RLCFRR compliance pathway assessments[1] are correct. Of note, CARB has proposed increasing EER values for PEV diesel vehicles from 2.7 to 5.0 and for PEV buses from 4.2 to 5.0. These changes are approved but not yet legislated. Also, The EER values in Oregon's policy were segmented since the implementation of the policy to account for different diesel end-uses within the transportation sector, which is more aligned with the California policy (Table 1). All three policies use 3.4 for the gasoline/light-duty vehicle EER and no updates are currently proposed.

[1] BC Hydro, January 5, 2018, *Re: Comments on British Columbia Low Carbon Fuels Compliance Pathway Assessment*

Table 1: EER values for electricity/diesel substitution by jurisdiction

	California		Oregon		BC
	Original Policy (2009)	Approved Changes to Policy (2019)	Original Policy (2015)	Updated Policy (2017)	Original Policy (2010)
All gasoline vehicles	3.4	3.4	3.4	3.4	3.4
All diesel vehicles			2.7		2.7
BEV or PHEV (substituting for diesel, primarily trucks)	2.7	5.0		2.7	
BEV or PHEV transit bus	4.2	5.0		4.2	
Heavy rail	4.6	4.6			
Light rail	3.3	3.3		3.3	
Street car/tram	3.1	3.1		2.1	
Trolley bus/cable car	3.1	3.1			
Forklift	3.8	3.8			
Transport refrigerated unit		3.4			
Aerial tramway				2.5	

Reproduced from BC Hydro comments on "British Columbia Low Carbon Fuel Compliance Pathway Assessment"[2], with the addition of light-duty vehicles Proposed California values from the Air Resources Board.[3] Oregon values from Department of Environmental Quality.[4]

2.2. Basis of the Californian Diesel/Electric EERs

Due to a lack of test data or vehicle-use data, the original EER for PEVs in the California LCFS was based on research conducted for the California Energy Commission in 2007.[5] That study estimated the EER for heavy-duty PEVs at 2.7 but did not reference a source or methodology supporting this value.[6] That EER initially applied

2 Ibid

3 California Air Resources Board (2018). Low Carbon Fuel Standard and Alternative Diesel Fuels Regulation 2018, Appendix A: Proposed Regulation Order, www.arb.ca.gov/regact/2018/lcfs18/lcfs18.htm

4 Department of Environmental Quality, Oregon Clean Fuels Program, 340-253-8080 Table 8 – Oregon Energy Economy Ratio Values for Fuels Used as Diesel Substitutes, https://secure.sos.state.or.us/oard/viewAttachment.action

5 California Air Resources Board (2009). *Proposed Regulation to Implement the Low Carbon Fuel Standard, Volume II, Appendices*, Appendix C-12

6 TIAX LLC (2007)., *Full Fuel Cycle Assessment Tank to Wheels Emissions and Energy Consumption*, 3-19

to PEV buses, but these vehicles were later given a separate EER of 4.2, based on preliminary test cycle data. The original California EERs for electric fixed-guideway transit vehicles (e.g. light rail, heavy rail, streetcars and trolley buses) are based on a comparison of diesel bus energy consumption, presumably for the same amount of service (e.g. passenger distance travelled). The data for this comparison comes from Californian data within the National Transit Database,[7] which is populated with in-use data from almost all transit providers in the US.

The proposal to update the EER for PEVs to 5 (i.e. for buses, trucks, and all other PEVs that substitute for diesel vehicles) is based on recent test cycles performed by CARB and by vehicle in-use data collected and analyzed by CARB.[8] CARB qualitatively decided on a value of 5 based on the correlation between vehicle average speed and EER Figure 1, and the assumption that the heavy-duty vehicles that electrify will be used for shorter and lower-speed trips.

CARB's test cycles are controlled vehicle trips meant to simulate a range of driving conditions that are typical to each test vehicle. The vehicles tested include:

- A drayage truck, which was a class 8 tractor trailer combination involved in short freight transport with the trip start and finish occurring within the same urban area (e.g. within a port yard or from a port to a warehouse). The drayage truck was tested with six cycles that simulate typical driving conditions.
- A parcel delivery truck, which was a smaller class 5 vehicle (e.g. Ford F-550 with a box) also involved in delivery of goods within an urban area. The vehicle was tested with two cycles that simulate typical driving conditions.
- A 40-foot bus, which was tested on three drive-cycles that simulate buses travelling within an urban core, along an arterial route and on a commuter route that includes freeway travel.

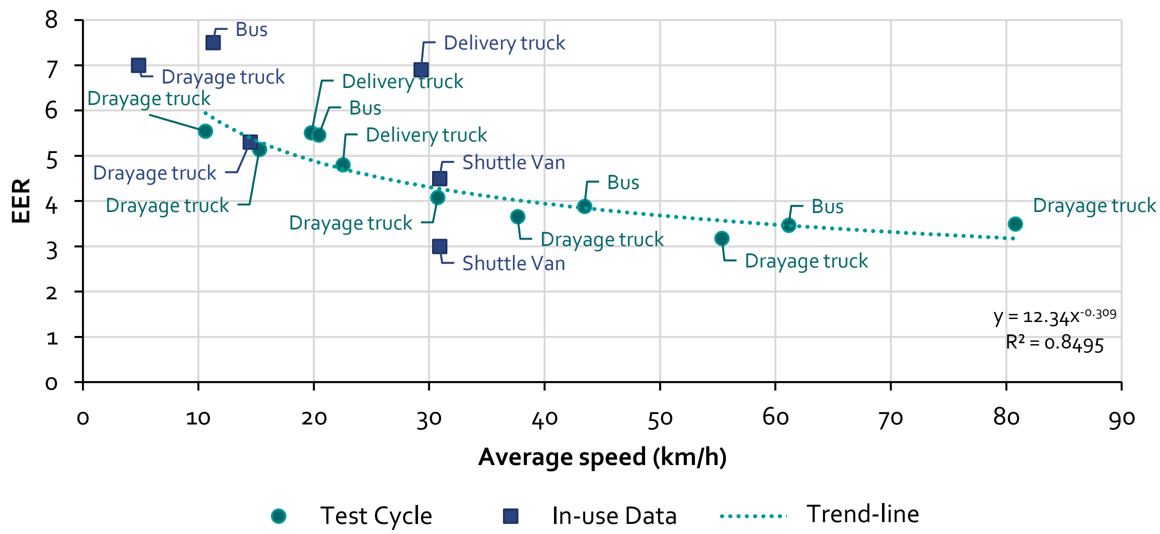
The in-use data were collected from vehicles operating in real-world use. Data were collected from 12 BEV buses over one year and three BEV drayage trucks over nine-months. Data were also collected from several lighter diesel vehicles: Four BEV parcel delivery trucks over half a year and three airport shuttle vans, also over several months.

[7] California Air Resources Board (2012). *Electric Rail in the Low Carbon Fuel Standard Program*, November 7 meeting

[8] California Air Resources Board (2018a). *Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles*

The test cycles showed a strong and statistically significant correlation between the average speed of the test cycle and the observed EER (Figure 1, teal circles). Test cycles with slower average speeds, which correspond to more starts and stops and more idle time, resulted in higher EERs. The in-use data confirmed this relationship, again showing a greater EER for vehicles travelling at lower average speeds. In most instances, the EER values for the in-use data (Figure 1, dark blue squares) are higher than the trend-line estimated from the test cycle data. This indicated that the EER values determined from the test cycles and the resulting correlation to average speed is conservative; in real-world driving, the efficiency gain of using an electric vehicle may be larger than in the test cycles.

Figure 1: EER vs. vehicle average speed with, CARB test cycle data with trend-line (estimated from test cycles) and in-use data collected by CARB



Data sourced from: California Air Resources Board (2018a). *Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles*

CARB's proposed EER for heavy duty PEVs is based on the test cycle and in-use data and the characteristics of the vehicles in question, but the value is still subjective given that a single EER must represent a range of vehicles operating in a variety of conditions. Based on Californian bus fleet operating data submitted to National Transit Database, 94% of buses operating in California have an average speed less than 21 km/hr (13 mph).[9] These data suggests that an EER of 4.8 would apply to almost all bus routes in California, while the average EER would be higher, based on the observed correlation between average speed and EER. CARB subjectively chose a

[9] California Air Resources Board (2018a). *Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles*

value of 5 based on the assumption that electric buses will tend to be used for shorter range and slower routes, compared to how conventional diesel buses are used.

Similarly, CARB also uses an EER of 5.0 for PEVs that are not buses, again under the assumption that the vehicles that electrify will be drayage and delivery trucks travelling slower and shorter routes rather than inter-regional freight trucks travelling faster and longer routes. Data from 1258 trips by drayage trucks in California find an average speed of 21 km/hr (13.3 mph),[10] which is similar to the California bus data. The average speed correlates to an EER of 4.8, rounded to 5 based on the expected usage of the electric vehicles (i.e. slower average speeds).

2.3. Basis of the Californian Gasoline/Electric EER

In draft versions of the LCFS regulation, the gasoline/electric EER, which applies primarily to light-duty vehicles, ranged from 3.0 to 4.1.[11] Participants in the policy-making process argued that the EER should be based on:

- Real-world driving data, rather than lab-tests that do not account for aggressive driving and operating in cold and hot ambient temperatures.
- Comparable vehicles, where the only material difference is the drive-train, to avoid including energy efficiency upgrades within the EER calculation that could be applied to both conventional and electric vehicles.

Research commissioned by the Western States Petroleum Association indicated that the EER could be at most 3.4 but would likely be much lower. However, this conclusion was based on testing pre-commercial PEVs dating from the late 1990's to the mid 2000's.[12]

The final regulation ultimately used an EER of 3.4 based on the average EER calculated from a comparison of:

- The 2011 Nissan Leaf (BEV, 99 $mpg_{equivalent}$) and Versa (conventional, 28.3 mpg)

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[10] Ibid.

[11] California Air Resources Board (2008). December 2 Changes to the Draft Regulation for the California Low Carbon Fuel Standard

[12] Western States Petroleum Association (2009). WSPA Comments on CARB's LCFS Energy Economy Ratios

- The 2011 Chevrolet Volt (PHEV, 93 $mpg_{equivalent}$) and Cruze (conventional, 28.4 mpg)[13]

While this is a reasonable estimate of the EER, there are three reasons this value is subjective. First, conventional and electric vehicles do undergo the same fuel economy tests and fuel economy tests do not account for all factors affecting fuel consumption in the real-world. The fuel economy for the conventional vehicles is based on the updated five-cycle testing that accounts for aggressive driving and operating in cold and hot ambient temperatures, in addition to the previous 2-cycle testing that includes a city and highway drive-cycle.[14] However, the fuel economy equivalents for the PEVs are based on a different test procedure that only uses the city and highway drive-cycles and adjusts fuel economy by 70% to account for real-world driving (i.e. the rated energy efficiency is lower than the tested energy efficiency).[15] As well, neither test procedure explicitly accounts for winds, hills, or turning.

