Title

Multijurisdictional Status Review of Low Carbon Fuel Standards, 2010–2020 Q2: California, Oregon, and British Columbia

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California, Oregon, and British Columbia

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Multijurisdictional Status Review of Low Carbon Fuels Standards, 2010–2020 Q2

Highlights

- California and British Columbia transportation fuel carbon intensity (CI) standards have been in effect since 2011, and Oregon's since 2016. Total transport energy consumption under the programs was over 23 billion gasoline gallon equivalents (gge) in 2019.
- By 2019, the transport energy share from lower-carbon alternative fuels rose under each program to about 11%, 8%, and 7% in California, Oregon, and British Columbia, respectively.
- Each program met its CI targets and accumulated a bank of credits, which represent greenhouse gas (GHG) emission savings beyond the annual target. Credits cover program deficits assessed for emissions above target levels and can be applied towards future compliance. California and British Columbia drew down their credit banks each year since 2017; Oregon's credit bank grew since the 2016 program start.
- Program credit prices in 2020 averaged $200/metric ton (MT), $132/MT, and $192/MT (all $USD) in California, Oregon, and British Columbia, respectively.
- In California, growth of cost-effective diesel substitutes led to over-compliance with the diesel pool standard (a 25% CI reduction for California in 2020), more than offsetting under-compliance in the gasoline pool (a 3% CI reduction there). The same is true in Oregon and British Columbia to a lesser extent.
- Renewable diesel (RD) generated a notable share of compliance credits in each jurisdiction, despite zero or near-zero volumes when the programs began. In 2019, RD accounted for more than 16% by volume of the liquid diesel pool in California and approximately 30% of alternative fuel energy and credits in British Columbia. RD was first credited in Oregon in 2019.
- Biomass-based diesel from used cooking oil grew rapidly; 2019 consumption increased by at least 70% over previous year in all three programs.
- Low-CI rated electricity (i.e., below the state grid average) accounted for approximately 4% of all credits in California beginning in 2019, after indirect accounting mechanisms that avoid the need for physical traceability became available. Oregon expanded its low-CI value electricity options in 2021 in a similar fashion to California.
- California's is the only program to track and penalize increasing CI of petroleum fuels. Additional deficits accrued in 2020, totaling 192,000 – 2.6% of the total – through Q2.
- All three programs continue to adopt amendments, including extending targets and program durations (20% CI reduction by 2030 for all); opt-in credits for alternative jet fuel (California and Oregon); use of advanced crediting for electric vehicle (EV) charging (California and Oregon); an EV rebate program funded by residential charging credit revenue (California); infrastructure capacity crediting for zero emission vehicle (ZEV) fueling (California); third-party verification (California and Oregon), and carbon capture and sequestration protocol (California).
- Washington state passed legislation adopting a Clean Fuel Standard to take effect in 2023.
- An online visualization tool and data repository, available at https://asmith.ucdavis.edu/data/LCFS, includes much of the data used in this report.

Introduction

A fuel carbon intensity standard, such as California's Low Carbon Fuel Standard (LCFS), Oregon's Clean Fuels Program (CFP) or British Columbia's Renewable & Low Carbon Fuel Requirements (RLCFR, also known as an LCFS), aims to reduce transportation sector greenhouse gas (GHG) emissions by incentivizing innovation, technological development, and deployment of low-emission alternative fuels and vehicles. These programs set a performance standard that considers the full lifecycle impacts of fuel production and use while treating all transportation fuels similarly, allowing consumers and markets to determine the path to compliance.

These policies set an average carbon intensity (CI) benchmark, measured in grams of carbon dioxide equivalent per megajoule of fuel energy (gCO_2e/MJ, based on equivalent-mass 100-year global warming potentials), that regulated fuels provided for use in the jurisdiction must, as a group, meet. All regulated fuel volumes are assigned a CI rating based on an assessment of their lifecycle (production to combustion) GHG emissions. Fuels with more emissions than the benchmark generate program deficits; those with fewer emissions earn program credits. The benchmark grows more stringent over time. Compliance requires sufficient credits to offset deficits. Fuel refiners, importers, or distributors are typically the obligated party, and can meet their obligation by reducing the carbon intensity of their fuel to meet the standard, generating credits internally, or purchasing credits from alternative fuel producers. Credits can be banked for future use and traded, creating a financial incentive to lower fuel carbon intensity.

Currently, three jurisdictions along the Pacific Coast of North America have operational LCFS policies as part of their broader strategy to lower GHG emissions: California, Oregon, and British Columbia (BC). This trio plus Washington, which enacted a Clean Fuel Standard to begin in 2023, pledged to pursue policies to create a market for lower carbon fuel in the region under the auspices of the Pacific Coast Collaborative Climate Leadership and Action Plan [1]. Brazil also has a transport fuel carbon intensity standard called RenovaBio, which applies only to renewable liquid fuels. Colorado, New Mexico, and New York have considered developing LCFS-like programs, and as of this writing, Canada has released a proposed federal fuel CI standard, to be finalized late in 2021 and take effect in December 2022.

This LCFS status report is the latest in a series of updates based on program metrics. It focuses on the programs in the Pacific Coast Collaborative (PCC) jurisdictions of California, Oregon, and BC, and covers 2010 through 2020 Q2 (the most recent data available at the time of writing). For ease of exposition in this report, we refer to this group of transport fuel CI standards as LCFS programs, and these jurisdictions as LCFS jurisdictions.

COVID-19 has significantly impacted the transportation sector. The pandemic led to a severe decline in demand for transportation fuels, especially in Q2 and Q3 2020. Supply of crude oil and petroleum products fell by nearly a billion barrels from 2019 to 2020 [2]. This downward demand shock decreased LCFS deficits and thus demand for credits. The demand decrease was more pronounced in the gasoline pool, since personal travel and work commutes were more strongly impacted than consumer behavior, and the surge in home delivery of goods supported demand in the logistics sector [3]. BC was the sole jurisdiction to adjust its 2020 standard, from 10% to 9.1%, to assist the oil and gas sector with low oil prices and demand resulting from the pandemic.

The remainder of this report is structured as follows: Section 1 introduces and provides an overview of the policies in the three jurisdictions, their reported CI trends, and program credit/deficit balance. Section 2 describes the sources of alternative fuel energy use and crediting in each jurisdiction over time under the policies. Section 3 outlines trends in the reported CIs of alternative fuels over time. Section 4 describes the state of markets for program credits in each jurisdiction. Section 5 discusses trends in primary program credit generators – the major transportation fuels, i.e., ethanol, biomass-based diesel, natural gas, and electricity, emphasizing the role of feedstocks, as well as sources of credit generation beyond fuel use. Section 6 explores potential interactions among LCFS jurisdictions and relationships between LCFS credit markets and fuel markets. Section 7 offers concluding remarks and highlights potential avenues for future research.

1. Jurisdiction and Program Status – Overview

LCFS programs along the North American Pacific Coast covered transportation energy demand totaling about 23.1 billion gasoline gallon equivalents (gge) in 2019, the latest year for which complete data are available for all three jurisdictions.[i] Demand in California comprises the vast majority, just over 18 billion gge of energy. Oregon and BC each have transportation energy demand between 10% and 15% of California's (**Figure 1**).[ii] Each policy evaluates alternative fuel emissions relative to the most applicable petroleum fuel: gasoline or diesel, which effectively creates two "pools" of conventional fuel and substitutes. Deficit obligations can be satisfied with credits from either pool.

Diesel fuel and its substitutes (the "diesel pool") comprised just under a fifth of reported transportation energy demand in California (19%), just over a third in Oregon (34%), and almost half in BC (49%). This divide between fuel pools matters for compliance patterns because each pool has its own distinct mix of alternative fuel possibilities. For example, ethanol can be blended with gasoline, and biodiesel with diesel, up to blending limits established by vehicle type and regulation. Some fuels, such as electricity and hydrogen, can be used to displace both gasoline and diesel. Electricity is readily used in light-duty cars, and thus has primarily appeared as a gasoline substitute in these programs but can also be used in some types of heavy-duty vehicles and is starting to penetrate there, as well.

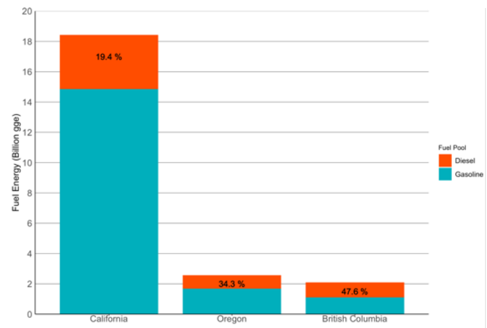

Figure 1. Jurisdiction Total Transportation Fuel Energy Used in 2019 by Fuel Type. gge = gasoline gallon equivalents (blendstock) as defined in each jurisdiction. BC's transport energy is 11.4% of CA's, OR's is 13.9% of CA's in 2019. Percentages in the figure reflect share of total energy from the diesel pool. Sources: [2] [3] [4].

LCFS policies regulate the average CI of all transportation energy consumed in jurisdiction. Figure 2 shows the schedule of annual CI reduction benchmarks as a percentage reduction from a base year for each jurisdiction. All three programs initially targeted a 10% reduction in CI over the first 10 years of implementation. California's standard was frozen from 2014–2015 due to a state court challenge related to its environmental analysis. The state's standard resumed with a program re-adoption in 2016. California's diesel standard was frozen in 2017 at 2016 levels (not depicted in Figure 2), also due to a state court case, and resumed in 2018. BC and California both set longer-term trajectories to achieve 20% reduction in the CI of transportation energy below 2010 levels by 2030 and lowered the 10% target for 2020 (to 9.1% and 7.5%, respectively). Oregon's current program targets a 10% reduction from 2015 levels by 2025; a 2020 Executive Order laid out targets of 20% in 2030 and 25% in 2035, still to be formalized by regulation.

Figure 2 also depicts the realized CI reduction for fuels reported under the program, measured as the percentage change in the energy-weighted average CI from baseline year levels, as a whole and for gasoline and diesel fuel pools separately. While average reported CI in all three jurisdictions remained close to target levels overall, the declines were driven by changes in the diesel pool, especially in the US jurisdictions and dramatically in California.

Under BC's 2019 CI reduction target of 8%, fuels achieved a 5.7% CI reduction overall, gasoline fuels achieving 2.8% and diesel fuels hitting 8.8% reductions. For California, in the first half of 2020 under a 7.5% CI reduction target, the comparable figures were 7.4% CI reduction overall, 3.2% reduction among gasoline fuels, and 25.3% reduction among diesel fuels. Through Q2 2020, Oregon's 2020 2.8% CI reduction was achieved through by a 1.1% reduction for gasoline fuels and 8.4% for diesel fuels. Where overall CI rating falls short of targets, compliance is achieved through drawing on a systemwide bank of credits from prior years.

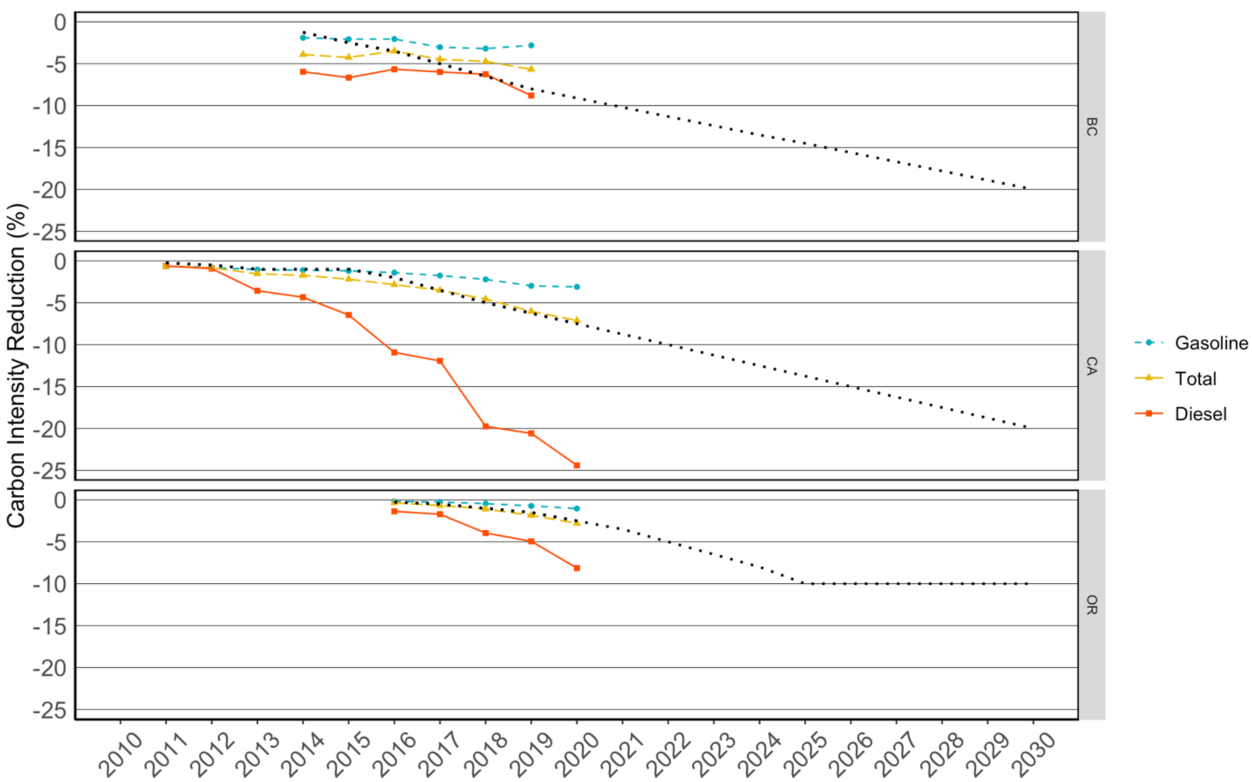

Figure 2. Percentage Reduction of Carbon Intensity by Fuel Pool and Schedules (dotted line). 2020 data, here and throughout the report, are through Q2 unless otherwise noted. 2020 data for Oregon, here and in other figures, do not reflect impact of residential electricity used as a fuel. In BC, there is insufficient information to plausibly estimate 2010–2013 credits by fuel pool. In California, the diesel standard was frozen at 2016 levels in 2017 (not depicted). Oregon has announced but not implemented a 2035 target of a 25% CI reduction. Sources: [4] [5] [6].

