APPENDIX F

METHODOLOGIES FOR ESTIMATING POTENTIAL GHG AND CRITERIA POLLUTANT EMISSIONS CHANGES DUE TO THE PROPOSED LCFS AMENDMENTS

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APPENDIX F

METHODOLOGIES FOR ESTIMATING POTENTIAL GHG AND CRITERIA POLLUTANT EMISSIONS CHANGES DUE TO THE PROPOSED LOW CARBON FUEL STANDARD AMENDMENTS

This appendix describes the methodologies staff used to estimate changes in GHG and criteria pollutant emissions due to the proposed LCFS Amendments.

A. Methodology for Estimating Changes in Criteria Pollutant Emissions from California Alternative Fuel Facilities and Petroleum-Based Projects

1. Estimated Emissions from the Increase in Production of Alternative Fuel in California

Staff expects the proposed amendments will increase the production of low carbon fuels in California, which will result in increased emissions at these production facilities. To estimate the increase in in-state low carbon fuel production (Table F-1), staff multiplied the estimated change in total production for each fuel (relative to the 2016 baseline) by the assumed proportion of low-CI production that will occur in-state (Table F-2).

Table F-1: Estimated Increase in In-State Low Carbon Fuels Production for 2019 to 2030 Relative to Baseline

	Cellulosic Ethanol (MMgal)	Biodiesel (MMgal)	Renewable Diesel (MMgal)	Alternative Jet Fuel (MMgal)	Renewable Propane (MMDGE)	Dairy RNG (MMDGE)
2019	0.47	28.44	39.77	1.24	2.39	1.13
2020	0.88	38.17	55.88	2.48	2.93	1.59
2021	1.35	47.89	68.27	4.96	3.35	2.11
2022	1.90	57.61	80.66	7.43	3.45	3.09
2023	2.59	81.92	80.66	9.91	3.45	5.05
2024	3.55	81.92	80.66	18.59	3.45	7.49
2025	4.79	81.92	80.66	24.78	3.45	10.46
2026	5.97	81.92	80.66	24.78	3.45	13.63
2027	7.32	81.92	93.05	24.78	3.45	16.92
2028	9.24	81.92	105.44	24.78	3.45	21.30
2029	11.04	81.92	105.44	24.78	3.45	25.83
2030	14.03	81.92	105.44	24.78	3.45	27.39

Table F-2: Assumed Proportion of Alternative Fuels Production in California

Fuel	Percentage	Notes
Cellulosic Ethanol	12%	Assumed the same percentage as 2016 in-state percentage of starch ethanol, as staff believes most cellulosic will come from bolt-on upgrades to convert corn kernel fiber or other cellulosic materials at existing starch ethanol plants.
Renewable Diesel, Gasoline, Propane, and Jet Fuel	12%	Assumed the same percentage as the 2016 California proportion for renewable diesel, obtained from LCFS data.[1]
Biodiesel	24%	Assumed the same percentage as the 2016 California proportion for biodiesel, obtained from LCFS data.
Dairy RNG	33%	Assumed[2]

Staff calculated increases in criteria pollutant emissions associated with the production increases by multiplying facility emission factors, summarized in Table F-3, by the assumed increase in in-state production.

Table F-3: Estimate Alternative Fuel Production Facility Emission Factors (tons/million gallons)

Fuel Production	TOG	ROG	CO	NOx	SOx	PM	PM_{10}	$PM_{2.5}$
Ethanol	0.251	0.198	0.124	0.125	0.032	0.374	0.196	0.112
Cellulosic Ethanol	0.279	0.220	0.218	0.232	0.094	1.439	0.634	0.361
Renewable Diesel, Gasoline, Propane, and Jet Fuel	0.725	0.407	0.290	0.094	0.013	0.022	0.022	0.021
Biodiesel	1.003	0.832	0.099	0.67	0.009	0.017	0.017	0.017
Dairy RNG	--	--	1.533	0.906	0.260	--	0.236	0.248

The methods for determining the estimated emission factors for each alternative fuel are described below.