Second, the gasoline equivalent fuel economy for the PEVs is calculated using a conversion factor that underestimates the volume of gasoline that is displaced. The gasoline equivalents are calculated using the using the lower heating value (LHV) of gasoline (1 gallon gasoline = 33.7 kWh),[16] where the energy content of gasoline is net of the energy embodied in water vapour in the combustion exhaust. Given that fuel economy testing has been continuously revised to better reflect real-world consumption, the fuel economy of conventional vehicles is very likely based on the higher heating value of gasoline (HHV, accounts for all energy released during combustion). Because drivers are unaware of the fraction of their fuel energy that is thermodynamically available to their engine, fuel economy should be measured in terms of HHV.

Using $mpg_{equivalent}$ based on LHV reduces the EER. This happens because the units of the numerator and denominator of the EER calculation are not consistent: The conventional vehicle consumes a real volume of gasoline, while the electric vehicle consumes a theoretical volume of gasoline that is adjusted to net out some of the

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[13] California Air Resources Board (2011). Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Amendments to the Low Carbon Fuel Standard. Stationary Source Division, Transportation Fuels Branch, Alternative Fuels Branch.

[14] Environmental Protection Agency, Detailed Test Information. Available at: www.fueleconomy.gov

[15] Good, D. (2017). EPA Test Procedures for Electric Vehicles and Plug-in Hybrids. Available at: www.fueleconomy.gov

[16] Electric and Hybrid Vehicle Research, Development, and Demonstration Program; Petroleum-Equivalent Fuel Economy Calculation; Final Rule, 10 CFR part 474, (June 12, 2000)

energy content. The LHV is about 11% lower than the HHV. Using LHV to calculate $mpg_{equivalent}$ yields an EER that is also 11% lower than if it were calculated using the HHV.

Finally, the EER used in the Californian LCFS is subjective because it is based on an average of two vehicle comparisons. The first subjective assumption embodied in the EER is that the Leaf/Versa and the Volt/Cruze are the correct comparison; They are certainly a reasonable comparison, but a PEV buyer may have chosen something else if they instead bought a conventional vehicle. Furthermore, there is variation in the fuel economy of the 2011 Versa and Cruze depending the engine and transmission available with specific trim-lines of those model: mpg varies by roughly 3 mpg across trim-lines, creating a variation of roughly +/-0.2 in the EER.

2.4. Basis of Oregonian EERs

The Oregon DEQ adopted the original CARB diesel/electric EER for buses (i.e. not the proposed value), noting only that this value is consistent with test data provided with BEV buses that are about to come into service in the state.[17] The DEQ used the National Transit Database to estimate Oregon-specific EERs for their electric transit vehicles (i.e. streetcars and the aerial tramway in Portland).[18] Oregon still uses the original CARB value of 2.7 for other PEV vehicles that substitute for diesel vehicles, which was based on the limited information available to CARB when the LCFS policy was first developed. The EER is 3.4 for the gasoline/electric substitution, also based on the Californian policy.

2.5. Basis of the British Columbian EER

The British Columbian RLCFRR uses an EER of 2.7 without any segmentation for the diesel/electric substitution. The EER is 3.4 for the gasoline/electric substitution. These values appear to be based on the original values in the Californian LCFS, though this has not been confirmed.

[17] State of Oregon Department of Environmental Quality, 2017, *Agenda Item F - Modifications to the Electricity Provision*. www.oregon.gov/deq/Rulemaking%20Docs/20170126itemF.pdf

[18] Ibid.

3. EER Values and Analysis by Segment

This section presents the data that is available to calculate EERs for each segment and to support policy recommendations for EER values in British Columbia. The data is sourced from many jurisdictions, including British Columbia when possible. This section begins with the research on trucks, followed by buses, rail, garbage trucks, marine applications and airport ground equipment. A final section covers research on light-duty vehicles to inform the gasoline/electric EER. Again, the research covers gasoline- and diesel-fuelled vehicles and equipment and their potential substitution with electrically powered vehicles and equipment. Wherever EER is mentioned, it refers specifically of the EER implied in the substitution of gasoline and diesel with electricity in transportation end-uses.

3.1. Medium- and Heavy-Duty Trucks

The only test cycle and in-use data we found describing the EER for trucks comes from the 2018 CARB study in support of the updated EERs, which focused on delivery and drayage trucks, as explained in Section 2.2 and depicted in Figure 1.[19] EERs in this study range from 6.9 (In-use data, average truck speed is 18 km/hr) down to 3.7 (test cycle data, average truck speed at 38 km/hr) (summarized in Table 2). The test cycle data are compared to in-use and simulated data points in Figure 2 and compared against CARB's correlation between average speed and EER.

While there were no test cycle or in-use data specific to British Columbia, Lajevardi et al. (Work in progress) simulate diesel and electric truck energy consumption using empirically-based drive cycles within the province.[20] The drive cycles were constructed from one month of in-use data from a fleet of 1598 drayage trucks operating out of the Port of Vancouver, showing an average trip speed of 18.7 km/hr. The simulated EER for the short-haul trips (short- and long-distance drayage, and travel on regional highways) ranged from 4.7 (average speed at 10 km/hr) down to 2.9 (average speed at 30 km/hr) (Table 2). The simulated EER for long-haul trips that are currently outside of the scope of electrification, due their trip length, ranged from 2.0 to 2.4, consistent with a higher speed drive cycle with few starts and stops (omitted from the table). Note

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[19] California Air Resources Board (2018a). *Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles*

[20] Lajevari, M., J. Axsen, and C. Crawford (Work in Progress). *Cost and GHG emissions estimates for alternative heavy duty truck drivetrain options in British Columbia*, to be submitted to *Transportation Research Part D: Transport and Environment.*

that the average speed of the observed drayage trucks was 18.7 km/hr, which implies a higher EER of 5.0 when calculated with CARB's observed correlation between speed and EER (Table 2).

We also consulted literature on alternative drivetrains for trucks, based in other parts of Canada and the US. There are other simulation data for electric delivery trucks showing that the EER is also sensitive to the ambient temperature, the payload of the vehicle, and the vintage and energy efficiency of the diesel vehicle. For example, Zhou et al. (2012) found a simulated EER of 5.3 for a delivery truck operating in downtown Toronto (average speed at 13 km/hr) when the ambient temperature is 20 ºC and the truck carries 50% of its rated payload. At 40 ºC and 10% payload, the EER increases to 6.8, while at -20 ºC and 100% payload the EER declines to 3.1 (Table 2).[21] Based on the work of Lee et al. (2013), calculating the EER based on 2012 model year diesel delivery trucks yields an EER that is 10% lower than when comparing to 2006 model year trucks (Table 2).[22] Similarly, the EER for class 8 trucks implied by research from the International Council on Clean Transportation is 2.5, but could be as low as 2.0 when comparing a PEV to the expected energy intensity of a 2025 or 2030 model year truck.[23] We would classify the ICCT EER as a literature-based value since it seems to be judgementally based on several simulation studies using European-based test cycles.

Figure 2 summarizes the truck EER estimates, categorizing each data point according to the type of data and the average speed of the drive cycle from which the EER was estimated (i.e., test cycle data are blue diamonds, in-use data are turquoise squares, simulated data are orange circles). CARB's correlation between average speed and EER is also in the figure. For a given average speed, simulated EERs tend to be lower than EERs determined from in-use data and test cycle data (Figure 2). At present, we do not have enough information to say whether simulations systematically underestimate the EER or if the simulated EER are lower because of differences between the simulated and tested or observed driving conditions. All EERs are

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[21] Zhou, T., Roorda, M. J., MacLean, H.L., Luk, J. (2017) *Life cycle GHG emissions and lifetime costs of medium-duty diesel and battery electric trucks in Toronto, Canada*. Transportation Research Part D, 55, 91–98 dx.doi.org/10.1016/j.trd.2017.06.019

[22] Lee, D.Y., Thomas, V.M, Brown, M.A., (2013). *Electric Urban Delivery Trucks: Energy Use, Greenhouse Gas Emissions, and Cost-Effectiveness*. Environ. Sci. Technol., 47, 8022−8030. dx.doi.org/10.1021/es400179w

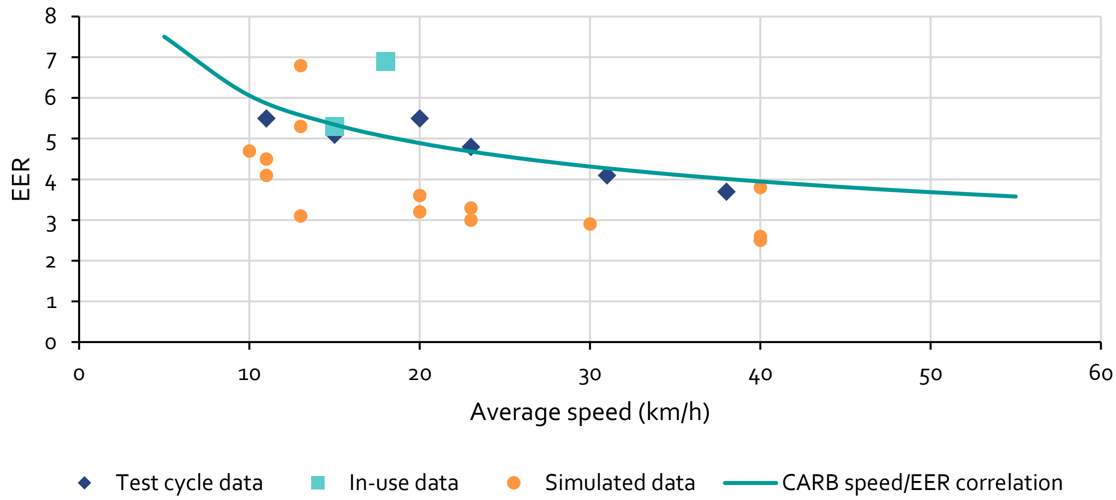
[23] International Council on Clean Transportation. (2017). *Transitioning to zero-emission heavy-duty freight vehicles*. Available from: www.icct.org

calculated assuming plug-in charging, so the difference is not due to an assumption of lower-efficiency wireless inductive charging.

