lcfs
low carbon fuel standards

June 10, 2008

California Low Carbon Fuel Standard Sub-Working Group Meeting: Credit and Carbon Intensity Calculations

DRAFT - FOR DISCUSSION ONLY

California Air Resources Board
California Environmental Protection Agency

1. OVERVIEW

1.a The $AFCI$ value is a weighted-average carbon intensity value calculated from ARB source-to-wheel lifecycle analyses. The $AFCI$ value can be calculated using either default carbon intensity values provided by ARB or custom carbon intensity values previously submitted to and approved by ARB. The $AFCI$ value includes emissions from direct and indirect land use change, and a vehicle drivetrain efficiency adjustment factor.

1.b For alternative fuels and biofuels used in transportation, compliance is determined by comparison to either the gasoline or diesel standard.

1.c LCFS credits are denominated in units of million metric tonnes ("MMT").

1.d For each fuel, credits are determined separately for the portion of the fuel used in each category:

i) light-duty and medium-duty applications (using the gasoline reference),
ii) heavy-duty and off-road applications (using the diesel reference).

The total credit is the sum of the credits obtained from each category.

2. CREDIT CALCULATION

Calculations apply to light-duty, medium-duty, heavy-duty, and off-road applications.

2.a LCFS credits are calculated according to the following equations:

$$Credits^{XD}(MMT) = \left(AFCI_{reference} - AFCI^{XD}_{reported}\right)(E^{XD}_{FF})(C) \qquad (4.1)$$

$$Credits^{TOT}(MMT) = Credits^{LMD} + Credits^{HD} \qquad (4.2)$$

where XD ="LMD" for light-duty and/or medium-duty applications; and XD ="HD" for heavy-duty and/or off-road application of the fuel;

$Credits^{XD}(MMT)$ is the amount of LCFS credits awarded (or in deficit) to a regulated party for providing fuels used in light-duty/medium-duty or heavy-duty/off-road applications;

$AFCI_{reference}$ is the average fuel carbon intensity of either the gasoline or diesel reference standard as shown in Tables 2.1 or 2.2, respectively. Table 2.3 shows the applicable reference standard for each fuel system;

$AFCI^{XD}_{reported}$ is the *adjusted* average fuel carbon intensity value reported by a regulated party for fuels used in light-duty/medium-duty or heavy-duty/off-road applications, as calculated by Equation 5.2.2;

E_{FF}^{XD} is the portion of the finished fuel energy used in light-duty/medium-duty applications or heavy-duty/off-road applications, in a given period. Depending on whether the calculation is done for compliance or credit, a given period corresponds to either the reporting frequency or to the frequency in which credits are determined.

C is a factor used to convert credits to units of MMT and has the value of

$$(\frac{tonne}{1x10^6\, gCO_2e})(\frac{MMT}{1x10^6\, tonne}) = 1.0x10^{-12}\,\frac{(MMT)}{(gCO_2e)};$$

$Credits^{TOT}$ is the total credit awarded or in deficit, in MMT.

3. DETERMINATION OF CARBON INTENSITY VALUES

3.a The ARB average fuel carbon intensity values are determined on a source-to-wheel basis using default data provided by ARB or custom values submitted to and approved by ARB.

3.b A carbon intensity value is calculated from the energy-weighted average of the LCFS-blendstock carbon intensity value(s) adjusted for vehicle drivetrain efficiency.

3.c The LCFS-blendstock refers to the blending component(s) that produce a finished fuel used in a motor vehicle. Each LCFS-blendstock corresponds to a fuel pathway. For instance, corn-ethanol, cellulosic-ethanol, and CARBOB are examples of LCFS-blendstock for gasoline. A LCFS-blendstock that is used directly in a vehicle is considered a finished fuel.

