B.C. Low Carbon Fuel Standard:

Coprocessing Methodology Protocol

Posted for comment on Oct 12, 2023.

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1 Introduction

The BC Low Carbon Fuel Standard (LCFS) was introduced to reduce the carbon intensity of transportation fuels supplied in BC. Each year, the LCFS prescribes reduction targets that fuel suppliers must meet. The reduction targets progressively decrease the average carbon intensity of fuels supplied in BC to achieve a 30% reduction in 2030. A fuel supplier generates positive compliance units (credits) by supplying fuel with a carbon intensity below the prescribed target for that year, and they incur negative compliance units (debits) by supplying fuel with a carbon intensity above the target.

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. The LCFS allows two methods for modelling the carbon intensity of a fuel: using the approved version of the excel based life cycle analysis tool called GHGenius or using an approved alternative method. The resulting carbon intensity is used in a carbon intensity application which is submitted to the Ministry. If the application is accepted, a fuel code that can be used in compliance reporting under the LCFS will be issued to the applicant.

In the last few years, the Ministry has been receiving more requests for approval of proposed carbon intensities for co-processed diesel and gasoline. Co-processing is when low-carbon and/or renewable feedstocks are used in combination with petroleum feedstocks during the refining process to produce blended fossil and low carbon fuel products. Typical insertion points of renewable feedstocks into an existing petroleum refinery are into a Hydrotreater (HT), Hydrocracker or Fluid Catalytic Cracker (FCC). Quantifying the volumes of low carbon fuel produced is challenging because the low carbon fuel is completely integrated and indistinguishable from the fossil fuel, and therefore cannot be directly measured using traditional methods. Determining the carbon intensity of the low carbon portion of a co-processed fuel is also a challenge because the energy consumption attributed to the production of the low carbon portion cannot be directly measured. This is important as only the renewable and/or low carbon portion of the co-processed fuel is eligible for earning positive compliance units under the LCFS. The fossil portion is considered a base fuel, which is automatically assigned a carbon intensity when reported, and is not eligible for positive compliance unit generation.

The Ministry is developing a methodology to address the challenges associated with determining the volume and carbon intensity of co-processed fuel. The proposed methodology is a balance between accuracy and reasonableness with some aspects of the proposed methodology differing from the co-processing methodology required by the Canadian Clean Fuel Regulations (CFR). The purpose of this paper is to outline the various elements of the proposed methodology as a starting point for policy related to co-processed fuels.

The Ministry is accepting feedback on the proposed co-processing methodology. Responses must be in writing and must be submitted by email or mail before 7 a.m. on November 6, 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 is posted online on the Ministry's website for comment at: https://gov.bc.ca/lowcarbonfuels.

2 Coprocessing Methodology

To evaluate the carbon intensities of co-processed fuels, the Ministry intends to establish a methodology for the parameters in the table below:

Table 1: Parameters of the Co-processing Methodology

Category	Parameters
Volume Quantification	**Renewable product volumes**
Carbon Intensity Modelling Inputs	**Hydrogen estimation**
	Other energy or chemical inputs estimation
	Co-product and intermediates volume
Testing and Instrumentation Requirements	**Frequency**
	Location
	Meter quality

The methodology outlines the minimum requirements for each parameter that will need to be met in order to obtain a 3-year fuel code for co-processed fuel. Additional data and analyses may be required on a case-by-case basis. The following sections discuss each parameter in detail. See Appendix A for a checklist that summarizes all requirements of the proposed methodology.

2.1 Renewable fuel volume estimation

For estimating the renewable fuel volume, the Ministry considered two options: Carbon 14 (C14) testing and Incremental allocation. The Ministry intends to require the use of C14 testing, as the ministry considers C14 testing, completed in accordance with ASTM (American Society of Testing and Materials) International D6866 - Method B, to be the more accurate method of estimating the renewable fuel volume.

2.1.1 C14 Testing

C14 testing is a method that can be used to identify the amount of renewable carbon present in a fuel or product. C14 is a radioactive isotope of carbon which is naturally present in the atmosphere. Due to photosynthesis, all living things contain the same concentration of C14 as the atmosphere. C14 testing is a well-established method and is most often used to identify the age of fossils or ruins but can also be used to identify the amount of biogenic content present within a predominately petroleum product.

ASTM D6866 is the standard test method developed by ASTM international to determine the biobased carbon content of solid, liquid, and gaseous samples using radiocarbon analysis. Two methods are proposed under the standard: Method B which utilizes Accelerator Mass Spectrometry (AMS) and Method C which uses Liquid Scintillating Counting (LSC). AMS is considered the most accurate method and can be used for solids, liquids, and gases[1].