Table 2: Summary of sources for truck EERs

Source	Number of Samples or Examples	Region	EER Value	Basis of EER	Avg. speed, km/hr	Basis of Speed
CARB (2018a), class 8 truck, test cycle data	4	California	5.5	Test cycle data	11	Test cycle data
			5.1		15	
			4.1		31	
			3.7		38	
CARB (2018a), delivery truck, test cycle data	2	California	5.5	Test cycle data	20	Test cycle data
			4.8		23	
CARB (2018a), class 8 truck, avg. of in-use data	12	California	5.3	In-use data	15	In-use data
CARB (2018a), delivery truck, avg. of in-use data	3	California	6.9	In-use data	18	In-use data
Lee et al. (2013)	6	Various	4.1-4.5	Simulated relative to two different levels of diesel truck efficiency	11	Three pre-determined drive cycles
			32.-3.6		20	
			3.0-3.3		23	
Zhou et al. (2017)	18	Toronto	5.3 (range is 3.1-6.8)	Simulated with various payloads and ambient temperatures	13	Representative drive cycles based on vehicle in-use data
			2.6 (range is 2.5-3.8)		40	
Lajevardi, in progress	3	Metro Vancouver	4.7	Simulated	10	Representative drive cycles based on 1598 drayage trucks in-use in BC
			2.9		30	
Lajevardi, in progress	1598	Metro Vancouver	5.0	Our calculation based on CARB speed/EER correlation	18.7	Avg. speed of 1598 trucks noted above
ICCT (2017)	Unknown	Unknown	2.5	Literature values	Unknown	Unknown

Figure 2: Summary of truck EER data points (Table 2) from vs. average drive cycle speed, compared against the CARB correlation between speed and EER



3.2. Buses

As with trucks, test cycle and in-use data used to determine an EER for PEV buses come from CARB's work in support of updated EERs for the California LCFS.[24] EERs in these tests ranged from 3.3, for a bus travelling a commuter route that includes freeway travel, up to 7.5 from in-use data for buses travelling in an urban core (Table 3, Figure 3).

We compare CARB's values to those estimated or used in a number of other studies. The bus EER implied by Bloomberg New Energy Finance's (BNEF) research appears to be consistent with CARB's proposed EER for buses. For city travel, the BNEF PEV bus archetype with a 250 kWh battery (roughly 200 km range) has an EER of 5, though this value does not have a specific drive cycle or average speed associated with it.[25] Another study (Correa et al., 2017) simulated energy consumption for a London, UK, drive cycle (13 km/hr average), finding a lower EER value (2.9) than would be

[24] California Air Resources Board (2018a). *Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles*

[25] Bloomberg New Energy Finance. (2018). Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2.

expected based on CARB's correlation between average speed and EER (roughly 5) (Figure 3).[26]

Currently, there are no estimates of bus EER specific to British Columbia, though Translink is launching a PEV bus pilot program that might eventually provide some relevant data.[27] In the meantime, CARB's correlation between speed and EER can be used to estimate EERs for British Columbia, based on the average speed of buses in the province. Translink publishes the average speed of its routes and we obtained similar data for the Victoria Regional Transit system (summarized in Figure 4). Across all routes in both systems, the average speed of buses in these systems is 26 km/hr, when excluding trolley buses which are already electrified.[28]

Using only the distribution of average speeds paired with the CARB speed-EER trend-line, the Translink and Victoria data suggest that an average EER of 4.5 might be appropriate for British Columbia, with 100% of routes having an EER somewhere between 4.1 and 5.3, based on average route speeds ranging from 15-25 km/hr (Figure 4). This average EER is somewhat lower than the 5.0 value proposed for California, where this value was chosen under the assumption that PEV buses serve slower routes. A similar judgement could be made for British Columbia, but it is easier to justify for California where buses likely travel more slowly: 94% of all bus routes in that state have an average speed that is less than 21 km/hr.[29] Excluding trolley buses, only 14-15% of bus routes in Metro Vancouver and Victoria have an average speed below this threshold, with 94% having an average speed somewhere less than approximately 30 km/hr.

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[26] Correa, G., Muñoz, P., Falaguerra, T., Rodriguez, C.R. (2017). *Performance comparison of conventional, hybrid, hydrogen and electric urban buses using well to wheel analysis*. Energy, 141, 537-549. doi.org/10.1016/j.energy.2017.09.066

[27] Translink (2018). *Translink Launches New Electric Bus Trial*

[28] Note that this average is not weighted by the intensity of bus travel on each route (e.g. bus frequency or passenger boardings). Translink data allowed an intensity-based weighting of average speed, but the Victoria data did not. As a test, we did weight the Translink data and it made little difference to the average speed of the routes.

[29] California Air Resources Board (2018a). *Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles*

Figure 3: Summary of bus EER data points (from Table 3) vs. average drive cycle speed, compared against the CARB correlation between speed and EER

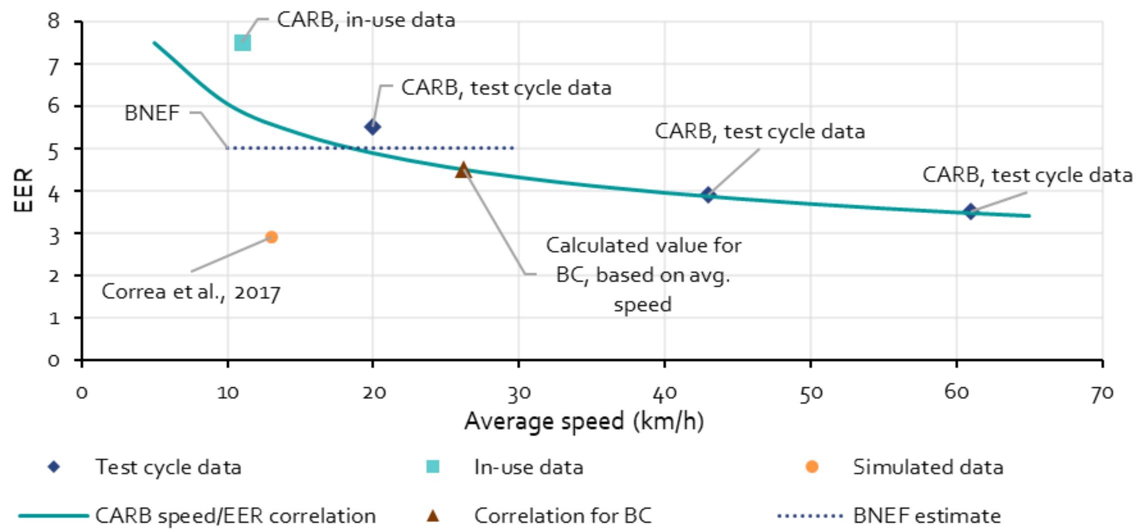
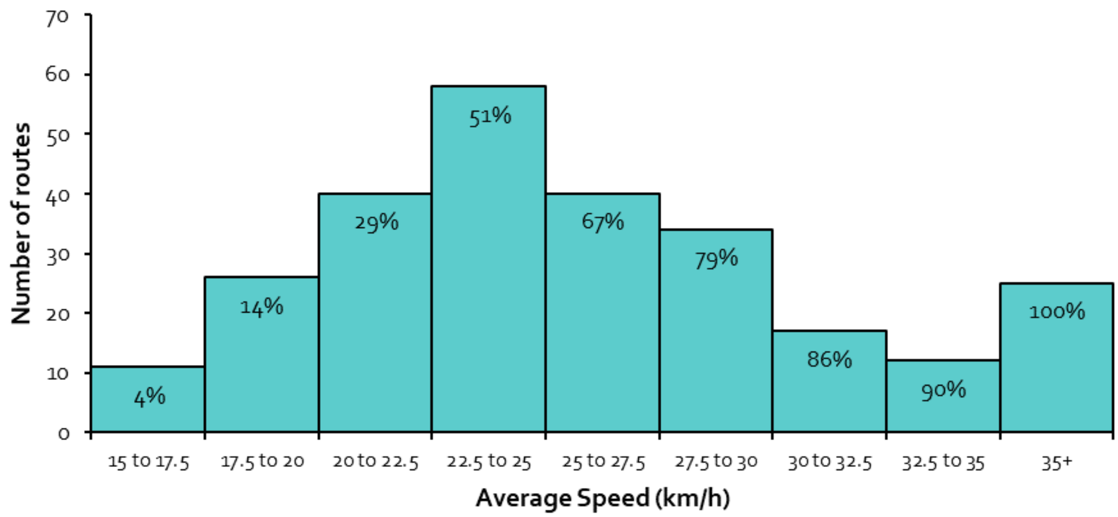


Table 3: Summary of sources for bus EERs

Source	Number of Samples or Examples	Region	EER Value	Basis of EER	Avg. speed, km/hr	Basis of Speed
CARB (2018a), urban core test	1	California	5.5	Test cycle data	20	Test cycle data
CARB (2018a), arterial test	1	California	3.9	Test cycle data	43	Test cycle data
CARB (2018a), commuter test	1	California	3.5	Test cycle data	61	Test cycle data
CARB (2018a), avg. of in-use data	12	California	7.5	In-use data	11	In-use data
BNEF (2018), bus with 250 kWh battery	Unknown	Unknown	5	Literature value	Unknown	Unknown
Correa et al. (2017)	1	London, UK	2.9	Simulated	13	Test cycle data
Translink and Victoria Regional Transit, avg. of non-trolley routes	263	Metro Vancouver, Victoria	4.5	Our calculation based on CARB speed/EER correlation	26	In-use data

Figure 4: Translink and Victoria Regional Transit routes by average speed, cumulative distribution notes in the data label



3.3. Trolley-Buses

CARB's estimate of trolley bus EER, based on California data from the National Transit Database, is somewhat higher than the value used in British Columbia: 3.1 versus 2.7. We could not get diesel and trolley-bus fleet energy consumption for Vancouver to make a comparable calculation. However, a Translink document considering GHG offset costs compares new 60ft diesel buses with new 60ft trolley-buses running on the same route. The energy consumption noted for each technology produces an EER of 3.4.[30] This value may not be representative of the entire trolley-bus and diesel bus fleet which also includes 40ft buses of varying vintages. Given that older diesel buses tend to less efficient than newer buses, 3.4 likely underestimates the EER for the fleet as a whole.

3.4. Light Rail/Skytrain

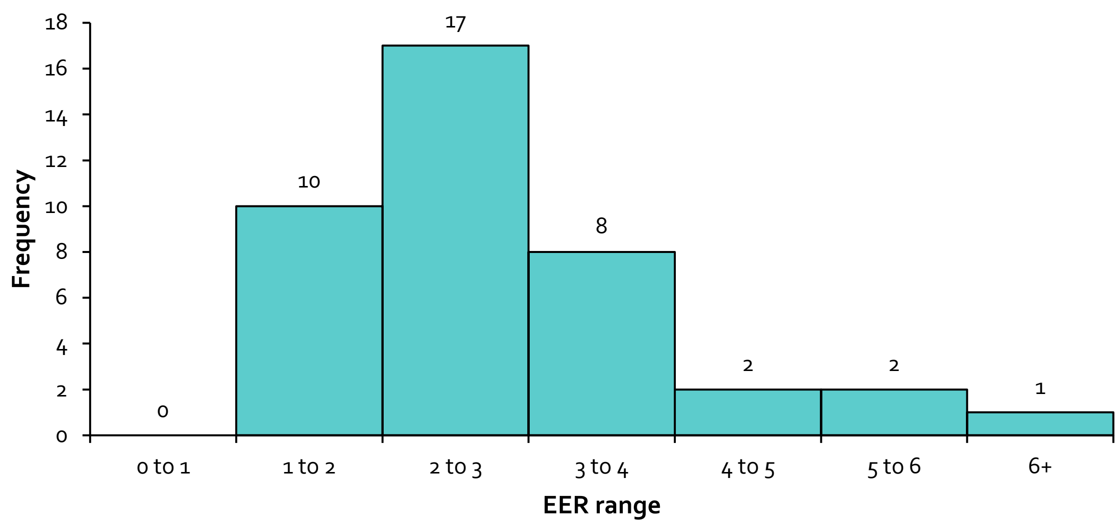
CARB's estimate of light rail EER, based on California data from the National Transit Database, is also somewhat higher than the value used in British Columbia: 3.3 versus 2.7. This EER is based on the energy per person km travelled by electric light rail versus standard diesel bus reported in the National Transit Database by Californian

[30] MVision Planning (2012). BC Transit and Translink Low Carbon and Electric Vehicle Offset Project, GHG Project Plan V2.0, prepared for Translink and BC Transit.

transit service providers that operate both modes. We could not get the data to make a comparable calculation for the Skytrain lines.

