B.C. Low Carbon Fuel Standard:

Technical Requirements Intentions Paper

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1 Introduction

The *Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act* (current Act) and the Renewable and Low Carbon Fuel Requirements Regulation (current Regulation) are known collectively as the B.C. Low Carbon Fuel Standard (LCFS). The Ministry of Energy, Mines and Low Carbon Innovation (Ministry) intends to amend the LCFS.

In Spring 2022, the Ministry passed the *Low Carbon Fuels Act* (new Act) to replace the current Act. The new Act is intended to enable more greenhouse gas reductions, broaden the scope of the LCFS and make the LCFS easier to understand, administer, and enforce.

The Ministry is developing regulations (new Regulations) that are intended to bring the new Act into force on January 1, 2024. The purpose of this paper is to discuss the technical aspects of the new Act and new Regulations that will come into force on January 1, 2024. In particular, this paper will discuss how compliance units (currently called credits and debits) will be calculated under the new Act. A new formula will be presented along with new and updated variables to be used in the formula. The new formula, variables, and default values were created in response to updated data and technology advancements.

The Ministry is accepting feedback on these changes. Responses must be in writing and must be submitted by email or mail before 7 a.m. on January 30, 2023, to one of the following addresses:

Email: lcfs@gov.bc.ca

Mail: Low Carbon Fuels Branch
B.C. Ministry of Energy, Mines, and Low Carbon Innovation
P.O. Box 9314 Stn Prov Govt
Victoria, B.C. V8W 9N1

This intentions paper has been posted online on the Ministry's website for public, Indigenous Partner and stakeholder comment at: https://gov.bc.ca/lowcarbonfuels.

2 Background

Under the LCFS, fuel suppliers must progressively decrease the average carbon intensity of their fuels to achieve a 30% reduction in 2030. The carbon intensity of a fuel represents the greenhouse gas emissions associated with its production and use as determined by a life cycle assessment, presented in terms of grams of carbon dioxide equivalent per mega joule (gCO_2eq/MJ) of the produced fuel. A life cycle assessment considers the emissions associated with each stage of a fuel product's life and all materials and energy used throughout the life cycle.

Under the current Act, a fuel supplier generates credits by supplying fuel with a carbon intensity below the prescribed target, and they incur debits by supplying fuel with a carbon intensity above the target. To remain compliant with the LCFS, a fuel supplier must ensure that debits incurred from supplying higher carbon fuels are offset by credits. To acquire credits a fuel supplier can supply low carbon fuels, purchase credits from other fuel suppliers, or enter into a Part 3 Agreement (soon to be called Initiative Agreements).

3 Calculating Compliance Units

Currently, LCFS credits and debits are calculated using the formula shown below, which can be found in Section 6(4) of the current Act:

$$\text{Credit or Debit} = (\text{CI Class x EER fuel} - \text{CI fuel}) \text{ x } \frac{\text{EC fuel}}{1\,000\,000}$$

Credit or Debit = the number of credits generated, if the number is positive, or the number of debits incurred, if the number is negative, for the compliance period;

CI Class = the prescribed carbon intensity limit for the compliance period for the class of fuel;

EER fuel = the prescribed energy effectiveness ratio for that fuel in that class of fuel;

CI fuel = the carbon intensity of the fuel;

EC fuel = the energy content of the fuel calculated in accordance with the regulations.

Credits and debits are terms used in the formula under the current Act. Starting January 1, 2024, the Ministry intends to use the term “compliance units” instead of credits or debits. Compliance units will be calculated using an updated formula (shown below and in Section 13(3) of the new Act. The term “number” in the formula below refers to the number of compliance units a fuel supplier is responsible for. It can be a positive or negative number. To be compliant with the LCFS, a fuel supplier’s compliance unit balance must be zero or greater at the end of each compliance period.

$$\text{number} = \left(\text{TCI x EER} - (\text{RCI} + \text{UCI})\right) \text{x} \ \frac{\text{EC}}{1\ 000\ 000 \text{ grams}}$$

TCI = the target carbon intensity for the fuel, as determined under Section 13(5) of the *Low Carbon Fuels Act;*
EER = the energy effectiveness ratio of the fuel, as determined in accordance with the regulations of the minister;
RCI = the recorded carbon intensity of the fuel;
UCI = the additional carbon intensity attributed to the use of the fuel, as determined in accordance with the regulations of the minister;
EC = the energy content of the fuel in megajoules, as determined in accordance with the regulations of the minister.

The new formula updates the names of some of the variables used in the current formula and introduces some new variables. See Appendix A for example calculations using the new formula presented above. The following sections explain each variable in detail.

3.1 Target Carbon Intensity (TCI)

The Target Carbon Intensity (TCI) is the carbon intensity that a fuel supplier’s average fuel mix would need to be to meet the carbon intensity reduction target in a given compliance period. It is very similar to the ‘CI Class’ variable used in the formula in the current Act. The TCI is calculated using the formula in Section 13(5) of the new Act:

$$TCI = BCI \text{ x } (1 - R)$$

BCI = the carbon intensity specified in section 19(a) of the *Low Carbon Fuels Act* for the base fuel for the category to which the fuel belongs;
R= the prescribed reduction for that category, expressed as a percentage.

The Base Carbon Intensity (BCI) is the carbon intensity prescribed by the new Regulations for the fossil-derived base fuel within each fuel category (diesel, gasoline, jet and other (if prescribed)). The BCIs will function as the baselines against which the alternatives in each category will be compared.

In the new Regulations, any alternative to a base fuel used in a light duty vehicle with a gross vehicle weight rating (GVWR) of 3,856 kg or less will be considered a gasoline category fuel and an alternative fuel used in a vehicle with a GVWR higher than 3,856 kg will be considered a diesel category fuel. Additionally, an alternative fuel used for heating or power generation in a remote community (as defined by the new Regulations) will be in the category of the fuel it is displacing. For example, electricity generated by solar power, which displaces the use of diesel for power generation in a remote community, will be considered a diesel category fuel. Note that the Ministry is considering including a jet fuel category. The addition of this category is currently under review and is undergoing additional analyses and consultation. If the category is included, an alternative fuel used in aircraft would be considered a jet category fuel.

BCI values were calculated using GHGenius 5.02 using updated data within the GHGenius model, Global Warming Potentials (GWPs) from the International Panel on Climate Change (IPCC) 5th assessment report (AR), and improved accounting (more aligned with IPCC accounting methods) of tail pipe carbon emissions. Using data from the 5th AR will align the LCFS with the rest of B.C. and Canada who are transitioning to using GWPs from the 5th AR for national greenhouse gas inventory reporting. The BCI for the diesel and gasoline fuel categories use a 2010 baseline while the BCI for the jet fuel category uses a 2024 baseline. The BCI values that will be used in the new Regulations are presented in Table 1 below.

Table 1: Base Fuels and their components

Fuel Category	Carbon intensity (gCO2e/MJ)
Diesel fuel category	94.38
Gasoline fuel category	93.67
Jet fuel category	87.33*

*The jet fuel category is currently under review and is undergoing additional analyses and consultation. Expect more material to be released in the coming months.

R values indicate the carbon intensity reduction target for each year (expressed as a percent). The Ministry recently amended the current Regulations under the current Act. Starting January 1, 2023, these amendments will implement a new schedule of carbon intensity reductions to achieve a 30% reduction in the existing fuel pools by 2030 (i.e., the target R value for the gasoline and diesel pools in 2030 is 30%). R values will be prescribed in the new Regulations as shown below. Note that the Ministry is also considering implementing a carbon intensity reduction target for jet fuel.

Table 2: R values for 2023 and beyond

Compliance Period	Percent Reduction for fuel in diesel and gasoline categories	Percent reduction for jet fuel category
2023	13.6%	Under review*
2024	16%	
2025	18.3%	
2026	20.6%	
2027	23%	
2028	25.3%	
2029	27.7%	
2030 and subsequent compliance periods	30%	

*The jet fuel category is currently under review and is undergoing additional analyses and consultation. Expect more material to be released in the coming months.

TCI values, calculated using the BCI and R values above, are shown in the following table. TCI values will not be prescribed in the new Regulations, but the BCI and R values used to calculate TCI will be.

Table 3: Calculated TCI values for 2023 and beyond

Compliance Period	**Calculated TCI for Diesel Class Fuel**	**Calculated TCI for Gasoline Class Fuel**
	(g CO_2e/MJ)	**(g CO_2e/MJ)**
2023	81.54	80.93
2024	79.28	78.68
2025	77.11	76.53
2026	74.94	74.37
2027	72.67	72.13
2028	70.50	69.97
2029	68.24	67.72
2030 and subsequent compliance periods	66.07	65.57

3.2 Energy Effectiveness Ratio (EER)

The Energy Effectiveness Ratio (EER) is a measurement of efficiency which compares the useful work output of an engine running on a low carbon fuel (e.g., renewable diesel) to the engine output of the base fuel (e.g., fossil derived diesel) it is displacing.

