Oregon’s Clean Fuels Program – A Review and Status Update

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ABSTRACT
Oregon implemented a fuel carbon policy called the Clean Fuels Program (CFP) in 2016. Modeled largely after the Low Carbon Fuel Standard (LCFS) operated by California, the Clean Fuels Program sets a declining target for the average life cycle carbon intensity (CI) of transportation fuels used in the state. The CFP incentivizes the deployment of emissions-reducing fuels and vehicles, and can contribute towards economy-wide GHG reduction goals. This paper reviews program data from the first three years of CFP operation, provides an overview of program characteristics, identifies key trends, and compares the CFP to the LCFS. While it is early in the program’s operational history and CI reduction targets are small, the available data indicates a program functioning as expected based on the experience of jurisdictions with similar programs. Aggregate emissions reductions have slightly exceeded targets resulting in the accumulation of a small bank of credits. Early compliance has largely been driven by blending of ethanol into retail gasoline and the introduction of greater volumes of diesel substitutes. Electric vehicles are a small but rapidly growing contributor to compliance. As targets grow more stringent, compliance will require greater volumes of low-carbon fuels to be brought to market.

Keywords: Oregon, biofuels, Clean Fuel Program, LCFS, life cycle analysis, climate policy
INTRODUCTION

The transportation sector accounts for 40% or more of greenhouse gas (GHG) emissions in California, Oregon, Washington, and British Columbia. Each of these jurisdictions is a signatory to the Pacific Coast Collaborative (PCC) Climate Plan, which pledges them to adopt a number of climate policy measures, including developing regional demand for low carbon fuels [1]. Oregon instituted its Clean Fuels Program (CFP) in 2016 as part of the PCC commitment and its state-level GHG emissions reduction strategy. The CFP is largely based on the Low Carbon Fuel Standard (LCFS), in operation in California since 2011. The CFP aims to reduce the GHG intensity of state transportation fuels by 10% over a ten-year period by providing a market to incentivize development and deployment of alternative fuels and vehicles with lower GHG emissions than conventional petroleum-based technologies.

The CFP sets an average carbon intensity (CI) standard for transportation fuels used in Oregon, with a few exemptions such as fuels going to military uses. The CI standard is measured in grams of carbon dioxide equivalent per megajoule of fuel energy (gCO\textsubscript{2}e/MJ). All fuels are assessed for lifecycle GHG emissions, covering all activities from production through combustion including production of raw materials, conversion or refining, transportation, and any significant GHG impacts due to market perturbations from the policy, including land use change associated with some biofuels. Each fuel receives a CI rating based on that assessment. Fuels with a CI rating above the target, like petroleum-based fuels (e.g., gasoline and diesel), accumulate one deficit for each tonne of GHGs they emit above the standard. Fuels with a CI rating below the standard generate one credit for each tonne of GHG emissions avoided relative to the CI target. For compliance, an obligated party must retire enough credits to offset generated deficits. Credits are tradeable by private contract, with or separated from the fuels that generate them, and act as compliance units as well as financial instruments, thus allowing a market price for emissions credits to emerge. Credit transfers must be registered with the CFP regulator, the Oregon Department of Environmental Quality. CFP credit sales to deficit-generating obligated parties typically generate a significant source of revenue for low carbon fuel producers.

The program is different from a cap-and-trade carbon allowance program, which prices all emissions; the CFP prices only emissions relative to the standard, penalizing emissions above the standard and rewarding savings below it. While cap and trade allowance permits and CFP credits both represent an amount of GHGs, they are not equivalent. Whereas cap and trade permits represent an allowance to emit a certain \textit{absolute} amount of GHGs, CFP credits reflect an emissions reduction relative to the specified CI target. Additionally, currently-used cap and trade permits only cover emissions from the tailpipe within the controlled jurisdiction and consider biogenic carbon to have no emissions, CFP credits account for the full lifecycle emissions of the fuels that generate them, and include some accounting of land sector emissions for the production of biofuels.

To achieve compliance each reporting period, obligated parties may reduce the CI rating of their fuels, generate their own credits, buy credits from other market participants (with or separated from the credit-generating fuel), or apply credits banked in earlier years. The CFP schedule of annual CI reduction targets builds toward its 10% reduction in the statewide fuel pool’s CI rating from 2015 levels by 2025: less than 1.0% in 2016 and 2017, 1.0% in 2019, 1.5% in 2020. Credits are earned against distinct nominal standards set for gasoline and its substitutes and diesel its substitutes; once earned, credits are fungible and bankable for future use without limit, in addition to being tradable. A recent Executive Order by Oregon Governor Brown called for extending targets through 2035 to reach 25% reduction in that year [2].
The fuel CI standard has emerged in a number of jurisdictions as a key climate policy focused on transportation, potentially difficult to decarbonize under economy-wide carbon prices at levels currently seen [3, 4]. British Columbia [5] has a similar policy in effect since 2011; Brazil is just embarking on one, and Canada is developing a fuel CI standard using the LCFS as a model [6, 7]. For more about transportation fuel CI standard policy design, including how it compares to a cap-and-trade, see [3,4]; for Oregon’s CFP regulation see [8].