To provide more context as to what the range of EER values for light rail/Skytrain could be, we calculated EER for all US transit providers reporting the use of light rail in the National Transit Database by comparing the energy per passenger km (pkm) between light rail and diesel buses (consistent with CARB 's methodology). The calculation uses data from 2015 and 2016 to check for consistency in EER values over time: they generally vary by less than +/- 20%. The average EER for 20 transit providers over two years (40 data points) is 2.7. The maximum and minimum EERs are 1.1 and 7.3, with 88% of EERs falling between 1 and 4 (Figure 5).

Figure 5: Distribution of light rail EER for US transit providers in 2015 and 2016, calculated from the National Transit Database



The variation in EER comes from differences in energy per vehicle km traveled (vkm) and ridership (pkm per vkm). These differences in energy intensity result from factors such as vehicle efficiency and vintage (e.g. hybrid bus vs. older bus) and intensity of transit use (e.g. routes with low versus high ridership).

For example, diesel buses in the San Diego Metropolitan Transit System have an average energy intensity per vkm (25-30 MJ/km), but average ridership is low at 8 to 9 pkm/vkm. On the other hand, its light rail system has a very high average ridership, at around 70 pkm/vkm (versus an average of 40 pkm/vkm for light rail calculated from the National Transit Database). The resulting EER is high at 5.3 to 7.3 in 2015 and 2016 respectively.

These data show that the EER that British Columbia and CARB use, 2.7 and 3.3 respectively are reasonable. However, the distribution shows that an EER calculated from British Columbian data, if it were available, could differ substantially.

3.5. Garbage Trucks

CARB's own estimate of garbage truck EER is based on in-use data collected by the National Renewable Energy Laboratory (NREL) under the Fleet DNA program.[31] This data only includes vehicle average speeds, so any estimate of EER is again based on CARB's speed/EER trend-line. The NREL data contains 452 samples, with an average speed of 14.8 km/hr, resulting in an EER of 5.3 (Table 4).

Data and research relevant to the EER of garbage trucks is relatively scarce and is primarily limited to vehicle average speeds based on in-use data. The available data indicates a range of possible EERs that are a function of a garbage truck's drive cycle and the energy efficiency of the diesel trucks.

This information includes one paper focussed on garbage truck operation in Surrey, British Columbia, with in-use drive cycle data provided by the City of Surrey.[32] Because the research was focused on fossil fuel powered garbage trucks, it does not provide EER or the energy intensity of an electric garbage truck. However, it does include the average speed of trucks travelling on a single route at, 6 km/hr, which would translate to an EER of 6.8, based on the speed/EER trend-line observed by CARB (Table 4).

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[31] National Renewable Energy Laboratory. (2018). *Fleet DNA Project Data*. Accessed September 10, 2018.

[32] Rose et al. (2012). *A comparative life cycle assessment of diesel and compressed natural gas-powered refuse collection vehicles in a Canadian city*. Available from: www.pdfs.semanticscholar.org

Table 4: Summary of sources used for garbage truck EER calculations

Source	Number of Samples or Examples	Region	EER Value	Basis of EER	Avg. speed, km/hr	Basis of Speed
Rose et al. (2012)	1	Surrey, BC	6.8	Our calculation based on CARB speed/EER correlation	6.0	In-use data
NREL Fleet DNA, Refuse Trucks (2018)	452	Multiple, USA	5.3	CARB speed/EER correlation	14.8	In-use data average
Sandhu et al. (2015); Zhao and Tatari (2017)	6	North Carolina and Illinois	3.1 to 5.7	In-use data*	15.1	In-use data average

*Diesel truck energy consumption is from in use data. The source of PEV truck energy consumption is not given, but is presumed to be either simulated or in-use data for a comparable drive cycle.

Zhao and Tatari (2017)[33] is the only paper we found that features an estimate for electric refuse truck energy consumption, provided to them by Motiv Electric Systems, a manufacturer of fully electric refuse trucks. We use diesel energy consumption estimates from a separate in-use study of six garbage trucks by Sandhu et a. (2015)[34] to calculate an EER that is independent of CARB's correlation, finding a value that ranging from 3.1 to 5.7. The variation in the EER is a function of the truck's route and vintage, where older trucks are less energy-efficient, resulting in a larger implied EER. Further uncertainty in these EER estimates exists because it is unclear whether the energy consumption estimate provided by Motiv Electric Systems is based on simulated or in-use data and it is also unclear what the real or assumed duty cycle is. In short, the EER calculated using information from Zhao and Tatari (2017) and Sandhu et al. (2015) could be biased because it is based on inconsistent methods and operating conditions.

The City of Surrey data yields the highest EER, but it may not be representative of typical drive cycles and EERs throughout British Columbia. It differs from the other sources on average speed, energy consumption, and stops per distance travelled. The average speed estimate provided by the City falls within the slowest 3% refuse truck speeds reported in NREL's Fleet DNA program (Figure 6). The energy consumption of 2 litres per km (or 21.1 kWh/km) reported by the City is over twice the average found by

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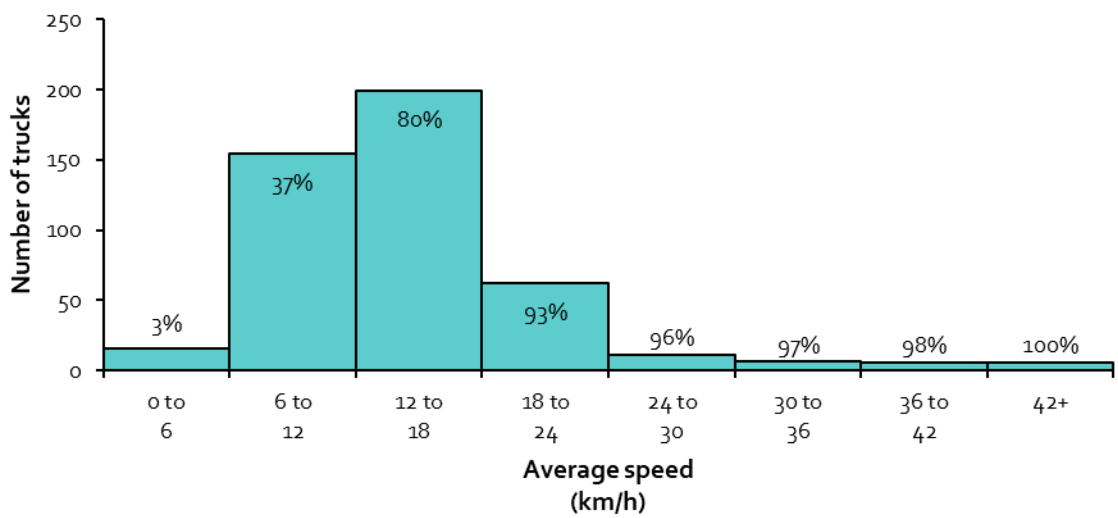
[33] Zhao and Tatari (2017). *Carbon and energy footprints of refuse collection trucks: A hybrid life cycle evaluation*. Available from: www.elsevier.com

[34] Sandhu et al. (2015). *Real-world activity, fuel use, and emissions of diesel side-loader refuse trucks*. Available from: www.elsevier.com

Sandhu et al. (2015) (0.85 litres per km or 9.0 kWh/km). These discrepancies can be explained by the unusually high number of stops per kilometre the City of Surrey's truck performs in comparison to NREL Fleet DNA's trucks. It is unclear what causes the truck to stop 2.5 times more than NREL Fleet DNA's truck with the most stops per kilometre. The discrepancy could be specific to the route that was studied based on the density of buildings, the layout of the blocks, and the traffic systems in place in a given area.

Figure 6: Distribution of NREL Fleet DNA refuse truck average driving speeds, with cumulative distribution noted in the data label



3.6. Marine Applications

Electrification of marine applications can be broken down into three categories: marine vessel propulsion, at-berth shore power, and cargo-handling equipment used in the port. Table 4 summarizes the literature on EERs for each of these applications. Although information on marine propulsion and cargo handling equipment is limited, there has been wide-scale testing to determine EERs for shore power in California, where CARB has calculated an EER using 890 measured data points.

Table 5: Summary of sources used for refuse truck EER calculations

Source and end-use	Number of Samples or Examples	Region	EER Value	Basis of EER	Metric used for EER
Kullmann (2016), marine propulsion	2	Sognefjord, Norway	3.6	Simulated energy consumption data	Consumption per trip; 181 kWh_e/trip and 672 kWh_{die}/trip
CARB (2018b), shore-power	890	California, USA	2.6	In-use energy consumption and air emission data	Energy generated on board, 28.4 GWh; Emission generated on board, 20,028 t CO_2 (equivalent to 74.4 GWh diesel)
U.S. Environmental Protection Agency (2017), shore-power	7	Multiple locations, USA	2.6	Simulated energy consumption and emission generation data	Energy generated on-board, 1.58×10^7 kWh; Emissions generated on board, 10,884 t CO_2 (equivalent to 4.04×10^7 kWh)
CARB (2018), cargo handling equipment	6 (1 for each type of equipment)	California, USA	2.7	Engine power/load ratings correlated to EER	Hours-weighted average EERs based on engine power and load

Marine vessel propulsion

The electrification of marine vessel propulsion is currently in its very early stages. As of 2018, about 190 battery-powered vessels exist, mostly under construction with handful in operation.[35] The most likely electrification path will see the adoption of plug-in hybrid systems until battery technology is light enough to power long distance navigation on a single charge.[36] BC Ferries not expect to use battery-powered propulsion in the foreseeable future based on its May 2018 announcement, preferring to maintain flexibility rather than acquiring ferries that can only operate on a single route.[37] Although Translink's Seabuses could be electrified, we were unable to find any media coverage of this possibility.