Concerns with using the C14 testing method have generally been related to cost, availability of testing facilities, and errors. C14 testing can be costly and is only available at a few locations within North America. Canada does not currently have commercial C14 testing facilities, so samples must be sent to the US to obtain a reasonable turnaround time. This can cause challenges, especially when samples contain animal products (e.g., tallow), as they require specialized certificates and veterinary reports to cross the border.

Though accuracy concerns have been raised in the past, they have largely been dismissed after new testing conducted by UC Davis in 2018 identified that the margin of error (3% absolute) stated within ASTM D6866 was overestimated for bio-based fuels. The standard error reported by UC Davis during a working group on October 19, 2018, was 0.22% for bio-based fuels with a minimum detection limit of 0.44% (i.e., biogenic content of measured fuels must be greater than 0.44%)[2]. These results were corroborated by a separate peer-reviewed study which found an accuracy of 0.26% and a 0.4% detection limit[3].

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[1] J. Lee, Z. Li, H. Wang, A. Plymale, and C. Doll. "Quantification of biogenic carbon in fuel blends through LSC 14C direct measurement and assessment of uncertainty", *Fuel*, vol 315, 2022.

[2] D. Rocke (2018, October 19). *Measurement Error in Percent Modern Carbon by C14 Analysis* [PowerPoint slides]. Department of Biomedical Engineering, University of California, Davis.

[3] M. Haverley, S. Fenwick, F Patterson, and D. Slade. "Biobased carbon content quantification through AMS radiocarbon analysis of liquid fuels," *Fuel*, vol 237, pp. 1108-1111, 2019.

2.1.2 Incremental Allocation

The incremental allocation method estimates the amount of low carbon fuel produced based on measuring the changes in total yields when comparing co-processing scenarios to baseline scenarios using only petroleum feedstock. This method assumes that yields from petroleum intermediates (i.e., partially refined petroleum products) remain constant. A discussion of the challenges with this approach are discussed in detail within the Hydrogen Estimation section below.

2.2 Hydrogen Estimation

Hydrogen is one of the largest contributors to the carbon intensity of some co-processed fuels. For this reason, it is important to accurately quantify the amount of hydrogen used to produce the renewable portion of the co-processed fuel. For estimating the amount of hydrogen used, four estimation methods were considered:

- Incremental Allocation;
- Step test;
- Stoichiometric allocation; and
- Statistical regression (multi-variable regression).

The Ministry intends to allow applicants to use three of these methods, provided certain criteria have been met:

Table 2: Criteria for using each Method

Method	**Criteria**
Step Test	Can be used if the physical characteristics of the crude and operating conditions of the HT, Hydrocracker, or FCC remain consistent over the test duration
Stoichiometric allocation	Can be used if Step Test is not feasible and co-processing occurs in a HT. Must be accompanied by CO_2/CO and fatty acid profile testing data
Statistical regression (multi-variable regression)	Can be used if above tests do not apply, provided it is shown to be accurate

The applicant would propose their desired hydrogen estimation methodology approach to the Ministry and explain why it is the most accurate for their process.

2.2.1 Incremental Allocation

In this approach, the amount of hydrogen attributable to the co-processed fuel is determined by the incremental change of hydrogen used during co-processing compared to a baseline, assuming a constant petroleum feed rate. If the petroleum feed rate varies, the hydrogen rate is normalized to ensure equal comparison. Data is usually obtained over an extended period of time (several months to a year) in order to establish an average.

The main issue with this approach is that refinery operations are constantly changing (e.g., composition of the crude oil, refinery operating parameters, catalyst age, and finished fuel specifications) which makes it unlikely that co-processing will occur at the established baseline condition. As a result, the hydrogen consumption rate established prior to co-processing may not accurately represent the hydrogen consumption attributable to the petroleum stream during co-processing. This could result in either an over or under estimation of hydrogen attributable to the renewable fuel when the incremental allocation method is used. An underestimation of hydrogen is particularly concerning as it would result in a carbon intensity with underestimated emissions. An underestimation of hydrogen is likely to occur when the co-processing occurs years after the baseline was established, as the hydrotreater catalyst becomes less efficient over time. It is also likely to occur when the sulfur, nitrogen, and aromatic content of the petroleum crude used during co-processing is lower than the petroleum crude processed during the baseline. For example, multi-variable linear regression analyses indicate that the hydrogen consumption is sensitive to the sulfur content, where a 0.5% increase in sulfur may increase hydrogen consumption by 8.9 to 13.3 liters (0.63 to 0.94 kg) of hydrogen/liter of petroleum crude[4].