[1] Hydrotreating of fats, oils and greases results in the production of renewable diesel, renewable gasoline, renewable jet fuel, and renewable propane. Because all four alternative fuels are produced at the same facilities, staff assumed the same proportion would be produced in California.

[2] In the period of 2012-2016, California dairies account on average 20 percent of the national milk production. Since the State is actively pursuing policies to incent California dairies to mitigate GHG emissions, by providing grants and other programs, staff assumes that the ratio of in-state production will be higher than California's share of milk production. Source: USDA, "Dairy Data, Milk Cows and Production by State and Region (Annual)," Website: https://www.ers.usda.gov/webdocs/DataFiles/48685/milkcowsandprod_1_.xlsx?v=42866, Accessed: November 2017.

- **Ethanol:** Staff divided the 2015 emissions from Aemetis Advanced Fuels, Pacific Ethanol's Madera and Stockton facilities, Pixley Ethanol, and Parallel Products facilities[3], by the 2015 total production volume of 192.47 million gallons obtained from LCFS data.

- **Cellulosic Ethanol:** Staff obtained average estimated criteria pollutants emissions of seven pre-commercial or "demonstration" cellulosic ethanol refineries in the U.S, and similar permit data for four commercial U.S. corn ethanol facilities that were selected randomly from available permit documentation, and calculated emission ratios between cellulosic ethanol facilities and corn ethanol facilities[4]. Staff then multiplied this ratio by the emission factors for California corn ethanol facilities to estimate the emission factors for cellulosic ethanol facilities in California.

- **Renewable Diesel, Renewable Gasoline, Propane, and Jet Fuel:** Staff assumed the production facility for these fuels to have similar emissions to a simple oil refinery. Staff divided the 2015 emissions of Kern Oil & Refining Co.[12] by the 2015 production volume for this facility obtained from LCFS data.

- **Biodiesel:** Staff divided 2015 emissions from American Biodiesel, Imperial Western Products, Crimson Renewable Energy, and Springboard Biodiesel facilities[12] by the 2015 production volume of 22.51 million gallons obtained from LCFS data.

- **Dairy RNG:** Staff obtained the criteria pollutants emissions for dairy RNG from GREET 2016, which encompasses the emissions from animal waste transportation, RNG production (anaerobic digestion of animal waste), upgrading, and compression. Staff assumed that 10 percent of RNG is flared and 90 percent is compressed for pipeline injection. Flaring emission factors were obtained from GREET 2016[6]. GREET 2016 has no emission factors for TOG, ROG, and PM. Because GREET generally provides much higher emissions estimates than actual California facilities, staff calculated average ratios of GREET emissions relative to actual emissions from California ethanol and biodiesel facilities, and assumed that dairy RNG projects have the same ratios. Staff then multiplied the ratios by the emission factors for GREET dairy RNG to estimate the emission factors for dairy RNG facilities in California.

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[3] Facility emissions were obtained from CARB's Facility Search Engine: https://www.arb.ca.gov/app/emsinv/facinfo/facinfo.php?dd=. Accessed: November 2017.

[4] Jones, Donna Lee, "Potential Air Emission Impacts of Cellulosic Ethanol Production at Seven Demonstration Refineries in the United States," *Journal of the Air & Waste Management Association*, 60:9, 1118-1143. DOI: 10.3155/1047-3289.60.9.1118, 2010.

2. Estimated Emissions Change from Implementation of Petroleum-Based Projects

Staff expects the proposed amendments will increase the number of petroleum-based projects. The LCFS provides opportunities to reduce the carbon intensity in conventional petroleum supply chains, which includes producing crude oil using innovative methods such as implementation of CCS, solar steam, and renewable electricity projects at oil fields. Solar steam projects in California's San Joaquin Valley, in particular, may be a significant source of LCFS credits through 2030. Staff estimated criteria pollutant emission reductions in the San Joaquin air basin by assuming that solar steam generation would displace generation of steam using natural gas fired steam generators. Staff estimated emission factors (Table F-4) for natural gas fired steam generators by dividing 2015 emissions data from CEPAM by 2015 steam generation volumes from the Division of Oil, Gas, and Geothermal Research (DOGGR).[5]