3.1 Calculation of Average Fuel Carbon Intensity

3.1.a The reported average fuel carbon intensity ($AFCI_{reported}^{XD}$) is calculated in the following steps:

1. Determine the *unadjusted* carbon intensity by calculating the energy-weighted carbon intensity value of all the LCFS-blendstocks that form the finished fuel. The LCFS-blendstock carbon intensity (BAFCI) values are provided by ARB CA GREET fuel pathways or custom fuel pathways.

2. Adjust the carbon intensity value from step 1 by applying the Vehicle Drivetrain Efficiency Adjustment Factor corresponding to the types of vehicle(s) in which the finished fuel is used. For each fuel, the corresponding application is categorized into light-duty/medium-duty, and heavy-duty/off-road applications.

3.1.b ***Step 1. Determine the unadjusted carbon intensity of the finished fuel***

The general equation for calculating the unadjusted carbon intensity of the finished fuel is:

$$AFCI_{FF}(gCO2e/MJ) = \frac{\sum_{i=1}^{n} BAFCI_i E_i}{\sum_{i=1}^{n} E_i} \quad (5.2.1)$$

where

$BAFCI_i$ is the average fuel carbon intensity of each LCFS-blendstock, i, determined by an ARB CA GREET fuel pathway;

E_i is the energy of each LCFS-blendstock, in MJ, determine from the conversion factors in Table 5.2.1.

i is the LCFS-blendstock index ;

n is the total number of LCFS-blendstocks that produce a system;

3.1.c ***Step 2. Determine the reported carbon intensity of the finished fuel by applying the appropriate vehicle drivetrain efficiency adjustment factor(s)***

The general equation is as follows:

$$AFCI_{reported}^{XD}(gCO2e/MJ) = \left(\frac{(AFCI_{FF}) \sum_{j=1to19} (K^j)(E_{FF}^j)}{\sum_{j=1to19} E_{FF}^j} \right) \quad (5.2.2)$$

where XD ="LMD" for light-duty and/or medium-duty applications; and XD ="HD" for heavy-duty and/or off-road application of the fuel;

$AFCI_{FF}$ is the unadjusted, average fuel carbon intensity of the finished fuel from step 1 (see Eqn. 5.2.1);

K^j is the vehicle drivetrain efficiency adjustment factor, listed in Table 5.2.2, corresponding to the type of vehicle(s) in which the fuel is used;

E_{FF}^j is the *portion* of the finished fuel energy, in MJ, used in a fuel-vehicle pair, j, listed in Table 5.2.2.

$AFCI_{reported}^{XD}$ is the average fuel carbon intensity value reported by a regulated party used to determine compliance and credit;

j is the fuel-vehicle index in Table 5.2.2;

3.1.d Fuel quantity denominated in the units shown in Table 5.2.1 must be converted to energy in MJ by multiplying by the corresponding energy density[1]:

Table 5.2.1 Energy densities of LCFS fuels.

Fuel (units)	Energy Density
CARBOB (gal)	119.53 (MJ/gal)
Diesel (gal)	134.47 (MJ/gal)
CNG (scf)	0.98 (MJ/scf)
LNG (gal)	78.83 (MJ/gal)
LPG (gal)	89.62 (MJ/gal)
Electricity (KWh)	3.60 (MJ/KWh)
Hydrogen (kg)	120.00 (MJ/kg)
Pure denatured Ethanol (gal)	80.53 (MJ/gal)
Pure Biodiesel/Biomass-based diesel (gal)	126.13 (MJ/gal)

3.1.e **Vehicle drivetrain efficiency adjustment factors.** ARB will use a vehicle drivetrain efficiency adjustment factor to take into account differences in engine drivetrain efficiencies between vehicles of the same category. The adjustment factor is determined by comparing the fuel economies, in miles per MJ, of an alternative fuel vehicle to that of a reference, conventional vehicle.

3.1.f Unless noted in Table 5.2.2, ARB will use the Energy Economy Ratio ("EER") published in the TIAX AB1007 report to determine the Vehicle Drivetrain Efficiency Adjustment Factor ("Efficiency Adjustment Factor") through the relationship

$$\text{Efficiency Adjustment Factor} = 1/\text{EER}$$

For light- and medium-duty applications, the adjustment factor reflects energy economy comparison of an alternative fuel vehicle to a comparable gasoline vehicle.