Together, Figure 1 and Figure 2 illustrate the divide between the gasoline and diesel pools and their roles in compliance with LCFS policies. Most of the transportation fuel consumed in each jurisdiction is E10, a blend of gasoline and 10% ethanol by volume. This 10% "blendwall" has limited the opportunities for credit generation by ethanol. In fact, alternative fuels in the gasoline pool accounted for less than half of all credits in all jurisdictions in recent years. In 2018, for example, gasoline and its substitutes constituted 80% of fuel energy in California, but the pool only generated about 40% of all credits.

In each program, fuels generated more program credits than deficits in early years, building a systemwide reserve, or bank, of credits available for compliance later, as CI targets tighten (Figure 3). BC and California both grew credit banks through 2016, then began to draw on that compliance reserve, with deficits outpacing credits (Figure 2). In California, both 2019 and 2020 through Q2 saw the pace of the bank drawdown slow, indicating that credit generation was "catching up" to deficit generation.[iii] Data for 2020 Q3 (not depicted here) showed net credit generation of about 115,000MT CO_2e. Overall, from 2011 through 2020 Q2, low carbon fuels in California generated 68.9 million LCFS credits while fuels with CI scores above the standard generated 61.4 million deficits, for a net of 7.5 million credits. In Oregon, the program totals were 4.6 million credits, 3.8 million deficits, and a net of 0.79 million credits from 2016 through 2020 Q2. In BC, data from 2013 through 2019 report 8.6 million credits and 7.4 million deficits, for a net of 1.2 million credits.

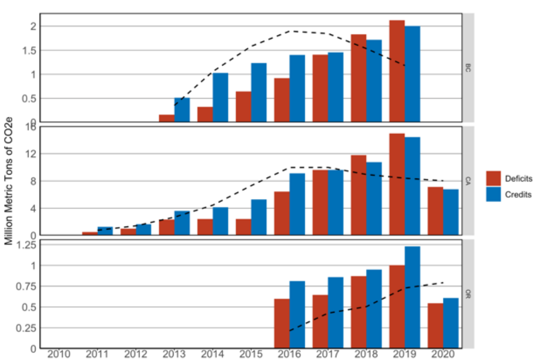

Figure 3. Total Credits, Total Deficits, and Cumulative Bank (dashed black line). Different scales per jurisdiction. Data coverage is as noted in Figure 2. Total program credits include those issued for infrastructure development for zero emission vehicle infrastructure in CA and "Part 3 Agreements" in BC. Sources: [4] [5] [6].

Not all credits issued are associated with emissions avoided due to cleaner fuels. The BC LCFS has, since its inception, included the possibility for companies to contract in "Part 3 Agreements" for projects expected to lead to low carbon fuel flows in the near future, often related to low carbon fuel production or delivery infrastructure; agreed-on credits are generated for the company at pre-agreed upon milestones in project execution. Part 3 Agreement credits were first distributed in 2015 and have accounted for between 5% and 15% of credits in years thereafter, though they can account for up to 25% of the previous year's system-wide obligation [7]. California added credit generation for zero emission vehicle (ZEV) fueling infrastructure capacity in 2019; stations open to the public are eligible to earn up to 5% of deficits generated in the prior quarter (2.5% apiece for hydrogen fueling stations and electricity fast chargers) for unused fueling capacity. In 2020, fueling capacity ZEV infrastructure credits for hydrogen and DC fast charging accounted for nearly 9%, and just over 4%, of their allowed allotments, respectively. The Oregon CFP has no analogous program; according to its rules, all credits must be tied to emissions reductions.

California's is the sole program to include provisions to account for appreciable increases in the average crude oil CI value above 2010 levels and include credit generation opportunities for reducing carbon emissions in oil production and refining relative to business as usual.[iv] "Incremental deficits" accrued to petroleum fuels for the first time in 2020 and are slated to continue in 2021, after the 2018 and 2019 assessments showed increased CI values of 0.23 and 0.41 gCO_2e/MJ, respectively. This resulted in just over 192,000 additional deficits, or 2.6% of the total, in the first half of 2020. Since 2015, innovative methods in oil production (e.g., solar used as process energy) and investments in refineries have generated about 30,000 credits.

2. Alternative Fuel Energy and Credits

Alternative (non-petroleum) fuels' share of total transportation energy increased under all the LCFS programs. Under the longest standing programs, the percent of alternative energy approximately doubled: growing from 3% to 7% between 2010 and 2019 under British Columbia's LCFS, and from 6% to 12% between 2011 and 2020 Q2 under California's program. The alternative fuel energy share in Oregon grew by about 1% in its first three years, from 7% to 8%, and edged above 9% in the first half of 2020 (Figure 4). California and Oregon program expansions to include electric off-road sources such as light rail accounted for a small portion of the alternative energy uptick starting in 2016 and 2018, respectively [4] [5].

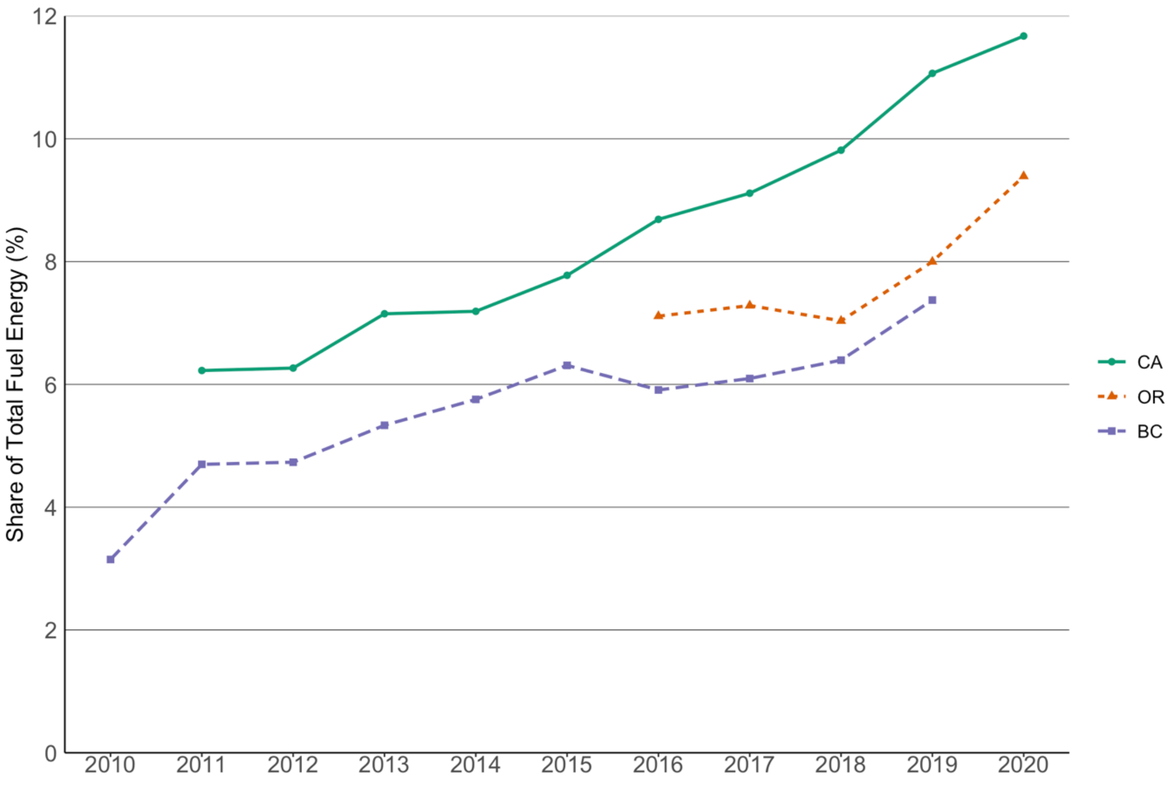

Figure 4. Alternative Fuels' Share of Total Transportation Energy in LCFS Jurisdictions. A small amount of alternative fuel energy increase in California and Oregon is due to program expansion. In this and other energy graphs, no adjustment is made for different fuels' on-road efficiency. Data coverage is as in Figure 2. Sources: [4] [5] [6].

Transport energy by fuel in each jurisdiction is detailed in and Figure 5 (left column). Liquid biofuel use grew everywhere, and non-liquid fuels like electricity and natural gas appeared to varying degrees. Ethanol continues to comprise the largest share of alternative fuel by energy content in all jurisdictions. It grew by almost 62% in BC between 2010 and 2018, before declining 11% in 2019 to a net 44% growth through that year. Liquid gasoline moved from 5% ethanol by volume systemwide at the program's outset to 7% in 2019. Ethanol remained close to 10% by volume of the liquid gasoline pool in the US jurisdictions.[v]

Biomass-based diesel — FAME biodiesel and HEFA RD grouped together[vi] — rose robustly in all three jurisdictions, especially in 2019. That year, biomass-based diesel's contribution to transport energy nearly matched ethanol's in Oregon and overtook ethanol by about 25% in BC. In California, biomass-based diesel accounted for nearly a quarter of liquid diesel by volume in 2019, up from under 1% in 2010.

In California and Oregon, renewable diesel use showed dramatic year-on-year growth after about program year 3, reaching 16% by volume of California's on-road liquid diesel fuel in 2019, and just over 4% in Oregon. BC saw dramatic growth in renewable diesel only more recently in 2019; it now makes up over 5% of on-road liquid diesel fuel and 30% of both alternative fuel energy and credits (Figure 5).

Table 1. Transportation Energy by Fuel Type in LCFS Jurisdictions, in million gge. Growth (%) column presents percentage changes from the first non-zero year to the most recent full data year. "Other" includes hydrogen and propane (plus renewable propane in Oregon, and renewable naphtha and alternative jet fuel in California). gge = gasoline (blendstock) gallon equivalents. gge is calculated using each policy's own energy density for petroleum gasoline. Data coverage is as in Figure 2. BBD = biomass-based diesel. Sources: [4] [5] [6].

BC LCFS	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 thru Q2	Growth (%)
Gasoline	1,043	983.5	942.3	955.6	994.3	1,017	1,068	1,063	1,034	1,051	-	0.77
Diesel	809.7	895.3	901.1	892.8	906.8	849.1	842.1	930.2	963.2	895.3	-	10.57
Ethanol	34.88	39.31	37.41	41.22	45.02	51.36	55.8	56.43	56.43	50.09	-	43.61
Biodiesel	14.58	22.83	20.93	22.19	23.46	24.1	24.1	24.1	26	25.36	-	73.94
Renewable Diesel	6.98	13.95	15.85	22.83	29.17	27.9	17.12	24.73	26.63	49.46	-	608.6
Fossil Natural Gas	0	0	1.9	3.17	4.44	6.98	7.61	8.88	12.05	15.14	-	380.1
Biogas	0	0	0	0	0	0	0	0	0	0.8	-	-
On-Road Electricity	0	0	0	0	0.01	0.02	0.03	0.04	0.09	0.03	-	50
Off-Road Electricity	3.8	3.85	4.07	3.96	3.85	3.91	3.9	4.41	4.44	4.66	-	22.63
Other	0	12.68	11.41	10.78	10.15	11.41	11.41	10.78	10.78	10.15	-	-19.95
Total Fuel	1,913	1,971	1,935	1,953	2,017	1,992	2,030	2,122	2,133	2,102	-	9.88
Ethanol share of finished gasoline (%)	4.72	5.55	5.53	5.95	6.23	6.94	7.21	7.08	7.31	6.54	-	38.56
BBD share of finished diesel (%)	2.7	4.08	4.14	5.02	5.85	6.01	4.96	5.31	5.56	8.25	-	205.6

CA LCFS	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 thru Q2	Growth (%)
Gasoline	-	13,125	13,211	12,973	13,334	13,445	14,053	14,069	13,779	13,738	5,498	4.67
Diesel	-	3,186	3,178	3,109	3,100	3,081	3,006	2,971	2,854	2,655	1,171	-16.67
Ethanol	-	1,004	993.4	996.4	1,000	1,010	1,076	1,061	1,079	1,049	406.9	4.48
Biodiesel	-	10.45	16.66	49.94	55.69	105.4	136.2	141.7	153.8	176.5	96.47	1,589
Renewable Diesel	-	1.55	7.55	100.2	96.71	141.5	219.1	287.5	328.7	529.6	242.3	34,068
Fossil Natural Gas	-	65.25	75.17	79.22		63.91	49.99	45.37	42.81	36.15	8.68	-44.6
Biogas	-	1.4	1.42	9.1	25.55	59.03	79.33	94.92	106.6	123.8	63.12	8,743
On-Road Electricity	-	0.39	1.36	3.72	8.74	13.41	22.82	32.89	53.38	67.6	29.07	17,233
Off-Road Electricity	-	0	0	0	0	0	39.43	44.83	45.49	50.16	23.96	27.21
Other	-	0	0	0	0	0	0	0.28	0.75	6.79	11.02	2,325
Total Fuel	-	17,394	17,484	17,321	17,706	17,919	18,683	18,748	18,443	18,433	7,551	5.97
Ethanol share of finished gasoline (%)	-	10.2	10.04	10.23	10.02	10.03	10.21	10.07	10.41	10.18	9.75	-0.2
BBD share of finished diesel (%)	-	0.4	0.8	4.81	4.9	7.76	11.02	13.14	15.03	21.73	23.2	5,332

