# Puget Sound Regional Transportation Fuels Analysis

Final Report

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Submitted to:

Puget Sound Clean Air Agency

Submitted by:

ICF

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# List of Abbreviations and Acronyms

| | |
|---|---|
| AADT | annual average daily traffic |
| AEO | Annual Energy Outlook |
| ANL | Argonne National Laboratory |
| ANS | Alaska North Slope |
| B20 | 20% biodiesel, by volume, blended with diesel |
| B5 | 5% biodiesel, by volume, blended with diesel |
| BAU | business as usual |
| BenMAP | EPA's Benefits Mapping and Analysis Program |
| BEV | battery electric vehicle |
| CARB | California Air Resources Board |
| CBG | Census Block Group |
| CBOB | conventional blendstock for oxygenate blending |
| CFP | Clean Fuels Program |
| CFS | Clean Fuel Standard |
| CHP | combined heat and power |
| CI | carbon intensity |
| CNG | compressed natural gas |
| DCFC | Direct Current Fast Charging |
| DGE | diesel gallon equivalent |
| E10 | 10% ethanol, by volume, blended with gasoline |
| E15 | 15% ethanol, by volume, blended with gasoline |
| E85 | 85% ethanol, by volume, blended with gasoline |
| eGRID | Emissions & Generation Resource Integrated Database |
| EIA | Energy Information Administration |
| EPA | Environmental Protection Agency |
| EV | electric vehicle |
| EVSE | electric vehicle supply equipment |
| FCV | Fuel cell vehicle |
| FOGs | fats, oils, and greases |
| $gCO_2e/MJ$ | grams of carbon dioxide equivalent per megajoule |
| GGE | gasoline gallon equivalent |
| GHG | greenhouse gas |
| GREET | Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model |
| GRP | Gross Regional Product |
| HD | heavy-duty |
| LCFS | Low Carbon Fuel Standard |
| LD | light-duty |
| LFG | landfill gas |
| MD | medium-duty |
| MOVES | Motor Vehicle Emissions Simulator |
| MSW | municipal solid waste |

| | |
|---|---|
| NEI | National Emissions Inventory |
| NGV | natural gas vehicle |
| OPGEE | Oil Production Greenhouse gas Emission Estimator |
| PHEV | plug-in hybrid electric vehicle |
| $PM_{2.5}$ | particulate matter less than 2.5 microns in diameter |
| PSCAA | Puget Sound Clean Air Agency |
| PSRC | Puget Sound Regional Council |
| RNG | renewable natural gas |
| SMR | steam methane reforming |
| UCO | used cooking oil |
| ULSD | ultra-low sulfur diesel |
| USACE | United States Army Corps of Engineers |
| VMT | vehicle miles traveled |
| VSL | value of a statistical life |
| WWT | waste water treatment |
| ZEV | zero emission vehicle |

# Executive Summary

## Key takeaways

- The Puget Sound region has a significant carrying capacity for low carbon fuels and the deployment of other low carbon fuel strategies.
- The Puget Sound region can achieve a 10%-16% carbon intensity reduction by 2030 with only modest changes to the transportation fuel supply.
- The maximum achievable carbon intensity reduction in the Puget Sound region is 26% by 2030.
- Compliance with a proposed Puget Sound CFS will require a range of investments in low carbon fuel production, retail distribution infrastructure, and advanced vehicle technologies.
- The economic impacts of compliance with a Puget Sound CFS are small, and would have a negligible impact on forecasted growth in the region.
- Air quality improvements resulting from the compliance scenarios will yield positive health impacts.

The transportation sector accounts for nearly 40 percent of greenhouse gas (GHG) emissions in the Puget Sound region.[1] In an effort to reduce these GHG emissions, and to improve air quality through the reduction of criteria air pollutants, the Puget Sound Clean Air Agency (the Agency or PSCAA) has sought to implement candidate actions in key focus areas including increasing zero-emission vehicle (ZEV) adoption, promoting alternative fuel use, and encouraging travel mode shifts. Public agencies are increasingly looking to low carbon fuel standards to achieve GHG reductions from the transportation sector. There are now low carbon fuel standards in California, Oregon, and British Columbia. Low carbon fuel standards are attractive to policy makers because they send a clear policy signal to investors that long-term solutions are needed for lower-carbon and cost-competitive transportation fuels.

ICF conducted a detailed analysis of the Puget Sound region's transportation fuels market and found that it has a significant carrying capacity for low carbon fuels, and the deployment of a low carbon fuel strategy such as a Clean Fuel Standard (CFS). ICF estimates that the maximum achievable carbon intensity reduction, under a CFS, in the Puget Sound region is 26% by 2030. Compliance with a proposed CFS will require a range of investments in low carbon fuel production, retail distribution infrastructure, and advanced vehicle technologies. The modeled economic impacts of compliance with a Puget Sound CFS are small, and have a negligible impact on forecasted growth in the region (less than one tenth of one percent impact on employment growth or gross regional product [GRP]). ICF's analysis of the air quality implications of the compliance scenarios indicates positive health impacts associated with the implementation of the Puget Sound CFS.

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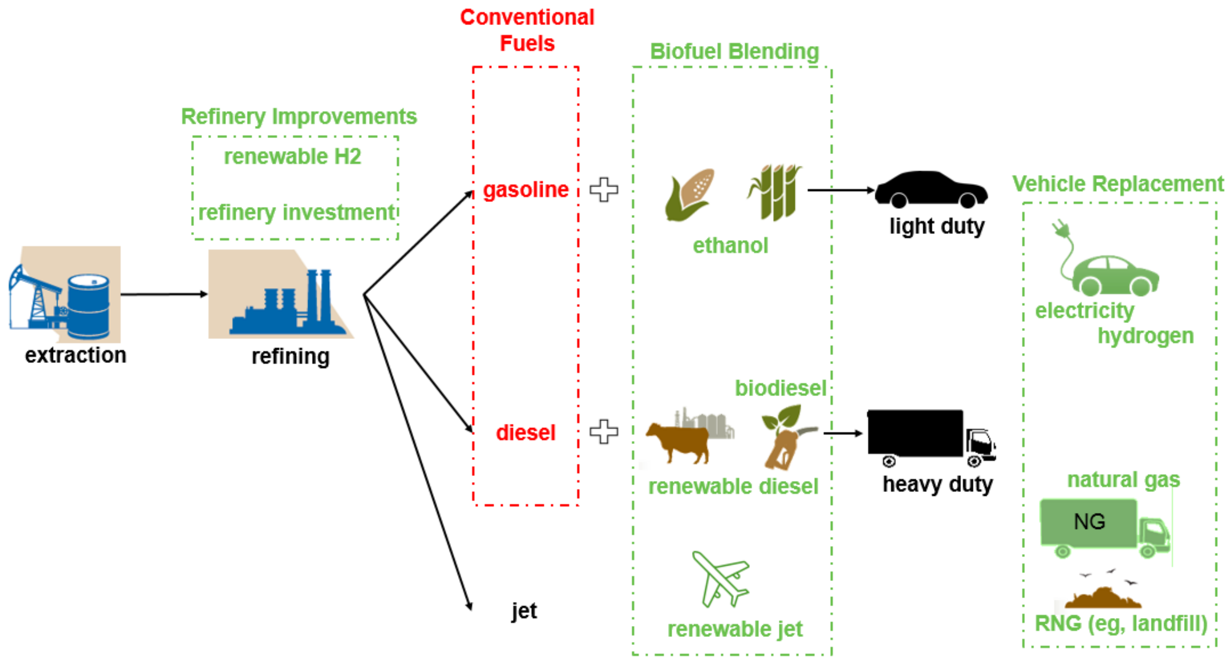
[1] Puget Sound Clean Air Agency, Greenhouse Gas Emission Inventory, June 2018. Accessed online August 2018 via http://www.pscleanair.org/DocumentCenter/View/3328/PSCAA-GHG-Emissions-Inventory.

The Puget Sound region, consisting of King, Kitsap, Pierce, and Snohomish Counties, consumes about 1 billion gallons of gasoline and 220 million gallons of diesel annually. There are significant biofuel production facilities within, or in close proximity to, the Puget Sound region including biodiesel production, renewable diesel production, and renewable natural gas (RNG) production. The region has demonstrated significant interest in electric vehicles (EVs), with a higher than national average adoption rate. There are no specific regulatory or policy drivers in the Puget Sound region that support the deployment of low carbon fuels. Low carbon fuel producers in and around the Puget Sound region export fuel to markets in California and Oregon where it is more valuable as a result of low carbon fuel policies.

ICF conducted scenario modeling to demonstrate the levels of carbon intensity reduction that could be achieved via a Clean Fuel Standard (CFS) in the Puget Sound region under different market conditions and considerations. ICF conducted scenario modeling using a fleet turnover-based model for the light-, medium-, and heavy-duty vehicle fleets in the Puget Sound region. The model includes assumptions regarding fuel economies, vehicle miles traveled, and other key parameters associated with transportation fuel consumption. The modeled compliance scenarios include a mix of vehicle and fuel strategies, and the model tracks the credits and/or deficits generated on a year-over-year basis for each model run.

ICF developed Washington-specific carbon intensity estimates for various transportation fuels included in the modeling. ICF aggregated supply, distribution, and production data to determine the baseline carbon intensity of transportation fuels within the agency's jurisdiction. ICF conducted this analysis by developing a Washington-specific version of the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model (GREET model) and reviewing currently certified carbon intensities from California's Low Carbon Fuel Standard (LCFS).

ICF conducted the scenario modeling by assuming that the proposed program operates on the same system of deficits and credits that define California's LCFS Program and Oregon's Clean Fuels Program. Petroleum-based transportation fuels (i.e., gasoline and diesel) with a carbon intensity higher than the standard generate deficits; these deficits must be offset on an annual basis by credits generated by lower-carbon fuels. Credits can be banked without holding limits and do not carry vintages. The figure below highlights the ways that deficits and credits are assumed to be generated in the program—note that fuels in red generate deficits and fuels listed in green generate credits in a low carbon fuel policy.




ICF modeled four scenarios, as summarized here and with some additional detail in the table that follows:

- Scenario A is focused on biofuel blending, with decreases in carbon intensity of those biofuels. The carbon intensity reduction target is 10% below 2016 levels by 2030.
- Scenario B is focused on electrification, and has a more rapid increase of EV deployment for both the light- and medium/heavy-duty vehicle sectors than what is included in the reference case or in other cases. The carbon intensity reduction target is set at 10% below 2016 levels by 2030.
- Scenario C is a blend of Scenario A and Scenario B, with a mix of increased biofuel blending, lower carbon intensity biofuels, and electrification. It is also introduces increased penetration of natural gas vehicles using renewable natural gas (RNG), small volumes of renewable jet fuel, and reduced carbon intensity at refineries through efficiency measures and renewable hydrogen. The carbon intensity reduction target is set at 16% below 2016 levels by 2030.
- Scenario D is meant to capture the upper limit of carbon intensity reduction that ICF viewed as feasible for the Puget Sound region by 2030. This includes more aggressive biofuel blending, lower carbon intensity biofuels, and more aggressive EV deployment in all vehicle segments. It also includes the increased penetration of natural gas vehicles using RNG, more substantial volumes of renewable jet fuel than included in Scenario C, and more aggressive carbon intensity reductions at refineries through efficiency measures and renewable hydrogen. ICF modeled this scenario in two ways with respect to the carbon intensity reduction target: we employed a 20% target by 2030, and then through iterative calculations determined that the effective maximum carbon intensity reduction through this scenario is 26% by 2030.

| Low Carbon Fuel Strategy | Scenario A: Biofuel Blending | Scenario B: Aggressive Elec | Scenario C: Mixed Technology | Scenario D: All-in Max |
|---|---|---|---|---|
| Biofuel Blending | | | | |
| Ethanol | • E15 by 2030 | • E10 | • E15 by 2030 | • E15 by 2030 |
| Biodiesel | • B10.5 by 2030 | • B5 by 2030 | • B20 by 2030 | • B20 by 2030 |
| Renewable diesel | • RD10.5 by 2030 | • RD10 by 2030 | • RD15 by 2030 | • RD20 by 2030 |
| Renewable jet | • n/a | • n/a | • 25 MG by 2030 | • 50 MG by 2030 |
| Vehicle Replacement | | | | |
| EVs / FCVs, LD | • 10% of new sales by 2025 | • 15% of new sales by 2025 | • 14% of new sales by 2025 | • 20% of new sales by 2025 |
| EVs / FCVs, Class 3-6 | • Baseline | • 7% of new sales by 2025 | • 7% of new sales by 2025 | • 7% of new sales by 2025 |
| NG / RNG | • 95% blend of RNG by 2024 | • Baseline | • 95% blend of RNG by 2024<br>• 5% NGVs into Class 7/8 fleet | • 95% blend of RNG by 2024<br>• 7% NGVs into Class 7/8 fleet |
| Refinery Improvements | | | | |
| Renewable $H_2$ | • n/a | • n/a | • 20% penetration | • 40% penetration |
| Refinery investment | • n/a | • n/a | • 5% efficiency improvement | • 10% efficiency improvement |

ICF's analysis demonstrates that the Puget Sound region can achieve a 10%-16% carbon intensity reduction by 2030 with only modest changes to the transportation fuel supply. Scenario A and Scenario B in ICF's analysis focused on modest changes to biofuel blending and more aggressive assumptions regarding electrification, focusing primarily on light-duty vehicles. Similarly, ICF's analysis of a 16% carbon intensity reduction by 2030 can be achieved with feasible changes to the transportation fuel supply—assuming that the price signal from the program is strong enough to attract lower carbon liquid biofuels, RNG, and that the credits generated from the program can help to defray the costs of purchasing more expensive vehicles like EVs, hydrogen fuel cell vehicles (FCVs), and natural gas vehicles (NGVs).