In the current Regulation, the EER values are based on the fuel class the alternative fuel falls into (i.e., diesel or gasoline class) and does not account for the end use of the fuel (i.e., vehicle type the fuel is used in). The Ministry is proposing to update the EER values to account for not only what fuel class the alternative fuel falls into, but also the end use of the fuel. This enables the prescription of several EER values within a single fuel type, allowing fuel suppliers to identify a more appropriate EER when justified. For example, in the current Regulation there are two EER values available for electricity (one for electricity that displaces the use of diesel fuel and one for electricity that displaces gasoline). In the new Regulations the Ministry intends to have one EER for electricity used in light duty vehicles and several EERs for electricity used in heavy duty vehicles to account for the type of vehicle the electricity is used in (e.g., Battery Electric Truck, Battery Electric Bus, Trolley bus, Fixed guiderail, or Marine Vessel).

The proposed EER values were chosen based on the best data available that includes considerations for operating in B.C., such as the temperature impacts of operating in a B.C. environment (see Appendix E for more details). In order to report fuel supplied in B.C. using the EER for a specific end use, the fuel supplier must have a reasonable expectation that the fuel will be used in the relevant vehicle or end use type. If no evidence is available or provided, the most conservative EER for the fuel type and category should be used. These values will be prescribed in the new Regulations.

Note that as part of the new Act, the Ministry has expanded the LCFS to enable the inclusion of a jet fuel class which will allow EERs to be calculated more accurately for fuels used in aircraft (as shown below).

Table 4: Energy Effectiveness Ratio (EER) for fuels in the Diesel category

Fuel/End-use Combination	**Diesel Category Energy Effectiveness Ratio**
Diesel	1.0
CNG	0.9
LNG (Spark Ignited Engine)	0.9
LNG (Marine)	1.0
Propane	0.8

Hydrogen (Fuel Cell Vehicle)	1.8
Hydrogen (Internal Combustion Engine)	0.9
Electricity (Battery Electric Bus)	3.8
Electricity (Trolley bus)	2.4
Electricity (Fixed Guiderail)	2.9
Electricity (Battery Electric Trucks)	3.2
Electricity (Shore Power)	2.8
Electricity (Marine)	2.3
Electricity (Remote Power Generation from Battery power)	2.6
Electricity (Remote Power Generation from Gasification)	2.9

Table 5: Energy Effectiveness Ratio (EER) for fuels in the Gasoline category

Fuel/End-Use Combination	Gasoline Category Energy Effectiveness Ratio
Gasoline	1.0
CNG	0.9
Propane	0.9
Hydrogen (Fuel Cell Vehicle)	1.8
Hydrogen (Internal Combustion Engine)	0.9
Electricity	3.0

Table 6: Energy Effectiveness Ratio (EER) for fuels in the Jet category

Fuel	Jet Category Energy Effectiveness Ratio
Electricity	2.5

3.3 Recorded Carbon Intensity (RCI)

The Recorded Carbon Intensity (RCI) of a fuel represents the carbon intensity of a fuel used in transportation. To determine the carbon intensity of a fuel, the greenhouse gas emissions from all stages of the fuel's life cycle must be combined. The Ministry intends to make changes to the stages of a fuel life cycle described in the current Regulation to improve the clarity and useability of the stages. The names of some stages and activities within a stage have changed, but there are no material changes to the stages or activities included within a stage (see Appendix B for more details).

The RCI variable is similar to the 'CI Fuel' variable used in the formula in the current Act. For fossil-derived base fuels, such as diesel, gasoline, and jet fuel, the RCI will be equal to the BCI for that category (see Table 1, above).

To determine the RCI of an alternative fuel which displaces the use of a fossil-derived base fuel, it is recommended that the producer of the fuel apply for a carbon intensity that represents their unique fuel production process. To apply for a unique carbon intensity, a fuel producer uses operating data from their facility to calculate the carbon intensity of their fuel in accordance with the regulations and using GHGenius 4.03. The Ministry intends to update the model requirement to GHGenius 5.02 under the new Act.

If a fuel producer does not believe that their process is accurately quantified in GHGenius 5.02, they may be able to use an alternative method for the affected stage, subject to Director approval.

Once the carbon intensity is calculated, the fuel producer applies for approval from the Director under the Act. If the Director approves the submitted carbon intensity, a unique fuel code associated with the carbon intensity would be created and published on the LCFS website in an Information Bulletin. Fuel suppliers can then use the published carbon intensities for reporting their fuels under the LCFS.

If a published carbon intensity for a fuel is unavailable, fuel suppliers may use the default carbon intensity for the fuel type prescribed in the new Regulations (see Table 7). The default values for alternative fuels are presented in Table 7 and are calculated in GHGenius 5.02 (with the year set to 2024) using updated data within the GHGenius model, GWPs from the 5th IPCC AR and improved carbon accounting methods. The electricity and natural gas defaults represent the average carbon intensity for the B.C. electrical grid and natural gas distribution system. All others represent conservative yet realistic values.

Table 7: Default Carbon Intensities

Fuel Category	**Carbon intensity (gCO2e/MJ)**
Electricity	12.11
Non-fossil diesel fuel	100.10
Non-fossil gasoline fuel	93.67
Non-fossil jet fuel	87.33
Hydrogen	123.96
Natural gas - CNG	63.91
Natural gas - LNG	90.11
Propane	79.72

An additional component of a fuel life cycle (not included in the stages list found in Appendix B) called avoided emissions can be included for some fuels. Avoided emissions represent the emissions that would have occurred if a waste feedstock had not been used for fuel production. Avoided emissions may be included in the life cycle for the fuels described in Table 8. The avoided emissions must be calculated using GHGenius 5.02 with the application of the universal counterfactuals and factors described in Table 8. The universal counterfactuals and factors represent current best practices within B.C. or nationally for disposal and use of the feedstock used to produce the fuel. The universal counterfactuals and factor must be applied if a fuel producer wishes to include avoided emissions within their fuel's life cycle, regardless of facility location. Once the counterfactual emissions are calculated in GHGenius 5.02 they must be adjusted by the factor in Table 8.

An example of a process that would result in avoided emissions is diverting municipal solid waste from a landfill to use for fuel production.

Table 8: Universal Counterfactuals

Fuel	Counterfactual	Factor
Natural gas produced from manure processed in a biodigester	Manure is stored as reported in the Canadian National Inventory Report until applied to land.	Fuel carbon intensity is to be credited with 100% of the counterfactual emissions, determined using the approved GHGenius.
Fuel produced from municipal solid waste diverted from a municipal solid waste landfill.	Municipal solid waste is deposited in a landfill with uncontrolled methane emissions.	Fuel carbon intensity is to be credited with 25% of the counterfactual emissions, determined using the approved GHGenius.
Natural gas produced from diverted organic food or yard waste processed in a biodigester	Organic food or yard waste is composted.	Fuel carbon intensity is to be credited with 100% of the counterfactual emissions, determined using the approved GHGenius.
Fuel produced from forest harvest residues	Forest residues are burned in slash piles or prescribed burns for wildfire management.	Fuel carbon intensity is to be credited with 100% of the counterfactual emissions, determined using the approved GHGenius.

3.4 Use of a fuel Carbon Intensity (UCI)

The Use of a fuel Carbon Intensity (UCI) represents the additional carbon intensity attributed to the use of the fuel and is a new variable in the formula used to calculate compliance units under the new Act. The RCI values discussed above assume that combustion occurs in an internal combustion engine in a vehicle. The UCI is added to the RCI to allow the LCFS to recognize end uses that may result in higher emissions during use than the RCI accounts for (i.e., the UCI will add additional emissions that might occur by combusting a fuel in a different engine). This is important because engines have different emission profiles, slippage, and efficiencies. For example, some dual fuel marine engines may leak methane, resulting in a higher carbon intensity. The UCI represents the difference between the combustion emissions (CO_2 equivalent) of the alternative fuel combusted in an internal combustion engine and a different engine.

The UCI values that are proposed for the new Regulations are shown in Table 9 (see Appendix D for additional details). A fuel supplier must include the UCI specified for their fuel and vehicle type, unless the Director is satisfied that a different UCI applies.

The UCI for fuel types that are not shown in the following table can be considered zero.

Table 9: Use of a fuel Carbon Intensity (UCI)

Fuel/Vehicle Combination	**UCI (gCO2e/MJ)**
LNG (marine)	23.0

3.5 Energy Content of the Fuel in Megajoules (EC)

The Energy Content of a fuel (EC) is expressed in units of megajoules (MJ) per litre (L), meter cubed (m^3) or kilowatt hour (kWh). Using the EC calculates LCFS compliance units on an energy basis instead of a volume basis. This aligns the formula with the aim of the LCFS which is to reduce the carbon intensity of fuel per unit of energy. EC values are shown below and will be prescribed in the new Regulations. The values below were taken directly from GHGenius 5.02 and are comparable to the values used in GHGenius 4.03.