OR CFP	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 thru Q2	Growth (%)
Gasoline	-	-	-	-	-	-	1,425	1,444	1,539	1,565	593.4	9.82
Diesel	-	-	-	-	-	-	778.3	749.6	786.7	789.8	352.9	1.48
Ethanol	-	-	-	-	-	-	116.8	114.6	113.5	114.4	46.06	-2.05
Biodiesel	-	-	-	-	-	-	48.95	52.71	53.17	61.97	32.55	26.6
Renewable Diesel	-	-	-	-	-	-	0	0.36	1.29	17.65	14.97	4,803
Fossil Natural Gas	-	-	-	-	-	-	0.66	1	1.6	1.53	0.72	131.8
Biogas	-	-	-	-	-	-	1	2.04	1.89	2.44	1.48	144
On-Road Electricity	-	-	-	-	-	-	1.26	1.56	2.13	2.79	0.09	121.4
Off-Road Electricity	-	-	-	-	-	-	0	0	1.9	2.44	1.54	28.42
Other	-	-	-	-	-	-	0.05	0.09	0.54	1.5	0.67	2,900
Total Fuel	-	-	-	-	-	-	2,372	2,366	2,502	2,560	1,044	7.93
Ethanol share of finished gasoline (%)	-	-	-	-	-	-	11.08	10.77	10.08	10.01	10	-9.66
BBD share of finished diesel (%)	-	-	-	-	-	-	6.28	7.02	6.87	9.65	14	53.66

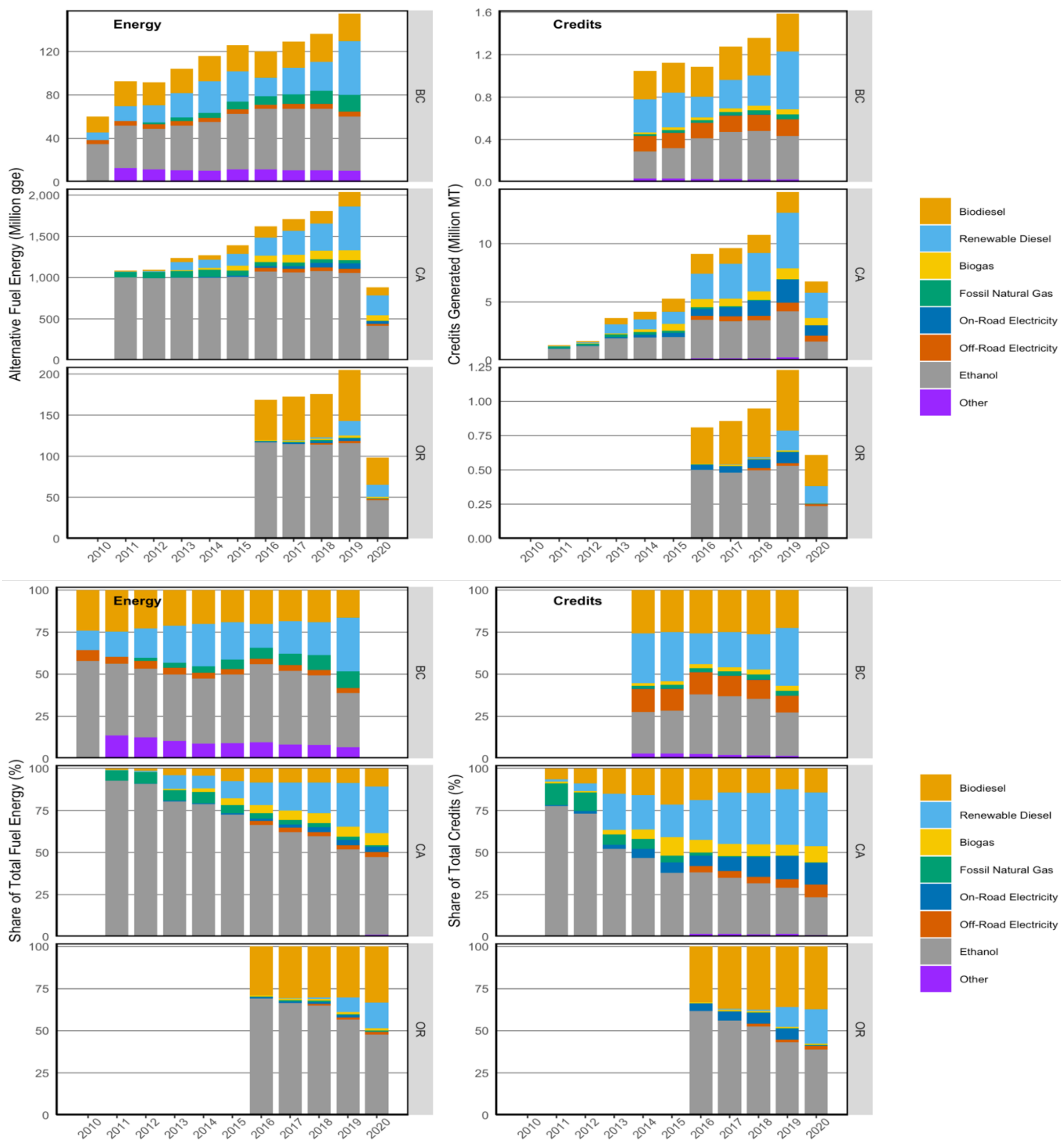

Figure 5. Alternative Fuel Energy and Credit Generation by Fuel Type, Volumes (top) and Shares (bottom). gge = gasoline (blendstock) gallon equivalents calculated using each policy's energy density for petroleum gasoline. Data coverage is as in Figure 2. In BC, credits by fuel type are estimated using data on fuel volumes and average CI ratings reported by BC Energy/Mines, for 2014 on; there is insufficient information to estimate BC 2010–2013 credits by fuel. "Other" includes hydrogen and propane (plus renewable propane in Oregon, and renewable naphtha and alternative jet fuel in California). Sources: [4] [5] [6].

Electricity and natural gas together constituted about 6% of the alternative energy in California and BC, and 1% in Oregon, at each program's outset. By 2019, non-liquid fuel energy contribution ramped up to 13% (BC), 14% (CA), and 5% (OR). In BC, natural gas energy about tripled, and came solely from fossil sources. Electricity use principally from off-road vehicles was steadier. In contrast, both natural gas and electricity grew sharply in California and Oregon. Natural gas use — predominantly biogas recognized under a book-and-claim system covering production delivered by pipeline from anywhere in North America — increased by about 140% in California (2010–2019) and in Oregon (2016–2019). Biogas accounted for 77% of transport natural gas use in California by 2019; reported fossil natural gas use declined in absolute terms. Natural gas makes much less of a contribution to transport energy in Oregon, but 67% of this energy was accounted for as biogas by 2019. Unlike California and Oregon, a significant share of heavy-duty vehicles in British Columbia run on propane, which accounts for much of the "Other" category – making up 8% of all fuel energy in 2019. Electricity from on-road vehicles grew faster than biogas in both US jurisdictions; in 2019, electricity contributed 5.8% of alternative energy in California, and 1.3% in Oregon.

Figure 5 also depicts program credits generated per fuel type over time (right column). An outsized credit contribution relative to fuel volume, as in the case of electricity, is an indicator of lower CI scores and/or greater on-road efficiency of fuel/vehicle combinations (higher EER). The relatively higher CI of ethanol is evidenced by more modest contribution to credit totals than to volumes: the non-ethanol fuels are playing an increasing role in credit generation over time. We examine carbon intensities of fuels in more detail in Section 3.

3. Carbon Intensity of Fuels

The lifecycle emissions of alternative fuels depend on feedstock production and extraction, fuel production, transportation of feedstocks and fuels, end use, and, in the US jurisdictions, the indirect land use change (ILUC) associated with particular biofuel feedstocks.[vii] "Fuel pathways" encompass all these steps in the supply chain; GHG emissions estimates associated with each step are summed, normalized by energy in the fuel, and assigned as a CI rating for a particular fuel pathway, or lifecycle. Each jurisdiction uses its own CI estimation model, often applying different analytical assumptions, so similar or identical fuel/feedstock combinations can receive different CI scores in each jurisdiction.[viii]

Each type of alternative fuel encompasses a range of CI scores (Figure 6, shown adjusted by Energy Efficiency Ratio, or EER),[ix] which precludes a firm ordering of alternative fuels by CI score. In general, CI differences within a jurisdiction are driven by feedstock choice, production process technology or energy, or transport mode – the LCFS is designed to elicit such choices or changes to lower the fuel's carbon footprint wherever along the supply chain is most cost-effective. For any fuel, carbon-saving differences anywhere along the supply chain can improve its relative position.

California has the most pathways, 835 as of 2021; Oregon has 387, and BC, 349 (Figure 6). Of these, ethanol constitutes the highest percentage (47% across all jurisdictions). Regulated parties can apply for certification of new pathways, expanding the list of options over time. California and Oregon added third-party validation and verification programs for the information going into CI calculations, with initial data years of 2020 and 2021, respectively. The BC government has verification authority.

California's CI scores have the widest range due to the well below-zero CI scores for biogas sourced from animal manure used as a fuel or as input to electricity production for EV charging. The negative CI scores are largely due to credits for avoided methane emissions relative to in-state business-as-usual manure management. In BC, below-zero CI scores are associated with ethanol from landfill waste, and facilities that produce biodiesel from animal products, evaluated under their lifecycle analysis model. Negative CI scores imply that each unit of fuel consumed results in a net reduction of GHGs in the atmosphere compared to the no-fuel alternative, and according to the relevant model being used (GREET versions for California and Oregon, GHGenius for BC).

The similarity in the US jurisdiction pathways reflects their overlap and similar CI rating systems. Diversity in electricity CI scores

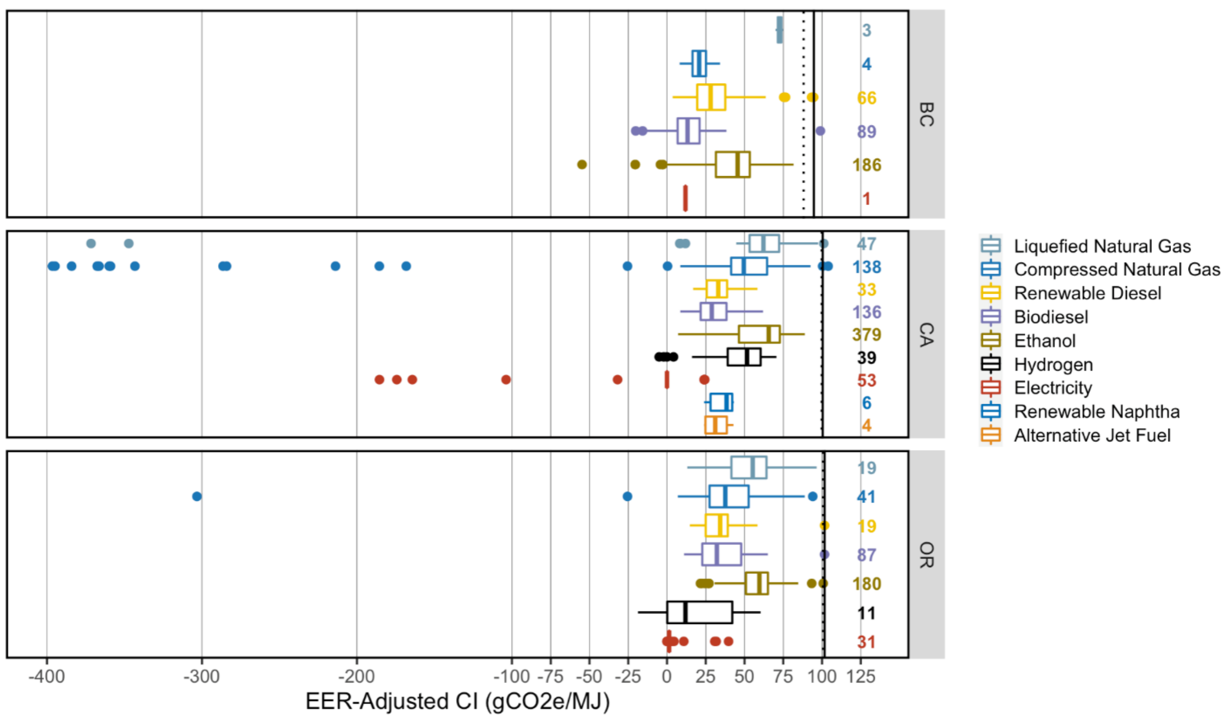

Figure 6. Summary of EER-Adjusted CI Scores for Certified Alternative Fuel Pathways by Fuel Type, and CI Reference Scores for Gasoline (solid black line) and Diesel (dotted black line), as of Jan 2021. Box-and-whisker diagrams for each fuel type indicate median (line in box), quartiles (box edges, and 1.5x interquartile range (whiskers); outliers beyond this are shown as dots. The total number of available pathways for each fuel type is reported to the right of each diagram. The BC electricity CI score depicted is for light-duty vehicles, and not listed among their pathways. Sources: [8] [9] [10].

across jurisdictions flows from different grid power sources as well as a variety of options to achieve CI scores lower than the area grid average in each place.[x] Not accounting for ILUC means BC's CI scores are lower than counterparts in the US. BC also has fewer fuel types than the US programs.