It is possible to address some of the issues discussed above by monitoring the crude oil parameters while co-processing to ensure that the crude does not move outside of the baseline parameters. If this occurs, a new baseline must be established. The drawback of this approach is that it requires the producer to stop co-processing on a regular basis for several months, which is a significant system upset. In addition, the time and expertise required of regulatory staff to review and monitor the data provided by the fuel producer to ensure that they remain within the baseline parameters is significant.

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[4] Calculation based on hydrodesulfurization estimate for the Handbook of Petroleum Processing, as referenced in the Kern oil carbon intensity application to CARB: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/b0079_report.pdf

2.2.2 Step test

This approach is like the incremental approach but uses a much shorter time period for establishment of the baseline and for obtaining data from co-processing operations, generally only a few days, to reduce the chance of variability within the crude oil and within the operating conditions of the refinery. This approach may offer improved accuracy over the incremental allocation method, but only at refineries that have large tank storage to ensure consistency of the petroleum crude over the duration of the step-test. Refineries that directly process crude arriving by pipeline may not see any advantages when using the step-test method since the crude will not be consistent over the course of the day. In contrast, refineries with large storage capacities that obtain a significant portion of their crude in large shipments may be able to accurately account for the hydrogen consumption of their renewable products using this method if they can ensure that the physical characteristics of the crude and operating conditions of the HT, Hydrocracker or FCC remain consistent throughout the step-test.

2.2.3 Stoichiometric allocation

This approach estimates the hydrogen consumption during the production of renewable products by the stoichiometric amounts required to hydrogenate the triglyceride and remove oxygen. A triglyceride may be converted to a renewable product by either the hydro-deoxygenation (removal of oxygen in the presence of hydrogen) or the decarboxylation (reaction which results in the removal a carboxyl group and release of carbon dioxide) pathway. Hydro-deoxygenation of one triglyceride will consume 12 molecules of hydrogen while decarboxylation consumes 6 molecules. In practice, both reactions occur simultaneously, but the ratio between the two reactions is affected by the hydrotreatment conditions, such as the presence of excess hydrogen. This ratio can be estimated by the amount of carbon monoxide and carbon dioxide produced, which is only produced from the decarboxylation reaction. In the absence of this information, a conservative estimate would be to assume all triglycerides were converted via hydro-deoxygenation and that all olefins within the triglycerides are saturated with hydrogen. Therefore, the exact composition of fatty acids within the feedstock (e.g., canola or tallow) must be known to ensure that hydrogen estimate is accurate and conservative.

The main issue with this approach is that it is an estimation method. However, it is possible to verify the key parameters, such as the fatty acid profile and the reaction extents from gas chromatography and PIONA (n-paraffins, iso-paraffins, olefins-naphthenes and aromatics) analysis. This approach could be useful for refineries where crude oil properties cannot be consistently maintained for a step test. Note that this approach will only work for refineries co-processing within a hydrotreater. Co-processing within an FCC will require a different approach, since the lipids are de-oxygenated by different means.

2.2.4 Statistical regression (Multi-variable regression)

This method estimates the hydrogen consumption of the renewable fuel by conducting a multi-variable regression on co-processing operating data. This statistical method evaluates the impacts of various operating parameters on hydrogen consumption to isolate the impact of the renewable feed on hydrogen consumption.

The advantage of this method is that it does not rely on a baseline, so does not have the inherent challenges associated with using a baseline previously discussed. Once developed, it is simple to use, as the hydrogen consumption can be estimated by a simple formula according to the operating conditions present at the refinery. However, it is important that the developed model is accurate and that the variables chosen to develop the regression model are the most significant contributors to hydrogen consumption. Various statistical methods exist for evaluating the efficacy of regression models, but they cannot ensure accuracy. This approach is suitable when step testing or stoichiometric allocation is not viable. Any proposed model would need to be reviewed by the Ministry for accuracy before acceptance.

2.3 Estimation of Other Energy and Chemical Inputs

In contrast to hydrogen, other energy and chemical inputs tend to have less of an effect on the carbon intensity of co-processed fuels and many of the estimation concerns previously described do not apply. The Ministry intends to allow the following two methods for quantifying the amount of other energy and chemical inputs used in co-processing, such as electricity, provided the method is proposed (with justification) to and accepted by the Ministry:

- Incremental Allocation; and
- Step test.

Another method may be accepted by the Ministry if it can be shown to be more accurate than the above two methods.