ICF estimates that the maximum achievable carbon intensity reduction in the Puget Sound region is 26% by 2030. ICF assumes that this can be achieved via the aggressive implementation of low carbon fuel strategies including, but not limited to, increased liquid biofuel blending (for ethanol, biodiesel, and renewable diesel), increased natural gas vehicle deployment (using RNG), accelerated EV deployment in light-, medium- and heavy-duty applications, renewable jet fuel blending, refinery efficiency improvements, and renewable hydrogen use at refineries.

ICF used the (Regional Economic Models, Inc) REMI model to characterize the macroeconomic and distributional impacts of compliance with a Puget Sound region CFS on different sectors and regions. REMI is a dynamic regional economic impact model that allows for a second-stage analysis to be conducted using outputs from ICF's analysis of expenditures required to achieve compliance as inputs and provides projections of the distributional impacts of the compliance scenarios being analyzed. The REMI model provided the ability to forecast impacts over time, across industry sectors, and among regions. In this study, the analysis modeled impacts through 2030 and for five regions: Snohomish County, King County, Pierce County, Kitsap County, and the Rest of Washington. Inputs to the REMI model for each scenario were derived from the outputs of ICF analysis of each compliance scenario, including expenditures for fuel production, distribution infrastructure (including transportation, storage, and retail infrastructure), vehicles, and fuel pricing.

ICF's analysis using the REMI model indicates that the impacts of compliance with a Puget Sound CFS are small, and have a negligible impact on forecasted growth in the region. ICF's analysis shows results ranging from a -0.099% to +0.017% change in regional employment levels to a -0.091% to -0.026% change in economic output (Gross Regional Product, or GRP) across the four scenarios. In other words, ICF's analysis indicates that the economic impacts across all four scenarios considered yield employment and GRP impacts less than 0.1%. It is also important to note that this change is on top of forecasted baseline economic growth in the region of 260,000 jobs and a 12% increase in GRP (2020-30). This means that, for example, a predicted change in job growth of +/- 1,000 would result in 261,000 new jobs or 259,000 new jobs in 2030. The trends revealed from the economic impact modeling indicate that fuel diversification, including through the increased use of electricity and natural gas as transportation fuels, can help increase GRP and employment in the region. The increased costs of advanced vehicle technologies, most notably EVs, and the assumed pass-through of compliance costs contribute to the slight reductions in GRP and job growth in the modeling.

ICF also analyzed the air quality and health impacts of the compliance scenarios developed. ICF's analysis focused solely on the air quality and public health impacts of changes in tailpipe (or downstream) fine particle pollution ($PM_{2.5}$) emissions resulting from each scenario. ICF's modeling considered the entire region, rather than individual "hotspots." Only PM-related health effects from direct emissions of $PM_{2.5}$ were included. ICF based the air quality impacts on a screening level modeling approach relying on the C-LINE[2] model. ICF implemented the analysis in two steps: 1) Estimate changes in $PM_{2.5}$ concentrations from implementing the CFS, reported at the Census Block Group (CBG) level (which is at suitable resolution to quantify human health benefits associated with $PM_{2.5}$ reductions); 2) Quantify human health benefits associated with the $PM_{2.5}$ reductions using EPA's Benefits Mapping and Analysis Program (BenMAP) to estimate reduction in adverse health impacts and the monetary value of human health benefits from implementation of the Puget Sound CFS in each of the four affected counties.

ICF's analysis of the air quality implications of the compliance scenarios indicates significant positive health impacts associated with the implementation of the proposed Puget Sound CFS. ICF reports one to six avoided all-cause mortality cases per year (including adults over 25 years old and infants under 1) from changes in $PM_{2.5}$ levels resulting from the implementation of the proposed Puget Sound CFS with a present value of benefits from a reduction in $PM_{2.5}$ levels in 2030 range from $13.8 million to $45.7 million. This estimate of health benefits does not include all $PM_{2.5}$ health endpoints, and also does not include health benefits of other tailpipe emissions reductions that would be achieved under a clean fuel standard.

[2] https://www.cmascenter.org/c-tools/

# 1. Introduction

The transportation sector accounts for nearly 40 percent of greenhouse gas (GHG) emissions in the Puget Sound region.[3] In an effort to reduce these GHG emissions, and to improve air quality through the reduction of criteria air pollutants and toxics, the Puget Sound Clean Air Agency (the Agency or PSCAA) has sought to implement candidate actions in key focus areas including increasing zero-emission vehicle (ZEV) adoption, promoting alternative fuel use, and encouraging travel mode shifts. Public agencies are increasingly looking to low carbon fuel standards to achieve GHG reductions from the transportation sector—there are now low carbon fuel standards in California, Oregon, and British Columbia; and the European Union's Fuel Quality Directive acts similarly to a low carbon fuel standard. Low carbon fuel standards are attractive to policy makers because they send a clear policy signal to investors that long-term solutions are needed for lower-carbon and cost-competitive transportation fuels.

Low carbon fuel standards can have an elegant design: any fuel that has a higher carbon footprint than the established regulatory standard generates deficits; and any fuel that has a lower carbon footprint than the standard yields credits. At the end of each year, deficits must be offset entirely by credits.

The primary objective of the analysis conducted and presented here is to bring clarity to the complexity of transportation fuel markets that impact the Puget Sound region—defined as the four counties within the Agency's jurisdiction, King, Kitsap, Pierce, and Snohomish counties—so that the Agency can fully understand the implications of a low carbon fuel standard as a candidate action to reduce GHG emissions. This objective was achieved over a series of steps and is reflected in the broader sections of this report.

- In Section 2, ICF outlines the baseline conditions for conventional and alternative fuel production, fuel supply, and fuel distribution in the four-county Puget Sound region. This section also includes a brief overview of the carbon intensity of current transportation fuel consumption, and assessment of the existing availability of in-state alternative fuel feedstocks (today and into the future).
- Section 3 reviews the scenario modeling conducted by looking at different combinations of strategies that could be implemented to reduce the carbon intensity of the transportation fuel supply in the Puget Sound region.
- Section 4 of the document reviews the economic modeling conducted for the analysis, with a focus on the macroeconomic impacts of low carbon fuel standard implementation across each of the scenarios considered. This includes a discussion of how different market actors will be impacted—including large and small businesses, local governments, and individuals.
- Section 5 of the document reviews the air quality impact analysis and health impact analysis.
- Section 6 includes ICF's key conclusions arising from the analysis.

[3] Puget Sound Clean Air Agency, Greenhouse Gas Emission Inventory, June 2018. Accessed online August 2019 via http://www.pscleanair.org/DocumentCenter/View/3328/PSCAA-GHG-Emissions-Inventory.

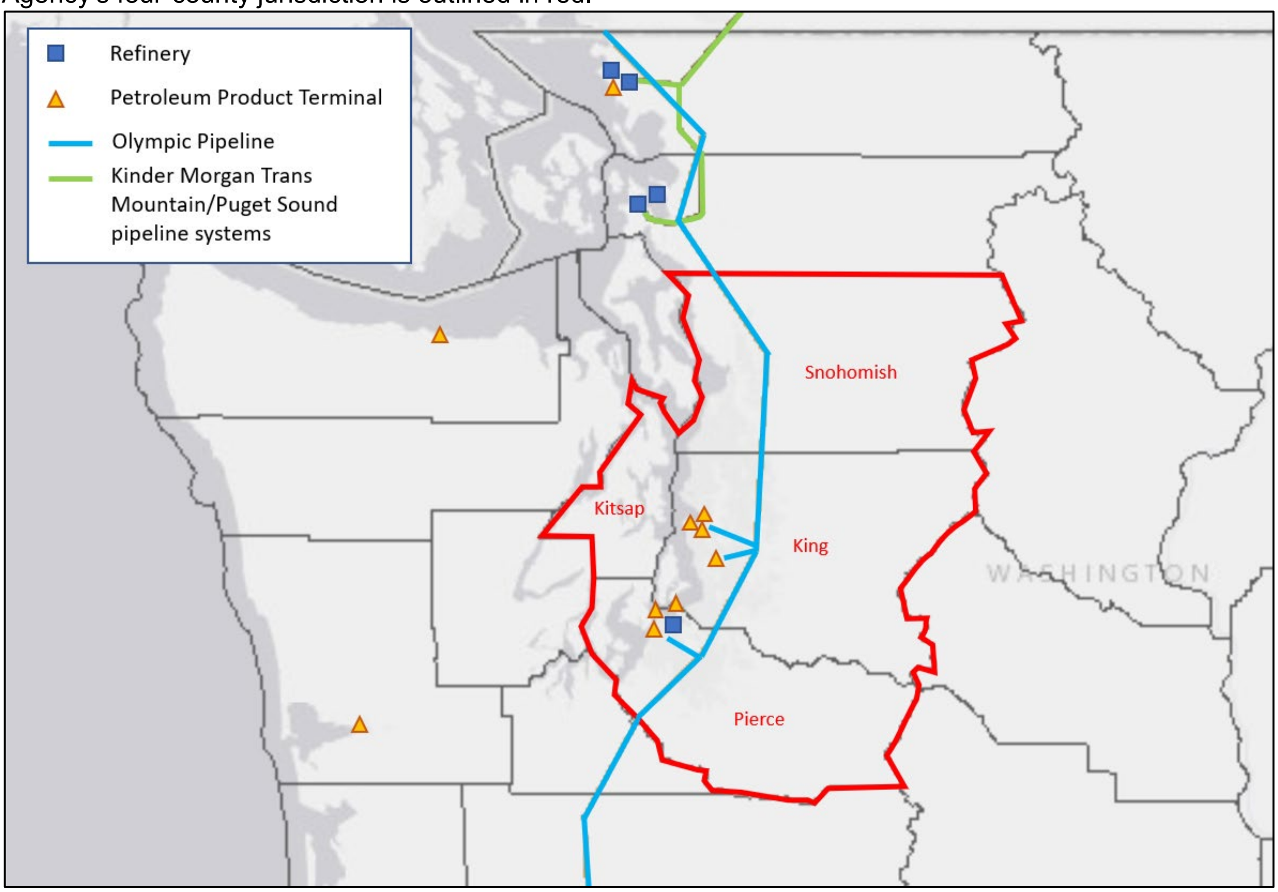
# 2. Overview of Puget Sound Transportation Fuels Market

## Puget Sound Fuel Supply and Distribution

### Petroleum Fuel Supply Chain

The Puget Sound region (Figure 1) is supplied with refined petroleum products by the Par Pacific Tacoma Refinery (formerly owned by U.S. Oil Refining Co.), the Olympic Pipeline from the four other Washington refineries, and marine tanker deliveries from other domestic and foreign sources. Gasoline and diesel move mostly by pipeline and barge into the region's bulk storage and distribution terminals. Biofuels, such as ethanol and biodiesel, are blended into the gasoline and diesel pools at these terminals. At the terminals' loading racks, fuel is loaded into tanker trucks for delivery to retail service stations for final sale to the consumer.