Based on first and most recent full data years available, alternative fuel reported CI scores declined an average 4.8% per year in BC, 5.4% in California, and 5.7% in Oregon. In every jurisdiction, diesel substitutes have lower CI scores compared to gasoline (Figure 7). Both California and Oregon had annualized declines of about 4% for alternative gasoline, and 6% for alternative diesel. The California decline reflects modeling changes in mid-decade that lowered CI scores for crop-based biofuels by about 10 gCO_2e/MJ. In British Columbia, alternative gasoline fuels' CI scores declined an average 5% per year, compared to 0.6% for alternative diesel fuels.

Disaggregating further, Figure 8 shows reported CI scores by fuel type over time. Ethanol reported average CI declined in all jurisdictions. In both BC and California, the volume-weighted average CI score of ethanol fell approximately 25 points from 2010 to 2019, the final full data year, and 5 points in Oregon from 2016 to 2019. Annualized ethanol CI score reductions in BC, California, and Oregon were 6%, 4%, and 2%, respectively. In California, the 2016 ILUC modeling change contributed about a 10 CI point reduction to the decline; lower-carbon process energy, yield improvements, and/or greater efficiency in co-product recovery were also factors [13]. Each jurisdiction has ethanol pathways with notably low CI scores, usually from using low CI process energy rather than fossil fuels, or add-on cellulosic processing capacity to allow corn kernel fiber to be converted to fermentable sugar. These (still uncommon) pathways could provide significant CI score reductions from the gasoline sector using existing technology if scaled, as could using higher blends of ethanol.

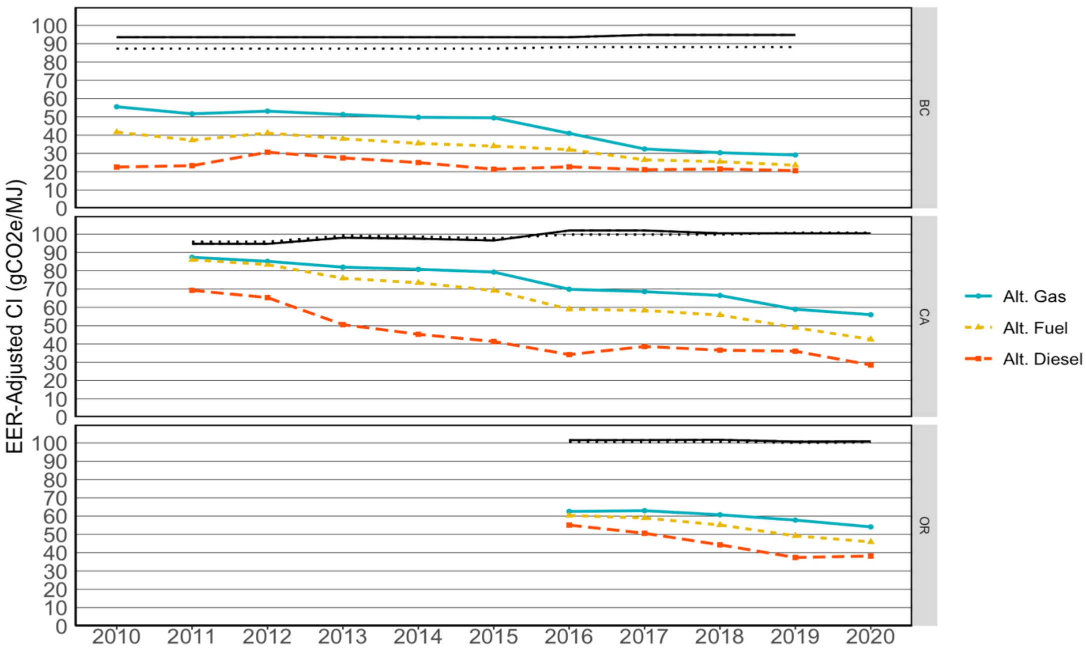

Figure 7. Average Reported EER-Adjusted CI Ratings for Alternative Fuels by Fuel Pool, Relative to Reference Scores for Gasoline (solid black line) and Diesel (dotted black line). Data coverage is as in Figure 2. Sources: [4] [5] [6].

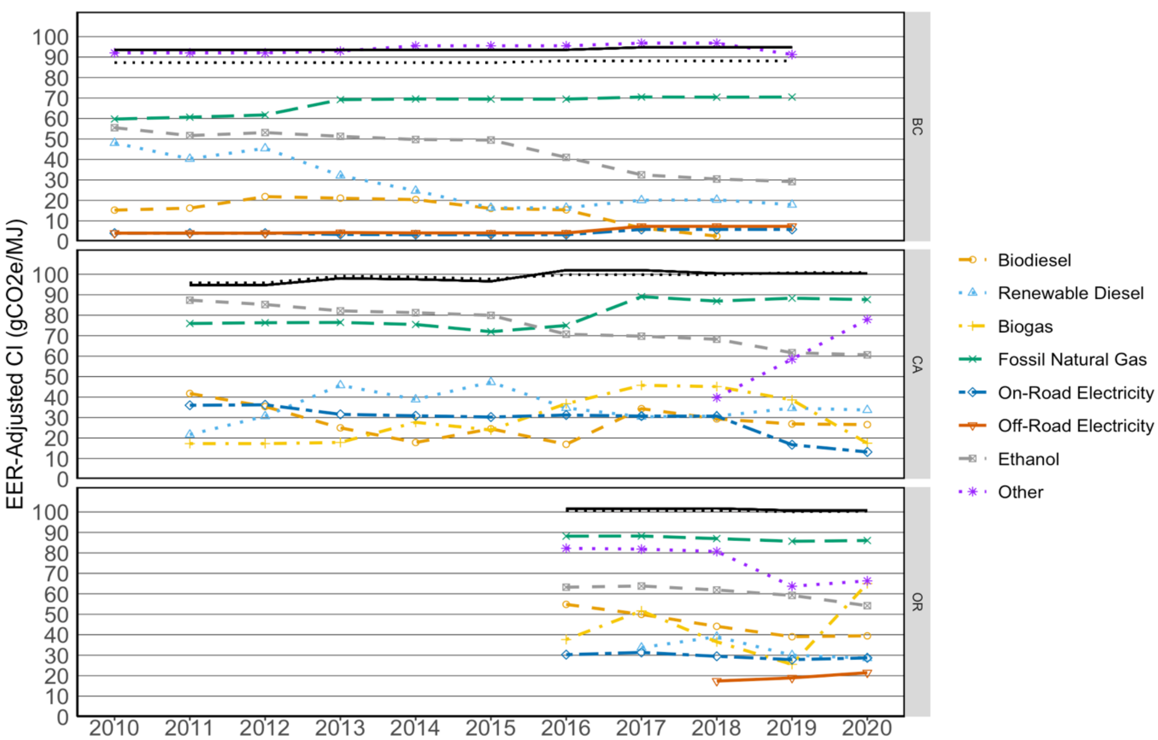

Figure 8. Average Reported EER-Adjusted CI Rating by Alternative Fuel Type Relative to Reference Scores for Gasoline (solid black line) and Diesel (dotted black line). Data coverage as in Figure 2. EERs applied for electricity are for light-duty vehicles and light rail for on-road and off-road categories, respectively. For a full list of program EERs, see [11]. The average CI score of biodiesel in 2019 was -1.62 in British Columbia. An error in Oregon data for 2016 and 2017 non-residential electricity use and credits yields (inaccurate) negative CI scores (see [12]; the displayed CI scores reflect only residential charging in those years. There is not enough publicly available information to calculate the off-road electricity CI score in CA. "Other" includes hydrogen and propane (plus renewable propane in Oregon, and renewable naphtha and alternative jet fuel in California). Sources: [4] [5] [6].

Light-duty EVs are another avenue for gasoline sector CI reductions. Electricity EER-adjusted CI scores are relatively low in these jurisdictions due to EV on-road efficiency and the mix of sources used to produce electricity, namely, a higher reliance on renewable energy, particularly hydropower in BC and Oregon. In BC, the electricity CI score increased due to source variability but remained low. In California, the EER-adjusted CI scores declined over the period; an EER update from 3 to 3.4 for light-duty vehicles in 2013 was part of the decline, as was a lower state-level electricity grid average CI score, which fell from just under 110 gCO_2e/MJ in the early part of the decade to about 83 gCO_2e/MJ in 2020 (or, in EER-adjusted terms, from 35 gCO_2e/MJ to about 24 gCO_2e/MJ). The decline in California on-road EV CI score below the grid average in 2019 and 2020 is due to new provisions allowing zero or low-CI rated electricity to apply to charging under contracts, via a book-and-claim system. Oregon's grid average CI score, calculated as a multi-year rolling average, has been more stable. There, utilities have the option each year to choose to apply utility-specific CI scores. New provisions allow book-and-claim for zero and low CI-rated charging, much like in California. Additional disaggregation in publicly available program data will be necessary for the ability to discern reported EER-adjusted CI scores that form the basis of credit generation as more electricity CI score options and EV types/EERs come into play in Oregon and California.

Among diesel substitutes, only biodiesel CI scores declined in all jurisdictions over the covered period. Oregon saw the steadiest drop in biodiesel CI scores, an annualized 8%. Renewable diesel (RD) CI score averages varied between 22 and 47 gCO_2e/MJ in California, and 29 and 39 gCO_2e/MJ in Oregon, and fell only in BC, from 48 to 18 gCO_2e/MJ. Due to the relative immaturity of RD production systems and the comparatively small volumes supplied before 2019, much of this variability may be explained by variation in feedstocks and supply chain practices. Biogas average CI score also varied considerably, bouncing between 26 and 65 gCO_2e/MJ in Oregon, and rising from 17 to 46 gCO_2e/MJ in California between 2011 and 2017, before declining again to 7 gCO_2e/MJ in California. British Columbia reported biogas use for the first time in 2019 however the volume is negligible and the CI score of that biogas was not reported.

An important component driving differences in pathway CI score within a particular fuel type is feedstock choice. Average fuel CI score by feedstock can be calculated using available California data, and show substantial differences. In 2020 Q2, California ethanol CI score from sugarcane and molasses averaged 46 gCO_2e/MJ, and from corn, 64 gCO_2e/MJ (decreasing beyond the 10-point reduction from the ILUC modeling change). California assigns a higher ILUC value to corn than does Oregon. After entry into the LCFS in 2019, cellulosic ethanol's reported 32 million gallons in 2020 through Q2 (over 5% of ethanol) had a reported CI average of 27 gCO_2e/MJ (over 10% of ethanol credits). Biomass-based diesel from crops (soy and canola oil) had an average CI score between 50 and 60 gCO_2e/MJ, from corn oil; tallow averaged about 30 gCO_2e/MJ; used cooking oil averaged about 21 gCO_2e/MJ.[xi] The principal sources for biogas, landfills and dairy digesters, had early 2020 CI scores averaging 54 gCO_2e/MJ and less than -300 gCO_2e/MJ, respectively. Feedstocks are discussed further below.

4. LCFS Credit Trading and Prices

LCFS policies include credit trading to allow firms to flexibly comply with the regulation, prompting a market for credits. A regulated party (e.g., refiner or fuel provider) accumulates deficits through the sale of fuels with CI scores above the standard, primarily gasoline and diesel. Deficits must be retired by matching with credits, primarily generated from alternative fuels. Regulated parties would be expected to purchase LCFS credits if the price of those credits is less than the marginal cost of lowering the CI score of their fuel enough to meet the standard. Credit prices theoretically reflect the industry's marginal cost of meeting the standard, or the cost of supplying the marginal energy unit of alternative fuel relative to its petroleum counterpart, subject to market and policy uncertainties and additional incentives from other state and/or federal policies [14].

Under the LCFS, regulated parties typically purchase credits to meet their incurred deficits, indirectly raising the cost of supplying petroleum fuels. At the same time, alternative fuels entering the fuel supply generate credits; the revenue from credit sales helps support low carbon fuel producers. The regulation is designed to send the necessary price signals to fuel markets for compliance; the program incentives, determined by the market price for credits, make alternative fuels cost competitive with their petroleum counterparts to the extent needed to meet the standard.[xii] If low carbon fuels are scarce, there are fewer credits, driving up the credit market price, adding to the relative incentive to bring low carbon fuel to market.

LCFS policies have generated substantial value to alternative fuels, shaped by the market price for credits and the CI reduction target. California's LCFS generated nearly $3 billion worth of credits in 2019, Oregon's generated over $150 million, and British Columbia's generated nearly $55 million (80 million CAD). To put into comparable terms, California's program generated an aggregate $1.50 in value per gge of alternative fuel energy, Oregon's generated $0.74, and British Columbia's generated $0.35 (0.46 CAD), under 6.25%, 1.5%, and 8% CI reduction targets, respectively.[xiii] Since the three programs are at different stages, demand for credits, and the resulting impact on prices, would differ even if the rest of the programs and policy environments were the same. As it is, differences in lifecycle accounting as well as policy environment (for example, mandated biofuel blend levels in Oregon and BC before their programs' starts, absent in California, but later supported by U.S. policy) can impact the additional cost of bringing fuels into a given market – thus also impact the credit price for that program.