Several studies have examined the California LCFS [4, 9-12], and the British Columbia low carbon fuels regulation [13]. Oregon’s program has not as yet been studied at similar depth, but its early years are of interest as an instance of the policy implemented: a) alongside a longer-standing, more mature policy in a larger jurisdiction, and b) for a reference year where renewable fuel mandates of E10 and B5 (10% ethanol by volume in gasoline and 5% biodiesel by volume in diesel) had already taken effect, reducing the efficacy of increasing biofuel volume up to those levels as an early-year compliance strategy, in contrast to California [14,15].

This study aims to contribute to information on Oregon’s Clean Fuels Program by examining and synthesizing publicly available data on the key metrics of the market response and compliance to Oregon’s Clean Fuels Program in its early years, from 2016 through 2018 Q3. Methods are outlined in the next section, followed by the presentation of results, discussion, and conclusions in subsequent sections. Comparative discussion of the CFP with other programs is focused in the final two sections.

METHODS
The study summarizes key program indicators and data synthesized from secondary sources using spreadsheet-based calculations, and provides policy and market context to help interpret data trends. The key data source is public CFP data from Oregon’s Department of Environmental Quality (DEQ), the administering agency, supplemented by other public data sources, and focuses on trends in transport energy and CFP credit and deficit generation, transport fuel carbon intensity ratings, and the credit market, focusing on the period 2016 through 2018 through Q3, the latest available data at the time of analysis. The study also employs, where appropriate, some comparative analysis of program policy design between the CFP and California’s LCFS, as well as comparisons to current or similar-stage developments in California’s LCFS to elucidate trends and their drivers.

RESULTS
Transport Fuel Energy
The first years of Oregon’s CFP did not see much change in transport energy reported under the program (Table 1). Gasoline and its substitutes – the “gasoline pool” – contributed around 65%, of total reported energy from 2016 through 2018 Q3, while alternative fuels contributed close to 7% over the same period. Liquid biofuels dominated alternative fuel energy in the program’s first year, providing 99%, decreasing slightly to 97% in 2018 through Q3, as energy from gaseous fuels and electricity in electric vehicles increased.

Among alternative fuels, ethanol dominated in terms of energy, but declined slightly over the period – close to 70% in 2016 and just under 66% in 2018 through Q3. Ethanol volumes were at or slightly above levels to satisfy the state requirement for E10 in gasoline, a 10% ethanol blend by volume that constitutes the overwhelming majority of U.S. retail gasoline sales. Higher ethanol blends like E85 can be used in flex-fuel vehicles, but are not widely available. Biomass-based diesel, consisting of FAME biodiesel and hydrotreated renewable diesel, also remained above the state required level of 5% by volume in diesel fuels. FAME biodiesel requires labeling
for fueling up to B20, and specialized equipment beyond that level; hydrotreated renewable diesel
is freely substitutable for diesel in infrastructure and vehicles.

Non-liquid alternative fuels made a growing contribution. For gaseous fuels, the extent of
any growth in use in Oregon is difficult to distinguish from a growth in reporting. Since the
gaseous fuels were rated as meeting 2025 program targets, they are not required to report to the
CFP but can opt in to the program to generate credits. In addition, there is a book-and-claim
system for the biogas portion considered as dispensed in state after distribution via common
carrier pipeline from anywhere in North America, if contracted for that purpose. For electricity
used as a transport fuel, growth in electric passenger vehicles is behind some of the increased use.
In September 2018, Oregon reported 17,759 electric passenger vehicles, and the CFP adopted
measures to include electric charging energy in the program without requiring the providing
entity to opt in.

It is difficult to attribute specific alternative fuel energy use in Oregon directly to the CFP
given other state and federal policies that also incentivized low-carbon fuel use during this period.
The federal Renewable Fuel Standard (RFS) promotes biomass-based diesel, biogas, and ethanol
nationwide. Oregon and the U.S. subsidize transport electricity through EV rebates and other
policies, although Oregon’s rebate program was delayed by a lawsuit [18]. The CFP incentives
are additional to these, and likely contributed to changes in alternative fuel demand. CFP targets
began relatively low, which resulted in a relatively small price signal to advanced fuel producers
and sufficient opportunities for compliance through low-cost marginal changes in fuels. As the
program has become more stringent year-by-year, credit prices have increased and the effect of
the CFP incentive should also increase and be easier to discern from other regulatory or market
forces.