Table 10: Energy Content (EC)

Fuel	Energy Content
Diesel fuel – fossil derived	38.65 MJ/L
Diesel fuel - biodiesel	35.40 MJ/L
Diesel fuel - HDRD	37.89 MJ/L
Diesel fuel - other	36.51 MJ/L
Electricity	3.6 MJ/KWh
Ethanol	23.58 MJ/L
Gasoline	34.69 MJ/L
Jet fuel – fossil derived	37.40 MJ/L
Jet fuel - other	36.00 MJ/L
Naphtha	34.51 MJ/L
Natural gas - CNG	38.27 MJ/m3
Natural gas - LNG	53.54 MJ/kg
Propane - LPG	25.62 MJ/L
Hydrogen	141.76 MJ/kg

Appendix A. Example Calculations

Example 1: In 2024, a fuel supplier supplied 15 million L of gasoline-category fuel into B.C. To meet the 5% annual average renewable content in gasoline requirement, 750,000 L of the gasoline-category fuel they supplied was ethanol with a carbon intensity of 45.00 gCO_2e/MJ. The following calculation shows the compliance units earned for their supply of ethanol:

$$\text{TCI} = \text{BCI x } (1 - \text{R})$$

$$\text{number} = \left(\text{TCI x EER} - (\text{RCI} + \text{UCI})\right) \text{ x } \frac{\text{EC}}{1\ 000\ 000 \text{ grams}}$$

BCI = 93.67 gCO2e/MJ (Ethanol is a gasoline class fuel and uses the BCI for gasoline found in the new Regulations)

R = 16% or 0.16 (This is the R value for gasoline class fuel (year 2024) and will be found in the new Regulations)

$$\text{TCI} = 93.67 \ \text{x} \ (1 - 0.16) = 78.68 \ \text{gCO2e/MJ}$$

EER = 1.0 (EER related to ethanol in the new Regulations)

RCI = 45.00 gCO2e/MJ (this is the published carbon intensity of the fuel, modelled by GHGenius 5.02)

UCI = 0.0 (The UCI is assumed to be zero since a UCI value for ethanol is not prescribed)

EC = 23.58 MJ/L (this is the EC value for ethanol found in the new Regulations)

$$= \left(78.68 \ \text{gCO2e/MJ} \ \ \text{x} \ 1.0 - (45.00 \ \text{gCO2e/MJ} + 0.0)\right) \text{x} \ \frac{23.58 \ \text{MJ/L}}{1\ 000\ 000 \ \text{grams}}$$

$$= .000794 \ \frac{\text{compliance units}}{\text{L}} \text{x} \ 750{,}000 \ \text{L of ethanol} = 595.63$$

$$= 596 \ \text{compliance units}$$

Example 2: The following calculation shows the compliance units incurred for supplying 550 million L of fossil-derived diesel in 2025:

$$\text{TCI} = \text{BCI x} \ (1 - \text{R})$$

$$\text{number} = \left(\text{TCI x EER} - (\text{RCI} + \text{UCI})\right) \text{x} \ \frac{\text{EC}}{1\ 000\ 000 \ \text{grams}}$$

BCI = 94.38 gCO2e/MJ (the BCI prescribed for diesel in the new Regulations)

R = 18.3% or 0.183 (This is the R value for diesel class fuel (year 2025) and will be found in the new Regulations)

$$\text{TCI} = 94.38\frac{\text{gCO2e}}{\text{MJ}}\ \text{x}\ (1 - 0.183) = 77.11\text{gCO2e/MJ}$$

EER = 1.0 (EER related to fossil-derived diesel in the new Regulations)

RCI = 94.38 gCO2e/MJ (BCI value for diesel prescribed in the new Regulations)

UCI = 0.0 (The UCI is assumed to be zero since a UCI value for diesel is not prescribed)

EC = 38.65 MJ/L (this is the EC value for fossil derived diesel prescribed in the new Regulations)

$$= \left(77.11\text{gCO2e/MJ}\ \ \text{x}\ 1.0 - (94.38\ \text{gCO2e/MJ} + 0.0)\right)\ \text{x}\ \frac{38.65\ \text{MJ/L}}{1\ 000\ 000\ \text{grams}}$$

$$= -0.000667\frac{\text{compliance units}}{\text{L}}\ \text{x}\ \ 550{,}000{,}000\ \text{L} = -367{,}117.03$$

$$= -367{,}117\ \text{compliance units}$$

Example 3: In 2026 a remote community in B.C. switched some of its diesel power generation to solar and produced 20,000 kWh of electricity from solar panels. The following calculation shows the compliance units earned:

$$\text{TCI} = \text{BCI x}\ (1 - \text{R})$$

$$\text{number} = \left(\text{TCI x EER} - (\text{RCI} + \text{UCI})\right)\ \text{x}\ \frac{\text{EC}}{1\ 000\ 000\ \text{grams}}$$

BCI = 94.38 gCO2e/MJ (The BCI for diesel is used since the solar panels replaced some of the diesel used in the community)

R = 20.6% or 0.206 (This is the R value for year 2026 and will be found in the new Regulations)

$$\text{TCI} = 94.38\frac{\text{gCO2e}}{\text{MJ}}\text{x}\ (1 - 0.206) = 74.94\ \text{gCO2e/MJ}$$

EER = 2.6 (EER for remote power (Remote Power Generation from Battery power) prescribed in the new Regulations)

RCI = 12.11 gCO2e/MJ (default RCI value for electricity prescribed in the new Regulations)

UCI = 0.0 (The UCI is assumed to be zero since a UCI value for electricity is not prescribed)

EC = 3.60 MJ/kWh (this is the EC value for electricity prescribed in the new Regulations)

$$= \left(74.94\ \mathrm{gCO2e/MJ}\ \ \mathrm{x}\ 2.6 - (12.11\ \mathrm{gCO2e/MJ} + 0.0)\right)\ \mathrm{x}\ \frac{3.60\ \mathrm{MJ/kWh}}{1\ 000\ 000\ \mathrm{grams}}$$

$$= 0.000658 \frac{\text{compliance units}}{\mathrm{kWh}} x\ 20{,}000\ \mathrm{kWh} = 13.16$$

$$= 13\ \text{compliance units}$$

Example 4: In 2024 a fleet of ferries with dual fuel engines (engines which can run on diesel or a mixture of diesel and natural gas) used 5.0 million kg of LNG with a carbon intensity of 60.0 gCO2e/MJ. The following calculation shows the number of compliance units incurred:

$$\mathrm{TCI} = \mathrm{BCI}\ \mathrm{x}\ (1 - \mathrm{R})$$

$$\text{number} = \left(\mathrm{TCI}\ \mathrm{x}\ \mathrm{EER} - (\mathrm{RCI} + \mathrm{UCI})\right)\ \mathrm{x}\ \frac{\mathrm{EC}}{1\ 000\ 000\ \mathrm{grams}}$$

BCI = 94.38 gCO2e/MJ (this is the BCI for diesel category fuel)

R = 16% or 0.16 (This is the R value for diesel category fuel (year 2024) and will be found in the new Regulations)

$$\mathrm{TCI} = 94.38 \frac{\mathrm{gCO2e}}{\mathrm{MJ}}\ \mathrm{x}\ (1 - 0.16) = 79.28 \mathrm{gCO2e/MJ}$$

EER = 1.0 (EER for marine LNG prescribed in the new Regulations)

RCI = 60.0 gCO2e/MJ

UCI = 23.0 gCO2e/MJ (UCI value prescribed for marine LNG in the new Regulations)

EC = 53.54 MJ/kg (this is the EC value for LNG prescribed in the new Regulations)

$$= \left(79.28\text{gCO2e/MJ x } 1.0 - (60.0 \text{ gCO2e/MJ} + 23 \text{ gCO2e/MJ})\right) \text{x } \frac{53.54 \text{ MJ/kg}}{1\,000\,000 \text{ grams}}$$

$$= -0.000199 \frac{\text{compliance units}}{\text{kg}} \; x \; 5.0 \text{ million kg} = -995.84$$

$$= -996 \text{ compliance units}$$

Appendix B. Details of the fuel life cycle stages

The Ministry intends to make changes to the stages of a fuel life cycle described in the current Regulation. The stages described in the current Regulation were based on the Ministry's understanding of Life Cycle Analysis (LCA) and the GHGenius model in 2010. Since then, LCA best practice and the GHGenius model have evolved. The intended changes would bring the regulatory stages into alignment with current practice, improve clarity around what should be included in each stage, and improve the ability to introduce alternative methods. The following are the stages of a fuel life cycle the Ministry plans to define in the new Regulations:

"direct land use change" means activities and processes associated with changing the use of land from another use to

(a) feedstock production and recovery,

(b) fuel production,

(c) roads for access to feedstock or an energy source,

(d) feedstock exploration activities, or

(e) pipelines, transmission lines or other means of transporting feedstock or fuel;

"feedstock production or cultivation" means activities, processes, fugitive emissions, leaks and flares associated with cultivating or producing feedstock, including, without limitation, land cultivation, soil organic carbon changes from land management, fertilizer production and use, harvesting, processing, handling and storage that occurs before transporting the feedstock for upgrading or to a fuel production facility.

“feedstock upgrading” means activities, processes, fugitive emissions, leaks and flares associated with upgrading feedstock from raw material to a material suitable for fuel production.

“feedstock transport” means activities, processes, associated with transporting feedstock from the location of production to an upgrading facility (if applicable) and to a fuel production facility, including, without limitation, the manufacture and maintenance of vehicles, vessels and pipelines used for transporting and leaks and spills that occur in the process of transferring the feedstock to a means of transportation or during transportation.

“feedstock co-products production” means activities, processes, fugitive emissions, leaks and flares associated with manufacturing or producing usable products other than the feedstock being analyzed, during feedstock production and upgrading activities.

"fuel production" means activities and processes associated with manufacturing or producing fuel at a fuel production facility, including, without limitation, fugitive emissions, flaring and leaks of substances during the fuel production process;

“fuel co-products production” means activities, processes, fugitive emissions, leaks and flares associated with manufacturing or producing usable products, other than the fuel being analyzed, during fuel production activities.