2.4 Co-product and intermediates Volume

The Ministry intends to require C14 testing to quantify the volume of any co-products produced. If C14 testing is not possible (e.g., in the case of coke it is difficult to obtain a sample) estimation methods may be proposed. For any co-products where C14 testing will not be used the applicant would propose their desired method and explain why it is the most accurate for their process.

In cases where the renewable volume of intermediates is needed for carbon intensity estimations, the Ministry intends to require C14 testing. Testing of intermediates is only necessary when the renewable volume of the intermediate must be quantified in order to determine other carbon intensity inputs (e.g. coke production). As a result, C14 testing only needs to be applied to certain intermediates, which would be determined on a case-by-case basis.

2.5 Testing Frequency

The Ministry intends to require monthly C14 testing on daily (or batch) samples of co-processed fuel and quarterly C14 testing on monthly samples of intermediates and coproducts. The frequency for other tests, such as the PIONA analysis used to support hydrogen consumption estimates, will be reviewed on a case-by-case basis.

The frequency of C14 testing can vary from daily (or batch) to annually. Testing by batch is only applicable to renewable fuel volumes, since it is taken on each tank of finished fuel product produced prior to sale. This can occur as frequently as every few days depending on the size of holding tanks used at the refinery. The accuracy of the estimates obtained will increase with the frequency of testing, but the costs for the producer will also increase and could become cost prohibitive. The Ministry sees the intended requirements as a good balance between accuracy and cost.

2.6 Test Location

The Ministry intends to require samples to be taken directly after the unit where the coprocessing takes place for intermediates and coproducts and from the final fuel holding tanks for the co-processed fuels.

Testing may be conducted on samples taken throughout the refinery, so it is important to identify the preferred sampling location. Sampling directly after the unit where co-processing takes place (HT, hydrocracker, or FCC) provides important information about how the renewable oil is divided between products and can be important for co-product estimation if co-products are produced. However, these intermediate streams may undergo further processing and separation, so may not accurately represent the renewable volume present within the final fuel products. Therefore, tests on samples taken from the final fuel holding tanks may be more accurate for renewable fuel volume quantification.

2.7 Meter quality

The Ministry intends to require custody transfer grade flowmeters (e.g., coriolis meters) for measuring the flow rates of the co-processed fuels and flowmeters with +/- 5% accuracy (e.g., orifice meters) for measuring the flow rates of coproducts and intermediates.

Flowmeters measure the volume or mass flowrate of liquid and gas streams and are often used to measure the fuel and process fuel rates throughout a refinery. These are used to determine mass balances around each unit and the refinery as a whole and are used in combination with C14 testing data to determine the renewable fuel and co-product volumes. Flowmeter measurement error usually ranges from 0.1% to 5% depending on the instrument. Custody transfer meters, such as coriolis meters, are considered the most accurate and are often used for fuel sales. With increased precision comes increased cost, so generally less expensive meters, such as orifice meters, are used on refinery intermediate and process streams and usually have an accuracy of +/- 4%.These meters are generally used to measure all flows within a refinery that are not associated with fuel sales, so C14 sampling points taken around the co-processing unit will likely be paired with mass flowrate data from these meters.

Appendix A. Checklist for Co-processing applications

Below is a proposed checklist to be used by the Ministry when evaluating co-processing applications.

Category	Parameter		Standard Approach	Applicant Approach	Meets Standard
Volume Quantification	Renewable product volumes		C14 Testing -ASTM D6866 Method B (AMS)		✓
Carbon Intensity Modelling Inputs	Hydrogen estimation		Step test (if consistent baseline), stoichiometric method with CO2/CO and fatty acid profile testing (if HT), or statistical regression (multi-variable regression)		✓
	Other Energy or Chemical input estimation		Step Test or Incremental Allocation unless another method can be shown to be more accurate		✓
	Co-product and intermediates volume		C14 Testing -ASTM D6866 Method B (AMS) If C14 testing not possible: incremental allocation or step testing with rationale as to why chosen method is the most accurate		✓
Testing and Instrumentation Requirements	Frequency	Fuel Product (Diesel, gasoline, Jet fuel)	Monthly on daily samples		✓
		Other streams (co-product/intermediates)	Quarterly on monthly samples		✓

	Location	**Fuel Product (Diesel, Gasoline, Jet fuel)**	Final product		✓
		Other streams (co-product/intermediates)	Directly after HT/FCC/Hydrocracker		✓
	Meter Quality	**Fuel Product (Diesel, Gasoline, Jet fuel)**	Custody transfer grade meters (e.g. coriolis meters)		✓
		Other streams (co-product/intermediates)	Meters with +/- 5% accuracy (e.g., orifice meter)		✓