Table F-4: 2015 Estimated Emission Factors for Solar Steam Displacing Steam Generated using Natural Gas Fired Boilers (tons/mm bbls cwe)

TOG	ROG	CO	NOx	SOx	PM	PM_{10}	$PM_{2.5}$
-1.34	-0.57	-0.47	-1.56	-0.27	-1.32	-1.32	-1.32

B. Methodology for Estimating Changes in Criteria Pollutant Emissions from Feedstock and Finished Fuel Transport

As discussed in the previous section, staff expects the proposed amendments will increase the production of low carbon fuels in California, which will increase the transportation and distribution of biofuel feedstocks and finished fuels. To estimate the in-state low carbon fuel production (Table F-1), staff estimated the proportion of low-CI production that will occur in-state, and multiplied this by the estimated change in total production for each fuel.

The amount of feedstock required to produce the low carbon fuels were calculated using the increase production volume and production yield of each biofuel. Assumptions regarding production yields were obtained from GREET 2016[6] and are tabulated in Table F-5.

[5] Steam injection rates for California oil fields were obtained from monthly production and injection reports at ftp://ftp.consrv.ca.gov/pub/oil/monthly_production_reports/. Staff assumed that 73 percent of steam was produced using steam generators and 27 percent in cogeneration units.

[6] Argonne National Laboratory (ANL), The Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model, 2016.

Table F-5: Assumed Production Yield of Low Carbon Fuels

Fuel	Feedstock	Yield
Cellulosic Ethanol	biomass (12% moisture)	85 gal/dry ton
Biodiesel	used cooking oil, tallow, vegetable oil	0.137 gal/lb
Renewable Diesel	used cooking oil, tallow, vegetable oil	0.139 gal/lb
Alternative Jet Fuel	used cooking oil, tallow, vegetable oil	0.141 gal/lb
Renewable Propane	used cooking oil, tallow, vegetable oil	0.142 lb/lb AJF

Staff estimated emission factors for on-road biomass and biofuel transportation (Table F-6) by dividing forecasted emissions of criteria pollutants for heavy-duty diesel trucks between 2019 and 2030[7] (which include emissions from diesel combustion, rubber tires, and break dust) by the forecasted volume of diesel consumed in heavy-duty diesel trucks[8]. This value was then converted to a per mile basis assuming a vehicle efficiency of 5 mpg[9].

Table F-6: Emission Factors of Heavy-Duty Diesel Trucks (g/mi/truck)

	TOG	ROG	CO	NOx	SOx	PM	PM_{10}	$PM_{2.5}$
2019	0.24	0.17	0.80	5.81	0.02	0.14	0.14	0.07
2020	0.23	0.16	0.80	5.53	0.02	0.14	0.14	0.07
2021	0.23	0.16	0.81	5.16	0.02	0.15	0.14	0.07
2022	0.22	0.15	0.82	4.76	0.02	0.15	0.15	0.06
2023	0.17	0.11	0.73	2.96	0.02	0.14	0.14	0.06
2024	0.18	0.11	0.75	2.95	0.02	0.14	0.14	0.06
2025	0.18	0.11	0.77	2.93	0.02	0.15	0.15	0.06
2026	0.18	0.11	0.79	2.91	0.02	0.15	0.15	0.06
2027	0.19	0.11	0.80	2.89	0.02	0.15	0.15	0.06
2028	0.19	0.11	0.82	2.88	0.02	0.16	0.15	0.06
2029	0.19	0.11	0.84	2.88	0.02	0.16	0.16	0.06
2030	0.19	0.12	0.85	2.88	0.02	0.16	0.16	0.06

Staff estimated the emission factors for rail transportation of biomass and imported alternative fuels (Table F-7) by dividing forecasted criteria pollutant emissions for class I line haul and class III shortline locomotives for years 2019 through 2030[7] by the

[7] CARB. Criteria Emissions (CEPAM) 2016 SIP - Standard Emission Tool. Website: https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php. Accessed: November 2017.