“fuel storage and distribution” means activities, processes, fugitive emissions, leaks, and flares associated with storing, handling and transporting fuel from the fuel production facility to and at the fueling station.

“fuel dispensing” means activities, processes, fugitive emissions, leaks and flares associated with the transfer of fuel from storage at a fueling station into a vehicle, vessel, aircraft or stationary engine for use in the engine of that vehicle, vessel, aircraft or stationary engine, or a device necessary for the intended use of the vehicle, vessel, aircraft or stationary engine, including, without limitation, leaks and spills that occur in the transfer process.

"vehicle or vessel operation" means combustion and use of fuel in the operation of vehicles and vessels, including, without limitation, in the operation of any device necessary to the intended operation or use of the vehicle or vessel.

"carbon sequestration into biomass" means the processes by which carbon is incorporated in biological feedstock in the feedstock production process.

Appendix C. Data used to determine UCIs

The new regulations will have an additional factor that can be applied to a fuel for higher exhaust emissions. The primary emission of concern is methane, as it has a high GWP. Natural gas engines without emission control can have methane slip issues when methane passes through the combustion chamber without being oxidized.

The natural gas engines that have demonstrated high levels of methane slip are large dual fuel engines such as those found in some marine applications.

Stenersen[1] recommended a methane emission factor of 40.9 g/kg of fuel (8.43 g/kWh) for low pressure dual fuel engines like the Wärtsilä engines used in marine applications in BC. The Stenersen report was based on measurements of actual LNG powered vessels. The Stenersen emission factor converts to 765 g/GJ of fuel and that results in a UCI of 23.0 gCO2e/MJ.

[1] Stenersen, D. and Thonstad, O., 2017. GHG and NOx emissions from gas fuelled engines. Mapping, verification, reduction technologies, SINTEF Ocean AS, Trondheim, Norway. https://pdfs.semanticscholar.org/9f9c/2ecc3719e26460bc6da7ff09786fb9f24708.pdf

Appendix D. Data that Informed EER Values

Energy Effectiveness Ratio (EER) is the ratio of the energy used by one fuel to perform a certain amount of work to the energy use by a second fuel to provide the same amount of work. Over time the EER can change due to changes in the efficiency of either system, thus it is only good practice to evaluate the ratios on a periodic basis.

The EER can be influenced by a number of factors, including the basic underlying efficiency of the propulsion system, the change in efficiency as a function of vehicle speed and load, and ambient temperatures. Understanding these concepts can help to understand why data from different sources can show some variation in the reported results.

Just as it is important to compare equivalent vehicles it is also important to compare equivalent system boundaries.

For most fuels, the Upstream Emissions in GHGenius include all emissions up until the point where the energy source is transferred to the vehicle. For liquid fuels that includes the emissions from the operation of the service station. For compressed fuels that includes the compression energy and any fugitive emissions from the refueling process.

The exception would be electricity. In GHGenius the electricity emissions are up until the point that the power leaves the grid. Any power conditioning or power transformation (from AC to DC, for example) are not included in the power production and transmission emissions and the vehicle energy use must start from this point.

In GHGenius the emissions are reported per unit of energy on a higher heating value (HHV) basis. LCFS programs in the United States report the emissions on a lower heating value (LHV) basis. The EERs calculated on a HHV basis will be different than those calculated on a LHV basis. The ratio of the two EERs will be different for every fuel.

Fuel economy data for Natural Resources Canada[2] or the US EPA[3] has been the source of data for many of the EERs that apply to light duty vehicles. The two sources use the same testing methodology and generally have the same data. They generally test the vehicles over a standardized driving cycle allowing for a direct comparison. There are a few exceptions that are discussed in the relevant sections. There is no equivalent testing of heavy-duty vehicles so alternative sources of data have been identified and used for the development of EERs of the diesel class fuels.

Gasoline Category EERs

There are five gasoline class EERs in the existing regulation. There is an EER for natural gas-based gasoline or renewable fuel in relation to gasoline class fuel, for compressed natural gas, for propane, for electricity and for hydrogen used in a fuel cell vehicle. Another EER for hydrogen used in a light duty internal combustion engine has been proposed.

The existing and proposed EERs are summarized in the following table.

Table 11: Gasoline Category EER

	Existing EER	Proposed EER
Gasoline (fossil and non-fossil) and alternative liquid fuels	1.0	1.0
CNG	1.0	0.9
Propane	1.0	0.9
Hydrogen (Fuel Cell Vehicle)	2.5	1.8
Hydrogen (ICE)		0.9
Electricity	3.4	3.0

Natural Gas Based Gasoline

Natural gas-based gasoline is a product that meets the existing specifications for gasoline and behaves the same as gasoline in a vehicle. Since it is essentially the same as petroleum based gasoline it has an EER of 1.0.

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[2] https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/fuel-consumption-guide/21002
[3] https://www.fueleconomy.gov/feg/findacar.shtml

Renewable Fuels

There are still a few vehicles being produced that are flexible fuel vehicles and are tested on gasoline and E85 by the US EPA and NRCan. The relative fuel economy on E85 averages 0.74 of that of the same vehicle tested on gasoline. This is the value that one would expect from the energy content of the two fuels (E85 has an energy content of 25.5 MJ/l and gasoline has 34.7 MJ/L, 34.7* 0.74/25.5=1.0), indicating no change in engine efficiency or an EER of 1.0.

There has been some real-world testing of ethanol blends undertaken in Europe[4] that indicates a higher energy efficiency with increasing ethanol contents. The study found that for E20/25, the thermodynamic efficiency (energy based) increases by 5% on average. This test data is limited to older vehicles and higher ethanol blends that are not currently being used in BC so there is no need to recommend a value that is different from 1.0 at this time.

Compressed Natural Gas

There are not currently any original equipment manufacturers that offer compressed natural gas vehicles. Natural gas vehicles were produced between 1995 and 2016. The EPA test data for recent vehicles is shown in the following table. Only the Chevrolet Impala was available in Canada.

[4] Geringer, Bernhard, Johann Spreitzer, Mattias Mayer, and Christian Martin. 2014. "Meta-Analysis for an E20/25 Technical Development Study - Task 2: Meta-Analysis of E20/25 Trial Reports and Associated Data." https://ec.europa.eu/energy/sites/ener/files/documents/Meta-Analysis_ReportFinal.pdf

Table 12: Gasoline Class CNG EER

Year	Vehicle	City MPG	Highway MPG	Combined MPG	Combined EER
2015	Honda Civic NG	27	38	31	
	Honda Civic Gasoline	29	37	33	0.94
2016	Chevrolet Impala Bi-Fuel CNG	16	24	19	
	Chevrolet Impala Gasoline	18	28	21	0.90
2014	Mobility Ventures MV-1 CNG	12	16	13	0.87
	Mobility Ventures MV-1 Gasoline	13	18	15	
Average					0.90

There are CARB and EPA after-market conversion kits available, but the approvals do not contain any fuel economy data. While there is no data available on the fuel economy performance of aftermarket conversions it is highly unlikely that they perform better than the OEM vehicles did.

An EER of 0.9, the average value rounded to a single digit, better reflects the performance of natural gas in spark ignited engines.

Propane

There are currently not any OEM propane vehicles available but Ford and General Motors do sell vehicles that can be converted. In Ford’s case there are approved qualified vehicle modifiers (QVM) that can produce propane powered vehicles and GM offers a “prep” ready engine to facilitate conversions. However, there is no fuel economy data available for these converted vehicles.

Between 2000 and 2004 there were bi-fuel propane vehicles available from some OEMs. The calculated EER from the EPA fuel economy website was either 0.73 or 0.92 depending on the year (0.92 for the 2001 and 2002, and 0.73 for the 2003 and 2004).

No OEM propane vehicles have been available since 2004. The 0.73 value seems very low and could be why the option was discontinued in 2005.

There have been some published studies on fleet trials using LPG[5] [6] [7] but the vehicles were not light duty vehicles under the BC definition.

It is proposed to reduce the gasoline class EER for propane from 1.0 to 0.9. This would be the same value as the CNG and since both fuels are gaseous fuels similar values would be expected. It is also the value from the 2001 and 2002 vehicles.

Electricity

The EER of gasoline class electric vehicles is influenced by a number of factors, which include:

- The fundamental efficiency advantage of an electric motor compared to the internal combustion engine. This is greater in city driving than with highway driving.
- The degree to which dynamic energy can be captured through regenerative breaking to recharge the battery in normal operation. This will vary with the design of the vehicle.
- The operating temperatures. Electric power from the battery is used to keep the passenger cabin and the battery pack at a suitable temperature both in cold weather and in hot weather.

The test procedure for gasoline powered vehicles is different than it is for electric vehicles but electric vehicle results are also adjusted to bring them closer to the expected real world values at normal operating conditions.

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[5] Superior Plus. 2020. Superior Plus Propane Case Study. https://propane.com/resource-catalog/resources/industry-fleet-autogas-business-case/
[6] US DOE. 2016. Case Study – Propane Bakery Delivery Step Vans. https://afdc.energy.gov/files/u/publication/case_study_propane_bakery_delivery.pdf
[7] US DOE. 2014. Case Study – Propane School Bus Fleets. https://afdc.energy.gov/files/u/publication/case-study-propane-school-bus-fleets.pdf

Since 2008, gasoline vehicles are tested over five cycles[8].