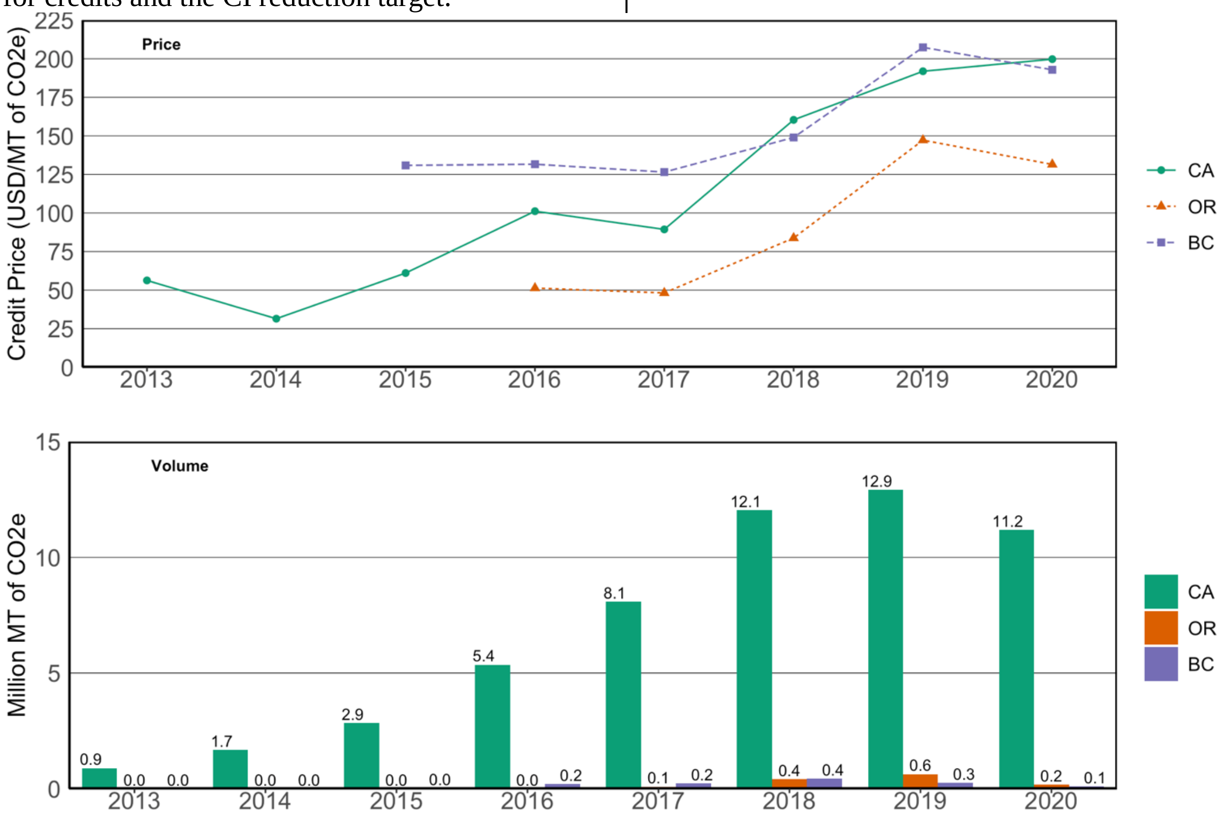

Figure 9. Credit Market Scope. Annual price is a volume-weighted average, in nominal US dollars (not adjusted to real terms). 2020 credit market data presented here are through the full year. Volumes refer to traded volumes. Sources: [15] [16] [17].

Cost containment is a protective measure for market-based environmental policies to limit the risk of economic harm under unexpected market conditions and solidify political coalitions needed to adopt the policy. California's LCFS implemented a Credit Clearance Mechanism (CCM) as its primary cost containment measure in 2016; Oregon's CFP also uses a CCM. Under the CCM, any entity with unmet deficit obligations at the end of a compliance period would be required to buy a prorated number of credits pledged to CCM by those with credits to sell. Transactions occur at up to the ceiling price, established at $200 per credit in 2016 and increasing at the rate of inflation thereafter. Remaining deficits can be carried forward to the following year with a 5% interest penalty. This mechanism was designed to resolve deficits that arose due to illiquidity, difficulty identifying counterparties for transactions, or deficits intentionally left unmet. In 2020, California's program added a backstop to the CCM, advancing credits from utilities' future allocations of residential EV charging credits up to a specified limit when obligated parties are otherwise unable to cover their deficits. These parties must purchase the advanced credits from utilities at the ceiling price; the utilities receiving the advanced EV credits must then repay the borrowed credits in subsequent years. British Columbia does not have a CCM, though the regulator could use Part 3 Agreements as a *de facto* cost containment mechanism, if needed.

Figure 9 shows that the price of traded credits grew substantially in all three jurisdictions since program implementation, to an average $200/MT, $132/MT, and $192/MT in California, Oregon, and British Columbia, respectively, in 2020.[xiv] Trade volume grew year-on-year in California and Oregon and hit a peak for BC thus far in 2018. Unsurprisingly given the relative size of its market for transportation fuels, California dominates in credit trading. In 2019, nearly 15 million credits were traded in California. Note that one credit may be traded more than once before being retired for compliance and can be traded in years after it was generated, meaning the number of credits being traded in the credit market may be greater than the number of credits generated from alternative fuels in any given year. California is the sole jurisdiction with public information on the distribution of credits, publishing periodic updates of an anonymized credit holding histogram on its LCFS Data Dashboard. In July 2020, for example, two entities combined to hold around 44% of banked credits, shrinking to about 42% in January 2021.[xv]

Uncertainty about the policy's longevity or form can also affect the market price for credits, since policy changes impact which actions, at what cost, are needed for compliance. California's LCFS underwent several legal challenges, one of which led to a freeze of the program's target due to issues with the program's environmental analysis; this necessitated a policy readoption in 2016 [18]. Over this period, from 2013 until mid-2015, credit prices remained relatively low, likely due to the lower standard coupled with uncertainty whether the policy would emerge intact from legal challenges. . As the standard tightened and policy uncertainty was eased by the passage of SB 32 in 2017, and the LCFS extended to 2030 in 2018, credit prices began to increase. The uncertainty and short-term decline in credit prices may have contributed to delaying growth in alternative fuel supply and higher credit prices in 2019 and 2020.

Incentives from LCFS programs in the US stack with federal and some other state incentives and regulations; this will affect the market for LCFS credits.[xvi] Most notably, many renewable fuels used in US transportation can generate Renewable Identification Numbers (RINs), which are tradable compliance instruments for the Renewable Fuel Standard (RFS). Fuel producers that sell eligible biofuels into a state with an LCFS can gain value from both RINS and LCFS credits. Biofuels covered under California and Oregon's LCFS policies also receive other federal incentives, including the biodiesel blender's tax credit, a $1 per gallon credit for blending biomass-based diesel into petroleum diesel. In BC and Oregon, renewable fuel mandates for liquid gasoline and diesel impacted ethanol and biomass-based diesel volumes from the programs' outsets. EV incentives in the form of ZEV mandates and rebates, particularly strong in California, play a strong role in EV adoption beyond LCFS incentives. Beyond policy interactions and policy uncertainty, changes in related markets such as agricultural products or petroleum fuels would also be expected to impact credit prices.

5. Fuel-Specific Developments

This section overviews trends within the primary fuel types reported under LCFS programs, signaling which of the wide range of potential CI values per fuel type, and what new production processes, are emerging as economically feasible as the standards have grown more stringent. California's fuel trends receive more attention, due to early LCFS implementation, the size of the fuel market, the significant value afforded to alternative fuels under the program, a lead role in making regulatory changes often adopted elsewhere, and the greater availability of public data.

Feedstocks

The feedstocks used to produce alternative fuels are a significant driver of a fuel's CI score, and one of the most important factors differentiating CI score within a fuel type. Figure 10–Figure **12** present alternative fuel volumes by feedstock type for non-electric fuels, as feasible and where applicable.[xvii] The remainder of this section refers to Figure 10–Figure **12** in discussing developments for each fuel type.

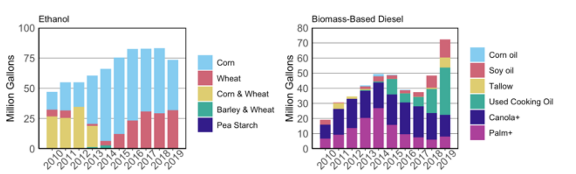

Figure 10. British Columbia Fuel Volume by Feedstock Type. Canola+ refers to a mix of canola oil with tallow and soybean oil. Palm+ represents the sum of refined palm oil, palm sludge oil, spent bleaching earth oil, and rapeseed oil. Source: [6].

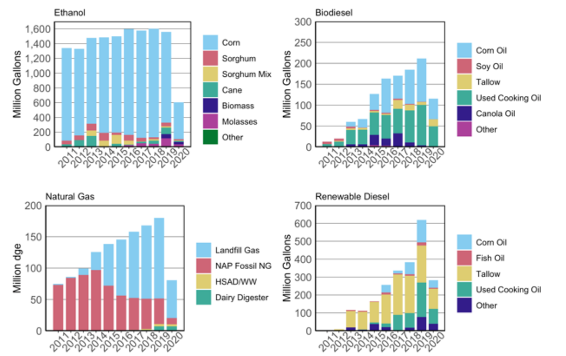

Figure 11. California Fuel Volume by Feedstock Type. HSAD = High-Solids Anaerobic Digestion, WW = Wastewater, NAP = North American Pipeline, NG = Natural Gas, and dge = diesel gallon equivalents. "Other" feedstocks include waste beverage, waste corn and sorghum seeds, and other unidentified feedstocks for ethanol. "Other" feedstocks are not explicitly identified for biodiesel, renewable diesel, and natural gas. Source: [4].

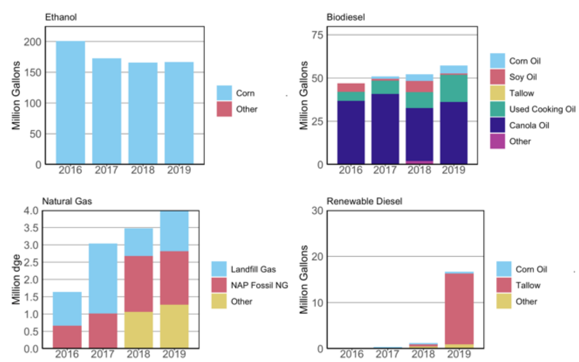

Figure 12. Oregon Fuel Volume by Feedstock Type. NAP = North American Pipeline, dge = diesel gallon equivalents. "Other" for ethanol, biodiesel, and renewable diesel refers to unidentified feedstocks receiving a default CI score. "Other" for natural gas is unidentified biogas feedstocks like landfill gas and dairy gas. Data not available for 2020. Source: [19] (Oregon CFP feedstock data is not yet publicly available from the Department of Environmental Quality (DEQ) but can be found at [11]).

Ethanol

Ethanol coming into the LCFS programs is primarily produced from corn. Recent developments include the first entry of cellulosic-based ethanol into the LCFS system, in California, in 2019, with an average CI rating of 27 gCO_2e/MJ. Cellulosic biomass contributed 5% of the volume (Figure 11) and 10% of the credits from ethanol in California in 2020 through Q2. Figure 13 illustrates the premium for cellulosic ethanol, a 2019 policy incentive of just over $1 per gallon, compared to just under 50 cents per gallon for corn. Overall, the 2019 California LCFS value ethanol credits generated totaled about $58 million for cellulosic biomass and $560 million for corn.[xviii] A higher policy incentive for a given fuel is due to a lower CI score, in the case of cellulosic fuels, partly due to no ILUC emissions. Only California supplies enough publicly available data to calculate the magnitude of the policy incentive for specific feedstock and fuel combinations. Virtually all of Oregon's ethanol is produced from corn (Figure 12). Much of the ethanol used in British Columbia is produced from wheat — over a third in 2019 (Figure 10) — which is seldom used in US ethanol production.

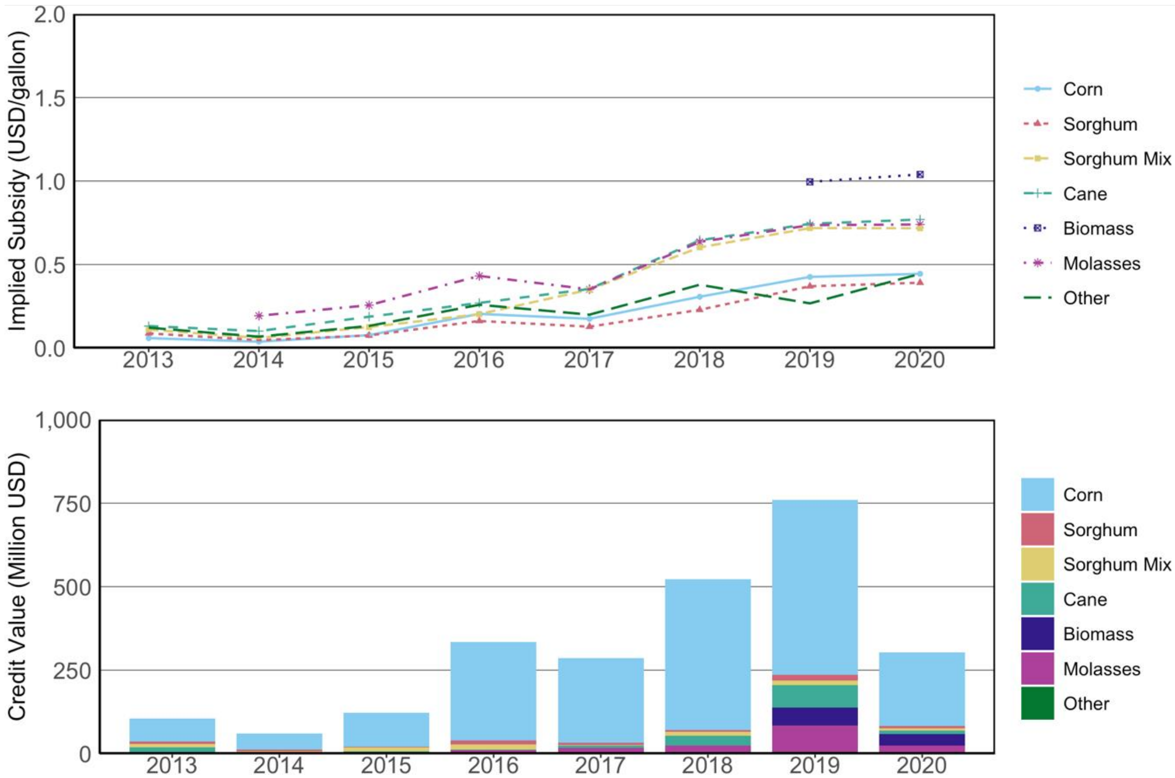

Figure 13. Average Implied Subsidies per Gallon of Ethanol by Feedstock (top) and LCFS Credit Value for Ethanol by Feedstock Type (bottom), California. All values are in nominal (current year) terms. Sources: [4].