Fuel Carbon Intensity Ratings

The CFP bases its incentives on a lifecycle analysis of each fuel “pathway” – a formalized
description of the full procurement, production, and distribution stages of bringing the fuel onto
the transport market in Oregon. Oregon’s CI assessment procedures are similar to those in
California, and draw on most of the same modeling systems. Pathway CI scores approved in
California are, by default, also approved in Oregon with some adjustments to account for the
different market destination and modeling choices. Approximately thirty pathways, mostly from
small producers [19], only have CI scores in the Oregon CFP; certain fuels by nature, such as
electricity, reflect in-jurisdiction conditions. Alternative fuel CI ratings are assessed using a
modified version of the Greenhouse Gases, Regulated Emissions and Energy Use in
Transportation (GREET) model, localized to reflect the fuel and transportation parameters in
Oregon. Differences in Oregon and California results from this model for liquid and gaseous
fuels are usually quite small, due to the small contribution of transport to lifecycle emissions for
these neighboring states. Oregon has higher average grid electricity CI score than California’s,
due to greater reliance on fossil fuel sources. The impact, however, is diluted by adjusting for
electric drivetrain efficiency in both programs, and, because Oregon offers an option to use
utility-specific CI scores rather than the average grid, which is attractive if the local utility has
low-emitting generation sources. For biofuel feedstock CI scores, both states use the same version
– including identical assumptions regarding nationwide levels of biofuel demand – of a
computable general equilibrium model, the Global Trade Analysis Project (GTAP) adapted to
include biofuels, to estimate land use change. For all feedstocks except corn, Oregon follows
California in using the Agro-ecological Zone Emission Factor Model (AEZ-EF) to estimate
emissions from the GTAP-estimated land use conversions, to use in calculating overall biofuel CI
score. Oregon draws on scenario analysis using the Carbon Calculator for Land Use Change
from Biofuels (CCLUB), which focuses on U.S. land use for corn-related land use change.
emission factors. The result is less than 8gCO2e/MJ from this source, less than half of California corn ILUC estimates. Thus, the overall CI score for a given corn-based pathway, but not other biofuels, is about 15-20% lower in Oregon’s program than California’s. Oregon’s use of CCLUB for corn but not other feedstocks was a modeling choice; no rationale was provided in the regulatory documents. Petroleum fuels’ lifecycle emissions are assessed in both programs using The Oil Production Greenhouse gas Emissions Estimator (OPGEE), with parameters adjusted to reflect emission differences due to a different portfolio of sourcing. Additional observations regarding the differences between the Oregon and California programs appear in the Discussion section.

Under the program, all eligible fuel pathways are assigned a CI rating and the number of transportation fuel pathways eligible in the program can grow alongside the number of distinct fuel sources, individualized to specified fuel volumes coming from particular physical plants. By the end of 2018, the CFP had 283 transportation fuel pathways from 163 registered parties. Several pathways are devoted to program reference fuels, the petroleum-based gasoline and diesel fuels used to calculate a baseline and which receive a statewide average CI rating, and for imported blends without a particular biofuel source identified, which assume a relatively high CI rating for the source-unidentified biofuel. Source-unidentified biofuels in imported finished blends accounted for a small share of biofuel use — no more than 5.5% of all biodiesel, or 6% of all ethanol in any given quarter. Among alternative fuels, ethanol accounted for 51% of pathways, and biomass-based diesel contributed an additional 25%, of which 80% was biodiesel and the remainder renewable diesel. Of the several pathways for electricity, some are pegged to a recent average annual CI rating of the Oregon electricity grid, and others are specific to utilities opting on an annual basis to choose their own average CI rating or the statewide grid average. EV charging from solar or wind sources also have pathways.

The CI ratings assigned to gasoline and diesel used in Oregon are averages of lifecycle emissions estimates tracked from the petroleum sources and refineries supplying the state, and are both near 100 gCO2e/MJ. The reference fuels for setting the 2015 baseline for CI reductions were E10 and B5 blends for gasoline and diesel pools, respectively; their CI ratings assume Midwest sourcing of corn for ethanol and soybean for biodiesel, and in 2018 were 98.64 and 99.61 gCO2e/MJ, respectively. Because the biofuels have a lower CI rating than the petroleum fuels, the blends’ CI rating is lower than the neat fuels’. In 2018, 20% biodiesel blends by volume in diesel, or B20, were reported in the program; the higher blend of the biodiesel lowers the CI rating by just over 6% compared to the B5 blend.

Figure 1 shows CI rating ranges for available CFP pathways by alternative fuel type in 2018, and gasoline and diesel’s CI ratings for comparison. Fuels can have a wide and overlapping range of CI ratings, so there is no simple rank ordering of fuel types; the specifics of supply chain emissions matter. Extremely negative values for some renewable natural gas (RNG) fuels refer to biomethane pathways generated by capturing otherwise uncontrolled sources of fugitive methane emissions, typically livestock manure lagoons. The fuel is credited with reducing the emission of this methane, provided it goes beyond regulations obligating control in Oregon. Potential sources are limited and are not yet producing large volumes of RNG for transportation [16]. CI ratings in Figure 1 are adjusted for Energy Efficiency Ratio (EER), to capture the on-road fuel/vehicle efficiency relative to a conventional petroleum fuel used in an internal combustion engine. The CFP’s EERs are 0.9 for natural gas in spark-ignition engines and 3.4 for residential electricity, which assumes all passenger cars.