Figure 1. Map of Petroleum Infrastructure in the greater Puget Sound Region. The Puget Sound Clean Air Agency's four-county jurisdiction is outlined in red.




Source: EIA U.S. Energy Mapping System, ICF notations

**Fuel Production and Crude Oil Supply**

Even though the state does not have any crude oil production, Washington is a major crude oil refining center with the fifth-largest refining capacity of any state in the United States.[4] Transportation fuels are produced at 5 refineries within the state of Washington. Crude oil is delivered to these refineries by pipeline, by rail car, and by marine tankers and is largely sourced from Alaska, North Dakota, Wyoming, and Canada.

### Crude Oil Logistics

Washington refineries source crude oil from both domestic and foreign sources. Historically, the Washington refineries have processed a combination of Alaska North Slope (ANS) crude oil and foreign imports delivered by tanker, as well as Canadian crude oil delivered by the Kinder Morgan Trans Mountain and Puget Sound pipeline systems. In the last 5-10 years, cheaper Bakken crude oil produced in North Dakota and Wyoming has been increasingly added to Washington refinery crude slates (refineries' choices of different crude oil blends). The Bakken crude oil supply is delivered by rail and has displaced some volumes of both ANS (see Marine-Domestic column in Table 1) and waterborne imports (see Marine-Foreign column in Table 1).[5]

### Crude Supply by Transport Mode

Domestic crude oil marine shipments, which averaged 209,500 barrels per day (b/d) in 2016, are the largest source of supply to the Washington refineries. All of this supply is assumed to come from Alaska. An additional 11,500 b/d were imported via marine vessel from foreign countries (excluding Canada). About 204,200 b/d were received from Canada in total, of which nearly all were delivered by Kinder Morgan's Trans Mountain and Puget Sound pipeline systems (~191,700 b/d by pipeline and ~8,200 b/d by rail and ~4,300 by ship). Washington refineries also received 131,600 b/d of Bakken crude oil delivered by rail from North Dakota and Wyoming. Table 1 shows a historical breakout of crude oil supply into the Washington refineries by transportation mode.

Table 1. Washington Crude Oil Supply by Transport Mode, b/d

| Year | Marine | | | Pipeline | Rail | | Total |
|---|---|---|---|---|---|---|---|
| | Domestic | Foreign | Canada | from Canada | Domestic | Canada | |
| 2016 | 209,525 | 11,516 | 4,341 | 191,673 | 131,627 | 8,208 | **556,890** |
| 2015 | 195,426 | 22,392 | 9,190 | 176,169 | 148,667 | 2,301 | **554,146** |
| 2014 | 233,884 | 49,181 | 9,907 | 151,570 | 150,595 | 5,770 | **600,907** |
| 2013 | 264,386 | 71,910 | 12,714 | 132,327 | 80,579 | 5,386 | **567,302** |
| 2012 | 257,472 | 95,699 | 9,545 | 135,939 | 19,236 | 1,030 | **518,921** |

Source: U.S. Army Corp of Engineers 2016 Waterborne Commerce of the United States Waterways and Harbors; EIA Company Level Imports, 2016, FERC Form 6 Trans Mountain (Puget Sound) Pipeline 2016, EIA Movements of Crude Oil by Rail between PAD Districts 2016

The changes in the crude slate from 2012 to 2016 reflect an increased reliance on Bakken and Canadian crude oil, with North Slope and foreign crudes being displaced. Canadian crude oil

[4] U.S. Energy Information Administration, "Washington State Profile" (Accessed February 8, 2019), https://www.eia.gov/state/analysis.php?sid=WA

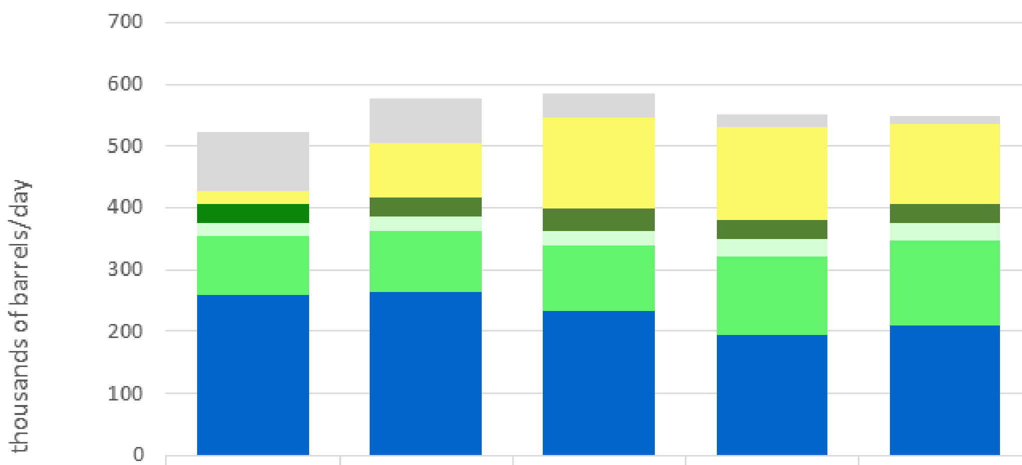
[5] U.S. Energy Information Administration, "PADD 5 Transportation Fuels Markets" (Accessed January 8, 2019), Page 35, https://www.eia.gov/analysis/transportationfuels/padd5/pdf/transportation_fuels.pdf.

transported to Washington by pipeline, rail, and ship increased by approximately 58,000 b/d from 2012 to 2016, driven by discounts on West Canadian crude relative to other available crudes. Meanwhile, crude-by-rail shipments to Washington from the Bakken shale region have increased by approximately 112,000 b/d from 2012 to 2016, though 2016 Bakken volumes were down from their peak in 2014 and 2015. The rise in Canadian and Bakken crude volumes has come at the expense of marine imports of foreign crude (down approximately 84,000 b/d from 2012) and marine receipts of Alaskan crude (down about 48,000 b/d from 2012).

### Crude Slate

Washington state refineries process ANS crude, Canadian oil sands, Western Canadian conventional crudes, Bakken crude oil, and other foreign imported crudes. As shown in Figure 2 the volume of ANS crude oil has been slowly declining over the previous five years, and the volumes of foreign imports (outside of Canada) has sharply declined. Bakken crude oil has significantly increased over the 5-year period, and Canadian imports have grown slowly. In 2016, the crude mix to the five refineries was 38% ANS, 36% Canadian crude, 24% Bakken, and 2% other foreign crudes (see Figure 2).

Figure 2. Washington Refineries' Historical Crude Slates




| | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|
| Other Imports | 95 | 72 | 39 | 21 | 12 |
| Bakken Crude | 22 | 88 | 146 | 149 | 129 |
| Canadian Oil Sands Bitumen | 30 | 31 | 38 | 32 | 31 |
| Canadian Synthtic Crude | 21 | 22 | 23 | 28 | 30 |
| Canadian Convential Light | 97 | 98 | 105 | 126 | 136 |
| Alaska North Slope | 258 | 264 | 234 | 195 | 210 |

Most of the Canadian crude is transported to Washington by pipeline, with a small amount coming by rail or waterborne vessel. The Bakken crude oil is delivered by rail car from the Midwest and the Alaskan North Slope crude moves by domestic marine vessels. "Other Imports" refers to foreign marine imports other than Canadian including crude coming from South America, the Middle East, Africa, and Russia.

## Refineries

There are five operating refineries in the Pacific Northwest region, all of which are located in northwestern Washington. These refineries have a combined operable distillation capacity of 637,700 (b/d).[6] Table 2 lists each refinery's operator, location, and operable capacity.[7]

Table 2. Washington Petroleum Refineries

| Operator | Location | Operable Capacity, b/cd |
|---|---|---|
| BP | Ferndale (Cherry Point), WA | 227,000 |
| Phillips 66 | Ferndale, WA | 105,000 |
| Shell | Anacortes, WA | 145,000 |
| Marathon | Anacortes, WA | 120,000 |
| Par Pacific* | Tacoma, WA | 40,700 |
| | **Total** | **637,700** |
| *formerly U.S. Oil and Refining | | |

Source: U.S. Energy Information Administration, Refinery Capacity Report, 2018

In 2016, the Washington refineries received an estimated 556,900 b/d of crude oil from domestic and foreign sources by pipeline, tanker, barge, and rail. This estimate is based on aggregated 2016 data of domestic waterborne receipts as tracked by the U.S. Army Corps of Engineers (USACE), foreign imports as tracked by the U.S. Energy Information Administration (EIA), and domestic rail movements reported by EIA.

Par Pacific's refinery in Tacoma is the only refinery within the four-county Puget Sound region. This refinery is not connected to any crude pipelines, so all crude is delivered by ship or rail. In 2016, the refinery imported 12,100 b/d of crude oil from Canada; 3,900 b/d were transported to the refinery's docks by barge from a crude export terminal in Westridge, British Columbia, at a terminus of the Trans Mountain Pipeline, while 8,200 b/d were delivered by rail via the rail border crossing in Blaine, WA and Eastport, ID. Another 1,700 b/d of Alaskan crude oil came into Par Pacific via ship. The rest of the refinery's crude oil is supplied by domestic rail movements from the Bakken.

### Fuel Supply Logistics

The Puget Sound region primarily receives its supply of refined petroleum fuels via the Olympic Pipeline, which delivers fuel into the region from the Anacortes and Ferndale refineries. Additional gasoline and diesel is supplied to the region from the Tacoma refinery and through waterborne imports into local terminals from foreign or domestic sources.

Washington refinery production also regularly supplies markets in Alaska and California via coastwise marine movements as well as some exports to foreign markets.

## Pipeline

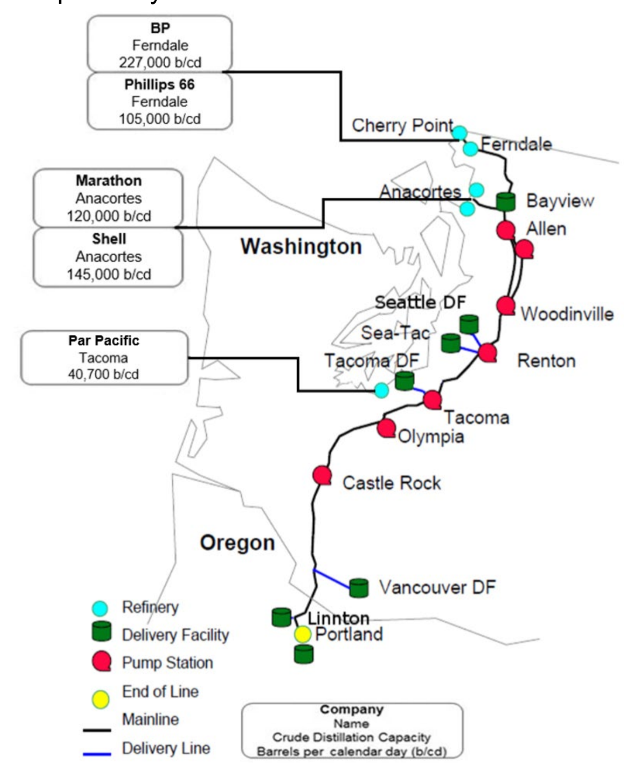
BP's 300,000 b/d Olympic Pipeline is the primary distribution asset linking the Anacortes and Ferndale refineries with major fuel markets in Washington and Oregon. The Olympic Pipeline is a

[6] U.S. Energy Information Administration, Refinery Capacity Report, Capacities represented in barrels per calendar day. http://www.eia.gov/petroleum/refinerycapacity/

[7] U.S. Energy Information Administration, "Refinery Capacity Report, 2018" (Accessed January 8, 2019), Refinery Capacity Data by individual refinery as of January 1, 2018, http://www.eia.gov/petroleum/refinerycapacity/.