[8] California Air Resources Board (CARB), EMission FACtors (EMFAC) 2014, Website: https://www.arb.ca.gov/msei/categories.htm, Accessed: November 2017.

[9] The International Council on Clean Transportation (ICCT), "The U.S. Supertruck Program Expediting the Development of Advanced Heavy-Duty Vehicle Efficiency Technologies," White Paper, June 2014, Website: http://www.theicct.org/sites/default/files/publications/ICCT_SuperTruck-program_20140610.pdf

forecasted volume of diesel consumed in these freight locomotives[10]. This value was then converted to a ton*mile basis by dividing by an assumed fuel efficiency for freight locomotives of 470 ton*mi/gal[11].

Table F-7: Estimated Emission Factors for Transportation by Freight Locomotives (10^{-3} g/ton*mi)

	TOG	ROG	CO	NOx	SOx	PM	PM_{10}	$PM_{2.5}$
2019	9.75	8.19	58.85	205.33	0.98	3.20	3.21	2.92
2020	8.77	7.37	58.82	193.41	0.97	2.95	2.96	2.71
2021	8.35	7.01	58.79	182.67	0.96	2.79	2.80	2.56
2022	7.86	6.60	58.77	171.08	0.95	2.62	2.63	2.41
2023	7.43	6.24	58.74	160.40	0.94	2.46	2.47	2.26
2024	6.90	5.79	58.71	147.36	0.93	2.26	2.27	2.08
2025	6.37	5.35	58.68	134.95	0.92	2.07	2.08	1.91
2026	5.88	4.94	58.66	122.51	0.91	1.88	1.89	1.74
2027	5.47	4.60	58.63	111.23	0.90	1.71	1.71	1.57
2028	5.08	4.26	58.61	100.30	0.89	1.53	1.54	1.41
2029	4.69	3.94	58.58	89.73	0.88	1.37	1.37	1.26
2030	4.33	3.64	58.56	79.77	0.87	1.21	1.22	1.12

These emission factors were then used to estimate emissions for feedstock and finished fuel transport using the following assumptions.

- **In-State Feedstock Transportation:** The cellulosic feedstock is assumed to be delivered by 25-ton capacity trucks (feedstock is adjusted for moisture content). The average roundtrip distance traveled per truck is assumed to be 50 miles. Used cooking oil is assumed to travel within a 100-mile radius of a refinery by 7,500-gallon capacity trucks. Tallow and vegetable oil are assumed to travel within a 300-mile radius of a refinery by rail, which is consistent with the transportation scenario of AltAir's biorefinery in Paramount, California[12].

- **In-State Biofuel Distribution:** In-state ethanol and biodiesel is assumed to travel by 7,500-gallon tanker trucks from a biorefinery to blending terminals. The average roundtrip distance traveled per truck is assumed to be 200 miles. Renewable diesel, AJF, and renewable propane are assumed to travel 20 miles

[10] CARB, Off-Road Diesel Emissions Inventory 2017, Website: https://www.arb.ca.gov/msei/ordiesel.htm, Accessed: November 2017.

[11] U.S. Department of Transportation, "Class I Rail Freight Fuel Consumption and Travel," Website: https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_04_17.html. Accessed: November 2017.

[12] AltAir Fuels, "Paramount, CA GreenJet Refinery," Website: https://www.smgov.net/uploadedFiles/Departments/Airport/Sustainability/20150126_AltAir_Presentation.pdf

roundtrip by 7,500-gallon tanker trucks to the blending facility, which is consistent with the distribution distance of renewable diesel from AltAir's biorefinery in Paramount, California[7].

- **Out-of-State Biofuel Transportation and Distribution:** Imported biofuel is assumed to travel by unit train from the U.S into California railyards located within a 200-mile radius from the state border. Biofuel is assumed to then travel 100 miles in 7,500-gallon tanker trucks to blending terminals.