- There is a city test which represents urban driving, in which a vehicle is started with the engine cold and driven in stop-and-go rush hour traffic.
- The highway test represents a mixture of rural and highway driving with a warmed-up engine, typical of longer trips in free-flowing traffic.
- The high speed cycle represents city and highway driving at higher speeds with more aggressive acceleration and braking.
- There is an air conditioning test to account for air conditioning use under hot outside conditions (35°C sun load).
- The final cycle is a cold temperature tests where the effects of colder outside temperatures on cold-start driving in stop-and-go traffic.

The emissions from all of these tests are combined into the vehicle fuel economy rating. The total test time is over 1.5 hours.

Electric and hybrid vehicles are tested over cycles 1 and 2 above and then a combined city highway cycle. In each case the vehicle starts with a full charge and drives over the prescribed cycle until the battery is discharged. The battery is then recharged and the power required to recharge it is measured.

There are no air conditioning tests, no cold weather tests, or high speed tests for electric vehicles. The air conditioning and cold weather tests would use more electricity than the city and highway tests and would change the fuel economy rating of the EV.

Despite the differences in the test procedure comparing the energy consumption of an EV and a gasoline powered car on the basis of the Federal fuel economy tests is still one of the best comparisons that we have available.

The following table compares the fuel economy ratings for matched pairs of vehicles using data from 2011, 2016, and 2021. There are many more electric vehicles available now, but they are built on dedicated EV platforms.

[8] Detailed Test Procedure. https://www.fueleconomy.gov/feg/fe_test_schedules.shtml

Table 13: Fuel Economy Comparisons

	EER City	EER Highway	EER Combined
2011			
BMW Active E	5.94	3.43	4.64
smart fortwo cabriolet	2.85	1.79	2.42
smart fortwo coup	2.85	1.79	2.42
2011 Average			3.16
2016			
Chevrolet Spark	4.13	2.73	3.50
Volkswagen e-Golf	5.04	3.00	4.00
Fiat 500e	4.48	3.12	3.86
smart fortwo coupe	3.70	2.38	3.06
Kia Soul	5.00	3.07	4.04
Ford Focus	4.23	2.68	3.50
2016 Average			3.66
2021			
Hyundai Kona	4.89	3.27	4.00
Kia Niro/Seltos	4.24	3.00	3.61
Mini Cooper SE	4.42	2.70	3.60
Volvo XC40 AWD	3.70	2.25	3.04
2021 Average			3.56

It has been widely established that the electric vehicle range varies with ambient temperature. The reason for this is primarily that some of the stored electricity is used to provide heat or cooling for the passenger compartment. There are some differences from vehicle to vehicle but all EVs show the same trends.

Real world testing of electric vehicles in Europe by the Norwegian Automobile Association[9] and Motor magazine found that the energy consumption increased by an average of 1.37% per degree Celsius over the range of -1°C to 22°C.

The comparison of the fuel consumption test data for electric vehicles versus an equivalent gasoline vehicle would suggest that the EER should be 3.46 (average of the 2011, 2016 and 2021 averages). However, the two test procedures are not the same, with the gasoline test procedure including a cold temperature cycle and the EV only tested at 20°C. There is no population weighted average temperature available for BC. The average temperature in Vancouver is 10°C and it is assumed that most of the vehicles will be operated in this region. In British Columbia a temperature adjustment would lower the EER to 3.0 based on the annual average temperature in Vancouver 3.46*(1-0.0137*10) =3.0.

This EER excludes the emission impact of producing the vehicle. Some vehicle manufacturers have reported the GHG emissions of producing an EV versus producing the equivalent gasoline vehicle and the EVs have 70 to 100% higher vehicle manufacturing emissions. Including these emissions in the EER calculation would reduce the EER to about 2.6. However, it is proposed to not include these emissions in the determination of the EER at this time.

Hydrogen Fuel Cell

There are some light duty fuel cell vehicles that are available on the market in BC. The official 2021 fuel economy data for the fuel cell vehicle and the comparable gasoline vehicle is shown in the following table.

Table 14: Light Duty Fuel Cell Vehicles

Vehicle	Weight, kg	City, MPG	Highway, MPG	Combined, MPG	EER, combined

[9] Norwegian EV Test data. 2022. https://docs.google.com/spreadsheets/d/1k1DOw-NwvW8E8tQeXlacnt201fNc5qZyAPC0_vnoFBw/edit#gid=735351678

Honda Clarity	1,843	67	66	66	2.06
Honda Accord	1,465	30	38	33	
Toyota Mirai	1,848	63	65	64	2.32
Lexus LS	2,130	25	33	28	
Hyundai Nexo	1,810	59	54	57	2.28
Hyundai Tuscon	1,500	23	28	25	

The average EER value is 2.22. The comparison is skewed by the Toyota comparison where the two platforms are the same but the ICE version competes in the luxury class and is much heavier than the fuel cell version. The other two vehicles have the fuel cell vehicles being heavier than the ICE versions.

There is the experience of the larger fuel cell vehicles in BC where low ambient temperatures increase the energy consumption of the vehicles. Some low temperature operation is included in the test procedure for gasoline vehicles but not in the test procedure for electric and fuel cell vehicles.

The proposed EER for hydrogen fuel cell vehicle for the gasoline class is 1.8. This a 18% reduction in average EER for the vehicles listed above to account for the lower real-world temperatures in BC (10°C) compared to the test temperatures (20°C)[10].

Hydrogen Spark Ignited Engine

[10] Henning, Mark; Thomas, Andrew R.; and Smyth, Alison. 2019. "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses". Urban Publications. 0 1 2 3 1630. https://engagedscholarship.csuohio.edu/urban_facpub/1630

Hydrogen has been promoted as a fuel for internal combustion engines in the past and the topic is receiving some new attention. BMW did produce a 12-cylinder engine for their 7 series vehicles. Ford also offered a hydrogen V10 as an industrial engine. There is no official test data available for either the BMW or Ford hydrogen engines and there are no OEM hydrogen vehicles available from any manufacturer at this time.

Hydrogen has a very high-octane rating and some other properties, such as its lower ignition energy requirement and higher flame velocity, are desirable properties for spark ignition (SI) engines. There are also some downsides and the engines are susceptible to backfire. A fully modified engine might be able to achieve a higher efficiency but just a conversion is more likely to perform similarly to other gaseous fuels such as natural gas as modifications to optimize the engine for hydrogen use, such as a higher compression ratio, are unlikely to be performed. Since hydrogen is likely to be used as a gaseous fuel, an EER the same as the gasoline class natural gas (0.90) is recommended until more information is available.

Diesel Category EERs

Diesel engines generally have a higher thermal efficiency than gasoline fueled spark ignited engines. Some alternative fuels that are used in modified diesel engines are spark ignited rather than compression ignited and the EERs for a fuel can be different for gasoline class applications compared to diesel class applications. The existing and proposed EERs are summarized in the following table. The proposed diesel class EERs are discussed below.

Table 15: Diesel Category EERs

	Existing EER	**Proposed EER**
Diesel (fossil and non-fossil)	1.0	1.0
CNG	0.9	0.9
LNG	1.0	1.0
LNG (spark ignited engine)	-	0.9

Propane	1.0	0.8
Hydrogen (Fuel Cell Vehicle)	1.9	1.8
Hydrogen (ICE)	-	0.90
Electricity	2.7	
Electricity (Battery Electric Bus)		3.8
Electricity (Trolley bus)		2.4
Electricity (Fixed Guiderail)		2.9
Electricity (Battery Electric Trucks)		3.2
Electricity (marine applications)		2.3
Battery Electric Airplanes		2.5
Shore Power		2.8

Non-fossil diesel

McCormack[11] reported one case study of the use of B20 in a transit bus fleet. The findings were that "The B20- and ULSD-fueled buses exhibited comparable fuel economy, reliability (as measured by miles between road calls), and total maintenance costs." The US DOE Alternative Fuel Centre[12] reports that

> *Engines operating on B20 have similar fuel consumption, horsepower, and torque to engines running on petroleum diesel. B20 with 20% biodiesel content will have 1% to 2% less energy per gallon than petroleum diesel, but many B20 users report no noticeable difference in performance or fuel economy.*

Karavalakis et al[13] reported on tests of heavy-duty engines using biodiesel and renewable diesel. Two engines were tested and the showed some difference in results.

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[11] McCormack, R. 2016.Biodiesel Performance with Modern Engines. https://www.nrel.gov/docs/fy16osti/66158.pdf
[12] https://afdc.energy.gov/fuels/biodiesel_blends.html
[13] Karavalakis, G., Jiang, Y., Yang, J., Durbin, T., Nuottimäki, J. and Lehto, K., 2016. Emissions and fuel economy evaluation from two current technology heavy-duty trucks operated on HVO and FAME blends. SAE International Journal of Fuels and Lubricants, 9(1), pp.177-190. https://www.researchgate.net/profile/Thomas-Durbin/publication/301236057_Emissions_and_Fuel_Economy_Evaluation_from_Two_Current_Technolo

One engine showed no significant changes in fuel consumption. The other engine did show an increase in fuel consumption higher than what would have been suggested from the change in energy density, but these findings were unsupported by other studies.

No change in the EER for biodiesel is recommended since most of the data available suggests no change in energy consumption.