Biomass-Based Diesel

The biodiesel and renewable diesel components of biomass-based diesel are sourced from similar lipid feedstocks. Biodiesel faces certain blending constraints in liquid diesel, often requiring labeling above B5 and more engine modifications, especially above B20; renewable diesel, as a drop-in fuel, faces no restrictions on blending with petroleum diesel, is more easily stored, and generally produces less NOx when burned. RD production can also occur via co-processing or batch processing of non-fossil oils at operational refineries, which also can undergo relatively modest retrofits to biofuel-only configurations.

The impressive growth of RD especially in California was noted above. Notable also is the rising use of lipid residues used as renewable diesel feedstocks, such as used cooking oil (UCO) and tallow from animal rendering, which make up the majority of all biomass-based diesel across all three jurisdictions as of 2019 (Figure 10–Figure 12). Tallow made up the majority of RD blends in California from 2013 and accounted for virtually all of Oregon's RD in 2019, the first year with any substantive RD volume in the state. Tallow appeared in British Columbia in large quantities in 2019, up 500% from 2018 and now comprising nearly 10% of all biomass-based diesel.

Figure 10–Figure 12 show that the feedstock composition of biomass-based diesel in British Columbia has been dominated by canola and palm products but transitioned away from palm starting in 2015 and increasingly toward UCO, tallow, and soybean oil. In 2019, 11% of biomass-based in BC used palm feedstocks, down from 50% in 2013. Oregon biodiesel is over 50% from canola but has also diversified into lower-CI residue feedstocks over time. Unlike the other jurisdictions, canola oil is only sparsely used in California for biodiesel production; corn oil is the dominant feedstock there, responsible for about half of biodiesel used in state. Corn oil recently earned about 50 cents more on average than canola and soybean oil due to its lower CI rating (Figure 14).

The most striking trend in biomass-based diesel was the dramatic increase in residue feedstocks across all jurisdictions in 2019; UCO volume doubled in BC, increased by 80% in CA, and 70% in OR from the previous year. For the average gallon of biodiesel and renewable diesel, UCO generates the largest implicit subsidy under California's LCFS, reflecting its relatively low average CI score, due in part to no ILUC or indirect effects assessment (about 22 gCO_2e/MJ in 2020). Figure 15 shows that renewable diesel produced from UCO earned an implicit subsidy of nearly $1.75 per gallon of fuel in 2019 on average and generated over $500 million of value in LCFS credits.

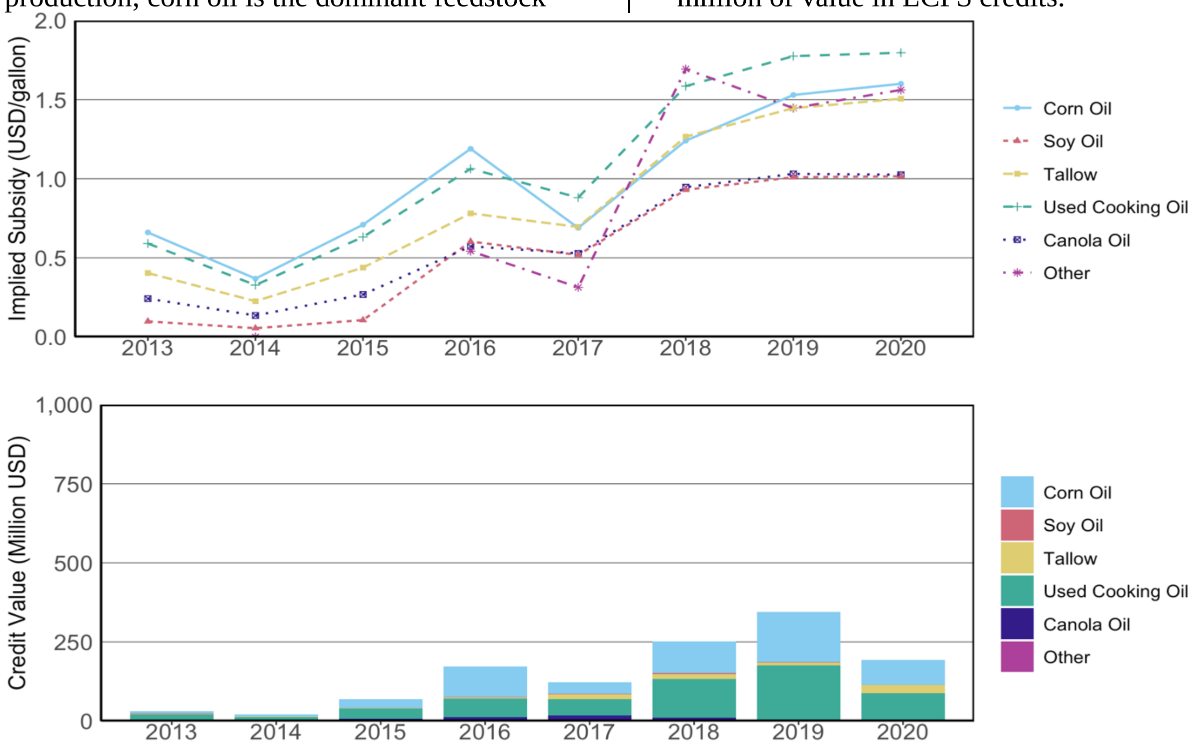

Figure 14. Average Implied Subsidies per Gallon of Biodiesel by Feedstock (top) and LCFS Credit Value for Biodiesel by Feedstock Type (bottom), California. All values are in nominal (current year) terms. Sources: [4].

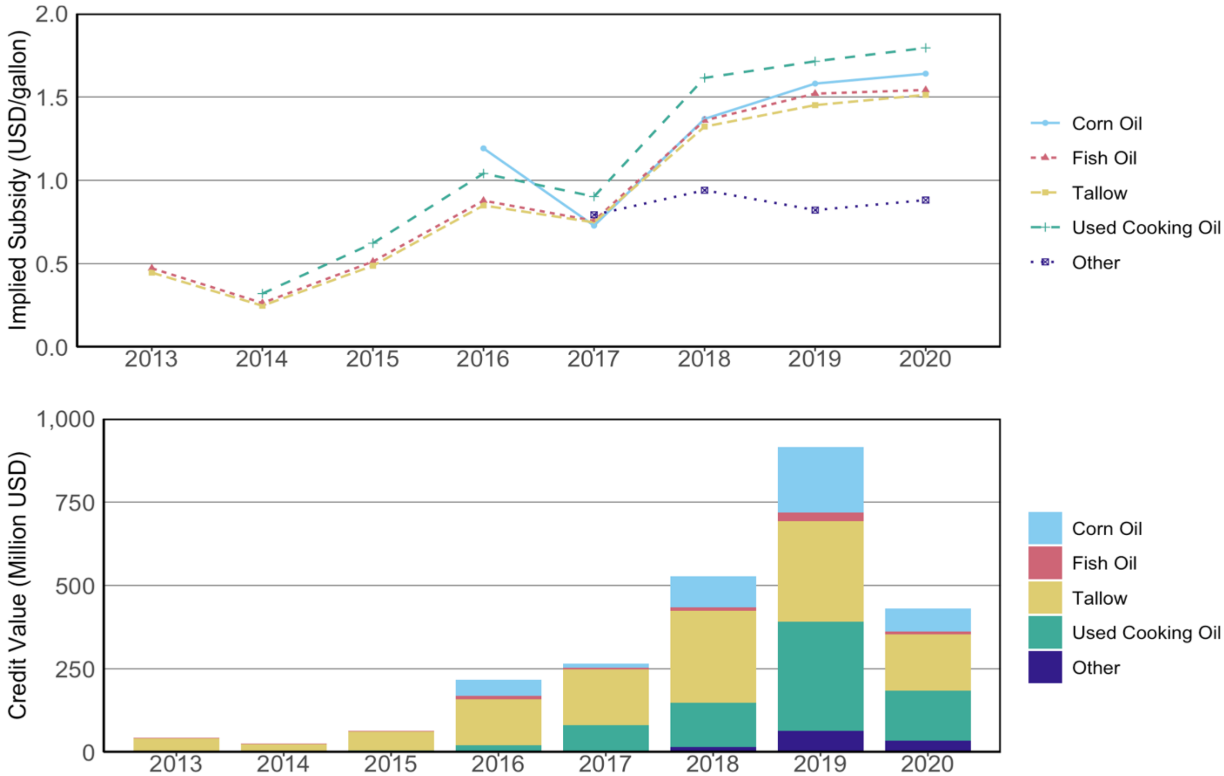

Figure 15. Average Implied Subsidies per Gallon of Renewable Diesel by (top) and LCFS Credit Value for Renewable Diesel by Feedstock Type (bottom), California. All values are in nominal (current year) terms. Sources: [4].

Despite higher CI scores and smaller implicit subsidies, RD from soybean oil appeared recently in California; CI scores for available pathways indicate soy oil as the primary component of the "other" category. Soybean oil may be attractive to refiners that seek to retrofit larger-scale facilities because vegetable oils provide a cleaner more homogeneous product that can be supplied in larger volumes [20]. The recent UCO boom has placed considerable pressure on domestic stocks; the feedstock is in high demand worldwide for low carbon fuels under LCFS and other alternative fuel programs due to its favorable CI rating [21]. This increase in demand has been met by supply constraints, especially due to the pandemic as restaurant dining, and thus waste oil collection, fell worldwide. UCO prices grew 50%, and tallow 30% over the last year [22].

Hydrotreated biojet fuel, a type of alternative jet fuel, or AJF (termed sustainable aviation fuel, or SAF, when sustainably sourced and produced), which is made from similar feedstocks via a similar process as RD, is starting to garner attention. California is home to one of the few hydrotreated biojet production facilities currently operational, and imports from other producers. In 2020, two of California's petroleum refineries with an aggregate capacity of over 380,000 barrels/day announced plans to convert to renewable fuel production (RD, biojet and renewable naphtha) in the early 2020s, though final capacity is likely to be less than when they were operating as conventional petroleum refineries. Additional expansion of biojet and RD production has been announced at other, smaller facilities.

Renewable Natural Gas

When organic matter decomposes in the absence of oxygen, the resulting "digester gas," composed primarily of methane, carbon dioxide, and water vapor, can be captured and purified into renewable natural gas (RNG). RNG is an alternative to conventional fossil natural gas, and, when purified to jurisdiction specifications, can use conventional natural gas transmission, distribution and infrastructure. As noted above, California's LCFS allows RNG produced anywhere in North America and delivered into a common-carrier pipeline to be contractually conveyed to CA and credited as if it were consumed in-state using book-and-claim accounting. RNG's increasing share of natural gas started in 2014, when biogas became eligible for higher RFS incentive, also using a book-and-claim system, and has been dominated by landfill gas, primarily from out of state. The growth in biogas from animal manure, usually from dairies, while still small in volume terms, is an important recent trend.

The first LCFS pathways for dairy gas were operational in 2017. While its use has risen sharply, it currently constitutes a small share of natural gas being used in California. Despite its small contribution by volume — 9% of transportation natural gas in the first half of 2020 — it was responsible for 48% of the natural gas credits in the same period. Dairy biogas created the most LCFS credit value among natural gas feedstocks in the first half of 2020 – over $50 million (Figure 16, bottom). Because of its far below zero CI scores (discussed in Section 2 above), dairy gas earned nearly $9 per dge on average in the first half of 2020, $8 more than landfill gas (Figure 16, top). Recent fuel pathway submissions leverage the low carbon nature of dairy gas beyond the natural gas vehicle fleet by using it as a fuel to generate electricity, which is then used to charge EVs.

While most of the biogas reported in the LCFS comes from out of state, California has ambitious goals for reducing methane emissions from the uncontrolled decomposition of organic waste; incentivizing RNG production through anaerobic digestion is one key measure in this effort. Once in-state methane reduction is regulated, new RNG pathways, regardless of source, will no longer benefit from avoided methane emissions in the lifecycle analysis.