- **Empty Returns of Truck and Train:** Staff adjusted the emission factors for empty returns to reflect the difference in environmental impacts from loaded and empty mileage. The differences in emissions are assumed to be proportional to the energy savings from weight reduction during empty returns. The Institute for Energy and Environmental Research (IFEU) suggests that commercial trucks and freight rail can achieve 3.1 percent and 5 percent of relative energy savings per 10 percent weight reduction, respectively[13]. Therefore, it is estimated that emissions of empty trucks are 21 percent lower than loaded trucks, and emissions of empty rail cars are 36.5 percent lower than loaded cars.

C. Methodology for Estimating Changes in Criteria Pollutant Emissions from Use of Alternative Jet Fuel

Staff is proposing an amendment to include alternative jet fuels (AJF) in the LCFS as an opt-in fuel to generate credits. Staff expects that the proposed amendment will increase the production of AJF and its use at California airports.

International Civil Aviation Organization (ICAO) is responsible for setting emission measurement procedures and compliance standards, which are based on a standardized landing and take-off (LTO) cycle developed to address ground level air quality issues. The LTO cycle is comprised of taxi-out, take-off, climb-out, approach, landing and taxi-in modes. Emissions between ground level up to 3,000 feet in altitude are included.

NASA[14] tested a variety of AJF fuel mixtures from January 19 to February 3, 2009, to assess changes in the aircraft's CFM-56 engine performance and emission parameters relative to operation with standard JP-8. The experiment results of JP-8 and Fischer Tropsch (FT)/JP-8 fuel blend are shown in Table F-9.

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[13] Institute for Energy and Environmental Research (IFEU), *Energy savings by light-weighting – II*, Final Report, Heidelberg, Germany, June 2004.

[14] The NASA Langley Aerosol Research Group. Website: https://science.larc.nasa.gov/large/data. Accessed: April 2017.

Table F-9: Criteria Pollutants of Fossil Jet Fuels (JP-8) and AJF Blend

		Engine thrust						
		4%	**7%**	**30%**	**45%**	**65%**	**85%**	**100%**
JP-8	**CO**	1031.68	611.71	92.84	41.87	26.25	25.60	28.47
	NOx	15.36	20.21	52.10	73.89	107.95	151.39	174.31
	NO	2.95	4.45	42.03	63.74	96.11	136.30	157.36
	HC	267.14	101.46	11.01	6.14	4.70	5.60	13.13
	SO_2	10.09	10.10	10.96	12.63	14.93	16.79	18.58
FT/JP-8 blend	**CO**	907.00	521.07	71.64	37.08	22.96	22.03	27.30
	NOx	14.24	16.38	47.63	66.44	95.90	134.80	159.01
	NO	3.05	3.74	38.96	57.11	84.68	120.07	142.30
	HC	232.63	91.92	7.40	4.70	3.94	3.82	5.74
	SO_2	4.52	4.63	6.64	7.62	9.27	11.12	11.66

The NOx and SOx emission reductions of an AJF blend during the LTO cycle were calculated based on the NASA experiment results shown above. Similarly, staff estimated the PM emission reductions of an AJF blend based on a study burning conventional and AJF blend fuels in a CFM56-7B commercial jet engine[15]. The calculated ratios of NOx, PM and SOx emissions for AJF blend fuels relative to fossil jet fuels are tabulated in Table F-10.

Table F-10: NOx, PM and SOx Emission of AJF Blend Normalized to Fossil Jet Fuels

	NOx	**PM**	**SOx**
Taxi (7% thrust)	0.81	0.35	0.46
Approach (30% thrust)	0.91	0.37	0.61
Climb (85% thrust)	0.89	0.64	0.66
Take-Off (100% thrust)	0.91	0.6	0.63

Staff estimated the percentages of fuel consumed during each phase of the LTO cycle assuming that fuel flow is proportional to engine thrust, which is corroborated by a study examining fuel combustion in six jet engines[16]. Using information from Tables F-10 and F-11, staff estimates that replacing conventional jet fuels with AJF blend fuels can achieve reductions of 12.6 percent, 45 percent and 40 percent for NOx, PM and SOx, respectively, for fuels consumed within the California air basin.