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35 Bloomberg. (2018). *The Next Ferry You Might Board Might Run on Batteries*. Available from: www.bloomberg.com

36 Canadian Broadcasting Corporation. (2018). *B.C. company develops battery for Swedish 'hybrid' ferry*. Available from: www.cbc.ca

37 Canadian Broadcasting Corporation. (2018). *Why BC Ferries won't be going all-electric anytime soon*. Available from: www.cbc.ca

Electric marine propulsion is currently limited to a couple of short-distance ferry trips, and our research yielded only one study comparing the energy consumption of electric and conventional vessels. In 2015, Norled, a Norwegian ferry service, was the first company to operate an electric ferry, launching the MS Ampere to ferry up to 120 vehicles per trip across 5.6 km route.[38] Kullmann (2016) performed a lifecycle assessment comparing the electric MS Ampere ferry to an existing similarly-sized conventional vessel navigating on the same route. The analysis simulates the energy consumption for each vessel using ship and trip specifications provided by Norled and finds a per trip consumption rate of 181 kWh for the electric ferry compared to 672 kWh in marine diesel for the conventional ferry, implying an EER or 3.6. A simulation comparing the MS Ampere to a hypothetical diesel-powered version of that vessel yields an EER of 2.6, indicating that in addition to the powertrain, the vessel vintage and design also affects the EER.

Shore power

Ships can reduce at-berth GHG and other air emissions by connecting to the on-shore power grid rather than using on-board diesel generators. The Vancouver Cruise Ship Terminal is one of over 10 ports around the world providing access to shore power.[39] CARB has conducted a comprehensive analysis to estimate an EER for shore power.[40] CARB measured the emissions from on-board generators of over 890 ships to infer the amount of diesel used to generate the electricity consumed by the ships, finding an average EER of 2.6. The United States Environmental Protection Agency (US EPA) developed a shore power emission calculation tool to help port authorities assess environmental benefits of using shore power. Using the examples given in the appendices that accompany that tool, the implied EER was also 2.6 for the six examples of ships connected to the grid. The calculator is based on data measured in a separate 2007 CARB analysis.[41] Our research found no quantification of the shore-power EER specific its application to British Columbia.

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[38] Corvus Energy. (2017). *World's First All-Electric Car Ferry*. Available from: www.corvusenergy.com

[39] International Council on Clean Transportation. (2015). *Costs and benefits of shore power at the port of Shenzhen*. Available from: www.icct.org

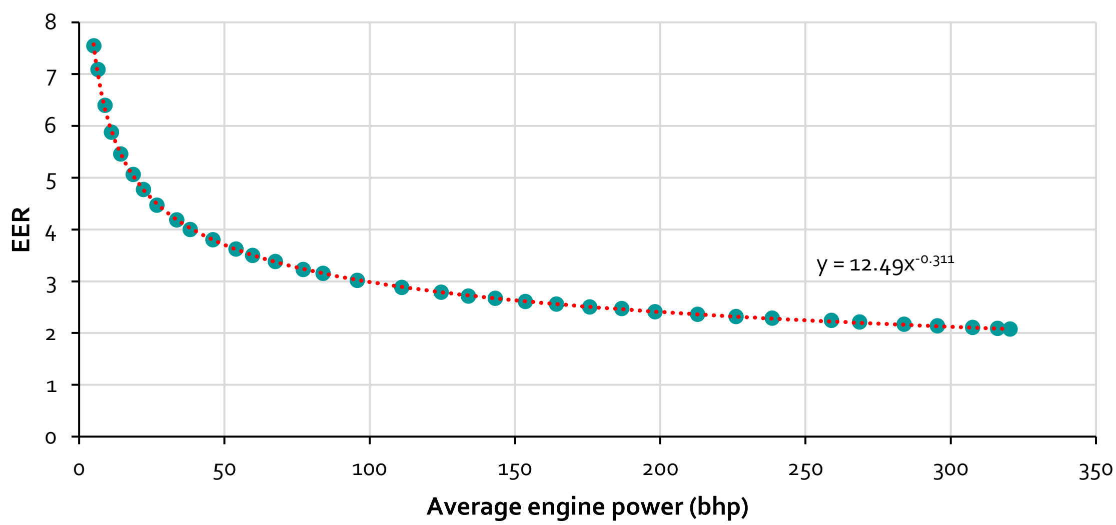
[40] California Air Resources Board. (2018b). *Attachment D: Analyses Supporting the Addition or Revision of Energy Economy Ratio Values for the Proposed LCFS Amendments.* Available from: www.arb.ca.gov

[41] California Air Resources Board. (2007). *Technical Support Document: Initial Statement of Reasons for the Proposed Rulemaking*. Available from: www.arb.ca.gov

Cargo-handling equipment

Cargo-handling equipment in ports accounts for only a small portion of the marine sector's energy consumption and emission production. However, CARB has provided a weighted average EER estimate of 2.7 for such equipment. The estimate is based on the EERs inferred for each type of equipment using a correlation between average engine power output (i.e. average brake horsepower, or bhp) and EER (Figure 7), based on in-use measurements from a sample from California bus and truck fleets. The correlation shows that equipment operating at high power tends to be more efficient, resulting in a lower EER. Equipment operating at a lower average power implies more starting and stopping and idle time, resulting in a higher EER.

Figure 7: EER versus brake horsepower curve



Graphically interpolated from Figure 1 of CARB. (2018b). *Attachment D: Analyses Supporting the Addition or Revision of Energy Economy Ratio Values for the Proposed LCFS Amendments*. Available from: www.arb.ca.gov

Estimates of EER for cargo handling equipment based on this correlation require two assumptions. The first assumption is that a correlation between bhp and EER that was derived from buses and trucks applies to other diesel-powered equipment. The second assumption is that the average engine power (bhp) for a piece of equipment can be approximated from its maximum rated engine power and its engine load factor (the portion of the rated engine power used during work); Actual engine power output is rarely measured directly.

CARB's estimates for the EERs of cargo handling equipment ranges from 2.5 to 3.9, based on data collected at the Port of Long-Beach (Table 6). The average EER is 2.7, weighted by hours of operation. This research found no data relevant to cargo handling equipment EERs from British Columbia (e.g. energy consumption, bhp, hourly operation by equipment type).

Table 6: Cargo-handling equipment EER estimate information

Equipment	Operational horsepower (bhp)	Annual operating hours (hrs)	EER
Bulldozer	80	1,900	3.2
Forklift-Diesel	40	55,723	3.9
Loader	176	14,112	2.5
Rubber Tired Gantry Crane	131	140,154	2.7
Container Side Handler	124	10,276	2.8
Container Top Handler	181	401,633	2.5
Weighted average	-	-	**2.7**

The cargo-handling equipment does not include yard trucks since they are included in the truck EER estimates.

3.7. Airport Ground Support Equipment

The aviation industry has the potential to reduce some of its emissions by electrifying ground support equipment (GSE) at airports, with roughly 10% of global GSE already electric.[42] GSE includes aircraft tractors, baggage and cargo tractors, belt loaders, fuel trucks, cabin service trucks and many more machines that service aircrafts on the ground and maintain airport operation. Literature on the energy efficiency improvement of electrifying GSE fleets is scarce and CARB has not measured or estimated EERs for airport GSE.

Despite this lack of data, we were able to infer EERs for GSE based on the correlation between average engine power and EER explained above in Section 3.6. The average equipment engine power (in bhp) was calculated by multiplying the typical maximum rated power for equipment by their respective load factors, which are reported in a study of 12 US airports from the Airport Cooperative Research Program (ACRP).[43] The EER was estimated for equipment servicing three sizes of aircraft (Table 7).

[42] National Renewable Energy Laboratory (2017). *Electric Ground Support Equipment at Airports*. Available from: www.afdc.energy.gov

[43] Airport Cooperative Research Program. (2015). *Improving Ground Support Equipment Operational Data for Airport Emissions Modeling*. Available from: www.nap.edu

Table 7: Average bhp and EER by equipment type and aircraft size

GSE type	Wide-bodied, Large Aircraft		Narrow-bodied, Medium Aircraft		Small Aircraft	
	Avg. bhp	EER	Avg. bhp	EER	Avg. bhp	EER
Aircraft tractor	230	2.3	143	2.7	55	3.6
Baggage tractor	14	5.4	14	5.4	14	5.4
Belt loader	13	5.7	13	5.7	13	5.7
Cabin service/catering truck	68	3.4	56	3.6	44	3.8
Cargo/container loader	23	4.7	-	-	-	-
Lavatory truck	34	4.2	34	4.2	34	4.2
Air conditioner	111	2.9	111	2.9	-	-
Air (turbine) starter	94	3.0	94	3.0	-	-
Auxiliary power unit	130	2.8	109	2.9	-	-
Ground power unit	-	-	75	3.3	60	3.5
Fuel/hydrant truck	118	2.8	65	3.4	41	3.9
Service truck	26	4.5	26	4.5	21	4.9
Water service	37	4.1	37	4.1	-	-

The weighted average EER for different sizes of aircraft are calculated based on the amount of time each piece of equipment spends on an aircraft of a given size as reported by ACRP. The EERs for a large, medium and small, aircraft are 4.1, 4.0 and 4.4, respectively (Table 8). This research found no data relevant to GSE EERs from British Columbia (e.g. energy consumption, bhp, hourly operation by equipment type).

Table 8: Summary of sources used for refuse truck EER calculations

Source	Number of Samples or Examples	Region	EER Value	Basis of EER	Metric	Basis of metric
Wide-bodied/Large aircraft						
ACRP (2015); CARB (2018)	100+	Multiple locations, USA	4.1	Engine power, fleet composition, and operation time	Multiple weighted EERs inferred from engine power-EER correlation curve	Survey of 12 airports; in-use data
Narrow-bodied/Medium aircraft						
ACRP (2015); CARB (2018)	100+	Multiple locations, USA	4.0	Engine power, fleet composition, and operation time	Multiple weighted EERs inferred from engine power-EER correlation curve	Survey of 12 airports; in-use data
Small aircraft						
ACRP (2015); CARB (2018)	100+	Multiple locations, USA	4.4	Engine power, fleet composition, and operation time	Multiple weighted EERs inferred from engine power-EER correlation curve	Survey of 12 airports; in-use data

3.8. Light-Duty Vehicles (Gasoline/Electric EER)

This section explores EERs for light-duty vehicles (i.e. the gasoline/electric EER) from three perspectives:

- First, it calculates the EER using CARB's method of comparing the Nissan Leaf with the Versa and the Chevrolet Volt with the Cruze and extends this comparison to the current model years. This comparison forms the basis of the current EER values in California, Oregon and British Columbia's fuel GHG regulations. Tracking this comparison since it was first made in 2011 can indicate whether the EER should be updated assuming no methodological change is needed for that calculation.
- Second, the analysis calculates the EER using a Canadian-sales weighted average energy intensity for conventional and electric vehicles (2017/2018 model year), to understand if the EER changes when it is based on a broader comparison of the vehicles market rather than on the comparison of two specific vehicle pairs.
- Third, this section looks at how the EER is expected to change in the future as the energy efficiency of both conventional vehicles and PEVs change in response to policies (e.g. federal vehicle emissions standards) and technological progress (e.g. lighter-batteries).