400-mile interstate pipeline system consisting of 12-inch, 14-inch, 16-inch, and 20-inch pipeline segments. The system transports gasoline, diesel, and jet fuel from the four northern Washington refineries to delivery points along the I-5 corridor, including the Harbor Island terminal cluster, Seattle-Tacoma International Airport, and the Tacoma terminal cluster in the Puget Sound area; the Vancouver terminal cluster in southwest Washington; and the major terminal cluster located along the Willamette River in Portland, Oregon.[8] Based on annual data reported by BP to the Federal Energy Regulatory Commission (FERC), flows along the Olympic Pipeline in 2016 averaged around 299,000 b/d, of which 165,000 b/d were delivered to terminals in Washington and 133,000 b/d were delivered to terminals in Oregon.[9] Figure 3 presents a map of the Olympic Pipeline system including delivery facilities and pump stations. A pipeline delivery facility is a location operated by the pipeline company where product is delivered from the pipeline system to one or more third-party distribution terminals that store the product before delivering it to end users, typically by truck. Pump stations, which are also operated by the pipeline company, are positioned along the pipeline to increase pressure to pump the product along the line.

Figure 3. Map of the Olympic Pipeline system[10]




The Par Pacific Refinery in Tacoma (formerly U.S. Oil and Refining) has a short dedicated pipeline to Joint Base Lewis McChord, which transports jet fuel.

8 BP Pipelines North America, "Olympic Pipeline" (Accessed January 8, 2019), http://www.olympicpipeline.com/.
9 Olympic Pipe Line Company, FERC Financial Report FERC Form No. 6: Annual Report of Oil Pipeline Companies, 2016 (Accessed January 8, 2019), http://www.ferc.gov/docs-filing/elibrary.asp.
10 BP Company Website- Olympic Overview with ICF notations.

### Ports

Terminals in the Puget Sound region receive and ship significant volumes of transportation fuels via marine vessels. Table 3 lists the ports in the region that shipped and received marine cargos of transportation fuels in 2016, the latest year for which domestic marine movement data is available from USACE. The table shows estimated inbound and outbound movements at the region's ports broken out between domestic shipments, internal movements within the Puget Sound, foreign exports as tracked by USACE, and foreign imports as tracked by EIA.

Table 3. Waterborne Movements of Transportation Fuels at Puget Sound Port Sectors, 2016, b/d

| | Inbound | | | Outbound | | |
|---|---|---|---|---|---|---|
| **Port Sector** | **Domestic** | **Foreign** | **Internal** | **Domestic** | **Foreign** | **Internal** |
| Seattle, WA | 766 | 4,838 | 4,661 | 1,211 | 1,497 | 454 |
| Tacoma, WA | 0 | 7,241 | 10,395 | 5,309 | 4 | 3,827 |
| **Total** | **766** | **12,079** | **15,056** | **6,520** | **1,501** | **4,281** |

Source: U.S. Army Corp of Engineers 2016 Waterborne Commerce of the United States Waterways and Harbors; EIA Company Level Imports, 2016

Ports within the four-county Puget Sound region received more than 27,000 b/d of motor gasoline and distillate fuel oil mostly from foreign markets and from other locations on the Puget Sound waterway (i.e., internal movements), most likely via barge from the Anacortes/Ferndale refineries. Most of the Puget Sound region's foreign product exports are shipped to the nearby Vancouver, Canada market.

### Terminals

Table 4 lists refined product terminals in the Puget Sound region. Transportation fuels move into these terminals by pipeline, barge, marine vessel, and rail. Product is stored at these facilities where it may be blended with biofuels and/or additives before being distributed by truck to retail gas stations and other end users.

Table 4. Puget Sound Terminals

| Operator | Location | No. of Tanks | Capacity, barrels | No. of Loading Bays | Accessibility |
|---|---|---|---|---|---|
| Phillips 66 | Renton, WA | 7 | 216,446 | 3 | Olympic Pipeline, Truck Rack |
| BP West Coast Products | Seattle, WA | 24 | 541,000 | 4 | Olympic Pipeline, Truck Rack, Barge, Rail |
| Kinder Morgan | Seattle, WA | 21 | 934,000 | 3 | Olympic Pipeline, Truck Rack, Barge |
| Shell Oil Products | Seattle, WA | 22 | 562,000 | 6 | Olympic Pipeline, Truck Rack, Barge |
| NuStar Energy | Tacoma, WA | 15 | 377,000 | 4 | Olympic Pipeline, Truck Rack, Barge, Vessel, Rail |
| Phillips 66 | Tacoma, WA | 7 | 12,343 | 2 | Olympic Pipeline, Targa Sound Pipeline, Truck Rack, Barge |
| Targa Sound Refining | Tacoma, WA | 42 | 1,456,925 | 5 | Olympic Pipeline, Truck Rack, Barge, Vessel, Rail |
| Par Pacific (U.S. Oil & Refining Co.) | Tacoma, WA | 54 | 3,000,000 | 6 | McChord Pipeline to AFB, Truck Rack, Barge, Vessel, Rail |

Sources: EIA Energy Mapping Tool, OPIS Petroleum Terminal Encyclopedia, 2018
Note: Storage capacity may include jet fuel, crude oil, and other unfinished products

## Importers and Rack Suppliers

There are quite a few parties involved along the fuel supply chain within in the four-county region. These parties can be wholesale marketers, who market and sell gasoline and/or diesel fuel at terminal racks, or importers who bring in foreign product by marine vessel or barge to marine-capable terminals in Seattle or Tacoma. Some importers are also marketers but some importers only import product and sell the fuel to another party to market the fuel at the truck rack.

Table 5. Washington Petroleum Importers and Wholesalers[11]

| Company | Importer | Rack Seller |
|---|---|---|
| BP Products West Coast | X | X |
| Cenex | | X |
| Chevron | X | X |
| ConocoPhillips | | X |
| Musket | | X |
| Shell | X | X |
| Sound Refining Inc. | | X |
| Tesoro | X | X |
| Texaco | | X |
| U.S. Oil* | X | X |
| Valero | | X |
| Vitol Inc. | | X |
| ExxonMobil | X | |
| Hartland Fuel Products | X | |
| Keyera Energy | X | |
| Mieco Inc. | X | |
| Nova Chemicals Olefins | X | |
| Terrapure Environmental | X | |
| Western Petroleum Co. | X | |
| Williams Olefins | X | |
| * May become Par Pacific now that refinery sale is complete | | |

**Fuel Demand**

Gasoline and diesel fuel are consumed in the state of Washington mostly for transportation use. Motor gasoline accounts for around 40% of Washington's consumption of petroleum products, followed by distillate fuel oil, which accounts for almost 20% of consumption. Distillate is mostly consumed by diesel vehicles, ships, and trains. The remaining 40% of petroleum consumption includes jet fuel, residual fuel oil, asphalt, aviation gas, lubes, and petroleum coke. While refinery production in the state exceeds the volumes consumed, Washington still imports small volumes of motor gasoline and distillate fuel oil to manage inefficiencies within the distribution system.

## Puget Sound Demand

The primary demand centers within the Puget Sound region are located along Interstate-5 (I-5) from Seattle to Tacoma. Estimated total consumption of motor gasoline and distillate fuel oil in the state of Washington was 256,000 b/d in 2016.[12] Table 6 lists Puget Sound consumption estimates of transportation fuels in 2016. Gasoline and distillate fuel oil demands are estimated based on an analysis of 2017 terminal disbursement schedules obtained from the Washington Department of Licensing. These schedules capture fuel sales over the terminal rack to trucks for

[11] Importer data is reported by the Energy Information Administration's Company Level Imports (https://www.eia.gov/petroleum/imports/companylevel/). The rack sellers are based on entities that have posted prices for petroleum products at terminals in the Puget Sound region, as available from Bloomberg. ICF estimates that these represent about 90% of the rack sellers.

[12] U.S. Energy Information Administration, "Washington Prices, Sales Volumes & Stocks by State" (Accessed January 10, 2019), https://www.eia.gov/dnav/pet/pet_sum_mkt_dcu_SWA_a.htm.

delivery to retail stations and other end users in Washington State. This data was aggregated for all the terminals within the four-county region. There was less than 1% change in sales on the state level from 2016 to 2017, so the 2017 terminal data was used as a reasonable estimate for 2016 demand. One caveat is that some of the truck distribution from these terminals may be delivered to consumers outside the four-county area (potentially inflating the four-county demand estimate) and some consumers within the four-county area may receive fuel by truck from terminals outside the four-county region (potentially decreasing the four-county estimate).

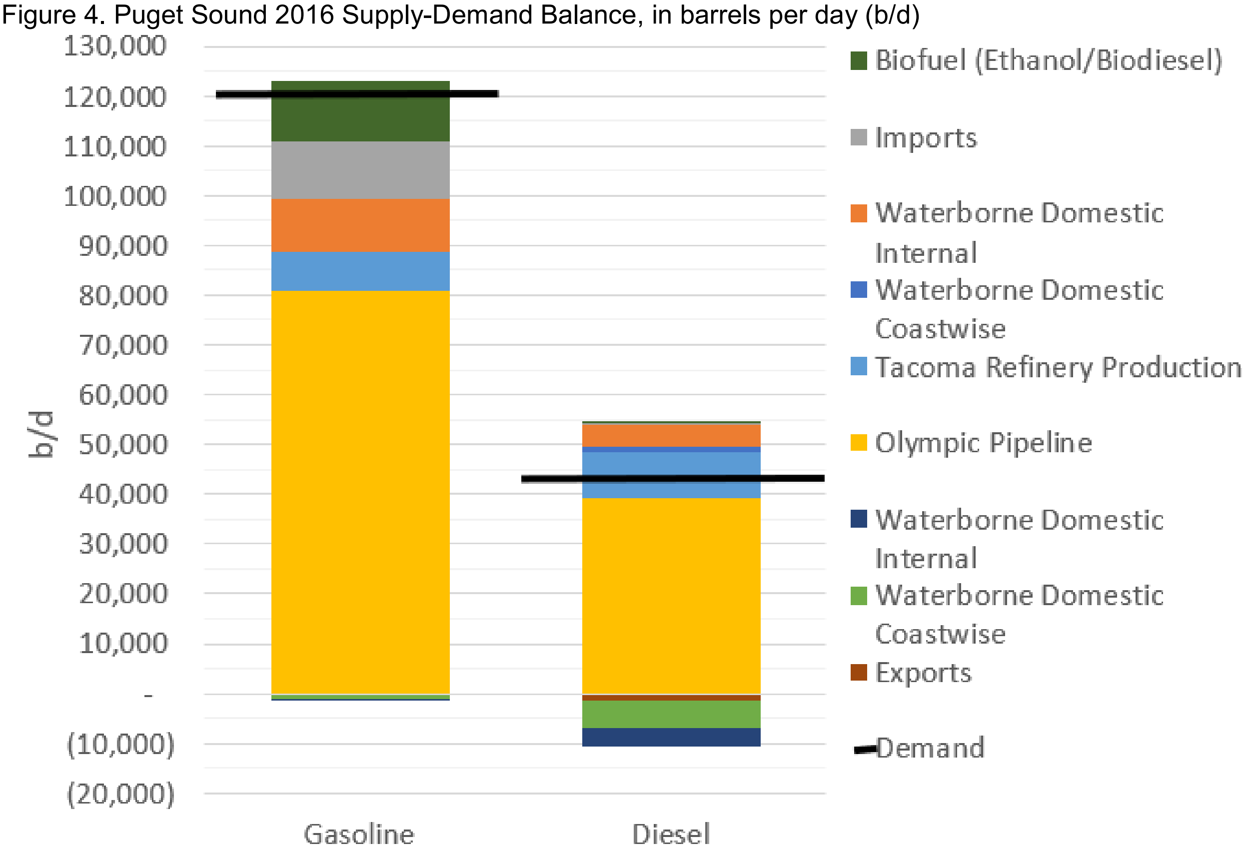
Table 6. Puget Sound Transportation Fuels Demand, 2016

| Product | 4-County Demand, b/d | Share of Total State Demand |
|---|---|---|
| Motor Gasoline | 121,300 | 66% |
| Distillate | 43,800 | 60% |
| **Total** | **165,100** | **64%** |

## Puget Sound Gasoline and Diesel Fuel Balance

Figure 4 depicts the supply-demand balance for the Puget Sound region in 2016 drawing on estimates of refinery production, as well as inbound and outbound product movements and renewable fuel blending. Gasoline supply into the region is 123,000 b/d of which an estimated 121,000 b/d is consumed within the region. Diesel fuel supply into the Puget Sound region is 55,000 b/d with only 44,000 b/d consumed within the region. In-region refinery production at the Par Pacific Tacoma Refinery only accounts for 15-20% of the four-county demand.