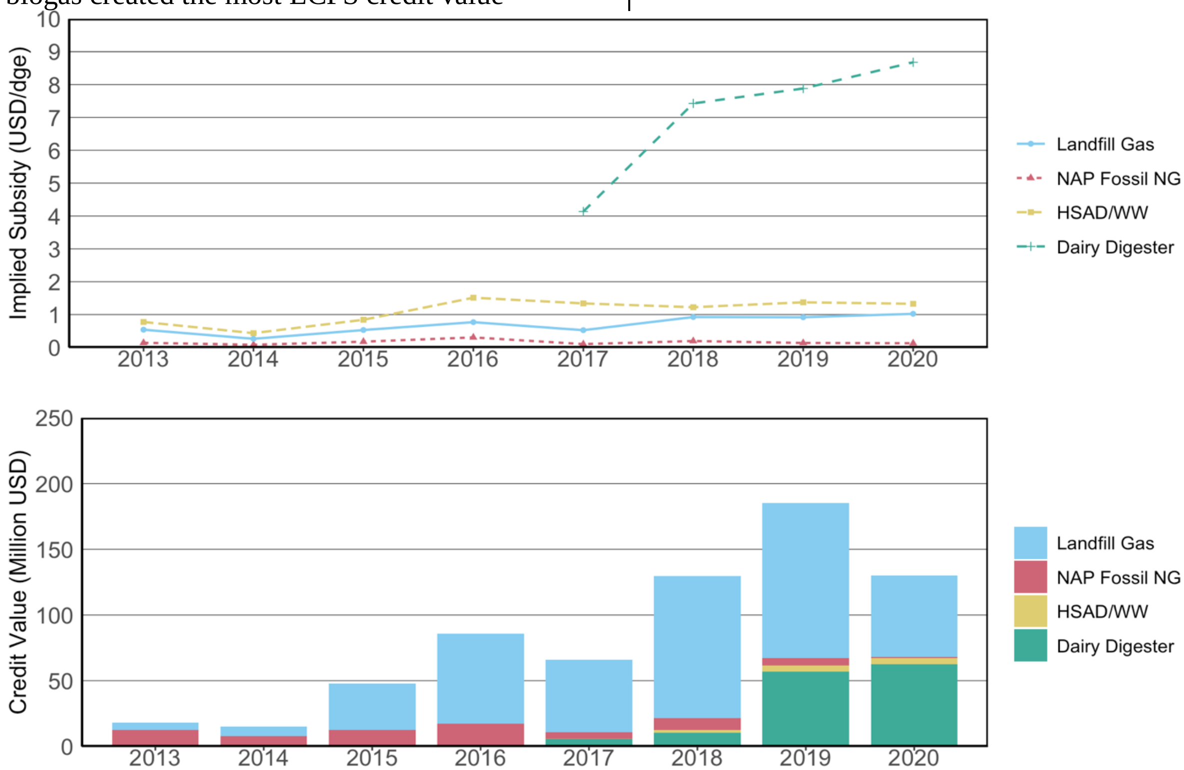

Figure 16. Average Implied Subsidies per dge of Natural Gas by Feedstock in California (top) and Total LCFS Credit Value for Natural Gas by Feedstock Type (bottom), California. All values are in nominal (current year) terms. HSAD = High-Solids Anaerobic Digestion, WW = Wastewater, NAP = North American Pipeline, dge = diesel gallon equivalents. Sources: [4].

RNG is also appearing in the Oregon transportation mix. In 2019, nearly a third of Oregon natural gas was from landfills, another third from fossil sources, and the remainder a mix of feedstocks (landfill gas and dairy gas using electricity, natural gas, or renewables as process energy) (Figure 12). RNG first entered British Columbia in 2019 at 0.8 million gallons.

Electricity

Earlier sections noted the growth of electricity as a transportation fuel and expanding opportunities for crediting. In California, after crediting became available in 2019 for EV charging at below the grid average CI score using book-and-claim accounting, uptake of the opportunity has been strong, especially for public access charging. LCFS reporting data indicates between 84% and 89% of light-duty EV charging occurred at home, about a quarter of which received credit for a CI score below the grid average.[xix] Low-CI sources comprised most of the remaining 15% of light-duty charging: approximately 95% non-residential EV charging in 2020 (Figure 17). Uptake of low-CI electricity among heavy-duty EVs was slower, reaching 56% in 2019 Q3. In Oregon, non-residential charging grew from 4% of all reported electricity use in 2016 to 8.5% in 2019. For Oregon residential charging, in 2019 utility-specific CI scores (below the state grid average) accounted for 11.3% of the energy and 17.1% of the credits [19].

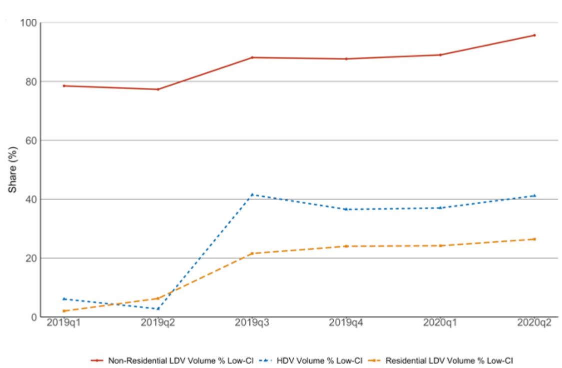

Figure 17. Share of On-Road EV Charging earning Low (Below-Grid-Average) CI Score by Quarter, 2019 Q1–2020 Q2. Assumes that all residential EV charging earning incremental credits earns a zero CI score. Source: [4].

Figure 18 shows average incentives per kilowatt-hour (kWh) from LCFS credits for light-duty EV charging in each jurisdiction. In California, the benefit was more than 17 cents/kWh on average in 2019 for on-road light-duty electric charging, slightly above the state's average retail price of 16.89 cents/kWh. Oregon's electricity incentive for light-duty EV charging has been lower than California's since 2016, only 12 cents/kWh in 2019. Oregon's incentive exceeds the average price of electricity in the state, approximately 9 cents/kWh that year.[xx] The incentive for light-duty EV charging in British Columbia, which makes up only 0.5% of all transport charging in the province, rose to over 20 cents/kWh in 2019 while off-road electricity, which is primarily light rail, earned 16 cents/kWh.[xxi]

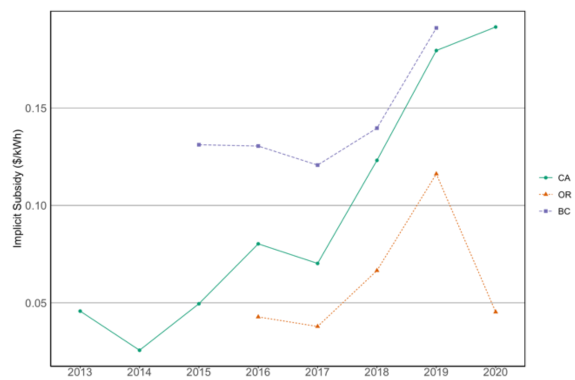

Figure 18. Annual Average Incentive per kWh of Light-Duty Vehicle Electricity by Jurisdiction. All values are in nominal (current year) terms and in USD. Assumes that all residential EV charging earning incremental credits in California earns a zero CI score. Sources: [4] [5] [6].

As for all credits, electricity credit revenue is realized upon sale of the credit, at timing up to the discretion of the credit holder. EV charging credits are most commonly generated by the utility supplying residences for residential charging, or the owner of charging infrastructure for non-residential. Other parties can be contractually designated as the credit generator, and incremental credits from residential charging at below grid-average CI can be claimed by a variety of parties, such as the utility, automaker, or third party, provided they can accurately quantify the amount of charging. In Oregon, unclaimed residential credits accrue to a designated backstop aggregator, which works with DEQ on expenditures. California has had general guidelines directing the electricity credit value to purposes that support the EV market; investor-owned utilities in Oregon face similar restrictions from the Public Utilities Commission regarding CFP EV credit revenue use. Credit value, in other words, does not necessarily or generally go toward lowering the retail price of electricity.

California recently adopted additional EV provisions, beyond the advanced credits to backstop the credit price ceiling (see above). Starting in late 2020, the majority of residential EV charging credit revenue moved from funding utilities' previous programs broadly supportive of the EV market to funding a statewide EV rebate program, currently $1,500 in typical situations. In contrast to the federal EV tax credit, or California's Clean Vehicle Rebate Program, the $1,500 rebate is available at the time of sale, rather than afterward. New provisions stipulate that a proportion of the remaining credit revenue go toward transport electrification benefiting disadvantaged, low income, and rural communities.

In early 2021, Oregon adopted electricity provisions in response to a gubernatorial order to explore ways to use the Clean Fuels Program to promote state EV goals. They include book-and-claim accounting for below-the-grid CI scores, like the California system, to generate incremental credits.[xxii] Unclaimed residential incremental credits will accrue to a newly designated incremental aggregator, to be spent in consultation with a new Equity Advisory Committee as well as DEQ. Oregon also instituted a system to advance EV credits for public vehicle or service fleets, essentially providing upfront credit loans to help get EVs into these fleets, which are then paid back over time through holding back electricity credits as they are generated for the life of the loan.

Both California and Oregon estimate electricity use for non-metered residential charging — currently the vast majority — on the small proportion of metered residential charging for which data are available. The regulations point to use of the best available information to develop the estimate, but methods and results are not currently made public.

Infrastructure, Carbon Capture and Sequestration, and Other Non-Fuel Credits

As noted in Section 1, British Columbia was the first jurisdiction to allow LCFS credit generation, via Part 3 Agreements starting at the program's outset, for activity in support of future low carbon fuel flows, rather than low carbon fuel flows themselves. California followed in its 2018 amendment package, but in a way that targeted ZEVs in line with its state goals, with ZEV infrastructure capacity credit provisions.[xxiii] The provisions essentially credit applicable infrastructure as if it were being used at its rated capacity, ensuring at least a partial income stream for new projects deployed before a sufficient vehicle fleet has emerged to fully use the capacity. In Oregon, by contrast, CFP credits must represent actual GHG reductions by law.

During the 2018 amendment and extension rulemaking, CARB also became the first LCFS jurisdiction to adopt a protocol outlining requirements for carbon capture and sequestration (CCS) underground to be the basis for credit generation. Project developers are subject to a variety of requirements pertaining to site selection and long-term monitoring for decades after underground injection has ceased. Crediting is prorated by volume of fuel delivered to California. Notably, CARB allowed projects that capture and sequester CO_2 from ambient air (as opposed to an exhaust or byproduct stream) to be eligible for LCFS credit generation, even if they are located outside of California and are unconnected to a fuel production system. Direct air capture was judged to be a critical technology for long-term climate mitigation, for which no existing carbon or environmental markets appeared capable of providing sufficient revenue to support new projects. At the time of writing, there are no CCS or direct air capture certified LCFS pathways, although several CCS pathways went through the public comment process in 2020.

6. Interactions Between LCFS Markets

The presence of three nominally similar LCFS markets on the West Coast of North America (with Washington state implementing its own in 2023) creates opportunities for interactions among them. More precise characterization and estimation of these interactions would require data collection and analysis that is beyond the scope of this paper, however some interactions can be discussed in qualitative fashion.

Effects of Proximate LCFS Markets

The LCFS programs in California, Oregon and BC operate independently of each other, however there are several avenues for potential interaction among them. All three jurisdictions share access to trans-Pacific shipping routes, as well as North American road, rail, petroleum pipeline, electrical and natural gas networks. All three receive most of their biofuels from agricultural regions to the east, with water-borne shipment a secondary route of import. While any alternative fuel policy potentially draws from similar global pools of alternative fuels, these three jurisdictions may be more likely to have overlap in potential fuel suppliers due to proximity. Fuel producers that sell into one of these three markets may have the logistical capacity to sell into either of the others. Differences in transport distance, regulatory or tax structure, and vehicle fleets would create differences in delivered price, carbon intensity, or total alternative fuel demanded in each jurisdiction, which would impact producers' choices regarding which market to sell to, and under what conditions. In this sense, we refer to these markets as "proximate," close enough that conditions in one market could impact the others through this likely overlap of potential fuel suppliers.

While most fuels can theoretically be transported anywhere on the globe before being consumed, transportation costs and capacity or regulatory constraints may functionally limit the capacity of some fuel producers to supply certain markets in a cost-competitive or timely fashion. The potential for competition over a finite alternative fuel supply could be exacerbated for proximate markets by the similarity in transport distances and potentially cost to bring fuels to the various markets. With LCFS-like policies on the rise — e.g., in PCC jurisdictions committed to adopting (and a fourth on the way) — jurisdictional-level projections of fuel availability and demand should account for the demand from other markets, especially ones that are geographically near, or that share regulatory, economic or technical characteristics [23].

California, in particular, presents a large demand for transportation fuels and despite agriculture's significant contribution to its overall economy, to date it has only supplied between 10% and 15% of its own demand for liquid biofuels; in various projections, it is not expected to supply its own demand for biofuels in the future [24] [25]. A quantitative analysis of aggregate fuel supply to the relevant jurisdictions is beyond the scope of this paper, however previous work identified likely sufficient supplies for the PCC jurisdictions to meet targets through 2030 [23], and a recent study into the feasibility of an LCFS in Colorado did not identify fuel availability as a significant obstacle.

Additional research is required to better understand the balance between alternative fuel supply and demand as more jurisdictions adopt policies like the LCFS, or other low carbon fuel supports. As global capacity to produce low carbon alternative fuels continues to grow, additional research will also be needed to better understand limitations and constraints that affect the flow of fuels around the globe. If cost, infrastructure, or regulatory factors limit the fungibility of fuels between markets, then a deeper understanding of interactions between proximate markets becomes more important. To the extent that proximate markets like the four PCC jurisdictions committed to low carbon fuels help create more certainty around future demand in North America and regionally, it may support more robust buildout of alternative fuel production capacity. Land use change concerns may limit the total amount of preferable, low carbon feedstocks that can be supplied [26]. As early adopters of LCFS policies, particularly California with its electrification goals, transition to a more EV-dominated fleet, their demand for liquid fuels would be expected to decrease from what it would have been otherwise, which would reduce pressure on aggregate regional and/or global liquid fuel supplies.[xxiv] Moreover, alternative fuel production facilities that establish with a focus on selling into early-LCFS markets but eventually struggle to reduce the CI scores of their fuels to keep pace with program targets may have the opportunity to switch to markets with less stringent targets, such as programs that adopted an LCFS after California.