All light-duty vehicle EER calculations use fuel efficiency ratings for light-duty vehicles derived from North American test-cycle data. Specifically, the calculations use the combined city/highway fuel efficiency data from Natural Resources Canada's fuel efficiency data files[44]: $L_{gasoline}$/100km for conventional vehicles and $kWh_{electricity}$/100km, with Litres of gasoline converted to MJ using the gasoline HHV of 34.66 MJ/L.[45] Using the HHV rather than the LHV is not only rational, it is also consistent with how fuel carbon intensities are calculated in the RLCFRR using the HHV values in the GHGenius 4.03a lifecycle GHG model.

The data used in this section is not specific to British Columbia, but rather applies to North America (fuel efficiency) and Canada (sales). Fuel economy/efficiency ratings are the same across North America and this research does not use any vehicle in-use data or vehicle sales data collected in British Columbia.

EER based on an extension of CARB's 2011 method

The gasoline/electric EER in the Californian LCFS is 3.4, which is the average of the EER values calculated by CARB for the 2011 Nissan Leaf vs. Versa and the 2011 Chevrolet Volt vs. Cruze, using the LHV of gasoline to convert electricity consumption to gasoline equivalents (2011 CARB LHV, Figure 8). When using the HHV of gasoline to convert between electricity and gasoline consumption, this average EER increases to 3.7 (CARB HHV, Figure 8). Since 2011, this EER value has changed as the vehicle models in question have been updated. For example, the EER of the Leaf/Versa combination fell to 3.0 in 2013 with the release of the new Versa but increased to 3.5 with the release of the improved 2014 Leaf. The EER of the Volt/Cruze varied somewhat depending on the specifics of each model year, peaking at 4.3 with the release of the 2016 Volt, only to fall to 3.4 with the release of the latest Cruze model. Presently, the average EER for the 2018 model years of these vehicles is 3.5, on an HHV basis (Navius HHV EER, Figure 8).

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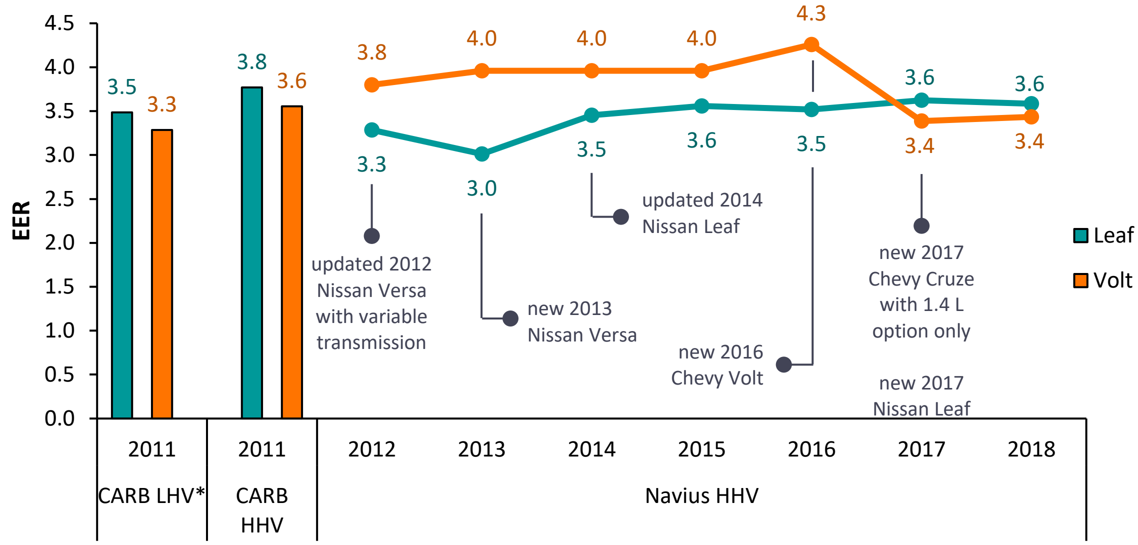
[44] Natural Resources Canada. (2018). *2018 Fuel Consumption Ratings*. Available from: www.open.canada.ca
Note that the values are the same as the EPA fuel economy ratings except for an error: NRCan's combined MPG value is based on the highway L/100km rather than the combined L/100km.

[45] National Energy Board. Energy Conversion Tables. Available from: http://www.neb-one.gc.ca

Figure 8: Evolution of Leaf/Versa and Volt/Cruze EER



EER based on Canadian-sales weighted energy intensity

Using a broader comparison of vehicles yields a higher EER. Based on Canadian vehicle sales for the 2017 model years, the weighted average EER for light-duty vehicles is 4.1.

This EER is based on a comparison of the top 14 best-selling PEVs with the slate of conventional vehicles sold. The vehicles are representative of the PEV market, making up over 85% of total Canadian PEV sales. They also feature at least one vehicle from every PEV class sold since January 2017. These include compact cars, mid-size cars, full-size cars, mid-size SUVs, and minivans.

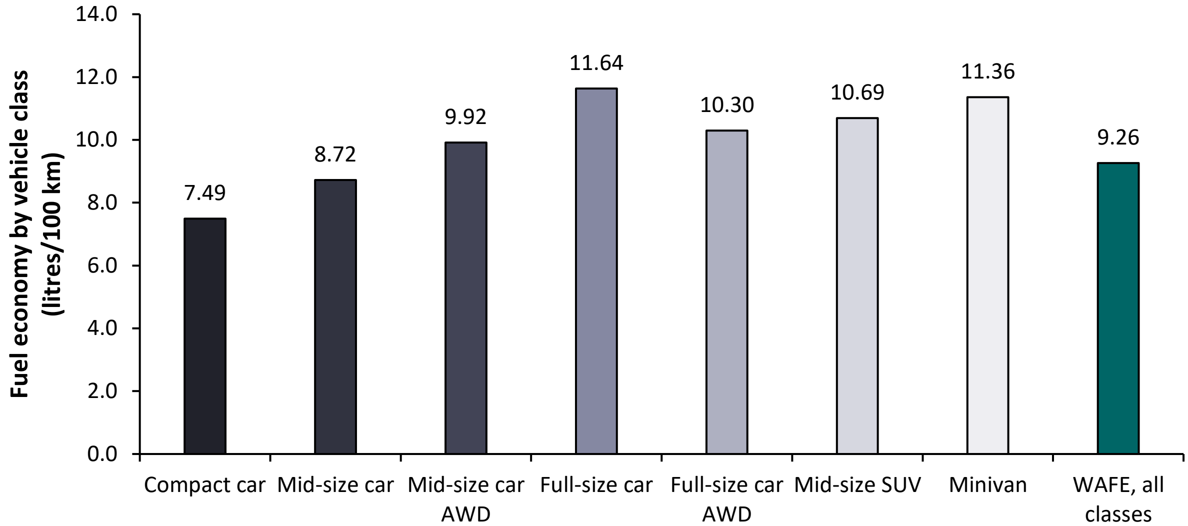
Each of the 14 PEVs was compared to a corresponding conventional vehicle class archetype i.e. a Chevrolet Volt was compared to a conventional compact car archetype. In many cases, the vehicle class listed in the NRCan fuel efficiency data was incorrect, in which case these were set judgementally based on vehicle size. The vehicles that make up each vehicle class are shown in Appendix A:. The fuel economy of each conventional vehicle class archetype was calculated using an average of the vehicles' 2017 NRCan fuel consumption ratings[46] weighted by each vehicle's 2017 sales.[47]

[46] Natural Resources Canada. (2018). *2018 Fuel Consumption Ratings*. Available from: www.open.canada.ca
Note that the values are the same as the EPA fuel economy ratings except for an error: NRCan's combined MPG value is based on the highway L/100km rather than the combined L/100km.

[47] goodcarbadcar. (2018). *2017 Year End Canada Vehicle Sales Rankings – Top 280 Best-Selling Vehicles*. Available from: www.goodcarbadcar.net

Figure 9 shows the calculated conventional vehicle fuel efficiency by class, weighted by sales, and the sales-weighted average fuel efficiency (WAFE) for all classes.

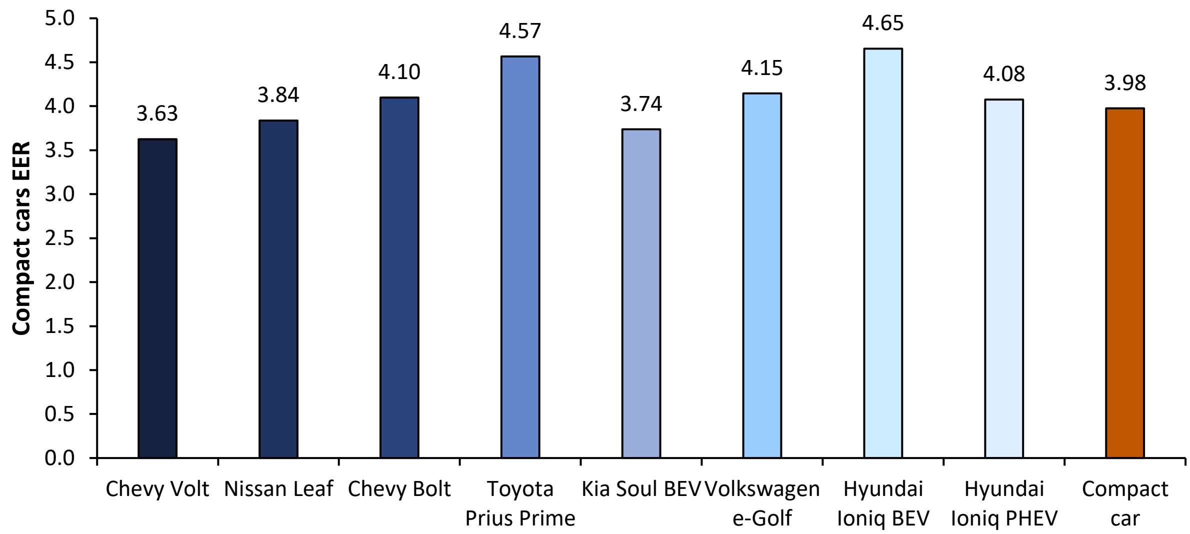
Figure 9: Weighted average fuel efficiency (WAFE) by vehicle class



The WAFE for all classes is 9.3 L/100km is based on 20 makes of compact cars, 21 mid-sized cars, 16 mid-sized all-wheel drive (AWD) cars, 7 full-sized cars, 5 full-sized all-wheel drive cars, 27 mid-sized sport utility vehicles, and 6 minivans.