Figure 2 shows the percentage CI rating reductions requirements needed for compliance each year from 2016-2025. To date, Oregon fuels slightly over-complied with the regulation.
Compared to required reductions from the 2015 baseline of 0.25%, 0.50% and 1.0% in 2016, 2017, and 2018 through Q3, respectively, reported reductions were 0.34%, 0.65%, and 1.0%, respectively, with the 2018 reduction an undercount due to a lag in calculating residential electricity credits. Starting in 2017 and continuing in 2018 through Q3, CI ratings declined from 2015 levels more in the diesel pool than in the gasoline pool: for the two periods, respectively, percentage CI reductions were 0.74% and 1.2% for the diesel pool, and 0.60% and 0.87% for the gasoline pool. Larger CI percentage reductions for diesel substitutes mirror the California LCFS experience. A decline over time in the contribution of unidentified biodiesel imported within finished diesel blends, from 5% in 2016 Q1 to less than 1% in 2018 Q3, but not for ethanol within finished gasoline blends, suggests a greater incentive to use and report lower CI-rated feedstocks in biodiesel.

Figure 3 averages the CI ratings of fuels reported under the CFP by fuel type per quarter. The average captures the mix of fuel pathways in use for each fuel type, weighted by volume (energy). The CI ratings for alternative fuels above 80gCO$_2$/MJ are for fossil-derived natural gas and propane; their average CI rating declined 1.4% and 0.7% respectively from 2016 to 2018 through Q3. The dominant compliance fuels, ethanol and biodiesel, are both amid the pack of the remaining alternative fuels, with ethanol having a consistently higher average CI rating among reported fuels. Ethanol’s average CI rating declined over the period by 1.4%. The average CI rating for biodiesel was lower in 2016 and fell by 13.8% for the same period. Such CI rating reductions within fuel types could reflect reduced emissions in production of fuels already coming into Oregon due efficiency gains, switching to or identifying lower-carbon sources of fuels being shipped to the Oregon market, or some combination thereof.

RNG average CI rating was lower than that of fossil natural gas throughout the reporting period, and showed some quarterly CI volatility on relatively small volumes of fuel. Average CI rating for reported biogas was 48.2 gCO$_2$/MJ in 2016 and 64.4 gCO$_2$/MJ in 2018 through Q3. Renewable diesel came under mandatory coverage only in the program’s second year, 2017, and had an average CI rating that increased 12.1% from 2017 to 2018 through Q3. The CI rating increases in biogas and renewable diesel could be due to availability of feedstock when growing from small levels, but it is difficult to discern a pattern in this short dataset with aggregated CI rating information. However, these two fuels showed a similar pattern – increases in reported CI ratings – in the early years of California’s LCFS. Residential charging electricity CI rating was calculated for 2016 and 2017 using DEQ publicly available data on crediting plus residential energy not reported publicly but obtained from DEQ. The nonresidential on-road electricity CI ratings calculated from program data yielded nonfeasible values for 2016 and 2017 between -17 and -6gCO2/e/MJ. Values can deviate from the statewide grid average due to utility-specific CI ratings and potential for zero emission charging from solar or wind electricity, but the negative CI ratings calculated here indicate an error in reported energy, associated credits, or both. DEQ is aware of the issue, which pertains only to on-road, nonresidential electricity, and accounted for about 5% of electricity credits and energy, and less than 0.5% of alternative energy and credits. The issue did not affect results reported involving electricity as part of an aggregate category. Calculating average CI for off-road electricity was impossible due to lack of information about how to allocate energy across utility areas, or transport modes, and the timing of the deployment of electric transit, which impacts crediting for displaced reference fuels. EERs for off-road electricity vary between 2.1 (fixed guideway streetcar), and 3.3 (light rail).

CFP Credits and Deficits

The CFP is implemented through a system of credits and deficits that accrue to fuels based on their CI ratings and total quantity dispensed. Through 2017, the last year for which complete program data had been reported at the time of analysis, the program had generated a cumulative...
1,755,906 credits and 1,332,589 deficits, against a standard that tightened from 0.25% CI reduction in 2016 to 1.0% in 2018. The credit surplus of 423,317 MT CO₂e indicated that regulated parties exceeded requirements to that point; it constitutes a system-wide “bank” of credits available for future use that can accumulate or be drawn down over time.

Through 2018 Q3, reported credits under the CFP totaled 2.4 million metric tons (MMT) CO₂e, without that year’s residential electricity credits yet accounted for, compared to total program emissions reduction requirements of 2.0 MMT. Figure 4 shows that credits exceeded deficits generated in every quarter for 2016 and 2017, resulted in accumulation of the system-wide surplus credit bank. That credit bank was drawn down slightly – by 1,682 credits – in the first three quarters of 2018 before 2018 residential electricity credits were counted. Residential electricity credits surpassed 40,000 in 2017.

Figure 5 breaks down CFP credit generation by alternative fuel type. The dominant liquid biofuels were also responsible for the majority of credit generation under the program from 2016 through 2018 Q3. Renewable diesel generated only began to generate credits in 2017, when it came under CFP coverage. Over the period credit generation from electricity – excluding 2018 residential electricity charging of EVs, but including electricity for charging offroad fixed guideway sources added to the program in 2018 – contributed roughly 4%. Light rail and streetcar electric energy in use prior to 2018 does not receive the credit for displaced fossil fuels that most alternative fuels do; new fixed guideway sources do. Credits from biogas, fossil natural gas, and propane each contributed a less than 1% share over the period, and increased significantly from 2016 to 2017 from this low level, by 77%, 49%, and 99%, respectively, potentially reflecting additional opt-in from existing sources in use in Oregon or contracted from outside the state.