3.1.g For heavy-duty applications, ARB will modify the EER values in the AB1007 report with a correction factor to reflect a comparison in energy economy relative to a gasoline vehicle.[2] (The EER values for heavy-duty application in the AB1007 report are determined by comparison to a diesel vehicle).

[1] Energy density factors are based the lower heating values of fuels in GREET using BTU to MJ conversion of 1055 J/Btu.

[2] The efficiency adjustment factor for HD diesel is determined by comparison to a LD gasoline vehicle due to the lack of data for gasoline used in HD applications. To maintain consistency with HD diesel, a correction factor of 1.16 (see Appendix C) for all HD applications of alternative fuels is used. This reflects a comparison of a HD vehicle to a comparable gasoline vehicle for all fuels.

Table 5.2.2 Illustrative examples of efficiency adjustment factors for light- and medium-duty (LMD), and heavy-duty (HD) vehicles. The efficiency adjustment factors are derived from the CEC AB1007 Report, data from the ARB Mobile Source Control Division, and U.S. EPA Fuel Economy Guide 2008 (shown in Appendix C). A correction factor is applied to heavy-duty applications of alternative fuels to reflect vehicle comparisons to a comparable gasoline vehicle.

j	Fuel / Vehicle Combination	EER Values	Correction Factor to use Gasoline Reference	Corrected Efficiency Adjustment Factor, K^j	Footnotes and Comments
1	Gasoline / LMD SI	1	n/a	1	
2	Diesel / LMD CI	n/a	n/a	0.86	See Appendix C
3	Diesel / HD CI	n/a	n/a	0.86	3
4	CNG / LMD SI	n/a	n/a	1.02	See Appendix C
5	CNG / HD SI	0.94	1.16	0.92	4
6	CNG / HD CI	0.94	1.16	0.92	4
7	LNG / HD SI	0.94	1.16	0.92	4
8	LNG / HD CI	0.94	1.16	0.92	4
9	LPG / LMD SI	1	n/a	1	5
10	LPG / HD SI	0.94	1.16	0.92	4
11	LPG / HD CI	0.94	1.16	0.92	4
12	Electricity / LMD BEV	4.1	n/a	0.24	6
13	Electricity / LMD PHEV	4.1	n/a	0.24	6
14	Electricity / HD BEV	2.7	1.16	0.32	4
15	Electricity / HD PHEV	2.7	1.16	0.32	4
16	H2 / LMD ICEV	1.3	n/a	0.77	5
17	H2 / LMD FCV	2.2	n/a	0.45	6
18	H2 / HD ICEV	1.2	1.16	0.72	6
19	H2 / HD FCV	1.9	1.16	0.45	6
20	E85 / LMD FFV	n/a	n/a	1.02	See Appendix C

(BEV = battery electric vehicle, PHEV=plug-in hybrid electric vehicle, FFV = flex fuel vehicle, FCV = fuel cell vehicle, ICEV = internal combustion engine vehicle, SI=spark ignition, CI=compression ignition)

[3] The efficiency adjustment factor for heavy-duty diesel is assumed to be the same as light-duty diesel.

[4] EER values from Table 3-8, TIAX TTW AB1007 Report for the California Energy Commission. Correction factor 1.16 is the diesel/gasoline EER calculated in Appendix C according to energy/mi values derived from the U.S. EPA Fuel Economy Guide 2008. All heavy-duty applications of fuels are adjusted to reflect comparison to a comparable gasoline vehicle. For instance, for CNG/HD/CI the adjustment factor = 1/(0.94*1.16). Previous adjustment factors in the March 2008 concept outline for heavy-duty application is derived from comparison to a diesel vehicle.

[5] EER values from Table 3-7, TIAX TTW AB1007 Report for the California Energy Commission. All light-duty adjustment factors are derived from comparison to a comparable gasoline vehicle.