Figure 4. Puget Sound 2016 Supply-Demand Balance, in barrels per day (b/d)



Import volumes are known via EIA's company level import data, and all other marine movements and exports utilize USACE data. Gasoline and diesel consumed within the four-county region is estimated based on terminal sales tax data from Washington Department of Licensing. Ethanol is estimated to be 10% of the gasoline consumed in the region, and biodiesel is estimated to be 0.5% of the diesel.[13] The Par Pacific Tacoma Refinery production is estimated based the terminal sales tax data from Washington Department of Licensing for their co-located terminal. Olympic Pipeline deliveries were estimated as the final variable to balance supply with demand and checked for reasonableness against Olympic Pipeline's deliveries into Washington State per FERC data.

### Natural Gas and Propane Fuel Supply Chain

Washington receives about one third of its natural gas supply from Canada transported by pipeline to U.S. markets, with the Sumas Center in Canada, near the border between Washington and British Columbia serving as the principal trading and transportation hub. Natural gas utilities in the region include Cascade and Puget Sound Energy. Natural gas is distributed via pipeline to a natural gas fueling station, where it is typically compressed on site for delivery to a vehicle. There are three publicly accessible natural gas vehicle fueling stations in the Puget Sound region—all of which dispense compressed natural gas (CNG)—that are owned by Clean Energy, Clean N Green, and Waste Management; there are another 12 privately (or fleet) accessible CNG stations in the Puget Sound region.

Propane or Propane autogas is a byproduct of refinery operations or natural gas processing. It is typically distributed from above ground storage facilities to local retail or private fueling stations via truck, and then dispensed accordingly on-site. In western Washington, propane autogas is supplied by Amerigas, Bluestar Gas, and Ferrellgas. Propane autogas is most commonly used in school bus applications or in fleet vehicles, so storage facilities at fueling stations do not need to be particularly large (relative to retail gasoline or diesel fueling stations).

## Alternative Fuel Supply Chains and Volumes

### Ethanol

Washington State does not have any active ethanol production facilities, although 18,850 b/d of ethanol was consumed in the state in 2015.[14] Based on the gasoline consumption estimates from the tax data, ethanol consumption in the Puget Sound region was estimated to be 12,100 b/d in 2016. Since the Pacific Northwest regionally produces only 6,700 b/d of ethanol and the facilities are located in Oregon and Idaho (more than 280 miles from the Puget Sound terminal clusters), the primary source of ethanol to the Puget Sound region is most likely corn-based ethanol by rail from the Midwest. Many of the in-region terminals can receive rail deliveries, so most terminals likely receive ethanol by rail with some others receiving ethanol via tanker truck.

[13] Based on WA Dept. of Agriculture sampling in previous few years
[14] PNW Publication, "Ethanol in the Pacific Northwest" (Accessed January 8, 2019), http://cru.cahe.wsu.edu/CEPublications/PNW710/PNW710.pdf

## Biodiesel

Based on the diesel consumption estimates and an estimated 0.5% biodiesel in the diesel pool, biodiesel consumption in the Puget Sound region was estimated to be ~220 b/d (3.3 million gallons/year) in 2016. The Puget Sound region has one small biodiesel production facility, General Biodiesel Seattle, which processes used cooking oil. This facility is most likely only supplying a small percentage of the Puget Sound region's biodiesel demand. Outside of the region, there is an REG biodiesel refinery with an annual capacity of 100 million gallons in Grays Harbor, Washington. In 2016, the facility produced 72.3 million gallons of biodiesel (4,700 b/d).[15] Biodiesel from this facility is transported via multiple modes, including for instance by barge, by truck, and by rail to terminals within the Puget Sound region for blending with diesel, exported to Canada, or shipped into California/Oregon markets by tanker.

## Renewable Diesel

There are only small amounts of renewable diesel currently consumed in the Puget Sound region—including in fleets at the Port of Seattle, Tacoma Public Utilities, and Seattle Public Utilities. Although chemically identical to conventional diesel, renewable diesel is not typically transported via pipeline to the West Coast because there are limited pipeline movements of diesel or distillate fuel oil products from where renewable diesel is primarily produced domestically today (in the Gulf Coast). This has the potential to change as more local and regional producers seek to distribute renewable diesel. Similarly, as petroleum refiners integrate co-processing of biomass or blending renewable diesel at the refinery, like the BP unit at the Cherry Point refinery, more renewable diesel is likely to be transported via pipeline. Producers outside of the Puget Sound region—like Neste's facility in Singapore or Diamond Green's facility in Norco, Louisiana—typically transport fuel via marine and/or rail to distribution terminals, where it is subsequently blended with conventional diesel.

## Renewable Natural Gas

Renewable natural gas (RNG) is transmitted and distributed using the same supply chain as natural gas (discussed in more detailed in the previous section)—using transmission pipelines and distribution pipelines. There are instances where RNG is produced and trucked to a fueling facility; however, this is typically limited to transportation distances less than 100 miles. The only difference is that the RNG is produced—via the capture, clean-up, and conditioning of biogas from some source (like landfills or water resource recovery facilities), and subsequently injected into the pipeline. While there are RNG production facilities in Washington, most of the RNG produced in Washington is currently injected into the pipeline and delivered to markets like California and Oregon where producers can take advantage of multiple incentives—credits from a low carbon fuel policy and RINs from the federal Renewable Fuel Standard—for using the fuel in a transportation application. There are fleets in the Puget Sound region using RNG, including Seattle Public Utilities, who recently announced using RNG in 91 Waste Management trucks, as

[15] Port of Grays Harbor Newsletter, "REG Grays Harbor biodiesel production nets record year" (Accessed January 17, 2019), https://www.satsop.com/assets/pgh_newsletter_2017-4.pdf

well as Pierce Transit using RNG in all of its CNG transit buses (which is about 125 buses, representing roughly 75% of the Pierce Transit fleet).

### Electricity

Electricity for electric vehicle (EV) charging is delivered through EV supply equipment (EVSE). EVSE is distinguished by the level of charging it can provide: Level 1 EVSE delivers power at a rating of 1.5 kW at 110 V (or about 5 miles of range per hour of charging), Level 2 EVSE delivers power at a rating of up to 19 kW (more commonly at 7 kW or about 20 miles of range per hour of charging) at 240 V, and DC fast charging (DCFC) EVSE can typically deliver electricity at up to 50 kW (or about 90 miles of charge per hour of charging), with some newer installations capable of delivering up to 150 kW. EV charging is typically grouped into two broad categories: at-home charging and away-from-home charging. The former typically represents about 70-90% of total electricity demand from light-duty EVs and is done using Level 1 or Level 2 EVSE. Away-from-home charging can occur at workplaces, shopping centers, or other destinations and typically uses Level 2 or DCFC EVSE. Electricity is delivered to the EVSE through the electrical distribution network of investor- and municipally- owned utilities. An average EV consumes about 3,600 kWh per year, assuming a vehicle efficiency of 300 Wh/mile and 12,000 miles driven. For plug-in hybrid electric vehicles (PHEVs), that operate using gasoline and electricity, the estimated annual electricity consumption is closer to 1,600 kWh—assuming that about 45% of miles are traveled using electricity rather than gasoline. In 2018, there were about 22,000 battery EVs and 9,600 plug-in hybrid EVs registered in the Puget Sound region. ICF estimates that these vehicles consumed about 95 GWh of electricity.

## Fuel Producers and EV Charging Providers

### Fuel Producers

Table 7 provides a list of alternative fuel producers in Washington operating today. Washington does not have any active ethanol or renewable diesel production facilities.

Table 7. Alternative Fuel Producers in Washington

| Fuel | Inside the Jurisdiction | In Washington-Outside the Jurisdiction |
|---|---|---|
| Ethanol | - | - |
| Biodiesel | General Biodiesel Seattle, LLC | REG Grays Harbor, LLC |
| Renewable Diesel | - | Cherry Point, BP Refinery |
| Renewable Natural Gas[16] | Cedar Hills Landfill in King County | Roosevelt Landfill- Klickitat County |
| | LRI Landfill in Pierce County | Horn Rapids Landfill- Benton County |
| | King County South WWTP in King County | |
| | Tacoma Central WWTP in Pierce County[9] | |

[16] Washington State University Energy Program. *Harnessing Renewable Natural Gas for Low-Carbon Fuel: A Roadmap for Washington State.* 2018. Available at: http://wwcleancities.org/DocumentCenter/View/3052/RNG-Roadmap-for-Washington_Commerce-WSUEP_Final-Report_Jan-2018?bidId=

## EV Charging Providers

Table 8 identifies the service providers that provide publicly accessible EV charging within the jurisdiction and their capacity, with a charge port count by the type of charging—including Level 1, Level 2 and DCFC equipment. Note there are also some privately owned chargers, at homes and businesses, that allow public access, but are not included in this list.

Table 8. Publicly Accessible EV Charging in the Puget Sound region[17]

| Entities Providing EV Charging | Level 1 | Level 2 | DCFC | Total |
|---|---|---|---|---|
| ChargePoint Network | 15 | 707 | 50 | 772 |
| SemaCharge Network | 0 | 337 | 0 | 337 |
| OpConnect | 10 | 10 | 0 | 20 |
| Webasto | 0 | 3 | 3 | 6 |
| GE WattStation | 0 | 1 | 0 | 1 |
| Greenlots | 0 | 8 | 12 | 20 |
| eVgo Network | 0 | 14 | 48 | 62 |
| EV Connect | 0 | 14 | 0 | 14 |
| Blink Network | 0 | 188 | 20 | 208 |
| Tesla | 0 | 78 | 4 | 82 |
| Electrify America | 0 | 5 | 23 | 28 |
| Other | 118 | 290 | 54 | 462 |
| **Total** | **143** | **1,655** | **214** | **2,012** |

# Carbon Intensity of Transportation Fuels

ICF aggregated supply, distribution, and production data to determine the baseline carbon intensity of transportation fuels within the agency's jurisdiction. ICF conducted this analysis by developing a Washington-specific version of the GREET model and reviewing currently-certified carbon intensities for the California Low Carbon Fuel Standard (LCFS). More details about the assumptions and analysis are included in Appendix A. The results of the analysis are summarized here.

## Gasoline, Diesel, and Jet Fuel Carbon Intensities

Table 9 summarizes the estimated 2015 baseline gasoline,[18] diesel, and jet fuel carbon intensity values. Crude Recovery & Transport were estimated with the Oil Production Greenhouse gas Emission Estimator (OPGEE)[19] using the methodology described in WA-GREET Methodology Section and Finished Fuel Transport Assumptions, respectively. The tailpipe emission factors are constant values taken directly from the GREET model.

[17] National Renewable Energy Laboratory (NREL) Alternative Fuel Station Locator Database. Accessed 8/15/2019. Available at: https://afdc.energy.gov/stations#/find/nearest
[18] Gasoline here refers to conventional Blendstock for oxygenate blending, or CBOB. This fuel is ultimately blended with ethanol at 10% by volume and sold as gasoline.
[19] More information is available at https://eao.stanford.edu/research-areas/opgee.