Ethanol was the majority credit generator in each quarter, although credit generation diversified, especially towards biodiesel (Figure 5). In 2016 Q1, ethanol generated 67% of credits and biodiesel generated 28% of credits. In 2018 Q3, the credit shares of ethanol and biodiesel were 55% and 41%, respectively. No public data are available on relative credit contributions of liquid biofuels from particular feedstocks, e.g., ethanol from corn or molasses, or biodiesel from soybean, canola, or used cooking oil.

**CFP Credit Market**

Regulated parties comply with the standard by retiring enough credits to cover any deficits they hold. This creates a demand and supply of program credits, and a market in which credit prices fluctuate to reflect current conditions. This market mechanism built into the CFP design encourages compliance at the lowest cost. Credit prices can be affected by market and policy uncertainty, availability and cost of emissions-reducing projects or lower emission fuels, expectations about future market performance, and about the CFP and other policies, including in-state provisions like the renewable fuel mandates and federal policies like the RFS, which shapes domestic use of alternative transportation fuels [21].

Market trading and contracting are left to the private sector; DEQ tracks the transfer of credits and credit prices. The regulation contains several provisions to smooth compliance difficulties and provide some protections against upside cost risk. Regulated parties may carry a deficit of up to 5% of the total deficits generated in one compliance period into the next year without penalty, which eases the compliance burden. Starting in 2017, the CFP also instituted a “credit clearance market” for the CFP, based on a similar mechanism in California’s LCFS, in accordance with
Oregon’s HB 2017. The provision aims to address short-term credit supply shortfalls and allow more time for producers to generate additional credits through increased supply of low-carbon fuels. It provides an end-of-year clearinghouse that comes into effect if regulated parties remain out of compliance, that is, hold deficits beyond the allowed 5% level. Deficit holders must purchase credits pledged into a pool by sellers at a price capped initially at $200 and adjusted for inflation thereafter. The mechanism will overcome instances of counterparties not locating each other or obligated parties not engaging in trading when obligations have not fully been met and credits are available for sale. It also sets a “soft” credit price cap for the program, since obligations on deficits remaining after the clearance market clearinghouse can be deferred until the next year with a 5% annual interest penalty. The regulation mandates a DEQ analysis if multiple parties defer their obligations or a single party defers for multiple years, as a form of market monitoring and oversight. The CFP includes additional layers of cost protection, for example, DEQ has authority to defer or suspend aspects of the program, under specified conditions. DEQ can act if an annual forecast by the Oregon Department of Administrative Services projects an inadequate supply of low carbon fuels to meet targets, as well as in the face of unexpected fuel shortages, or credit market disruption.

DEQ reports monthly on credit trading, including number of transfers, volumes, and average credit prices. The first program year and 2017 Q1 saw only a handful of trades for a small number of credits. Substantially more credits traded hands in 2018 as the standard doubled in stringency to 1%; credit prices for the just-over 420,000 credits traded that year climbed to close to $84. Credit prices for 2019 Q1 averaged about $134, on an upward trajectory for an average $145 in March (Figure 6). Roughly 37% of registered parties, or 61 entities, had participated in the credit market by March 2019, up from 24 entities through February 2018.

The CFP provides incentives that impact the net cost per unit of fuel delivered to the state, that depend on the credit price, fuel CI rating and CI targets. Retail prices reflect a variety of cost and market conditions, including policy impacts, as well as production costs, profit margin and competitive factors. Calculated changes in net cost may be reflected in prices to the extent that producers and retailers pass CFP incentives through to consumers. Table 2 provides an illustration of inferred cost impact to consumers for the components of E10 and B5 fuels, and their sum for the blended fuel for 2017, 2018, and 2019, using CI rating information based on reported CFP data on ethanol and biodiesel. DEQ’s posted formula on added fuel cost differs, and focuses on assessing blended fuels rather than blending components, and focuses on imported B5 and E10 blends without identified biofuel components, which are assigned Midwestern ethanol and biodiesel CI ratings [21,23]. At a $134 average credit price through 2019 Q1, the petroleum fuel in an E10 gallon would incur a $0.05 cost due to deficits accrued, and the ethanol volume in that gallon with a CI rating at the 2018 average through Q3 would receive a $0.04 per gallon subsidy, summing to under a $0.02 net cost. Similarly, the petroleum-based volume inside a B5 gallon in 2019 would incur a charge of $0.06, and the biodiesel volume would receive an incentive of about $0.04, for a less than $0.02 net cost. Note that these findings pertain to each gallon of fuel, to give an idea of net impact to consumers on prevalent fuel blends.