[6] EER values from ARB Mobile Source Control Division. All heavy-duty applications of fuels are adjusted by 1.16 to reflect comparison to a comparable gasoline vehicle.

3.2 Default Value Approach to Determining the LCFS-Blendstock Carbon Intensity

3.2.a ARB will provide the default values for the determination of the LCFS-blendstock average fuel carbon intensity ($BAFCI_i$). Default values where little is known about the origin of the supply chain, represent more conservative estimates of GHG emissions; default values in which the calculation includes more detailed information, are less conservative. ARB will provide a tiered look-up table of default values based on the level of data provided.

3.2.b **Fuel pathways.** The ARB fuel pathways released in April 2008 are shown in Table 5.2.3. These values are included for discussion purposes only and are still under development. Values shown do not include land use change. For details on the GREET pathways for each fuel, see the following documents on the ARB website.

Ultra-low sulfur diesel (http://www.arb.ca.gov/fuels/lcfs/042308lcfs_ulsd.pdf)
Corn-ethanol (http://www.arb.ca.gov/fuels/lcfs/042308lcfs_etoh.pdf)
CARBOB (http://www.arb.ca.gov/fuels/lcfs/042308lcfs_carbob.pdf)
CaRFG (http://www.arb.ca.gov/fuels/lcfs/042308lcfs_carfg.pdf)
Natural gas (http://www.arb.ca.gov/fuels/lcfs/042308lcfs_cng.pdf)

Table 5.2.3 Preliminary summary of the ARB fuel pathway and corresponding LCFS-blendstock carbon intensity values released in April 2008. **Values DO NOT include land use change or vehicle drivetrain efficiency adjustment factor.**

(These values are under development and are shown for discussion purposes only).

Fuel production pathway	LCFS Blendstock Carbon Intensity (BAFCI) gCO2e/MJ
CARBOB - Crude from all sources including CA. Refined in CA	95.2
CaRFG[7] (with 5.75 wt.% ethanol) from CARBOB and ethanol	96.6
CNG - CA average electricity	69.3
CNG - CA marginal electricity	67.9
ELECTRICITY - CA Average	164.4
ETHANOL - Dry mill, using corn grown in the MW, and ethanol transported to CA.	75.6
ETHANOL - Wet Mill, using corn grown in the MW, and ethanol transported to CA.	89.0
ULSD[8] - Crude from all sources including CA. Refined in CA	99.4

[7] CaRFG is a finished fuel and is not considered a LCFS-blendstock. It is included here for discussion purposes.
[8] ULSD is considered a finished fuel (if used directly in a vehicle) or as a LCFS-blendstock for biodiesel (B5 or B20).

APPENDIX A. Calculations of Carbon Intensity Values and Credits

Example 1: CA Reformulated Gasoline

Refiner A uses conventional crude oil as the feedstock for CARBOB that is mixed with ethanol from corn and cellulosic materials. All gasoline is used in light-duty applications.

Sample calculation:

The following figure illustrates the possible fuel-vehicle combination(s).