[15] Lobo, Prem, Hagen, D.E., Whitefield, P.D., "Comparison of PM Emissions from a Commercial Jet Engine Burning Conventional, Biomass, and Fischer-Tropsch Fuels," *Environmental Science & Technology*, 2011, 45 (24), pp 10744–10749.

[16] Carter, Nicholas A., Stratton, R.W., Bredehoeft, M.K., and Hileman, J.I., "Energy and Environmental Viability of Select Alternative Jet Fuel Pathways," 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, San Diego, CA, AIAA 2011-5968, 31 July - 03 August 2011.

Table F-11: Power Setting, Time and Fuel Consumption in LTO Cycle

Mode	Engine thrust	duration (mins)	LTO Fuel consumption
Taxi-In and Taxi-Out	7%	26	32.56%
Take-Off	100%	0.7	12.52%
Climb	85%	2.2	33.45%
Approach	30%	4	21.47%

Approximately 1.69 percent, 32.29 percent, and 0.97 percent of jet fuels are consumed by intrastate, interstate and international flights, respectively, during the LTO cycle, while the remainder are consumed during cruise[17]. Intrastate flights consume all LTO fuels within the California air basin, while outbound interstate and international flights consume 62.25 percent of LTO fuels within the California air basin (during taxi-out, take-off and climb). Therefore, staff estimates that approximately 22.4 percent of total jet fuels loaded onto aircraft at California airports are combusted within the California air basins.

Combustion of jet fuels also contribute to CO and unburned hydrocarbon (UHC) emissions. However, studies on AJF combustion show conflicting results for emissions of these two criteria pollutants relative to conventional jet fuel. Studies show that CO and UHC emissions are very low at higher power settings and only significant at the lowest power setting[18]. Reductions in these two pollutants when using AJF are most pronounced at near idle settings[16]. One study shows that 100 percent FT fuels result in 21 percent and 31 percent reduction in CO at ground idle (3 percent engine thrust) and at 7 percent idle respectively, while 50 percent FT fuel blends result in 4 percent and 18 percent reduction in CO at ground idle and at 7 percent idle, respectively[19]. Another study concluded that use of AJF results in 10 to 25 and 20 to 30 percent reduction in CO and UHC during idle, respectively[20]. In contrast to the reductions discussed above, ASTM research reports concluded that CO and UHC emissions were highly variable because of the low emission level, but the AJF blend showed an increase in CO (5 to 9

[17] CARB, 2016 Vision 2.1., Website: https://www.arb.ca.gov/planning/vision/downloads.htm, Accessed: November 2017.

[18] Boeing Company, UOP, U.S. Air Force Research Laboratory, "Evaluation of Bio-Derived Synthetic Paraffinic Kerosenes (Bio-SPKs)," Report Version 5.0, Committee D02 on Petroleum Products and Lubricants, Subcommittee D02.J0.06 on Emerging Turbine Fuels, Research Report D02-1739, ASTM International, West Conshohocken, PA, 28 June 2011.

[19] Timko, Michael T., Herndon, S.C., Blanco, d.E., Wood, E.C., Yu, Z., Miake-Lye, R.C., Knighton, W.B., Shafer, L., DeWitt, M.J., Corporan, E., "Combustion Products of Petroleum Jet Fuel, a Fischer-Tropsch Synthetic Fuel, and a Biomass Fatty Acid Methyl Ester Fuel for a Gas Turbine Engine," *Combustion Science and Technology*,183:10, 1039-1068, DOI: 10.1080/00102202.2011.581717, 2011.

[20] Corporan, Edwin, Edwards, T., Shafer, L., DeWitt, M.J., Klingshirn, C.D., Zabarnick, S., West, Z., Striebich, R., Graham, J.,Klein, J., "Chemical, Thermal Stability, Seal Swell, and Emissions Studies of Alternative Jet Fuels," *Energy & Fuels*, 25, 955-966, 2011.

percent) and UHC (20 to 45 percent), which might be explained by reduction in flame temperature and combustion efficiency[18,21].