DISCUSSION

Oregon and California have substantially different fuel markets. Oregon’s is about one-eighth the size of California’s, its CFP has been in effect for three years vs. eight for the LCFS, and Oregon uses proportionally more diesel (35% vs. 22%). The relative contribution of diesel and gasoline fuels matters, since there are currently more cost-competitive substitutes for diesel than gasoline, though less potential future credit growth from light-duty electric vehicles.
California has considerable in-state petroleum fuel production—both crude oil production and refining—while Oregon has none and is reliant on imported fuels. However, the program design of Oregon’s CFP closely resembles California’s LCFS. Both programs use a common modeling basis for lifecycle carbon intensity assessments, and adjust results to local conditions. Oregon DEQ works closely with the California Air Resources Board, the California regulatory agency overseeing the LCFS, to make fuel pathways certified in the California program available under the CFP, adjusted for the Oregon destination, with a minimal amount of duplicated work. Oregon DEQ’s rulemaking in cost containment followed California’s with a similar program but with additional provisions and modifications to meet local concerns and legislative mandates. Both programs allowed opt-in crediting for alternative jet fuel starting in 2019, and expanded crediting to cover off-road electricity. Each state retains discretion over the design of its program, however, and there are several differences between the two, including:

- indirect land use change (iLUC). The CFP uses a different value (from a different modeling system) for iLUC emissions for fuels that use corn as a feedstock. As a result these fuels have a lower CI rating (and gasoline standard baseline, based on E10 fuel with Midwest corn ethanol) under the CFP than the LCFS. Other iLUC values (and modeling) are the same in both programs.

- electricity credits. Oregon ensures all residential electricity charging is credited in the CFP through a backstop aggregator that receives any unclaimed credits served by an electric utility. California’s LCFS assigns credits to the electrical distribution utility or its designee. The CFP also allows electric utilities the annual choice to earn credits based on the recent average CI rating of electricity sourced by the utility instead of the state grid average, providing an incentive for the utility to lower its own CI rating, although without reflecting the fungibility of power supplied by the grid and introducing the potential for inconsistencies over time in carbon accounting. The LCFS does not offer electric utilities a similar choice, although recent changes allow the crediting for charging based on marginal as opposed to average carbon intensity, or for using non-biomass renewable electricity at a zero CI. These pathways typically apply to registered pathway holders, not residential charging.

- credit market monitoring and design. Oregon’s CFP requires an annual low carbon fuel supply forecast to foresee potential low carbon fuel supply issues. DEQ has the authority to defer program aspects and must perform “root cause analysis” in the event of a forecast supply shortage or actual credit or fuel market disruptions. CFP allows a 5% net deficit carryover for regulated parties into the following compliance year without penalty (“small deficit” provision). California’s LCFS has none of these provisions, but is in the final stages of implementing an additional cost containment mechanism in the form of advancing future residential electricity credits at the credit cap price in the case of a systemwide credit shortfall, within some limits and subject to a payback schedule.

- sources of credits and deficits and pathway validation. California’s LCFS allows crediting for carbon savings due to innovations in crude production and refining and assigns additional deficits for substantive increases in state average fossil fuel CI rating over time; Oregon’s CFP, with no in-state refineries, does not. Finally, the LCFS adopted several design elements in 2019 that Oregon’s CFP does not have, such as third-party independent validation of information used in CI rating calculation, a protocol for crediting carbon capture and sequestration, and limited crediting for hydrogen and electric vehicle fueling infrastructure capacity [8,11].

California and Oregon cooperate as part of the Pacific Coast Collaborative (PCC), an agreement between California, Oregon, Washington, and British Columbia to take action on climate change, including creating a regional low carbon fuel market. California and British Columbia adopted clean fuel policies in 2010. Oregon followed in 2016. In Washington, 2015 legislation effectively barred an LCFS there until 2023; legislation to lift that barrier did not pass in 2018 or subsequently.
The PCC commitment involves working together to align programs toward “an integrated West Coast market for low carbon fuels” [1]. This could involve a regional program spanning multiple jurisdictions or a formal linkage allowing credit trading across jurisdictions. That approach would face several significant technical and design challenges to harmonize key program elements such as CI accounting methods, program CI targets and stringency, and cost containment mechanisms [4]. Absent a formal linkage agreement, the low carbon fuel programs in California, Oregon, and British Columbia have an aggregate impact on fuel markets that can link credit price movements across jurisdictions, especially if sources of low carbon fuel supply overlap and are limited. Fuel producers can be expected to balance a range of economic, contractual and technical factors when choosing a market. In theory, markets with high credit prices would typically attract more of the available fuel supply, exerting downward pressure on those market prices; the converse would be expected in markets with a low credit price. Adjustment would be expected to continue until producers either are indifferent between jurisdictions as destinations for the next unit of fuel, or hit some other barrier to selling more fuel. How this and any other interaction mechanisms play out is for future research to identify and characterize; assessment of interactions is challenging due to the limited history of these programs, few comparable programs globally, the dynamic nature of the interaction, and other market conditions at play within and across jurisdictions. In general, the presence of multiple jurisdictions with similar policies to support low carbon fuels would tend to strengthen the signal to invest in low carbon fuel production capacity, at the same time as creating potential competition across jurisdictions for a limited fuel supply at any given time, depending on the stringency of the policies [4]. How the implementation of similar, yet distinct, programs in different jurisdictions impacts the flow of alternative fuels to particular markets – such as, how the presence of California’s LCFS may impact the trends seen here under Oregon’s CFP in its early years – is a question for future research.