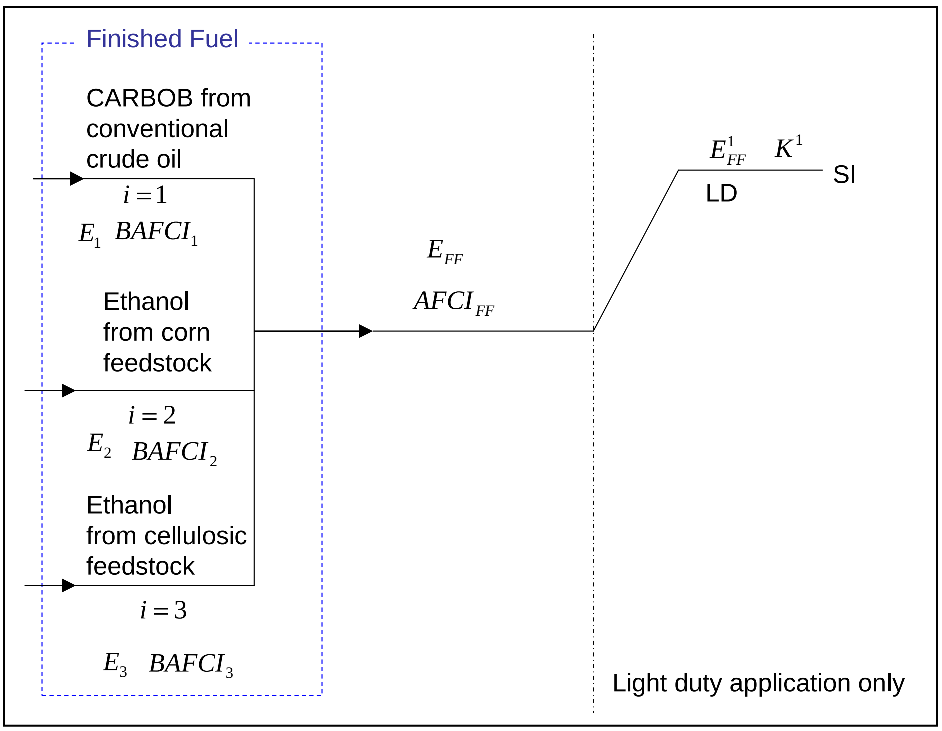

Figure B.1. Illustrative diagram of the fuel-vehicle combination used to calculate the corresponding LCFS average fuel carbon intensities for CA reformulated gasoline. In this example, only conventional crude oil is considered. The ethanol used for oxygenate blending comes from two different feedstocks, corn and cellulosic materials. The subscript *FF* refers to the finished fuel. Each LCFS-blendstock is denoted by *i*. *K* is the vehicle efficiency adjustment factor corresponding to gasoline/SI in Table 5.2.2.

Let

i =1 = CARBOB from conventional crude oil
i =2 = ethanol from corn feedstock
i =3 = ethanol from cellulosic feedstock

These correspond to LCFS-blendstocks for gasoline.

The *j* value in Table 5.2.2 is *j*=1 corresponding to Gasoline/LMD/SI with Vehicle Efficiency Adjustment Factor of $K^1 = 1.0$.

Using the ARB GREET fuel pathways, the LCFS-blendstock average carbon fuel intensity value, $BAFCI_i$, for each gasoline LCFS-blendstock is determined. The overall $BAFCI$ of the finished fuel is determined by

$$AFCI_{FF}(gCO2e/MJ) = \frac{(BAFCI_1)(E_1) + (BAFCI_2)(E_2) + (BAFCI_3)(E_3)}{E_1 + E_2 + E_3}.$$

The AFCI for gasoline is

$$\boxed{AFCI^{LMD}_{reported}(gCO2e/MJ) = (AFCI_{FF})(1.0)}$$

In this case, $E_{FF} = E_1 + E_2 + E_3 = E^1_{FF}$, is the total energy of finished gasoline used for light-duty transportation application.

The overall credit received (or in deficit) for gasoline used in light-duty application, according to Eqn. 4.1, is

$$Credits^{LMD}(MMT) = \left(AFCI_{gasoline} - AFCI^{LMD}_{reported}\right)(E_{FF})(C)$$

Where $Credits^{TOT} = Credits^{LMD}$

is the total credit received (or in deficit) for the fuel provider.

Example 2: CNG

CNG producer A is providing fuel for light-duty and heavy-duty transportation use in CA. The CNG is produced by the same process but comes from

A = Within California and
B = Outside of California

In the heavy-duty category, the fuel is used in spark-ignited and compression-ignited engines.

Sample calculation:

The following figure illustrates the possible fuel-vehicle combination(s).