Market Interactions

The emergence of carbon credits and other environmental instruments have created a set of tools, markets, and stakeholders that possess both the capacity and incentive to adapt to market dynamics. Given that most transportation fuels can be used widely within the extensive network of fuel transportation infrastructure that has been constructed, alternative fuel suppliers and markets should be able to adapt to changes in markets to maximize profits. As alternative fuel suppliers expand capacity to accommodate increasingly stringent policies and shift delivery to markets that, all else equal, earn them the most credit revenue, the markets for credits themselves will respond to those changes.

An increase in the credit price in one market could incentivize alternative fuel suppliers to increase profits by delivering more of their fuel to that market, until marginal returns equilibrate across markets. If shifting fuel supply reduces the supply of compliance credits as well, obligated entities may respond by bidding up the price of credits to ensure they satisfy regulatory requirements. In practice, many factors influence total returns to fuel suppliers, including regulatory or infrastructure constraints on fuel supply or credit price, local economic conditions, policy actions, transportation costs, and vehicle fleet composition, which could lead to persistent differences in net revenue for similar fuels in different markets. How these factors affect interactions between credit prices of the multiple markets in practice is complex, no less because net revenue may equate in different markets at different credit prices, due to differences in targets and carbon accounting, as well as other market factors. Established long-term contracts, regulatory constraints, and perceived risk also play a role in this decision. Further research is required to characterize the nature and magnitude of these competitive pressures and to determine the degree to which they are reflected in LCFS credit market prices.

Harmonization and Linkage of Markets

Since fuel and LCFS credit markets can interact with each other as discussed above, there may be opportunities to increase aggregate efficiency, reduce costs, minimize volatility, and support constructive cross-jurisdictional interactions by harmonizing or linking LCFS programs. Linkage between market-based carbon policies can take a variety of forms, from explicit linkage in a common market, like the Western Climate Initiative that oversees the joint cap and trade market adopted by California and Quebec, to policies that facilitate more efficient low carbon fuel supply for use within market jurisdictions without the need for additional transportation of physical fuel. California, Oregon, and British Columbia are all signatories, along with Washington, to the Pacific Coast Action Plan on Climate and Energy (2013) and the Pacific Coast Climate Leadership Action Plan (2016), committing members to the adoption of LCFS programs and creating a framework for information exchange and informal coordination between regulatory officials. CARB has offered significant support to policy makers and staff in other jurisdictions, and the implementing agencies coordinate on emerging issues, leading to a discernable commonality between many provisions of these programs.

Even without a formal linkage agreement, the fuel and credit markets in LCFS jurisdictions are connected via common fuel suppliers, shared infrastructure, and exposure to similar market conditions. To some extent, they are harmonized by a shared basic structure: a focus on lifecycle analysis, with credit banking and trading, and a common vision of deep GHG reductions over the long run. Formal linkage could permit credit trades and/or generation of credits in one jurisdiction for fuel delivered in another, e.g., through a book-and-claim setup.[xxv] Harmonizing or linking markets serves several key functions. Administrative and compliance costs can be reduced by decreasing or eliminating the need for duplicative analyses. Jurisdictions that possess comparatively less regulatory capacity can reduce their policy development burdens by adopting provisions that have been developed and refined elsewhere. Adopting similar tracking, analysis, trading, and settlement practices can put fuel producers in a position to adapt more easily to changing market conditions, including switching markets to maximize revenue. Policy adaptations to a range of conditions, with information exchange, can lead to more robust policy across the board.

Multiple markets expand the aggregate demand for the production of low carbon fuels and give producers additional certainty regarding long-term demand for their fuel. If the multiple markets are also harmonized, they send a more coherent incentive signal about aggregate demand for progressively lower carbon fuels as defined under the programs, especially if jurisdictions share analytical methods and adopt similarly stringent targets. Harmonization or linkage could reduce the risk of "fuel shuffling" or "leakage," in which providers preferentially sell low carbon fuels to markets with fuel carbon intensity policies and high carbon fuels to those without. Leakage leads to reduced emissions within the jurisdictions that regulate carbon, without any actual reduction in global emissions. As more jurisdictions adopt comparable climate policies, there are fewer markets for high carbon fuels to be shuffled to, which means that reductions credited under a jurisdiction's policy are more likely to reflect actual changes in aggregate emissions and contribute to the attainment of global emissions targets.

Formal linkage of programs, including aggregate emissions reductions targets from fuel transportation across all participating jurisdictions, could lead to lower aggregate compliance costs through economies of scale and less need to transport fuels to specific markets. Producers could theoretically be credited in one LCFS jurisdiction for physical fuel delivery to another with a more readily available market. This is attractive from GHG emissions- and cost-lowering perspectives but would also mean that co-benefits of low carbon fuels, such as reduced air pollutant emissions, might be concentrated in one jurisdiction, with the potential to exacerbate equity issues in the transportation system.

The three jurisdictions that have implemented carbon markets to date have done so with only limited formal alignment of program provisions. Specifically, Oregon recognizes fuel pathways certified in California as valid, provided appropriate modifications are made to reflect the differing transport distances and methods. As more jurisdictions adopt similar policies, however, there may be a need to expand the portfolio of harmonization tools or consider formal linkage. More generally, the LCFS jurisdictions have harmonized the evolution of the policy by moving in similar policy directions, often with California acting first. For example, California recently instituted third-party validation and verification, Oregon is in the process of adopting a similar program, and BC is considering it. California led in expanding credit opportunities, including for off-road EVs, and biojet; Oregon followed. Specific provisions targeting equity improvements have recently entered California's LCFS, and even more recently Oregon's. All three jurisdictions have announced CI reduction targets of 20% by 2030. The trend does not hold across the board, however. California is the only jurisdiction to assess additional deficits for increasing average CI in conventional fossil fuel over time, and to allow credit generation in the fossil fuel sector for upstream CI reductions in production or at the refinery level.[xxvi]

Full linkage of LCFS programs is not without challenges, however. Adoption of compatible LCA analytical assumptions is not necessarily a prerequisite for linkage but would radically simplify the process. Variations in stringency of requirements and timeframe create another challenge to linkage. At present, the three jurisdictions with LCFS programs all have different targets for 2021 through 2030. This means that even if analytical assumptions were identical across all three, the same shipment of fuel would generate a different number of credits in each, both because of the different CI reduction percentage targets and because the baseline average CIs from which that reduction is measured also differ, due to different fuel sourcing, different lifecycle accounting methods, and different program start years. While linkage could include alignment of target levels or stringency, this may deny jurisdictions the flexibility to set target levels most appropriate to their own needs or preferences. Without alignment, linkage of some sort could be achieved by allowing cross-jurisdiction credit trading, either in selective circumstances (e.g., as a cost-containment mechanism) or more broadly, as negotiated to balance cost reductions with desired in-jurisdiction co-benefits.

7. Conclusion

This report overviews public data from the three fuel carbon intensity programs in California, Oregon, and British Columbia for trends to date in market response under these incentives. The analysis shows that more and lower carbon fuels were brought into these jurisdictions under each program, broadly as expected from program design. As noted in various sections, additional transparency and common data standards or formats across programs would facilitate market trend analysis. In particular, EV data include aggregations of credit or volume data that make the reported CI score difficult or impossible to discern. Estimates of unmetered residential EV charging activity used for crediting in the US jurisdictions are not publicly available, nor is the underlying data used to derive these estimates. Where we uncovered irregularities in the data, particularly in early-year program data, it was noted above and reported to the appropriate regulatory authority. Credit generation irregularities represented a small fraction of total credit generation in their given years. Data about credit market behavior is sometimes sparse at present. While California periodically publishes a histogram summarizing credit holding patterns, more nuanced data and reporting from all jurisdictions would permit a better sense of aggregate exposure across the fuel sector to future fluctuations in credit or fuel markets. Additional quantitative transparency into the LCAs used to generate pathway CI scores would also allow a better understanding of the scalability of alternative fuel production pathways and the bottlenecks which prevent such expansion.

Finally, further research into fuel market response as these programs increase in stringency and evolve and as other jurisdictions adopt similar policies will help shed light on complexities of market interaction and aggregate demand. This research is critical for the compliance outlook for these programs, as well as to explore incompletely understood relationships surrounding global capacity for biomass production and the associated land use change risks, technological evolution in energy systems, and consumer preferences.

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Endnotes

[i] The figures and tables in this report reflect available data per jurisdiction. California and Oregon data go through 2020 Q2 (2019 being the last complete data year at the time of analysis), and British Columbia data go through 2019. Data for the first half of 2020 are presented where available and should be interpreted with the COVID-19 lockdowns, as well as other market factors (like tightened CI standard) in mind.

[ii] Transport energy in Washington state will add nearly 18%, or 3.9 billion gge, under an LCFS-like program in the region when its Clean Fuel Standard begins in 2023 [1].

[iii] As described in the introduction, the transport realities accompanying pandemic may have made 2020 compliance easier to attain.

[iv] This set up differs from most crediting activity, which is for carbon emission reductions relative to the annual benchmark.

[v] E85 blends used in flex-fuel vehicles are currently the principal way proportional ethanol use can increase. In 2019, US EPA put into place regulations to allow 15% blend of ethanol (E15) by volume in gasoline fuel year-round [28], recently vacated by the courts. Neither California nor Oregon currently carries E15 blends.

[vi] FAME is fatty acid methyl ester and HEFA hydro-processed esters and fatty acid conversion processes. Biodiesel (BD) and renewable diesel (RD) in this report refer to FAME and HEFA process fuels, respectively.

[vii] ILUC is market-mediated land conversion caused by increasing aggregate consumption of similar products. For example, if soybean oil is shifted from its customary use in food or feed and instead used to produce fuel, the consumers of the now-displaced oil will need to procure alternative supplies. The demand for additional feedstock

can lead to land conversion to expand crop production; even if the oil being used for fuels does not come from recently converted land, the resulting fuel sparks growth in demand that can lead to land clearance.

[viii] Oregon and California both use the GREET modeling system and adapt it to state conditions and estimate ILUC with a version of the GTAP model plus an emission factor model for land conversion, although Oregon uses a separate model for corn ethanol emissions factor conversion, resulting in a lower ILUC CI estimate [29]. Pathways certified in California can be used in Oregon, with state-specific adjustments such as transport CI; Oregon has approximately 30 additional facilities not reporting to California (Peters, personal communication). BC acknowledges ILUC but does not account for it, and uses a different LCA model, GHGenius, built for Canadian fuels.

[ix] EER is the motive efficiency of the alternative vehicle/fuel combination relative the ICE/petroleum fuel reference and is used in the calculation of GHG savings due to the fuel, for program crediting. For example, light duty electric vehicles use an EER of 3.4 under all three programs, which means that the conversion of electricity to transportation is approximately 3.4 time more efficient than the conversion of gasoline. For a list of program EERs for California and Oregon see [11].

[x] In California, low- or zero-CI score electricity is accessible via book-and-claim contracts with low carbon sources. In Oregon, utilities can opt in to receive their area-specific CI score.

[xi] Renewable diesel typically has a CI score slightly higher than biodiesel, as it requires additional processing.

[xii] Regulators don't place any unit tax or subsidy on any particular fuel or technology, but the policy acts as an implicit tax-subsidy scheme through the credit price.

[xiii]Each jurisdiction has different prescribed energy densities that determine the total amount of alternative energy in gge terms.

[xiv] If a shift in the marketplace allowed for low carbon fuels to become more readily available at lower cost, credit price could decrease with more stringent CI targets.

[xv] Historical data on credit holdings is not maintained on the site.

[xvi] Other incentives can close a cost gap for bringing a fuel to market, meaning a fuel becomes cost competitive at a lower LCFS credit price than would be the case if the LCFS were the only policy in play.

[xvii] British Columbia feedstock information is not categorized by fuel type, meaning we are unable to differentiate feedstocks used in biodiesel and renewable diesel separately. There is no BC natural gas graph since through 2018, its natural gas was composed solely of fossil sources.

[xviii] Here and throughout this section, total credit value reflects credits generated in a given year evaluated at the average market price for LCFS credits that year.

[xix] The calculation assumes that these credits are generated at a zero CI score. ARB does not provide information on electricity energy volumes being credited below the grid average.

[xx] California and Oregon average retail electricity prices are collected from the Energy Information Administration's State Electricity Profiles at https://www.eia.gov/electricity/state/.

[xxi] Average per-kWh incentives for off-road electricity in California and Oregon aren't reported here due to insufficient data at the time of writing.

[xxii] However, unlike the California system, where "incremental credits" are only earned on residential charging (although low-CI charging is accessible for charging elsewhere), in Oregon incremental credits can be earned for both residential and non-residential charging.

[xxiii] For hydrogen stations, this is based on the station's daily dispensing capacity. For fast chargers, it employs a formula which results in an assumption that a charger's capacity is a number of kWh approximately equal to its nameplate capacity in use for four hours out of any 24-hour period.

[xxiv] In California, under state targets petroleum fuel demand would decline in the late 2020s.

[xxv] This is a step shy of a single system-wide program, with one compliance instrument. Note that book-and-claim is already used to allow certain low carbon fuels -- namely zero-CI electricity or renewable natural gas -- produced outside the jurisdiction to be credited for use in an LCFS jurisdiction of any electricity or natural gas, bypassing the need for delivery of that physical product. This similarly expands potential supply and reduces costs to achieve aggregate emissions reductions.

[xxvi] California is home to about 3.5% of U.S. oil production and fifteen oil refineries, but fewer over the last decade (down from twenty in 2010) [30] [31] [32]. BC contributes roughly 2% of Canadian oil production and has two oil refineries [27], importing mostly by pipeline from Alberta. Oregon has no internal oil refining, and imports most of its transport fuel.