United Parcel Service (UPS)[14] reported on a two week renewable diesel case study. The test involved the use of renewable diesel in class 6, 7 and 8 trucks. Fuel economy and emissions tests at NREL's ReFUEL Laboratory showed that in general when switching from conventional petroleum diesel to renewable diesel, the thermal efficiency of a cycle remains relatively constant and observed changes in tailpipe carbon dioxide, fuel consumption, and fuel economy are primarily driven by changes in fuel properties such as hydrogen-to-carbon ratio, density, and lower heating value.

No change in the EER for renewable diesel is recommended.

Compressed Natural Gas

Natural gas can be used in heavy duty vehicles either by converting a diesel engine to a spark ignited engine or by introducing a small amount of diesel fuel along with the natural gas to initiate the combustion process.

The heavy-duty spark ignited engines are the most common NG diesel class engine. CumminsWestport is the dominant manufacturer in this field. In BC these engines are used in buses and garbage trucks.

A natural gas fueled, converted diesel engine has a different power curve than the diesel engine it replaces. This means that the EER can vary with the duty cycle and how

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gy_HeavyDuty_Trucks_Operated_on_HVO_and_FAME_Blends/links/57f1de7408ae280dd0b27fd0/Emissions-and-Fuel-Economy-Evaluation-from-Two-Current-Technology-Heavy-Duty-Trucks-Operated-on-HVO-and-FAME-Blends.pdf

[14] UPS: Renewable Diesel Case Study. https://www.bsr.org/en/collaboration/groups/future-of-fuels/case-studies/ups-renewable-diesel-future-of-fuels-case-study

frequently the engine can operate in the load/speed range of the maximum engine efficiency.

There are a large number of transit buses that have been converted to CNG using the Cummins Westport spark ignited engines. It is very difficult to compare the performance of identical diesel and CNG buses. While there are a number of studies that are available, the NG buses are often compared against older diesel buses, and they are not always used on the same routes making the comparisons less than ideal.

The data reviewed included reports from the National Renewable Energy Laboratory[15] [16], the US Federal Transit Authority database[17], Coast Mountain Bus operating data supplied by TransLink, and the US Department of Energy[18] for information on NG trucks.

The data shows a range of EERs from about 0.82 to 1.0. The wide range would appear to be partially a function of the duty cycle for the engine.

The existing EER in the regulations is 0.9. It is recommended that this value be retained as it is the mid-range value rounded to a single digit. It may be slightly high for bus applications but lower than the data for higher load application such as refuse haulers. There are BC fleets of both types of vehicles but no data that would allow a weighted average to be calculated.

Liquid Natural Gas (CI)

Compression ignition engines generally use LNG as the fuel. This is for both technical reasons and because these vehicles are usually larger and need to carry more fuel to provide an adequate range. Examples of these types of engines are the Westport HPDI

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[15] National Renewable Energy Laboratory. 2015. https://www.nrel.gov/docs/fy15osti/63893.pdf

[16] National Renewable Energy Laboratory. 2015b. Developing a Natural Gas-Powered Bus Rapid Transit Service: A Case Study. NREL/TP-5400-64756. https://afdc.energy.gov/files/u/publication/ng_powered_bus_service.pdf

[17] Federal Transit Administration. 2020. 2019 Fuel and Energy. https://www.transit.dot.gov/ntd/data-product/2019-fuel-and-energy

[18] Laughlin, M. and Burnham, A., 2014. Case Study-Compressed Natural Gas Refuse Fleets (No. DOE/CHO-AC02-06CH11357-1401). Energetics, Inc., Columbia, Maryland; Argonne National Laboratory, Argonne, Illinois. https://afdc.energy.gov/files/u/publication/casestudy_cng_refuse_feb2014.pdf

engines and the Wärtsilä engines that are used in Seaspan and BC Ferries. There are other manufacturers of these compression ignition engines, sometimes these are called dual fuel engines as they use some diesel to initiate the combustion process.

The original EER for LNG was based on the performance of the Westport HPDI engine. The production of that engine in North America ceased in 2013. A newer version of the HPDI engine has been produced by Volvo and sold in Europe. Test data on this engine and an identical diesel truck has been published[19]. The EER was 1.0 for this test.

Wärtsilä produces a dual fuel natural gas engine that is used in the marine fleets in British Columbia. There are two different engine models that are used with different capacities, but both use the same dual fuel capability.

Wärtsilä provides fuel consumption data at different rated loads for all of their engines. The data is presented as total energy as well as the natural gas and diesel fuel consumption. This information is available for the dual fuel natural gas engines as well as the equivalent fuel oil engines. The Wärtsilä data is presented on a lower heating value basis but for our purposes this has been converted to a higher heating value basis. This information is shown in the following table.

Table 16: LNG Marine Engines

	NG engine, kJ/kWh	**Fuel Oil engine, kJ/kWh**	**EER**
100% load	6,662	7,327	1.100
75% load	6,852	7,200	1.051
50% load	7,610	7,517	0.988
Simple average	7,042	7,348	1.04

The only real-world data that is available for BC for the same vessel with diesel and with LNG is for the two Spirit Class ferries. The other vessels that use LNG in BC are all new builds without the historical pair. Even the Spirit Class vessels are not a perfect match because they were re-engined. The EER for the two vessels using the 24-month

[19] Transport. 25 January 2019. www.transport.de

periods before and after the conversion is 0.95. The vessels operate at relatively light load and the EER is lower at lower loads. The other marine LNG engines operated in BC may operate at higher loads.

The manufacturer's data would suggest an EER above 1.0 when the engines are operated at high load but the one set of operational data with engines operated at lower loads would suggest an EER of less than 1.0. Since no sales weighted data is available for the different uses are available, the recommendation for the EER for LNG used in compression ignition engine is 1.0, the rounded average value for the two classes. This is applicable to both road and marine LNG use in compression ignition engines.

Liquid Natural Gas (SI)

LNG can also be used in spark ignited engines. The use of LNG compared to CNG for the fuel storage will provide greater range and thus may be attractive for some fleets. In these applications the LNG is generally gasified prior to use and the appropriate EER for those situations would be the compressed natural gas value of 0.90.

Propane

Propane is not a fuel that can be used in a diesel engine without an additional fuel or spark plug being used to initiate the combustion process due to its high octane value and thus low cetane value. Having said this, many of the case studies that are available used diesel powered vehicles as the comparison vehicle. One reason for this would be the upfront conversion costs require large volumes of the lower cost fuel to be consumed to make the business case for conversion. High fuel volumes mean either high mileage vehicles or large vehicles that have low fuel economy. Many of these larger vehicles tend to be diesel powered vehicles.

The fleet trials mentioned in the light duty discussion had a wide range in EERs, 0.72 to 0.86 and even suggestions of close to 1.0. The propane diesel class EER should be less than the gasoline class value since the diesel engine is more efficient than spark ignited gasoline engines. A value of 0.8 would be appropriate as this would be the rounded average of the fleet trials available.

Hydrogen in HD Fuel Cell

Hydrogen fuel cells have also been employed as the propulsion system for buses in North America and Europe. Hydrogen fuel cell buses have been operated in BC in the past.

Eudy and Post[20] reported on the progress of fuel cell electric bus (FCEB) development in the United States. They reported that as of August 2020 that there were 64 FCEB in operating in various US transit systems. This report reported on less than one year of operating data with respect to fuel consumption. Fuel economy comparison against diesel buses was only available at one site as other sites used CNG buses as the comparison. The one California diesel site reported an EER of 2.2.

This is the same value as the gasoline class value described in the previous section. Since the diesel engine is known to be more efficient than a gasoline engine one would have expected that the EER for the diesel class would be less than that of the gasoline class. One possible explanation for this is the driving cycle. More stop and go driving for a bus provides more opportunity for regenerative braking and capturing more energy that is often dissipated through braking in a conventional vehicle. This also raises the question of should the same EER be used for buses as for heavy duty trucks.

Henning[21] reported on the fuel consumption versus temperature for four fleets in Norway, Ohio, California, and BC. This data suggests that an EER for a hydrogen fuel cell bus in BC should be lower than the EER employed in California. Henning did not

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[20] Eudy, L. and Post, M., 2021. Fuel Cell Electric Buses in US Transit Fleets: Current Status 2020 (No. NREL/TP-5400-75583). National Renewable Energy Lab.(NREL), Golden, CO (United States). https://www.osti.gov/servlets/purl/1772437

[21] Henning, Mark; Thomas, Andrew R.; and Smyth, Alison. 2019. "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses". Urban Publications. 0 1 2 3 1630. https://engagedscholarship.csuohio.edu/urban_facpub/1630

have as many data points as the information used for battery electric vehicles, but 3 trials found an average of 1.8% increase in energy consumption for every one degree C below the base temperature (20°C).

Fuel cells for heavy duty trucks is a sector where there is very little information available but for which it is expected that there could be significant market uptake in the future. Hunter[22] reported on the simulation of fuel consumption for Class 8 and Class 4 trucks using various fuels. They did this for three driving cycles. The EER ranged from 1.3 to 2.5 for a heavy-duty truck. This was not temperature corrected and was based on simulations and not actual data.

The EER for a hydrogen fuel cell bus of 2.2 (before temperature adjustment) is reasonable if adjusted for temperature, as it is the midpoint of the EER range of 1.3 and 2.5 for a heavy-duty truck. At an average temperature of 10°C, the temperature adjusted EER would be 1.8 (2.2*0.86).