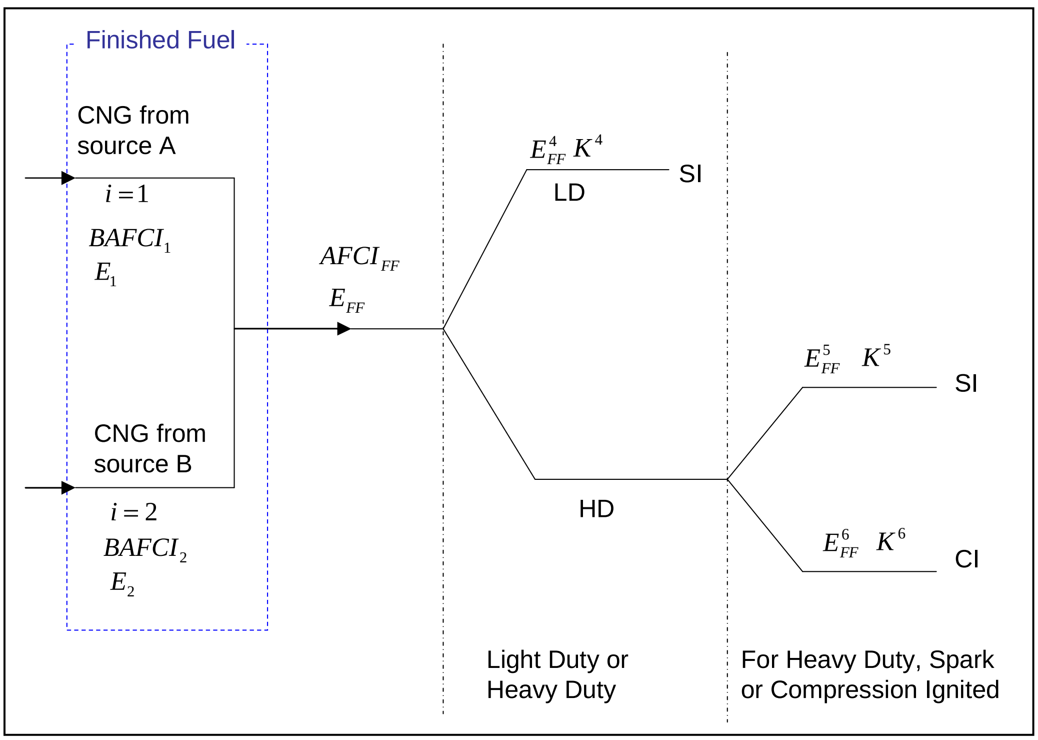

Figure B.2. Illustrative diagram of the fuel-vehicle combinations used to calculate the corresponding LCFS average fuel carbon intensities for natural gas. In this example, the natural gas comes from two difference sources and is used for light-duty (LD) and heavy-duty (HD) applications. The calculations take into account the engine efficiency adjustment factors *K* in Table 5.2.2 for CNG/LD/SI, CNG/HD/SI, and CNG/HD/CI. The calculation also considers the energy used in each engine type, spark-ignited (SI) or compression-ignited (CI). The subscript *FF* refers to the finished fuel. Each LCFS-blendstock is denoted by *i*.

First, determine how the finished fuel is produced. See dashed box in Figure A.2.

Let

i =1 = CNG from source A (corresponding to CNG pathway 1)
i =2 = CNG from source B (corresponding to CNG pathway 2)

These correspond to LCFS-blendstocks for CNG.

The *j* values in Table 5.2.2 are *j*=4, 5, and 6 corresponding to Vehicle Efficiency Adjustment Factors of K^4, K^5 and K^6 for CNG/LMD/SI, CNG/HD/SI, and CNG/HD/CI, respectively.

Determine the amount of fuel used in each engine type.

$E_{FF} = E_1 + E_2$ is the total energy of the finished fuel from each of the blendstocks.