CONCLUSION

Oregon’s Clean Fuels Program took effect in 2016 and generally performed as expected, based on experiences from similar fuel carbon policies in California and British Columbia. As the CI target decreased, small volumes of a number of low carbon fuels began to be deployed in the state, providing modestly more compliance credit than required through the first three years. Compared to California, the closest analogue, the scope for early credit generation was limited by a baseline that embedded higher biofuel blends of E10 and B5. However, Oregon also benefitted from any innovations already instituted in the fuel market or incented by the California program, as well as the increasing supply of compliance fuels such as renewable diesel, not previously used in the state. As in California, ethanol blended into retail E10 gasoline provided the majority of compliance credits through early years. Two factors will shape ethanol’s contributions moving forward. First, how much will average CI ratings of ethanol entering the state decline? Lower-carbon ethanol pathways are in use, especially in California, but the lowest-carbon ethanol pathways have not appeared in substantial volumes in either state, suggesting that non-ethanol low carbon fuels are more competitive compliance options. Second, can ethanol expand in volume beyond the 10% “blendwall,” and if so by how much? Even if ethanol’s CI rating does not significantly decline, greater penetration of E15, E85, or other mid-level ethanol blends could put ethanol’s contribution to compliance on an upward trajectory. E85 has seen growth from very low rates, but higher ethanol blends have not penetrated appreciably in either state. Future incentives may open up new opportunities for ethanol as a compliance fuel, but the track record to date records a somewhat limited capacity for ethanol to provide deeper GHG emissions reductions to meet more stringent targets, absent additional innovation. Other fuels that are growing rapidly in volume under currently available technologies look to be the likely source of CFP credit growth under increasingly ambitious targets. Electric vehicles are a small part of the
Oregon fleet at the moment; their deployment rate over the coming decade will exert a substantial impact on the fuel market and the scope of additional credit generation options needed for compliance with the CFP. If, as in California, renewable diesel becomes a much more important compliance fuel, concerns about the CI rating depending on the sustainability of its feedstock will also become more prominent [12].

The analysis of DEQ data revealed a data reporting error that had a small effect on aggregate credits generated; DEQ was made aware of the issue. This analysis relied on publicly available data, and is not intended to be a systematic audit or program evaluation. Within that scope, it did not reveal any systematic irregularities in program design or reporting. Continued external monitoring of this program, like any important environmental regulation, is advised. The institution of third party CI data auditing, as underway in California, would be an important program extension and is planned. Assessment of the GHG impacts of this and similar programs, especially where CI ratings diverge from environmental impact, is also warranted.

For other jurisdictions considering an LCFS, Oregon’s CFP indicates potential for a relatively small jurisdiction to implement a fairly complex climate policy, aided by jurisdictional cooperation that provided a policy template as a starting point and streamlined the administrative burden for preparing and implementing the regulation. Technical assistance from academic experts helped address critical questions and informed the program’s development. Public program and market data contain invaluable information about alternative fuels’ relative costs, market readiness, and forthcoming prospects, which could inform other jurisdictions considering an LCFS. If interest in the policy spreads more broadly, other jurisdictions can learn from those that have gone before, and inform an evolving policy blueprint that delineates core principles, optional modules, and other desired features more systematically given a diversity of settings. Aligned implementation would enhance overall policy impact, which is especially desirable given the global nature of the climate crisis.

ACKNOWLEDGMENTS
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AUTHOR CONTRIBUTIONS
The authors confirm the following contributions to the paper: Witcover and Murphy contributed to study conception and design; Murphy and Witcover divided the data collection, analysis and initial interpretation of results (Murphy focused on credit market and fuel pathway characterizations and Witcover on the other topics); Witcover prepared the draft manuscript except for the sections pertaining to the Murphy analysis, which Murphy drafted. Witcover took the lead in the Discussion, and Murphy in the Conclusions and Abstract; both authors reviewed, commented, and edited on the others’ analysis and write-up. All authors reviewed results and approved the final manuscript. The author(s) do not have any conflicts of interest to declare.
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Table 1. Total transportation energy use reported in Oregon’s CFP (million gge*, unless otherwise noted).

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2017</th>
<th>2018 thru Q3</th>
<th>% change 2016–2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline**</td>
<td>1,432</td>
<td>1,451</td>
<td>1,165</td>
<td>1.3%</td>
</tr>
<tr>
<td>Diesel**</td>
<td>801.0</td>
<td>772.1</td>
<td>620.5</td>
<td>-3.6%</td>
</tr>
<tr>
<td>Ethanol</td>
<td>125.2</td>
<td>122.9</td>
<td>86.8</td>
<td>-1.8%</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>49.4</td>
<td>53.2</td>
<td>40.6</td>
<td>7.6%</td>
</tr>
<tr>
<td>Renewable diesel**</td>
<td>--</td>
<td>0.38</td>
<td>0.73</td>
<td>NA</td>
</tr>
<tr>
<td>Fossil natural gas</td>
<td>0.66</td>
<td>1.02</td>
<td>1.22</td>
<td>52.9%</td>
</tr>
<tr>
<td>Biogas</td>
<td>1.02</td>
<td>2.08</td>
<td>1.30</td>
<td>103.5%</td>
</tr>
<tr>
<td>Propane (LPG)</td>
<td>0.05</td>
<td>0.11</td>
<td>0.33</td>
<td>97.2%</td>
</tr>
<tr>
<td>Electricity (non-residential)**</td>
<td>0.05</td>
<td>0.08</td>
<td>1.37</td>
<td>68.7%</td>
</tr>
<tr>
<td>Electricity (residential)*</td>
<td>1.28</td>
<td>1.56</td>
<td>--*</td>
<td>22.2%</td>
</tr>
</tbody>
</table>