It is recommended to use an EER of 1.8 for the diesel class hydrogen fuel cell EER. This uses the actual data adjusted for temperature and does not consider the simulations since these vehicles are not yet in operation.

Hydrogen in ICE

Hydrogen used in diesel class engines can follow several different approaches. The engine could be converted to a spark ignition approach such as used in the CumminsWestport natural gas engines; the other approach would be to apply the compression engine approach where some diesel fuel is used to initiate the combustion process. This latter dual fuel approach could use as little as 5% diesel fuel or it could use much higher ratios of up to 50% diesel.

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[22] Hunter, Chad, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birky, and Chen Zhang. 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-71796. https://www.nrel.gov/docs/fy21osti/71796.pdf.

There is little real-world data available on the use of hydrogen in dual fuel engines but there has been academic work undertaken. This includes work undertaken by Suzuki et al[23], Chintala et al[24], and Karagoz et al[25]. The papers all show that the efficiency changes with the proportion of hydrogen in the total fuel requirement. They also show that the impact at different engine loads does vary. The papers show efficiency losses between zero and 15% depending on the engine load and the hydrogen substitution level. There has been real world data from natural gas dual fuel engines that documents the efficiency loss from 100% diesel fuel use[26]. They found that the efficiency loss averaged 7% and varied from zero to twenty five percent.

It is recommended that an EER of 0.9 be used for compressed hydrogen (7% efficiency loss rounded to a single digit) used in dual fuel diesel engines. This value is also supported by the academic studies cited. This has been based more on the data from the natural gas dual fuel trials than the laboratory-based hydrogen information.

Electricity

Electricity can be used in a number of different transportation applications. The EER can vary with the application. Previously there was just one EER for all electricity applications in the diesel class. It is proposed to have a number of different EERs for the different applications.

Battery Electric Bus

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[23] Suzuki, Y., Tsujimura, T. and Mita, T., 2015. The performance of multi-cylinder hydrogen/diesel dual fuel engine. SAE International Journal of Engines, 8(5), pp.2240-2252. https://doi.org/10.4271/2015-24-2458

[24] Chintala, V. and Subramanian, K.A., 2017. A comprehensive review on utilization of hydrogen in a compression ignition engine under dual fuel mode. Renewable and Sustainable Energy Reviews, 70, pp.472-491. https://doi.org/10.1016/j.rser.2016.11.247

[25] Karagöz, Y., Sandalcı, T., Yüksek, L., Dalkılıç, A.S. and Wongwises, S., 2016. Effect of hydrogen–diesel dual-fuel usage on performance, emissions and diesel combustion in diesel engines. Advances in Mechanical Engineering, 8(8), p.1687814016664458. https://doi.org/10.1177/1687814016664458

[26] Atkins Limited. 2016. Low Carbon Truck and Refuelling Infrastructure Demonstration Trial Evaluation. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/581858/low-carbon-truck-trial-final-report.pdf

There are a number of sources of information on the energy consumption of battery electric buses. The relative performance of the buses is expected to vary significantly due to the same three reasons that there is variation in the gasoline class EER, namely, the duty cycle, the quantity of regenerative breaking employed, and the ambient temperatures.

The Federal Transit Database[27] has 26 transit fleets that reported more than 100,000 kWh of electricity consumption and more than 100,000 gallons of diesel fuel. The EER from this dataset was 4.1. The diesel fuel consumption is 0.67 l/km which is higher than the diesel fuel consumption reported by TransLink, this could indicate that there are a large number of 60 ft buses in the fleet. High diesel fuel consumption would lead to higher EERs if 60 ft buses were compared to 40 ft battery electric buses. The first battery electric buses were 40 ft buses, so this comparison is possible.

There have been a number of NREL reports[28] [29] [30] on electric bus trials in different locations in the United States, mostly in California. In some cases the comparison was made to CNG buses in the same fleet rather than diesel buses. The EERs ranged from 2.8 to 5.2 (compared to diesel for the various fleets). Climate wise the San Francisco region is the closest to Vancouver and this fleet has an EER of 2.8.

Public information on the performance of battery electric vehicles in Canada is limited. Toronto Transit[31] has a fleet of 59 battery electric buses and they did report some data for the 2020 calendar year. They have buses from three manufacturers, New Flyer,

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[27] Federal Transit Administration. 2020. 2019 Fuel and Energy. https://www.transit.dot.gov/ntd/data-product/2019-fuel-and-energy

[28] Eudy, L. and Jeffers, M., 2020. Long Beach Transit Battery Electric Bus Evaluation (No. NREL/TP-5400-75582). National Renewable Energy Lab.(NREL), Golden, CO (United States). https://www.osti.gov/servlets/purl/1665840

[29] Eudy, L. and Jeffers, M., 2021. Foothill Transit Agency Battery Electric Bus Progress Report. Data Period Focus: Jan. 2020 through June 2020 (No. NREL/PR-5400-76259). National Renewable Energy Lab.(NREL), Golden, CO (United States). https://www.osti.gov/servlets/purl/1760662

[30] Eudy, Leslie and Matthew Jeffers. 2018. Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-72864. https://www.nrel.gov/docs/fy19osti/72864.pdf.

[31] Toronto Transit Commission. 2021. TTC's Green Bus Program: Preliminary Results of TTC's Tutak, W., Grab-Rogaliński, K. and Jamrozik, A., 2020. Combustion and emission characteristics of a biodiesel-hydrogen dual-fuel engine. Applied Sciences, 10(3), p.1082. https://www.mdpi.com/2076-3417/10/3/1082/pdf

Nova, and BYD. They reported electricity use of 4.4 to 5.4 MJ/km with significant seasonal variation. The diesel bus energy consumption is not available but typical values are 18 MJ/km. This would suggest EERs of 3.3 to 4.1.

Macron[32] reported on winter electric bus trials in Edmonton. They reported energy use from 3.7 to 5.0 MJ/km. There were three buses tested, one with diesel heat, one electric heat and one with both. In this case the manufacturer with the diesel/electric heat reported the highest energy consumption. The diesel buses reported energy use of 18 MJ/litre. This would put the winter EER in the range of 3.6 to 4.9.

TransLink has been operating a few battery electric buses. The electric buses are used from a transit centre that has only hybrid buses so a direct diesel comparison is not available. Comparing the electricity consumption to the diesel consumption of a 40 ft bus in the TransLink fleet would yield an EER of 4.1. There is some seasonal variation in the data.

The stop and go nature of a bus route provides more opportunity for regenerative braking and leads to a higher EER than a light duty battery electric vehicle. It also means that more variation between one city and another can be expected. The simple average of all of the EERs shown above is 4.0, however energy for passenger heat is not reported in most cases and some of these EERs will need to be temperature adjusted for BC conditions. It is recommended that an EER of 3.8 (0.95*4.0) be used for battery electric buses until more BC data can be collected.

Battery Electric Truck

There is not as much public data on battery electric trucks as there is on battery electric buses. NREL's last report was published in 2016 (Prohaska et al)[33]. This report covered class 6 electric trucks. The test site was between Seattle and Tacoma Washington, so

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[32] Macron. 2016. Electric Bus Feasibility Study.
https://www.edmonton.ca/documents/transit/ets_electric_feasibility_study.pdf
[33] Prohaska, R., Ragatz, A., Simpson, M. and Kelly, K., 2016, June. Medium-duty plug-in electric delivery truck fleet evaluation. In *2016 IEEE Transportation Electrification Conference and Expo (ITEC)* (pp. 1-6). IEEE. https://www.osti.gov/servlets/purl/1248082

similar climate to the lower mainland of BC. The electricity consumed was from on board telematics and would not be the exact system boundary required for GHGenius. NREL assumed a 90% charging efficiency. That is the electricity consumed was 1/0.9 times the electricity measured at the track. The EER for this fleet was 3.2 after adjustment for the charging efficiency.

Hunter[34] modelled battery electric vehicles in addition to fuel cell vehicles. The vehicles were mostly long-haul trucks without significant opportunities for regenerative braking. The EER for the battery electric trucks ranged from 1.7 to 3.3 and are all higher than the fuel cell vehicles. These regulatory cycles at high speeds do not have the same potential for recovering energy through the regenerative braking and this means that the EERs are less than what has been demonstrated in some of the real-world driving cycles.

It is recommended that an EER of 3.2 be used for battery electric buses until more BC data can be collected. This is based on the NREL report of actual data rather than on the simulations.

Trolley Bus

TransLink is the only transit operator in Canada that still uses trolley buses. There are five trolley bus systems left operating in the United States.

TransLink supplied operating data for the trolley buses. The electricity consumption is the AC power into the transformer system and that is the appropriate value for an EER for GHGenius. The information was for the year 2020. The power consumed and the service kilometers were reported. The energy consumption was 2.36 kWh/km.

The transit centre that the trolley buses operate out of had both regular and hybrid 40 ft buses so a direct comparison is not available. A regression analysis of the diesel fuel

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[34] Hunter, Chad, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birky, and Chen Zhang. 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-71796. https://www.nrel.gov/docs/fy21osti/71796.pdf.

usage by transit centre and the bus types at each centre produced an energy consumption of 0.0205 GJ diesel/km for a 40 ft diesel bus for the same period. This results in an EER of 2.4.