$E_{FF}^4 = x^4 E_{FF}$ where x^4 is the fraction of fuel used for CNG/LMD/SI and
$E_{FF}^5 = x^5 E_{FF}$ where x^5 is the fraction of fuel used for CNG/HD/SI and
$E_{FF}^6 = x^6 E_{FF}$ where x^6 is the fraction of fuel used for CNG/HD/CI.

Using the ARB GREET fuel pathways, the LCFS-blendstock average carbon fuel intensity value, $BAFCI_i$, for each CNG LCFS-blendstock is determined. The overall $BAFCI$ of the finished fuel is determined by

$$AFCI_{FF}(gCO2e/MJ) = \frac{(BAFCI_1)(E_1) + (BAFCI_2)(E_2)}{E_1 + E_2}$$

The AFCI for light-duty use is

$$AFCI_{reported}^{LMD}(gCO2e/MJ) = (AFCI_{FF})(K^4)$$

The AFCI for heavy-duty use is

$$AFCI_{reported}^{HD}(gCO2e/MJ) = \frac{AFCI_{FF}\left[(K^5)(E_{FF}^5) + (K^6)(E_{FF}^6)\right]}{E_{FF}^5 + E_{FF}^6}$$

The overall credits received (or in deficit) for CNG used in light-duty and heavy-duty application, according to Eqn. 4.1, are

$$Credits^{LMD}(MMT) = \left(AFCI_{gasoline} - AFCI_{reported}^{LMD}\right)(E_{FF}^4)(C)$$ and

$$Credits^{HD}(MMT) = \left(AFCI_{diesel} - AFCI_{reported}^{HD}\right)(E_{FF}^5 + E_{FF}^6)(C)$$

Where $Credits^{TOT} = Credits^{LMD} + Credits^{HD}$ is the total credit received (or in deficit) for the fuel provider.

Example 3: Hydrogen

Producer A is providing hydrogen for light-duty and heavy-duty transportation use in CA. For each category, the fuel is used in hydrogen internal combustion and fuel cell vehicles. The hydrogen is produced from electrolysis using electricity from CA grid.

Sample calculation:

The following figure illustrates the possible fuel-vehicle combination(s).