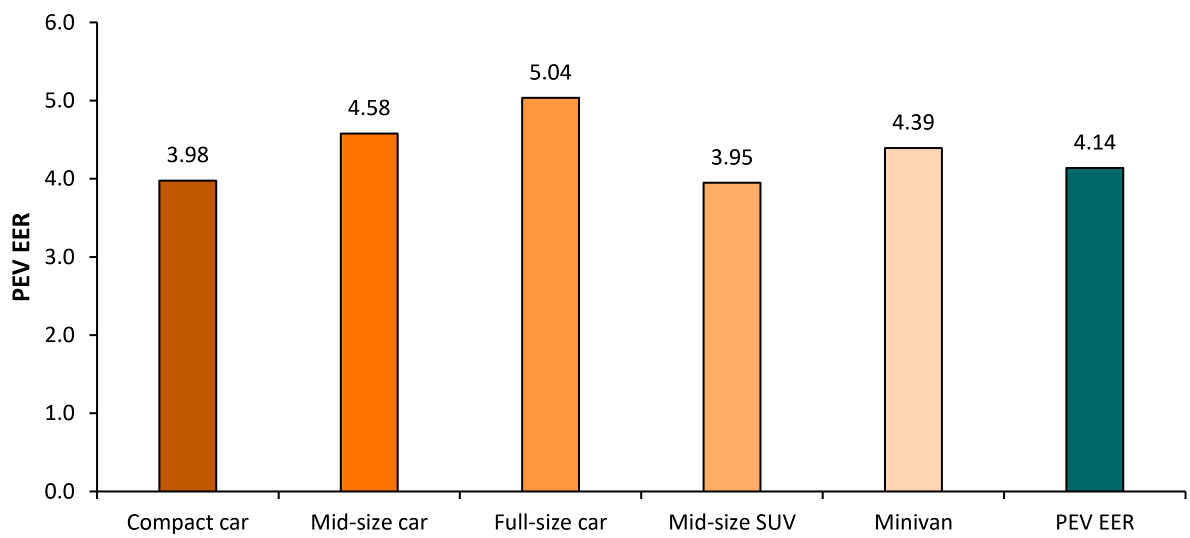
The energy consumption of each PEV was compared to the weighted fuel efficiency of each class archetype. An average EER weighted by vehicle sales was calculated for each class. For example, the weighted EER for compact cars is 4.0, influenced by the larger sales of the Volt and Leaf (Figure 10), whereas the simple average is 4.1. The sales-weighted EER for each vehicle class ranges from 4.0 to 4.4, and the overall sales-weighted EER for all vehicle classes is 4.1 (Figure 11).

Figure 10: Compact plug-in electric vehicle EERs



Note that the EER for the Volt and Leaf are calculated relative to the sales-weighted fuel efficiency of compact cars and is different than when calculated relative to the Cruze and the Versa as in Figure 8.

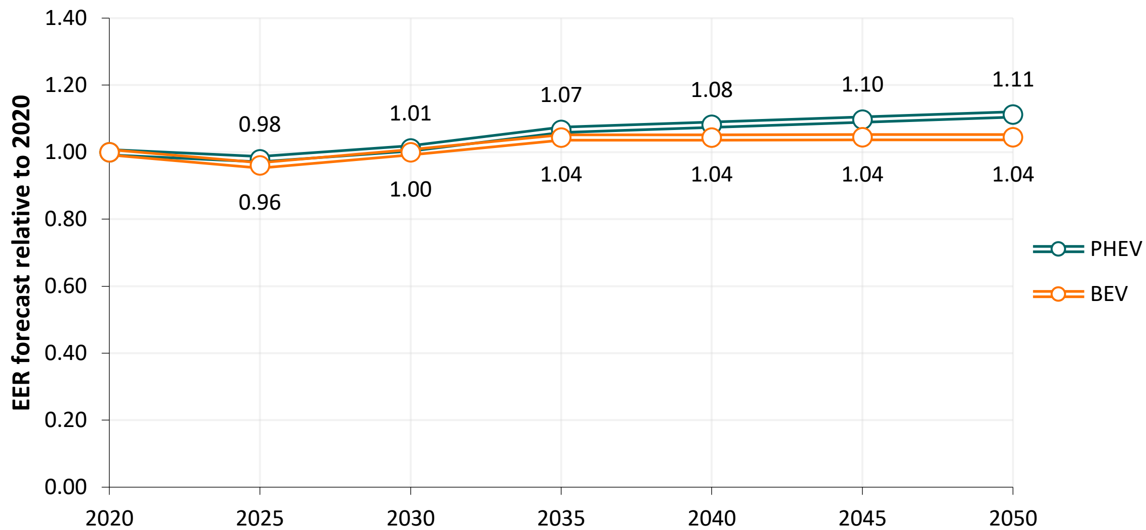
Figure 11: Weighted average plug-in electric vehicle EER



Future trends in light-duty vehicle EER

The EER may change in the future as the energy efficiency of conventional vehicles and PEVs changes. Because of vehicle emissions standards and fuel economy standards in Canada and the United States, the energy efficiency of conventional vehicles will likely improve through vehicle light-weighting and drivetrain improvements. Similarly, the vehicle glider of PEVs (e.g. frame, body, wheels) is also likely to become lighter, as will the batteries, increasing the efficiency of these vehicles. Vehicle simulation modelling by the Argonne National Laboratory in the U.S. indicates that these improvements will increase the energy efficiency of both conventional vehicles and PEVs by 25-30% over the next 30 years.[48] While there is some uncertainty in the evolution of these technologies, the simulation results show that the gasoline/electric EER may increase by 5-10% higher over the 2030-2050 relative to 2020.

Figure 12: Forecasted Trends in EER for mid-size light-duty vehicles



*Source: Moawad A. et al. (2016). Assessment of Vehicle Sizing, Energy Consumption, and Cost through Large-Scale Simulation of Advanced Vehicle Technologies. Available from: www.autonomie.net

[48] Moawad A. et al. (2016). *Assessment of Vehicle Sizing, Energy Consumption, and Cost through Large-Scale Simulation of Advanced Vehicle Technologies*. Available from: www.autonomie.net

4. Discussion and Policy Recommendations

4.1. Summary of the Research

Past, current and proposed diesel/electric energy efficiency ratios (EER) by jurisdiction: Initially, the same diesel electric EER was used for the fuel GHG intensity standards implemented by California Air Resourced Board (CARB) and Oregon's Department of Environmental Quality (DEQ), and by the Province of British Columbia. We have determined that this value of 2.7 was first used in California and was essentially an educated guess made before adequate testing was possible. More recently, CARB and Oregon's DEQ have acknowledged different EER values that imply greater energy efficiency from the electrification of diesel-fuelled vehicles and equipment. Notably, the proposed EER values for buses and other medium- and heavy-duty PEVs in California is 5, based on vehicle test cycle and in-use data and assuming that electric vehicles will primarily travel urban routes (shorter, lower speed routes with more starts/stops). Similarly, the current EERs for transit vehicles (e.g. rail and trolley bus) in California and Oregon are based on in-use data taken from the National Transit Database. CARB has also conducted tests to determine the EER for shore-power and cargo handling equipment at ports, where these latter tests provide data that can also be used to infer the EER for airport ground equipment.

Gasoline/electric EERs: The gasoline/electric EER, which quantifies the fuel substitution that occurs with the adoption of electric light-duty vehicles, is 3.4 in all three regions' policies. This value is based on a comparison of the tested fuel economy of 2011 Nissan Leaf and Versa and the 2011 Chevrolet Volt and Cruze. The electricity used by the PEVs is converted to gasoline equivalents using the lower heating value (LHV) of gasoline, which only accounts for the energy in the fuel that is theoretically available to the engine through combustion. In contrast, fuel economy/efficiency ratings are almost certainly expressed on a higher heating value (HHV) basis (i.e. all combustion energy is included).

Evidence available for diesel/electric EER values used British Columbia: The initial value of 2.7, applied to all vehicle segments, is based on an out-of-date perspective (older, limited data). To inform an update of this value, we reviewed all available evidence for EERs in British Columbia, though the data specific to the province is limited. Helpfully, CARB's analyses of test data reveal a strong relationship between vehicle average speed and EER (or average engine power output and EER). CARB estimated a trend-line for this relationship that can be used to infer EER values for other regions if one knows the average speed of the vehicles. The remaining literature is fairly sparse and limited. Furthermore, EERs determined from the literature tend to rely on vehicle simulation data rather than test data. In the case of trucks, simulations produce EERs that are almost always lower for a given average speed than indicated by the CARB test data.

Evidence available for gasoline/electric EER values used British Columbia: The current value of 3.4 is based on a comparison of the 2011 model year of two vehicle pairs. To inform a potential updated value, we extended this comparison to the current vehicle model years and corrected the EER calculation to use the gasoline HHV. For a broader perspective on this EER, we also calculated the sales weighted energy consumption of PEVs and conventional vehicles within the comparable vehicle classes (e.g. compact car versus mini-van) based on fuel consumption test data. Finally, to understand how the EER may change in the future as a function of efficiency improvements to PEVs and conventional vehicles, we analyzed simulation data that forecasts archetypal vehicle energy consumption to 2050.

Key issues involved in updating British Columbia's EER values: Drawing from our research, there are number of issues to consider when selecting or updating EERs. These issues relate to the fact that an EER is a simplification with a degree of subjectivity: it cannot be measured for each vehicle. There is inherent uncertainty in selecting a single EER value for any type of vehicle or segment. Data can be drawn from test cycle data, in-use data, simulation data or other literature, which vary by assumptions of drive cycle and other conditions in a particular region – and different data sources can give different results. Consequently, when choosing an EER one should consider:

- Should a policy use a single EER, or a different EER for several vehicle segments?
- Should test-cycle data and in-use data be given greater weight than vehicle simulation data
- Should the EER be defined for an average drive cycles in a segment, or based on drive cycles that are more likely electrify?
- Should an EER be fixed for the long-term (e.g. until 2030), or should there be a plan to update the EER with regular research as the energy intensity of the vehicles in question evolves or as new evidence emerges?
- When local data is not available, should values from other jurisdictions be adopted or adjusted to account for differences in average speed, starts and stops, payload, climate, etc.?

- For light-duty vehicles and the gasoline/electric EER, should it be based on a specific vehicle comparison or should it be based on some weighted-average comparison of light-duty vehicles for each vehicle class?
- Is there a value to simply adopting updates from another region, for example harmonizing with the California LCFS values that are supported by CARB's research?