Total fuel: 2,411 2,404 1,918* -0.28%
Ethanol volume as percent of liquid gasoline pool: 11.1% 10.8% 10.1%
Biomass-based diesel volume as percent of liquid diesel pool: 5.7% 6.3% 6.1%

<table>
<thead>
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<th>2018 thru Q3</th>
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<td>1.56</td>
<td>--*</td>
<td>22.2%</td>
</tr>
</tbody>
</table>

Total alt fuel: 169.8 173.2 132.3* 2.00%
Total alt fuel (percent of total energy): 7.1% 7.3% 6.9%
Non-biofuel portion of alt fuel: 1.0% 1.9% 3.2%

* gge = Oregon Clear Gasoline (finished gasoline blend not containing ethanol) gasoline gallon equivalents.
Credited energy from residential electricity used as a transportation fuel for 2016 and 2017 were obtained from DEQ; it was not yet available for 2018 at the time of analysis, affecting asterisked categories. Fuel stocks carried into the program were assessed in the first compliance period.
** Gasoline and diesel each comprise the clear petroleum fuel (finished motor fuel gasoline and diesel, respectively, not containing biofuel) and the petroleum portion of biofuel blends. Renewable diesel was not mandated as a covered fuel in the program in 2016 but may have been used in the state with no tracking of its associated Cl rating. In 2018, the program expanded to include off-road electricity used in, for example, fixed guideway applications such as light rail, aerial tram, and streetcars. Source: [16].

Table 2. CFP policy incentives for fuels in E10 and B5. Assumes (a) reported average annual CFP credit prices and Cl ratings for ethanol and biodiesel, (b) program values for fuel energy densities and petroleum Cl ratings, and (c) E10 and B5 as 10% ethanol by volume in blended gasoline and 5% biodiesel by volume in blended diesel, respectively. Reported sums may differ from arithmetic due to rounding. *2019 calculations use average credit prices through March 2018 average ethanol and biodiesel Cl ratings through Q3 (62.99gCO2e/MJ and 44.93gCO2e/MJ, respectively), and 2018 Cl ratings for gasoline (100.77gCO2e/MJ) and diesel (101.65gCO2e/MJ). Source: [10, 15].

<table>
<thead>
<tr>
<th>Fuel Blend components</th>
<th>2019*</th>
<th>2018</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>E10 (gallon)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>$0.052</td>
<td>$0.029</td>
<td>$0.013</td>
</tr>
<tr>
<td>Ethanol</td>
<td>-$0.037</td>
<td>-$0.024</td>
<td>-$0.013</td>
</tr>
<tr>
<td>Sum</td>
<td>$0.016</td>
<td>$0.005</td>
<td>$0.00</td>
</tr>
<tr>
<td>B5 (gallon)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>$0.060</td>
<td>$0.033</td>
<td>$0.015</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>-$0.044</td>
<td>-$0.028</td>
<td>-$0.015</td>
</tr>
<tr>
<td>Sum</td>
<td>$0.015</td>
<td>$0.004</td>
<td>$0.00</td>
</tr>
</tbody>
</table>
Figure 1. CI rating ranges for alternative fuel pathways in Oregon’s CFP, 2018. Bars represent CI rating ranges for pathways certified in the program and available for use, adjusted for EER. The high end of the first bar segment represents the average CI rating of available pathways. Sources: [16, 17, 20].

Figure 2. CFP Annual average % CI rating reduction of reported fuels and compliance targets of gasoline and diesel fuel pools. “BL” refers to the baseline, that is, the CI rating for reference fuels — motor gasoline and on-road diesel — used in Oregon in 2015. Data Source: [16].

Figure 3. Quarterly CI rating by fuel category, CFP. Reported ratings are adjusted for Energy Economy Ratio (EER). The calculation excludes non-residential on-road electricity vehicle charging, and off-road electricity use covered in the program starting in 2018, due to insufficient data and a data reporting error (see text). Data source: [16].

Figure 4. Oregon CFP carbon credits, deficits, and systemwide “bank.” Annual data 2016–2017; 2018 through Q3 only. Data for 2018 presented excludes residential electricity credits. Data source: [16].

Figure 5. Alternative fuel net CFP credits (left) and credit shares (right). Calculations exclude residential electricity credits in 2018. All quarters of 2016–2017, 2018 through Q3 only. Data source: [16].

Figure 6. Average monthly CFP credit prices, transaction volumes, and number of transfers reported to DEQ 2017 through March 2018. Data source: [22].
Reported % CI reduction is calculated based on credits and deficits, overall for composite of gasoline & diesel fuels.
*CI ratings are adjusted for EER; residential electricity — assumes grid avg CI and light duty vehicles (passenger cars); for 2038, reports EER-adjusted grid average CI due to insufficient data.