Table 9. Summary of estimated 2015 WA Gasoline, Diesel, and Jet Fuel CI, in grams of carbon dioxide equivalent per megajoule ($gCO_2e/MJ$)

| Fuel / Lifecycle Component | | $gCO_2e/MJ$ |
|---|---|---|
| Gasoline (CBOB) | Crude Recovery & Transport | 13.13 |
| | Refining & Transport | 14.53 |
| | Tailpipe Emissions | 73.94 |
| | **Total** | **101.60** |
| Diesel | Crude Recovery & Transport | 13.13 |
| | Refining & Transport | 11.97 |
| | Tailpipe Emissions | 74.86 |
| | **Total** | **99.96** |
| Jet Fuel | Crude Recovery & Transport | 13.13 |
| | Refining & Transport | 3.93 |
| | Tailpipe Emissions | 73.21 |
| | **Total** | **90.28** |

## Alternative Fuel Carbon Intensities

Table 10 through Table 16 summarize the estimated alternative fuel pathway carbon intensities (CIs) calculated using the WA-GREET model. For some alternative fuel pathways such as renewable diesel or renewable natural gas, ICF determined that pathways approved in California's LCFS Program were the best choice for representative values for fuels that could be delivered to Washington.[20]

Table 10. Ethanol Pathway CI ($gCO_2e/MJ$)

| Ethanol Pathway | | Corn | Sorghum |
|---|---|---|---|
| US Average | | 76.02 | 63.48 |
| CA-LCFS Pathways | All | 72.59 | n/a |
| | from CA | 62.34 | n/a |
| | excluding CA | 74.52 | n/a |
| *Indirect Land Use Change (included in CIs)* | | *19.8* | *19.4* |

Table 11. Biodiesel Pathway CI ($gCO_2e/MJ$)

| Biodiesel Pathway | UCO[b] | Tallow | Soy | Canola | Corn Oil | Additional Modifications to WA-GREET |
|---|---|---|---|---|---|---|
| WA Average | 16.24 | 36.37 | 52.76 | 47.94 | 22.28 | Reduced trucking distance from plant to refueling station to 50 mi[a] |
| US Average | 19.48 | 43.32 | 56.06 | 51.53 | 26.71 | - |
| Indirect Land Use Change (Included in CIs) | 0 | 0 | 29.1 | 14.5 | 0 | - |

[a] The average distance of Washington's two biodiesel plants to Seattle.
[b] Used cooking oil

[20] CARB Low Carbon Fuel Standard Current Look up Table, Tier 1, Tier 2, and Legacy Fuel Pathway Table. Available at: https://www.arb.ca.gov/fuels/lcfs/fuelpathways/current-pathways_all.xlsx

ICF notes that biodiesel from used cooking oil (UCO), tallow, and corn oil do not have indirect land use change[21] values because they are waste products or byproducts of other processes. Used cooking oil is collected from restaurants and other commercial facilities; tallow is the byproduct of rendering facilities; and corn oil is a byproduct of corn ethanol production (and in this case, the indirect land use change impact is accounted for in the carbon intensity of corn ethanol, rather than corn oil based biodiesel).

Table 12. Renewable Diesel and Renewable Jet Fuel Pathways CI ($gCO_2e/MJ$)

| RD Pathway | UCO | Tallow | Soy | Corn/Sorghum | Additional Modifications to WA-GREET |
|---|---|---|---|---|---|
| US Average | 20.84[22] | 32.17[23] | 53.86[24] | 32.795[25] | CA-LCFS Approved Pathways |
| International | 21.25[26] | 35.28[27] | - | 37.39[28] | CA-LCFS Approved Pathways |

Table 13. Electricity Generation and Delivery CI, and Light Duty BEV Pathway CI ($gCO_2e/MJ$)

| Electricity Pathway | Production Average | Pathway Average (for LD BEV)[29] | Wind | Solar | Biogas to Electricity | Modifications to WA-GREET |
|---|---|---|---|---|---|---|
| Puget Sound | 68.03 | 20.0 | 0 | -0 | - | |
| WA Average | 28.8 | 8.47 | 0 | 0 | 49.94 | |
| US Average | 153.94 | 45.3 | 0 | 0 | 139.30 | • Biogas to electricity- Feedstock and fuel CI of Landfill CNG pathway with assumed efficiency of 33%<br>• Reduced transportation distance to 0 miles because produced on-site |

[21] The indirect land use change impacts of biofuels, also known as ILUC, relates to the concept that there are unintended consequences of releasing more carbon emissions due to land-use changes globally induced by the expansion of croplands for biofuel production in response to the increased global demand for biofuels.
[22] Average of CA-LCFS Approved Louisiana Pathways T2N-1138, T2R-1204, T2N-1197, T2N-1198
[23] Average of CA-LCFS Approved Louisiana Pathways T2N-1139, T2R-1205, T2N-1200
[24] CA-LCFS Approved Pathway T2N-1137
[25] Average of CA-LCFS Approved Louisiana Pathways: T2N-1199 & T2N-1144
[26] Average of CA-LCFS Approved Pathways T2N-1046 (Singapore), T2R-1117(Singapore), T2N-1289 (Finland).
[27] Average of CA-LCFS Approved Singapore Pathways: T1R-1040, T1R-1041, T1R-1043, T1N-1382 and Finland Pathways: T2N-1239 & T2N-1264
[28] CA-LCFS Approved Singapore Pathway T1R-1045
[29] This is the estimated pathway for a light-duty BEV accounting for the Energy Economy Ratio (EER) of 3.4.

Table 14. RNG Pathway CI ($gCO_2e/MJ$)

| RNG Pathway | Landfill Gas | WWTP | Manure | Separated Organics | Forestry/Forest Residue | Modified Cells |
|---|---|---|---|---|---|---|
| US Average | 70.75 | - | - | - | - | - |
| WA Average | 23.28[30] | 43.02[31] | -263.955[32] | -37.56[33] | 0.34[34] | • 100 mi Transportation Distance from CNG Plant to Refueling Station |

Table 15. Hydrogen Pathway CI ($gCO_2e/MJ$)

| Hydrogen Pathway | RNG (landfill gas) | Fossil Gas |
|---|---|---|
| WA Average | 52.41 | - |
| US Average | 87.8 | 105.71 |

Table 16. Natural Gas & Propane Pathways CI ($gCO_2e/MJ$)

| Fuel | CI |
|---|---|
| Propane US Average[35] | 83.19 |
| Natural Gas, US Average | 79.21 |

[30] The US Average listed is the CI for the so-called Temporary Fuel Pathway Code in California's LCFS program. The average carbon intensity of RNG from landfill gas delivered to California is closer to 45-50 g/MJ (based on ICF analysis of data reported by CARB). The WA Average is lower because of a cleaner electricity grid and much shorter transmission distances for the RNG, assuming it is produced and consumed in the State of Washington.
[31] CA-LCFS Approved Pathway T2N-1156
[32] CA-LCFS Approved California Pathways: T2R-1062 & T2N-1143
[33] Assumed to be Municipal Solid Waste to CNG (Off-site Refueling)
[34] Assuming a fermentation process. CA-LCFS Approved Pathway T2N-1248
[35] California Air Resources Board LCFS Final Regulation Order. Table 7-1 Lookup Table for Gasoline and Diesel and Fuels that Substitute for Gasoline and Diesel. Available at: https://www.arb.ca.gov/regact/2018/lcfs18/frolcfs.pdf

## Alternative Fuel Feedstocks

ICF identified feedstocks that are currently available for alternative fuel production in Washington. Table 17 describes the feedstocks and the types of fuel they could be used to produce.

Table 17. Feedstocks Considered in Resource Assessment

| Feedstock | Potential Finished Fuel | Description |
| --- | --- | --- |
| Agricultural residue | Ethanol | The material left in the field, orchard, vineyard, or other agricultural setting after a crop has been harvested. Inclusive of unusable portions of the crop. |
| Agricultural starch crops | Ethanol | Starch-based feedstocks containing long complex chains of sugar molecules which can be easily converted to fermentable sugars |
| Agricultural sugar crops | Ethanol | Crops produced as major sources of sugar, syrup, and other sugar substances. |
| Animal manure | RNG, Renewable $H_2$, Electricity | Manure produced by livestock, including dairy cows, beef cattle, swine, sheep, goats, poultry, and horses. |
| Renewables | Electricity | A source of energy that is not depleted by use, such as water, wind, or solar. |
| Fats, oils, and greases (FOGs) | Biodiesel, Renewable diesel | Long chain fatty compounds that are byproducts of cooking, such as fryer grease (yellow grease) and grease traps (brown grease). |
| Forestry and forest product residue | Ethanol, RNG, Renewable $H_2$ | Biomass generated from logging, forest and fire management activities, and milling. Inclusive of logging residues, forest thinnings and mill residues. Includes materials from public forestlands, but not specially designated forests and includes sustainable harvesting. |
| Landfill gas (LFG) | RNG, Renewable $H_2$, Electricity | The anaerobic digestion of biogenic waste in landfills produces a mix of gases, including methane (40-60%). |
| Municipal solid waste (MSW) (compost or lignocellulosic) | Diesel | Refers to the organic fraction of waste which is typically landfilled, such as paper products, certain yard trimmings (e.g., branches), and construction and demolition debris. Does not include the portion that is used in other industries, such as composting. |
| Oil Seeds | Biodiesel, Renewable diesel | Oil seed crops are grown primarily for the oil contained in the seeds. The oil content of oilseeds ranges from 1-2% for small grains such as wheat, to greater than 40% for rapeseed (canola). |
| Source Separated Organics | RNG, Renewable $H_2$, Electricity | Waste generators segregate compostable materials from other waste streams at the source for separate collection. Examples of organic materials include food, garden and park waste, wood and wood waste, textiles, sludge, rubber, and leather. |
| Wastewater treatment (WWT) | RNG, Renewable $H_2$, Electricity | Wastewater consists of waste liquids and solids from household, commercial and industrial water use. In the processing of wastewater, sludge is produced, which can be anaerobically digested to produce methane. |

Table 18: Feedstocks Currently Available for Alternative Fuels in Washington

| Feedstock Category | Feedstock | Quantity | Source |
|---|---|---|---|
| Agricultural Starch Crops | Corn, grain | 19,975,000 | • Unit: bushels/year<br>• 2016 total production<br>• Reported by the USDA National Agricultural Statistics Service[36] |
| | Wheat | 157,290,000 | |
| Agricultural Sugar Crop | Sugar Beets | 91,000 | • Unit: tons/year<br>• 2016 total production<br>• Reported by the USDA National Agricultural Statistics Service[36] |
| Oilseed Crop | Canola | 58,900,000 | • Unit: pounds/year<br>• 2016 total production<br>• Reported by the USDA National Agricultural Statistics Service[36] |
| Agricultural Residues | Corn Stover | 133,883 | • Unit: dry tonnes/year<br>• Reported from the US DOE Bioenergy Knowledge Discovery Framework 2016 Billion Ton Report[37]<br>• Base case assuming 1% annual yield improvement and average biomass price |
| | Wheat Straw | 1,279,342 | |
| Forest | Whole Trees | 3,393,043 | |
| Forest Residue | Mill Residue | 110,711 | |
| | Logging Residue | 613,013 | |
| Source Separated Organics | Food Waste | 174,475 | |
| | Yard Trimmings | 89,305 | |
| Animal Manure | Dairy Cow Manure | 5,449 | • Unit: million wet tonnes/year<br>• 275,000 head of dairy cows as reported from Washington Department of Commerce[38]<br>• 80 lbs manure per day per 1000-pound dairy cow manure production constant from USDA[39]<br>• 680 kg average mass of Dairy Cow from CA-LCFS simplified calculator [40] |
| Landfill Gas | LFG | 32.62 | • Unit: million dekatherm/year<br>• Current as of September 2018<br>• Includes LFG collected and flared<br>• Comprehensive of landfills in Washington in the planning stage, under construction, and operational<br>• Reported from the US EPA Landfill Methane Outreach Program[41] |
| Wastewater Treatment Plants | WWTP | 5.8-17.3 | • Units: Billion Gallons per Year<br>• Inclusive of wastewater treatment plants that have influent rates greater than 17 million gallons/day, which is the threshold above which energy projects become viable<br>• Reported by the American Gas Foundation. *The Potential for Renewable Gas: Biogas Derived* |