4.2. Policy Recommendations

Drawing from our analysis and the uncertainties within in, we provide some general policy recommendations for EERs in the British Columbia RLCFRR, which are followed by recommendations for each transportation segment:

- **The current diesel/electric EER of 2.7 should be updated:** Better information is now available versus when the value was set. As well, both CARB and Oregon's DEQ have proposed significant changes indicating that the original British Columbian value should be reassessed.
- **The diesel/electric EER of 2.7 is too low for current electrification opportunities:** Research indicates that the current EER of 2.7 is too low for all near-term opportunities to electrify diesel vehicles and equipment like bus, drayage and delivery trucks, and garbage trucks. However, this value might still serve as an average for all diesel consuming vehicles and equipment, especially in the long-term if faster, long-range, freight truck transportation is electrified. An EER of 2.7 also appears to be reasonable for shore-power, cargo handling equipment at ports and potentially for marine propulsion.
- **Setting multiple diesel/electric EER values (by segment) is more accurate:** Both CARB and DEQ set several EER values, by segment. The reviewed research, which uses several types of data, indicates that there are significant differences by segment, varying from around 2 to 5. Therefore, it seems reasonable for British Columbia to follow suite with CARB and the DEQ, though from a practical standpoint, it would be ideal to keep a low number of segments.
- **The diesel/electric EERs should be based on reasonable applications of electrification:** While it is not possible to forecast which diesel vehicles will be electrified first, it does seem reasonable to follow CARB's assumption that slower, lower-range routes are more likely to electrify. It thus makes sense to focus on drayage routes for freight trucks, and bus routes with slower average speeds. While electrified vehicles might develop to be better suited for all possible routes in the long-term, it seems likely that these slower/shorter routes would remain electrification priorities in the context of the RFLCCR. This policy requires a 10%

reduction in transportation fuel carbon intensity by 2020, relative to 2010, and a proposed 15% reduction by 2030. Neither the time frame nor the reductions should require electrification of long-ranged diesel vehicles.

- **Test data and in-use data should be given more weight than simulation data or literature estimates when choosing EERs:** This includes the relationship between speed and diesel/electric EER derived from test data and confirmed by in-use data. Simulation data is useful for identifying the factors that most affect EER, but the simulation literature does not demonstrate that it is calibrated to real-world results. Literature estimates of EER or energy consumption are typically reasonable, but the sources and methods behind those estimates are not fully transparent.

- **The EERs should be updated over time:** While it is not ideal to change policy rules too often, it does make sense to update EER values periodically as technologies change and new data becomes available. The same practice is already used for fuel carbon intensity values.

- **More British Columbia-specific data relating to EERs should be collected, but in the in the meantime, adapt insights from other regions (e.g. CARB data):** While the recent CARB in-use data is not perfect for the case of British Columbia, the CARB analysis finds that average drive cycle speed is a major determinant of an EER. In the absence of other information, it is reasonable to use the CARB estimated trend-line (based on average speed) to help estimate diesel/electric EER values in British Columbia.

- **British Columbia should consider harmonizing its EERs with the values used by CARB:** While we provide some recommendations for EER updates below, there could be value in British Columbia simply aligning its EERs with those of CARB. CARB is a well-reputed institution that has extensive capacity and experience in setting and updating environmental policy. British Columbia is a smaller region (1/10 the population) and has less resources to conduct similar analyses. Thus, British Columbia might consider to following the lead of CARB, either by directly using its updated values, or by conducting simple analyses to adjust the values for the case of British Columbia (where justified and where data exists).

Drawing from the data available, we suggest the following recommendations for an update of BC's EER values, for each of the major vehicle segments we've identified:

- **Medium and Heavy-Duty Trucks:** Given that commercially available vehicles are all designed for short-range urban travel, we recommend updating the EER based on slower drayage routes. British Columbian data for drayage trucks indicate an average speed of 18.7 km/hr. Using CARB's speed-EER trend-line, that corresponds to an EER between 5.0 which is identical to CARB's proposed value. All other data in this report indicate that this value is reasonably representative of medium-duty trucks as well (e.g. urban delivery vehicles).

- **Transit Buses (Non-Trolley)**: CARB has recommended an EER of 5.0, while DEQ recommends 4.2. British Columbian data suggest that its buses tend to have slightly higher average speeds (26 km/hr) compared to those in California, where 94% of routes have speeds lower than 21 km/hr. Using the CARB trend-line, the British Columbian speeds correspond to a slightly lower EER of 4.5. However, if we assume that electrification for slower urban routes is more likely, then harmonizing with CARB's proposed value of 5.0 seems reasonable, in which case buses and trucks could be in the same segment, which is also harmonized with CARB's proposal.

- **Trolley-buses:** A comparison of new diesel buses to new trolley buses suggests and EER of at least 3.4. Local research and data should be used to confirm this EER if they become available.

- **Light/rail:** Both the CARB EER of 3.3 and the value of 2.7 used in British Columbia are reasonable. If British Columbia were to harmonize with CARB's EERs, the value of 3.3 is just as defensible as 2.7. Local research and data should be used to confirm this EER if they become available.

- **Garbage trucks:** Not much information is available for garbage trucks in general or specific to British Columbia. Therefore, including them in the same segment as buses and trucks seems reasonable. The only point of information for British Columbia provides an average speed for a single route: one can calculate EER for this route based on the CARB trend-line (which would be about 6.8), but the other sources of data indicate that it is not likely representative of garbage trucks. The US distribution of garbage truck average speeds are more similar the transit buses or truck speeds noted above, meaning that EERs would be similar between the segments.

- **Marine propulsion:** There is very little data describing the EER of marine propulsion. The EER from a single simulated example is 3.6 but could be as low as 2.6 when evaluated within a fully controlled experiment (i.e. same vessel, different power train). A specific segment probably is not needed at present, since no electrification is expected in the near future and there is almost no data to support a unique EER. Instead, the regulator or policy participants should monitor ongoing research.

- **Shore power and marine cargo handling:** Although we found no data sources specific to British Columbia, it seems reasonable to apply the substantial research by CARB. Direct measurements of on-board diesel generator emissions and estimations of cargo handling equipment emissions all indicate that an EER of 2.6 or 2.7 is would appropriate for a "marine" segment. Nonetheless, there could be differences between California and British Columbia that could result in different EERs. For example, a different mixture of ships with different types of generators may dock in British Columbia ports. Likewise, it is possible that a different mix of cargo handling equipment is used. To rule out this situation, additional data gathering could focus on obtaining British Columbia shore power data (e.g. from the Vancouver cruise ship terminal), comparing the types of vessels docking in each region as well as the types of cargo handling equipment used in these ports.

- **Airport ground support Equipment (GSE):** We did not find data specific to British Columbia, but instead estimated an EER based on the mix of equipment operating at 12 US airports, using CARB's observed relationship between average engine power and EER. Based on this analysis, an EER of 4.0 to 4.1 seems reasonable for British Columbia. However, establishing an airport GSE segment is not as well supported by this research as it is for other segments (e.g. trucks and buses). Using this EER value assumes the mix and utilization of GSE at British Columbian airports is the same as in the US. Furthermore, the relationship between engine power output and EER is itself uncertain because it based on buses and trucks and because engine power output is rarely observed directly. Finally, US data indicates that not all GSE uses diesel: a substantial shore is also powered by gasoline, natural gas and liquid petroleum gas), meaning electrification does not automatically affect diesel consumption.

- **Light-duty vehicles:** Although CARB has not indicated that it is reviewing the gasoline/electric EER that primarily applies to light-duty vehicles, we recommend updating the value in the British Columbia RLCFRR. At the very least, the EER should be based on a comparison of PEV and conventional vehicle energy consumption that is calculated using the gasoline HHV; this method is logical and consistent with how fuel carbon intensities are calculated for the RLCRFF. We also recommend that the EER be updated to account for the sales-weighted average of the vehicles in question – many new vehicle models in several vehicle classes have since become available since CARB estimated the current EER based on the 2011 Nissan Leaf/Versa and 2011 Chevrolet Volt/Cruze. When using the sales weighted method with the gasoline HHV for 2017/2018 model year vehicles, the EER is 4.1 rather than 3.4. Finally, this EER calculation should be updated periodically to account for improvements in vehicle fuel consumption testing and changes in vehicle offerings, vehicle efficiency, and sales.

Appendix A: Vehicle Class Tables

Make	Model
Compact Cars	
ACURA	ILX
AUDI	A3
BUICK	Verano
CHEVROLET	Cruze
CHEVROLET	Sonic
CHRYSLER	200
FIAT	500L
FORD	Focus
HONDA	Civic
HYUNDAI	Elantra
KIA	Forte
MAZDA	3
MERCEDES-BENZ	B-Class
MINI	Cooper
MITSUBISHI	Lancer
NISSAN	Sentra
NISSAN	Versa
TOYOTA	Corolla
VOLKSWAGEN	Golf
VOLKSWAGEN	Jetta
Midsize Cars	
ACURA	TLX
ALFA ROMEO	Giulia
AUDI	A4
BMW	3-Series
BMW	3-Series

BUICK	Regal
CADILLAC	ATS
CHEVROLET	Malibu
FORD	Fusion
HONDA	Accord
HYUNDAI	Sonata
KIA	Optima
LEXUS	ES
LEXUS	IS
LINCOLN	MKZ
MASERATI	Ghibli
MAZDA	6
NISSAN	Altima
TOYOTA	Camry
VOLKSWAGEN	Passat
VOLVO	60 Series
Midsize AWD Cars	
ACURA	TLX
ALFA ROMEO	Giulia
AUDI	A4
BMW	3-Series
BMW	3-Series
BUICK	Regal
CADILLAC	ATS
FORD	Fusion
INFINITI	Q50
JAGUAR	XE
LEXUS	GS
LEXUS	IS
LINCOLN	MKZ

MASERATI	Ghibli
MERCEDES-BENZ	C-Class
VOLVO	60 Series
Full-size Cars	
CADILLAC	XTS
JAGUAR	XJ
KIA	Cadenza
LINCOLN	Continental
MASERATI	Quattroporte
MERCEDES-BENZ	S-Class
VOLVO	90 Series
Full-size AWD Cars	
AUDI	A7
BMW	7-Series
CADILLAC	XTS
LEXUS	LS
VOLVO	90 Series
Mid-size AWD SUVs	
ACURA	MDX
AUDI	Q5
BMW	X3
BUICK	Enclave
CADILLAC	XT5
CHEVROLET	Equinox
DODGE	Journey
FORD	Edge
GMC	Terrain
HONDA	Pilot
HYUNDAI	Tucson
INFINITI	QX60

JEEP	Grand Cherokee
KIA	Sportage
LAND ROVER	Discovery
LEXUS	RX
LINCOLN	MKC
MAZDA	CX-9
MERCEDES-BENZ	GLE-Class
MITSUBISHI	Outlander
NISSAN	Pathfinder
PORSCHE	Cayenne
SUBARU	Forester
TOYOTA	Highlander
TOYOTA	RAV4
VOLKSWAGEN	Touareg
VOLVO	XC60
Minivans	
CHRYSLER	Pacifica
DODGE	Grand Caravan
HONDA	Odyssey
KIA	Sedona
MAZDA	5
TOYOTA	Sienna