D. Methodology for Estimating Changes in Criteria Pollutant Emissions from Use of Biodiesel and Renewable Diesel

See Appendix G to the ISOR.

E. Methodology for Estimating Changes in GHG Emissions Attributable to the Low Carbon Fuel Standard

Table F-12 summarizes the methodology developed by staff for attributing GHG emission reductions associated with actions taken under the proposed amendments to either the LCFS or to other programs. GHG emission reductions associated with a given action are only assigned to the LCFS if complying with the LCFS can be argued to be the primary reason for the action. For example, the adoption of EVs by California consumers is most appropriately attributed to the ZEV regulation and other State and federal vehicle rebate programs. However, the use of renewable electricity in place of grid average electricity to charge these vehicles is most appropriately attributed to the LCFS. Therefore, staff has attributed only the incremental GHG emission reductions associated with using renewables to lower the CI value of electricity below the grid average CI to the LCFS.

Table F-12: Attribution of GHG Reductions for the LCFS Proposed Amendments

Fuel or Project Type	Action	Primary Attribution
Electricity	Switch to EVs that are charged with electricity at the grid average CI	Light-duty/heavy-duty/off-road ZEV regulations and other vehicle incentive/rebate programs.
	Use of renewables to reduce the CI for charging below the grid average	LCFS
Hydrogen	Switch to FCEVs using hydrogen produced with 33 percent renewable content	Light-duty/heavy-duty/off-road ZEV regulations and other vehicle incentive/rebate programs. SB 1505 requiring 33 percent renewables.

[21] Edwards, Tim, Meyer, D., Johnston, G., McCall, M., Rumizen, M., Wright, M., "Evaluation of Alcohol to Jet Synthetic Paraffinic Kerosenes (ATJ-SPKs)," Report Version (1.10), Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants, Subcommittee D02.J0 on Aviation Fuels, Research Report D02-1828, ASTM International, West Conshohocken, PA, 1 April 2016.

	Use of greater than 33 percent renewables to reduce the CI of hydrogen used in FCEVs	LCFS
Natural Gas	Switch to NG vehicles operating with fossil NG	Vehicle incentive/rebate programs and low NG prices relative to diesel
	Switch from fossil NG to landfill RNG	RFS – cellulosic RIN value
	Switch from landfill to dairy digester RNG	LCFS
Propane	Switch from fossil propane to renewable propane	LCFS
Starch Ethanol	Use of starch ethanol with an average CI of 80 g/MJ	RFS – 20 percent CI reduction to qualify as renewable fuel
	Reduction in CI of ethanol below 80 g/MJ	LCFS
Sugar Ethanol	Use of sugar ethanol with an average CI of 50 g/MJ	RFS – 50 percent CI reduction to qualify as advanced biofuel
	Reduction in CI of sugar ethanol below 50 g/MJ	LCFS
Cellulosic Ethanol	Use of cellulosic ethanol with an average CI of 40 g/MJ	RFS – 60 percent CI reduction to qualify as cellulosic biofuel
	Reduction in CI of cellulosic ethanol below 40 g/MJ	LCFS
Refinery Projects	Implementation of projects under the RIC and renewable hydrogen for refineries provisions	LCFS
Crude Projects	Implementation of solar steam, solar/wind electricity, and CCS projects under the innovative crude provision	LCFS
Biodiesel	Use of vegetable oil based biodiesel with a CI of 50 g/MJ	Blenders tax credit and RFS – 50 percent CI reduction to qualify as biomass-based diesel
	Reduction of CI below 50 g/MJ using waste based feedstocks	LCFS
Renewable Diesel	Use of vegetable oil based renewable diesel with CI of 50 g/MJ	Blenders tax credit and RFS – 50 percent CI reduction to qualify as biomass-based diesel
	Reduction of CI below 50 g/MJ using waste based feedstocks	LCFS

Alternative Jet Fuel	All emission reduction	LCFS