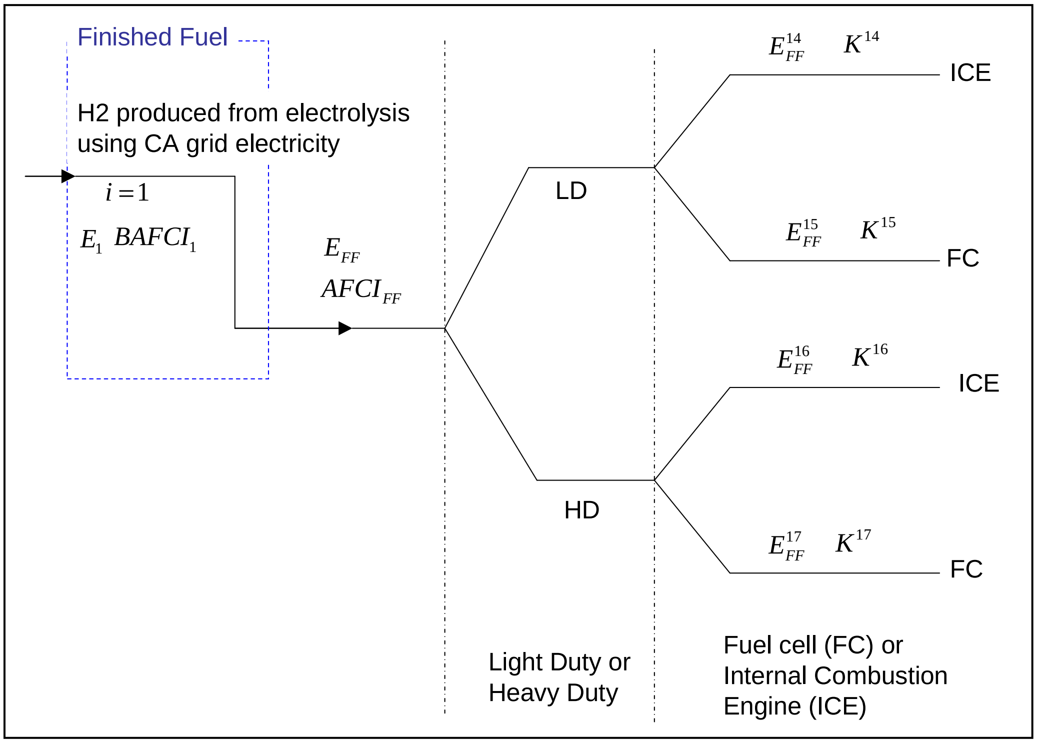

Figure B.3. Illustrative diagram of the fuel-vehicle combination used to calculate the corresponding LCFS average fuel carbon intensities for hydrogen produced from electrolysis using CA grid electricity. The fuel is used in light-duty and heavy-duty internal combustion (ICE) and fuel cell (FC) vehicles. The subscript *FF* refers to the finished fuel. Each LCFS-blendstock is denoted by *i*. *K* is the vehicle efficiency adjustment factor corresponding to the type of fuel-vehicle pair in Table 5.2.2.

First, determine how the finished fuel is produced. See dashed box in Figure A.3.

Let

i =1 = H2 produced from electrolysis using electricity from CA grid

This corresponds to the LCFS-blendstock for hydrogen.

The *j* values in Table 5.2.2 are *j*=16, 17, 18, and 19 corresponding to Vehicle Efficiency Adjustment Factors of K^{16}, K^{17} K^{18} and K^{19} for H2/LMD/ICEV, H2/LMD/FCV, H2/HD/ICEV and H2/HD/FCV, respectively.

Determine the amount of fuel used in each engine type.

$E_{FF} = E_1$

$E_{FF}^{16} = x^{16} E_{FF}$ where x^{16} is the fraction of fuel used for H2/LMD/ICEV and
$E_{FF}^{17} = x^{17} E_{FF}$ where x^{17} is the fraction of fuel used for H2/LMD/FCV and
$E_{FF}^{18} = x^{18} E_{FF}$ where x^{18} is the fraction of fuel used for H2/HD/ICEV and
$E_{FF}^{19} = x^{19} E_{FF}$ where x^{19} is the fraction of fuel used for H2/HD/FCV.

Using the ARB GREET fuel pathways, the LCFS-blendstock average carbon fuel intensity value, $BAFCI_i$, for the selected H2 LCFS-blendstock is determined. The overall $BAFCI$ of the finished fuel is determined by

$$AFCI_{FF}(gCO2e/MJ) = (BAFCI_1)$$

The AFCI for light-duty use is

$$\boxed{AFCI_{reported}^{LMD}(gCO2e/MJ) = \frac{(AFCI_{FF})\left[(K^{16})(E_{FF}^{16}) + (K^{17})(E_{FF}^{17})\right]}{E_{FF}^{16} + E_{FF}^{17}}}$$

The AFCI for heavy-duty use is

$$\boxed{AFCI_{reported}^{HD}(gCO2e/MJ) = \frac{AFCI_{FF}\left[(K^{18})(E_{FF}^{18}) + (K^{19})(E_{FF}^{19})\right]}{E_{FF}^{18} + E_{FF}^{19}}}$$

The overall credits received (or in deficit) for hydrogen used in light-duty and heavy-duty applications, according to Eqn. 4.1, are

$$Credits^{LMD}(MMT) = \left(AFCI_{gasoline} - AFCI_{reported}^{LD}\right)(E_{FF}^{16} + E_{FF}^{17})(C) \quad \text{and}$$

$$Credits^{HD}(MMT) = \left(AFCI_{diesel} - AFCI_{reported}^{HD}\right)(E_{FF}^{18} + E_{FF}^{19})(C)$$

Where $Credits^{TOT} = Credits^{LMD} + Credits^{HD}$ is the total credit received (or in deficit) for the fuel provider.