The recommended EER is 2.4 for electricity in this application. This is the EER from the local fleet.

Fixed Guiderails

The Federal Transit Database[35] has data on six systems in their monorail and Automated Guideway modes. There was a significant range in the energy requirements for these systems ranging from 1.89 to 11.3 kWh/km. The average value was 5.77 kWh/km or 20.8 MJ/km.

The energy consumption for the Vancouver Sky Train for the years 2019 and 2020 was provided by TransLink. The average value for the two years was 2.93 kWh/km or 10.5 MJ/km. This is slightly higher than the value for the trolley bus.

Translink also operates a diesel commuter train, the West Coast Express, within the greater Vancouver region. Comparing the energy consumption of the electric Sky Train to the West Coast Express results in an EER of 3.5. Commuter trains are generally heavier than light rail, so this value should be adjusted to provide a comparison at comparative load. The Oakridge National Laboratory has data on the energy efficiency of light rail and commuter rail on a passenger-km basis that can be used (1307 and 1589 BTU/passenger-mile, respectively)[36]. The EER adjusted for load is 2.9 (3.5 * 1307/1589).

The recommended EER is 2.9 for electricity in this application.

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[35] Ibid.

[36] Stacy C. Davis and Robert G. Boundy. 2022. Transportation Energy Data Book: Edition 40. Oakridge, TN: Oakridge National Laboratory. ORNL/TM-2022/2376. https://www.nrel.gov/docs/fy21osti/71796. https://tedb.ornl.gov/wp-content/uploads/2022/03/TEDB_Ed_40.pdf

Marine Vessels

BC Ferries has purchased a number of diesel hybrid ferries (the Island Class). These vessels could be electrified with larger battery capacity and battery charging while in port. These vessels are not currently operating on electricity.

Two electric ferries have been delivered in Ontario but they are not scheduled to start operations until 2022. These ferries are new builds and there is not an identical diesel ferry available for a direct comparison. The EER needs to be built from a more theoretical basis until comparable data is available.

Diesel hybrid ferries are already electric drive; they just use diesel fuel to produce the electricity. The EER will be a function of the fuel consumed to produce the power versus the supply of power from the grid. The in service EER will depend on the engines used.

Marine Diesel Electric engines have reported efficiencies of between 38 and 46%[37] [38]. The EER would range from 2.2 to 2.6 but these need to be adjusted to take into account the battery recharging efficiency. If we assume a 90% charging efficiency, the same as NREL assumed in their analysis of a battery electric truck, then the average EER would be 2.3.

If BC Ferries does proceed with the electrification of their Island Class vessels then they will have operating data for the same vessel on diesel and on electricity and would be able to confirm the EER. Until that data is available the recommended EER for this application is 2.3

Shore Power

Emissions from vessels running auxiliary diesel engines at berth can be significant contributors to air pollution and GHG emissions. The initial efforts at expanding shore power were driven by concerns over local air quality but the approach is also effective in

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[37] Cummins QSK95. https://mart.cummins.com/imagelibrary/data/assetfiles/0043513.pdf
[38] Wärtsilä 31DF Product Guide. https://go.wartsila.com/l/251562/2022-06-15/2v95qyq?MP_Content_Center=MP-Product-guide-W31DF&_ga=2.182185191.1983799421.1671145266-1556635461.1671145266

reducing GHG emissions. Shore power is a means of electrifying some transportation related energy requirements.

The US EPA[39] published a report on shore power technology. The report deals mostly with criteria air contaminants but it does cite one source with an emission factor for CO_2. That source was Corbett and Conner[40] and was 690 g CO_2/kWh of electricity produced by the auxiliary engines.

The US EPA[41] also has a shore power emission calculator that allows users to calculate the emission reductions for shore power for specific projects. The emission factors used for CO_2 are 696 g CO_2/kWh for marine diesel oil and 707 g CO_2/kWh for heavy fuel oil.

The CO_2 emission factor for diesel fuel in GHGenius is 68.6 g CO_2/MJ. That produces an energy consumption factor of 10.06 MJ diesel/kWh at 690 g CO_2/kWh or an energy consumption factor of 10.14 MJ diesel/kWh at 696 g CO_2/kWh.

The average value is 10.10 MJ diesel/3.6 MJ of electricity or an EER of 2.8.

The recommended value for shore power EER is 2.8.

Jet fuel Category

Non-fossil Jet

There is limited information on the efficiency of renewable fuels used in aviation. Sustainable aviation fuel (SAF) has lower density but higher energy content per kilogram of fuel compared to conventional kerosene, which brings some aircraft fuel-efficiency advantages due to lower fuel burn and less fuel mass to board to achieve the

[39] US EPA, 2017. Shore power technology assessment at US ports. https://www.epa.gov/sites/default/files/2017-05/documents/420r17004-2017-update.pdf

[40] Corbett, J. J., & Comer, B. (2013). Clearing the air: Would shoreside power reduce air pollution emissions from cruise ships calling on the Port of Charleston, SC? Pittsford, NY: Energy and Environmental Research Associates. https://www.coastalconservationleague.org/wp-content/uploads/2010/01/EERA-Charleston-Shoreside-Power-Report-.pdf

[41] US EPA. 2022. Shore Power Emissions Calculator. https://www.epa.gov/system/files/documents/2022-05/shore-power-ems-calc-v2022a-2022-05-04.xlsx

same mission. The impact is expected to be small and not warrant an EER other than 1.0 for this application of liquid renewable fuels in the diesel class.

Battery Electric Airplanes

Battery electric airplanes are gaining interest from some carriers. Air Canada plans to purchase 30 planes from Heart Aerospace. The first plane is expected to enter service in 2028. The plane has not yet had a test flight.

There are other electric plane manufactures including magniX who have worked with Harbour Air to convert a DHC-2 Beaver float plane. That plane has made test flights. magniX have also designed the all-electric Alice Aircraft, a clean sheet design, and that aircraft had its inaugural flight in September 2022.

ICCT[42] investigated electric airplanes of different sizes and reported the cruise efficiency or the electric plane and a jet fueled aircraft of the same size. The EER ranges from 3.2 for a 9 seat plane to 2.0 for a 90 seat plane. The 90 seat plane was not practical as only 3% of the battery could be used for the mission, the other 97% would be the required reserve.

There is very little information that can be used to determine the EER at this time since there have been so few flights. It also appears that the EER may be a function of the seating capacity of the airplane. The planes that Air Canada is buying are expected to be larger than the plane that the ICCT calculated an EER of 3.2 for but smaller than the plane with an EER of 2.0. A conservative EER of 2.5 is recommended rather than the mid-point of the range until more data is available. This is lower than some other electrification options, but airplanes will have to carry the weight of the batteries, a load that doesn't exist for shore power.

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[42] Mukhopadhaya, J. and Graver, B., 2022. Performance Analysis of Regional Electric Aircraft. https://theicct.org/wp-content/uploads/2022/07/global-aviation-performance-analysis-regional-electric-aircraft-jul22-1.pdf-1.pdf

Remote Power Production

More than half of the off-grid power produced in British Columbia is generated with a diesel powered generator system.

There is relatively little public real-world data on the in service efficiency of diesel powered generators. One report for Yukon Energy[43] reported that diesel generator systems in the Yukon produced 3.9 kWh/litre of diesel fuel consumed. This would be a higher heating value efficiency of 35.4%. It was also reported that newer units might have efficiencies as high as 39.1%. Note that many manufacturers report efficiency using lower heating values as that provides higher numbers, but all fuel is sold in North America on a higher heating value when it is sold on a heating value basis.

Information on eight diesel generating systems in BC yielded an average efficiency of 34.9%, very close to the reported value from Yukon energy. There was a significant range in the information and there was a tendency for higher efficiencies for larger systems.

Assuming that remote diesel power generation has an efficiency of 35% is an appropriate assumption.

Alternative Liquid and Gaseous Fuels

There are a number of alternative fuels that could be used in place of diesel fuel for remote power generation. Biodiesel and HDRD would be direct drop-in fuel replacements. These both have a recommended EER of 1.0 for transportation applications and there is no reason to suggest that the stationary application should be any different.

Other alternative fuels, such as LPG and perhaps CNG, could be distributed to remote locations but they would require a modified engine. The duty cycle in a transportation application may be different than it is in a stationary application but there would also be

[43] InterGroup Consultants Ltd. 2011. Diesel & Thermal Electricity Generation Options. https://www.yukonenergy.ca/media/site_documents/charrette/docs/papers/THERMAL_YEC_Background_Paper.pdf

the opportunity to tune the engine for the specific fuel to obtain the maximum efficiency in stationary applications.

The EERs that have been established for transportation applications should be adequate for the stationary power generation applications.

Direct Power Generation - Batteries

Solar or wind energy could be used in conjunction with batteries to supply remote power. Run of river hydro could also be used to supply power. There will be some power loss in charging and discharging batteries so an EER less than 1/0.35=2.86 would be appropriate for these applications. A value of 2.6 is a 10% discount for the charging losses, the efficiency loss assumed by NREL in their EV truck trial and is the recommended value.

Biomass Gasification

There is one small biomass gasification system in BC that generates a small amount of electricity. It is possible to generate a CI for these systems in GHGenius. The EER for these systems would be 2.9 (1/0.35) if connected directly to the grid and 2.6 if they are used to charge batteries with the assumed 10% loss for charging and discharging batteries.