36 https://www.nass.usda.gov/Statistics_by_State/Washington/index.php
37 https://bioenergykdf.net/billionton2016/overview
38 http://www.commerce.wa.gov/wp-content/uploads/2018/02/Energy-RNG-Roadmap-for-Washington-Jan-2018.pdf
39 https://www.nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcs143_014211
40 https://www.arb.ca.gov/fuels/lcfs/ca-greet/tier1-dsm-calculator-corrected.xlsm)
41 https://www.epa.gov/lmop/project-and-landfill-data-state

| Feedstock Category | Feedstock | Quantity | Source |
|---|---|---|---|
| | | | *from Biomass Feedstocks and Upgraded to Pipeline Quality, 2011*[42] |
| Municipal Solid Waste | MSW | 5,095,890 | • Units: tons<br>• MSW currently directed to landfills for disposal<br>• Reported by the Washington Department of Ecology, 2016[43] |
| Fats, Oil, and Greases | Animal Fat and Used Cooking Oil | 89,837 | • Unit: tons<br>• Includes animal fat and used cooking oil collected for rendering or processing in commercial quantities<br>• Reported by the Washington Department of Ecology, 2016[43] |
| Renewables | Solar Potential | 4.43 | • Units: $kWh/m^2/day$<br>• 136.1 MW currently installed[44]<br>• Expected to install an additional 339 MW over the next 5 years[44]<br>• Annual average daily total solar resource in Washington averaged over surface cells of 0.1 degrees in both latitude and longitude, or about 10 km in size.<br>• Reported by the National Renewable Energy Laboratory Geospatial Solar Data[45] |
| | Wind Capacity Potential | 177,298 | • Units: MW<br>• Includes installed (3,075 MW) and technologically feasible potential wind capacity at 80 meters in Washington<br>• Reported by the National Renewable Energy Laboratory WINDExchange[46] |

ICF notes that we did not assume that these feedstocks are freely available for alternative fuel production. Many of these feedstocks are currently used for other purposes and therefore the price of the feedstock will largely depend on the cost of replacing the feedstock with another material. For example, animal manure is widely used as an alternative to chemical fertilizers. The cost of the animal manure will largely depend on the current market price of synthetic fertilizer. A brief list of feedstock competitors is included below in Table 19.

[42] http://www.eesi.org/files/agf-renewable-gas-assessment-report-110901.pdf
[43] https://ecology.wa.gov/getattachment/77d93c8c-b4d0-4186-a7f3-6ede70bec4c8/Material-Recovery-and-Disposal-2016.xlsx
[44] Solar Energy Industries Association. Available at: https://www.arb.ca.gov/regact/2018/lcfs18/frolcfs.pdf
[45] Solar Summaries https://www.nrel.gov/gis/data-solar.html.
[46] https://windexchange.energy.gov/maps-data/321

Table 19: Competition for Feedstocks

| Feedstock | Competition |
|---|---|
| Agricultural Residue | Animal feed; livestock bedding (e.g., straw from grains); carbon sequestration, and; benefits to agricultural land such as reduced soil erosion, soil nutrient recycling, and maintenance of soil organic matter and fertility. |
| Agricultural Starch Crops | Animal feed, food markets |
| Agricultural Sugar Crops | Animal feed, food markets |
| Oilseed Crops | Animal feed, food markets, protective coatings, |
| Animal Manure | Fertilizers and compost materials; electricity production (e.g., poultry litter), and; manure being diverted for existing anaerobic digestion systems. |
| Fats, Oils and Greases | Animal feed; liquid biofuels production (e.g., biodiesel), and; cosmetics and soaps. |
| Forestry and Forest Product Residue | Electricity production; fuel for boilers, kilns, dryers; pulp-and-paper; pellet and briquette manufacturing; landscaping (e.g., bark chips); fertilizer for forest land; particleboard manufacturing, and; animal bedding (e.g., shavings and sawdust). |
| Landfill Gas | Electricity production; industrial process heat; existing LFG contracts for biogas. |
| Municipal Solid Waste (food, leaves, grass, lignocellulosic) | Recycling; fertilizer production through composting (e.g., food scraps, yard trimmings), and; waste-to-energy (i.e., heat, electricity). |
| WWT Gas | Fuel for WWTP process heat, and; electricity production. |

## Alternative Fuel Production from Domestic Feedstocks

ICF developed finished fuel estimates for the Washington state feedstocks outlined in Table 18 above. ICF estimated the maximum technical potential for annual fuel production from each of these feedstocks, as highlighted in Table 20 below. For each fuel, we have reported the volume in units of millions of gasoline gallon equivalents (M GGE). It is very difficult to predict what a “moderate” amount of production from in-state feedstocks would be or could mean. Ultimately the fuels delivered and feedstocks used will depend on small price and CI differences across a wide range of fuels and feedstocks from many regions including Washington, Oregon, California, the Midwest, and Canada. So, “moderate” as a fraction of the maximum can be estimated from the table below. But, “moderate” in the sense of “most likely”, is highly speculative at this point.

Table 20. Alternative Fuel Feedstocks and Potential Finished Fuel Production

| Feedstock Category | Feedstock | Quantity (Annual) | Likely Fuel | Max Tech Potential (M GGE) |
|---|---|---|---|---|
| Agricultural Starch Crops | Corn, grain | 19,975,000 bu[a] | Ethanol | 38-42 |
| | Wheat | 157,290,000 bu | Ethanol | 290-302 |
| Agricultural Sugar Crop | Sugar Beets | 91,000 tons | Ethanol | 1.7-2.0 |
| Oilseed Crop | Canola | 58,900,000 lbs | Biodiesel Renewable Diesel | 8.3-8.7 |
| Agricultural Residues | Corn Stover | 133,883 dry tonnes | Ethanol | 8-10 |
| | Wheat Straw | 1,279,342 dry tonnes | Ethanol | 57-60 |

| Feedstock Category | Feedstock | Quantity (Annual) | Likely Fuel | Max Tech Potential (M GGE) |
|---|---|---|---|---|
| Forest | Whole Trees | 3,393,043 dry tonnes | RNG | 170-250 |
| Forest Residue | Mill Residue | 110,711 dry tonnes | RNG | 5.5-8.2 |
| | Logging Residue | 613,013 dry tonnes | RNG | 30.7-45.4 |
| Source Separated Organics | Food Waste | 174,475 dry tonnes | RNG | 8.7-12.9 |
| | Yard Trimmings | 89,305 dry tonnes | RNG | 4.5-6.6 |
| Animal Manure | Dairy Cow Manure | 5,449 wet tonnes | RNG | <1 |
| Landfill Gas | LFG | 32.62 million Dth[b] | RNG | 120-140 |
| Wastewater Treatment Plants | WWTP | 5800-17300 MGY[c] | RNG | 0.4-1.2 |
| Municipal Solid Waste | MSW | 5,095,890 tons | RNG | 220-240 |
| Fats, Oil, and Greases | Animal Fat & UCO | 89,837 lbs | Biodiesel Renewable Diesel | <1 |

a) bu is a bushel, b) Dth is a dekatherm, c) MGY is million gallons per year

Canola oil and landfill gas are the only feedstocks that are being used in commercial quantities today to produce alternative fuels, biodiesel and RNG, respectively. With respect to canola oil, the introduction of a low carbon fuel policy is highly unlikely to induce more consumption of canola oil as a biodiesel feedstock because the CI of the finished fuel is not as competitive as waste-based feedstocks like yellow grease or used cooking oil. The larger biodiesel producers are all seeking to diversify their feedstocks with the intent of reducing exposure to higher priced virgin oils, and the higher Cis that are affiliated with these fuels. The average weighted CI of biodiesel in California's LCFS program is consistently less than 40 $gCO_2e/MJ$, indicating that suppliers are primarily delivering biodiesel produced using lower CI feedstocks. It is unlikely that a low carbon fuel policy in the agency's jurisdiction will induce further production of biodiesel using canola. Rather, ICF anticipates that a low carbon fuel policy would incentivize the delivery of liquid biofuels from low carbon feedstocks, like used cooking oil, tallow, or corn oil, to the extent feasible. Given that there are constraints on the availability of these resources, and competition for them in other markets, it is conceivable that there would still be "local" demand for biodiesel from canola oil.

With respect to RNG, there is room for increased investment and utilization of feedstocks, including landfill gas, animal manure, wastewater treatment plants, and municipal solid waste. Despite the high RNG production potential in Washington—as much as 600-700 M GGE when considering the potential for thermal gasification of biomass (including of agricultural residues, forestry products, and forestry residues)—it is unlikely that the introduction of a low carbon fuel standard in the study region will induce investment into these projects beyond what is currently planned. There is a confluence of factors driving this assumption: first and foremost, there is limited renewable natural gas consumption in the Puget Sound region. The RNG facilities that are in place are sending most of their fuel to California to take advantage of the opportunity to generate credits under both the LCFS program and the federal Renewable Fuel Standard program. There is a flurry of investment nationwide in low carbon RNG projects, most notably in non-landfill gas projects, all with the intent of taking advantage of very low CI values for these feedstocks in the California market. While many of these projects may not come online, it is still likely that a significant share of the RNG that is currently being delivered to California, which is largely landfill gas, will be displaced from California and seek other markets. With the introduction of a low carbon fuel policy in the Puget Sound region, it would be a natural landing place for that gas, and much more cost effective than developing newer projects.

In general, ICF views the technical RNG production potential as unlikely to materialize absent complementary policies that reward RNG production for use in non-transportation applications. Absent that type of program, much of the RNG potential in Washington will remain unrealized.

Lastly, the agricultural feedstocks—like corn, wheat, corn stover, and wheat straw—that can be used to produce ethanol are unlikely to be developed as a resource for low carbon transportation fuel production in the region. While the volumes of these feedstocks are substantial, there are significant hurdles to constructing new ethanol production facilities, and the ethanol production industry is generally trending towards converting existing production facilities to lower carbon ethanol production, rather than building new facilities to accommodate lower carbon feedstocks. Most of the existing ethanol production facilities in the country are in the Midwest, where the concentration of low-carbon feedstocks is greater than in other states, giving them a competitive advantage over any potential new facilities that could be built elsewhere.

The liquid biofuel industry is currently focused on developing renewable diesel projects—with more than one billion gallons of additional capacity announced over the past 12 months, including expansion of facilities in Singapore and Louisiana, the conversion of an existing refinery in North Dakota to produce renewable diesel, and the Ferndale project representing a joint venture between REG and Phillips 66. These facilities will likely put significant pressure on the demand for waste-based feedstocks like waste grease, yellow grease, corn oil, and used cooking oil. ICF generally believes that the liquid biofuel market will gradually transition to co-processing of biomass feedstocks at existing refineries as a means of circumventing the capital costs of developing new facilities. If this prediction is correct, the expansion of biofuel production in Washington will likely be limited to co-processing projects at the existing refineries in Tacoma, Ferndale, and Anacortes (Table 2). Because of the high predicted future demand for waste-based feedstocks, we anticipate that much of the biomass feedstock used in Washington State will be forestry products, which are widely available. We assume, for instance, that there will be about 4-6 demonstration or pilot projects at refineries around the country, including one in Washington by 2028, with a total capacity of co-processed biomass of roughly 100-120 million gallons per year.

While low carbon fuel policies can spur local low carbon fuel production, there are many more factors that must be considered than the regulation, and production may not necessarily occur in the jurisdiction where the regulation is enacted. For context, the volume of alternative fuels delivered to California has increased substantially since the start of the LCFS[47]. But, consider, for instance, the size of California's transportation fuels market. The state produces roughly 200 million gallons of the 1.5 billion gallons of biofuels consumed in the state—and all of its commercial scale production facilities were in place before the introduction of the LCFS program. And there is a small, but robust biodiesel production industry in California—producing roughly 20-30 million gallons of the nearly 150 million gallons being consumed. Similarly, more than 90% of the RNG that is consumed in California is delivered from out of state. California is moving towards more RNG production in-state, particularly from the dairy industry; however, this has largely been spurred by California's Short Lived Climate Pollutant Reduction Strategy that was implemented to reduce methane emissions, and catalyzed by multi-million dollar grants from the State, rather than exclusively due to the price signal from the LCFS program.

This is not to say that low carbon fuel policies cannot spur local investment in alternative fuel production, rather, the potential for new facilities is limited given the high upfront capital costs for fuel production and competition from existing producers. Low carbon fuel programs generally favor the utilization of existing assets and incentivize those facilities to reduce the carbon intensity of the fuels currently produced. However, the available resources to western Washington and surrounding areas, including the variety of potential feedstocks for low carbon fuel production may lead to higher-than-expected buildout of local production facilities.

[47] Based on ICF analysis of LCFS program data presented by CARB, available at https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm.

# 3. Low Carbon Fuel Scenario Modeling

The objective of the scenario analysis is to demonstrate the levels of carbon intensity reduction that could be achieved for a CFS under different market conditions and considerations, and at what (estimated) cost.[48] The intent of scenario modeling is to help inform policy development, but is not meant to be deterministic with respect to the shape and/or design of any policy, or prescriptive with regards to compliance. Furthermore, the scenarios are not meant to be predictive forecasts.

ICF conducts scenario modeling using a fleet turnover-based model for the light-, medium-, and heavy-duty vehicle fleets in the Puget Sound region. ICF downscaled a Washington-based model of transportation fuel consumption that our team previously built for a study of petroleum reduction potential.[49] The model includes assumptions regarding fuel economy, vehicle miles traveled, and other key parameters associated with transportation fuel consumption. The modeled compliance scenarios include a mix of vehicle and fuel strategies, and the model tracks the credits and/or deficits generated on a year-over-year basis for each model run. Table 21 below summarizes the strategies considered in the analysis, and the information thereafter explains how these strategies were bundled into different scenarios for analysis.

Table 21. Low Carbon Fuel Strategies Considered in Analysis

| Strategy | Description of Strategy Considered in Scenario Modeling |
|---|---|
| Ethanol | • Increased ethanol blending<br>• Lower carbon intensity through feedstock management or agronomic practices (e.g., nitrogen inhibitors, reduce till / no till, and cover crops)<br>• Lower carbon intensity through operational changes at production (e.g., carbon capture and storage) |
| Biodiesel | • Increased biodiesel blending<br>• Lower carbon intensity through feedstock management<br>• Lower carbon intensity through operational changes at production |
| Renewable diesel | • Increased renewable diesel consumption<br>• Lower carbon intensity through feedstock management<br>• Lower carbon intensity through operational changes at production |
| Renewable jet fuel | • Increased renewable jet fuel consumption<br>• Focus on WA boundary conditions—only considering renewable jet fuel blended in WA. |
| Zero-emission vehicles Light-duty | • Increase EV and hydrogen fuel cell deployment rates<br>• Increased utilization factor for PHEVs due increased infrastructure availability |
| Zero-emission vehicles Heavy-duty | • Consider deployment of electric and hydrogen fuel cell vehicles in different vocations: work trucks, delivery vans, transit buses, goods movement applications, etc. |
| Natural Gas | • Increase penetration of natural gas vehicles in specific vocations: transit buses, refuse trucks, short haul trucks, etc.<br>• Increase penetration of renewable natural gas (RNG) in transportation |

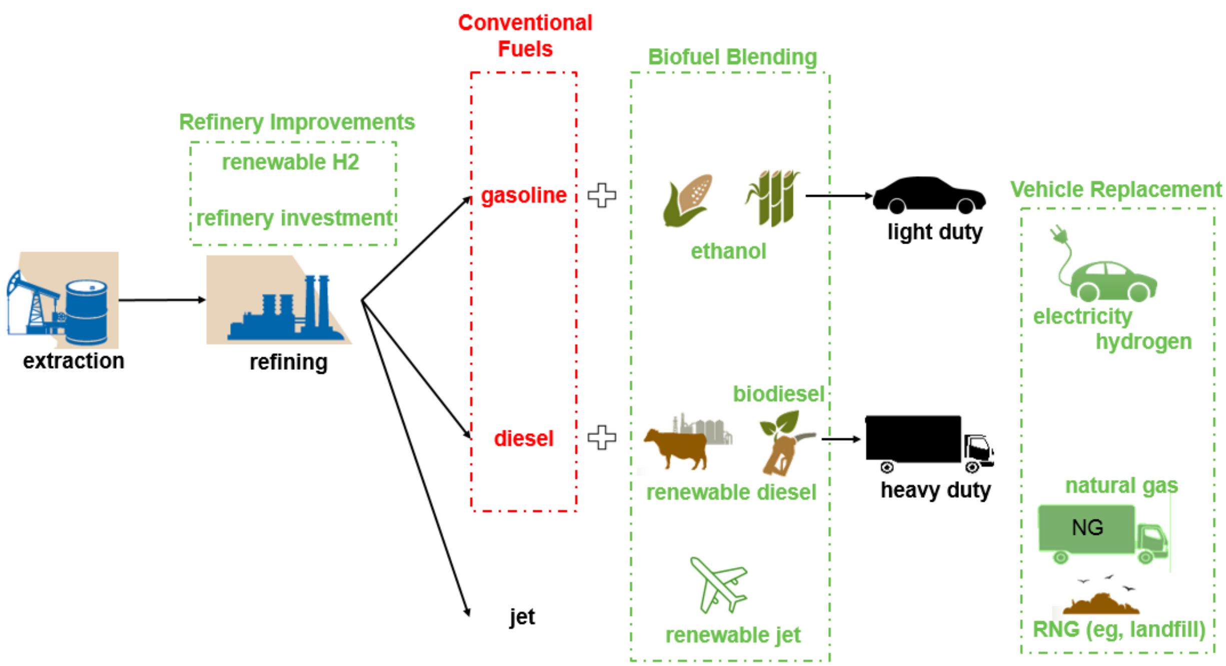
[48] Note that the costs are addressed in Section 4.
[49] ICF, Half the Oil: Pathways to Reduce Petroleum Use on the West Coast, 2016. Available online at https://www.ucsusa.org/sites/default/files/attach/2016/01/ICF-Half-the-Oil-CA-WA-OR.pdf.

| Strategy | Description of Strategy Considered in Scenario Modeling |
|---|---|
| | sector |
| Upstream Emission Reductions | • Refinery efficiency<br>• Renewable hydrogen into refiners (from SMR of RNG) |

## Summary of Scenario Modeling

ICF conducted the scenario modeling by assuming that the proposed program operates on the same system of deficits and credits as California's LCFS Program and Oregon's Clean Fuels Program. Petroleum-based transportation fuels (e.g., gasoline and diesel) with carbon intensities higher than the standard generate deficits; these deficits must be offset on an annual basis by credits generated by lower-carbon fuels. Credits can be banked without holding limits and do not carry vintages.[50] Figure 5 below illustrates the ways that deficits and credits are assumed to be generated in the program, along with the various deficit- and credit-generating pathways. ICF notes that we do not explicitly address the issues associated with interaction of the Puget Sound Clean Fuel Standard with other low carbon fuel standards in the scenario modeling, but consider it in our discussion of the economic impacts of the compliance modeling.

Figure 5. Deficit (in red) and Credit (in green) Generation Pathways




[50] This refers to the year in which the environmental attribute was generated.

## Biofuel Blending

Liquid biofuels are blended into gasoline, diesel, or jet fuel to generate credits. These biofuels include ethanol, biodiesel, renewable diesel, and renewable jet fuel. They are each produced from various feedstocks. Broadly speaking, there are two opportunities to generate credits via biofuel blending: 1) lower carbon feedstocks and process improvements and 2) petroleum displacement via increased blending.

1. Lower carbon feedstock and process improvements. Low carbon fuel policies incentivize the use of lower-carbon feedstocks, often waste or byproducts of other processes. For instance, California's LCFS program includes significant volumes of biodiesel from corn oil, a byproduct of corn ethanol production, and used cooking oil as well as renewable diesel made from tallow. However, it is important to note that there is potential to decrease the carbon intensity of biofuels from conventional or virgin feedstocks, like ethanol from corn or biodiesel from soy oil, as well. This can be achieved through a combination of upstream agricultural practices[51] and process improvements at the biorefinery.
2. Petroleum displacement via increased blending. The other way that biofuels generate credits is through increased blends into conventional fuel supply, thereby increasing the use of low carbon fuels while decreasing petroleum-based fuels.

## Vehicle Replacement

Vehicle replacement refers broadly to the introduction of alternative-fuel vehicle technologies, which tends to happen at a slower rate than biofuel blending because it requires fleet turnover in light-, medium-, and/or heavy-duty vehicle sectors. The strategies within this bucket include electric vehicle deployment, hydrogen fuel cell vehicle deployment, and natural gas vehicles. Though the strategies focus on vehicle turnover and the introduction of alternative fuel vehicles, ICF scenario modeling also considers strategies to decrease the carbon intensity of the fuel. For instance:

- For electric vehicles, ICF decreases the carbon intensity of electricity over time to be consistent with commitments and regulations requiring increased renewable energy content in electricity generation. The carbon intensity reduction path for electricity generation in the Puget Sound region, starting around 60 g $CO_2$e/MJ is expected to decrease to 30 g $CO_2$e/MJ by 2030. This translates to approximately 18 g $CO_2$e/MJ and 9 g $CO_2$e/MJ for a light-duty BEV pathway, respectively. See Appendix A for further discussion of electricity generation and supply to the Puget Sound.
- Although ICF assumed only modest increases for hydrogen fuel cell vehicle deployment (currently there are not any hydrogen fueling stations in WA), we did assume that a portion of the hydrogen consumed as a transportation fuel would be generated from renewable resources, including the steam methane reformation of renewable natural gas or electrolysis using renewable electricity.

[51] Lewandrowski, J.; Rosenfeld, J.; Pape, D.; Hendrickson, T.; Jaglo, K. and Moffroid, K (2019): The greenhouse gas benefits of corn ethanol—assessing recent evidence, Biofuels, DOI: 10.1080/17597269.2018.1546488.

- In the case of natural gas vehicles, ICF assumed that the CFS in the Puget Sound region would follow a similar but more rapid trajectory in the displacement of fossil natural gas with RNG than has been observed in California's LCFS and Oregon's CFP. In California and Oregon, RNG represents more than 70% and 50% of the natural gas consumed in the transportation sector, respectively.[52]

The coupling of alternative fuel vehicle deployment and the potential decrease in the carbon intensity of the associated alternative fuel makes for significant carbon intensity reduction potential for these strategies.

## Refinery Improvements

ICF also considered the potential to generate credits through operational and process-oriented changes at the refinery. These include refinery efficiency improvements and the introduction of renewable hydrogen for use in hydrocracking and catalytic hydrotreating.

**Refinery Efficiency**

ICF used data from EPA's Greenhouse Gas Reporting Program to estimate emissions by refinery across Washington, thereby establishing a baseline in carbon dioxide equivalent emissions rate. Emissions were characterized by major refinery process (e.g., flaring, catalyst coking, vents, etc.) and combustion units (e.g., heaters and boilers). Allocating combustion emissions between heaters and boilers was performed using available boiler/heater capacities averaged across the Petroleum Administration for Defense District (PADD) level and applied to Washington.

With the emissions baseline established, a list of mitigation technologies for implementation at refineries was developed. For each technology the level of emissions reduction (as a percentage), the cost to implement, and the penetration rate (i.e., percentage of refineries already implementing this reduction measure) were estimated. Each mitigation technology was then applied to a specific emission source, either at a refinery process level (e.g., flaring, catalytic coke, etc.) or to a portion of combustion emissions (e.g., heaters and boilers). The results were tailored to Washington-specific refinery characteristics.

ICF used the same methodology for credit generation via refinery efficiency improvements that the California Air Resources Board (CARB) has developed as part of the LCFS program.

**Renewable hydrogen**

Hydrogen is used by refiners in hydrocracking—converting high-boiling constituents in crude oil to lower boiling constituents like gasoline and diesel—and in catalytic hydrotreating to reduce the sulfur content of diesel. Refinery use of hydrogen has increased in recent years. Hydrogen is typically produced via steam reformation of natural gas. About 35% of natural gas use at refineries is attributable to hydrogen production—this presents significant opportunities for refiners to generate credits by switching from fossil natural gas to RNG in the aforementioned processes. However, the competition for RNG as a transportation fuel may present some

[52] Based on ICF analysis of data provided by the California Air Resources Board (https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm) and the Oregon Department of Environmental Quality (https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels-Data.aspx).

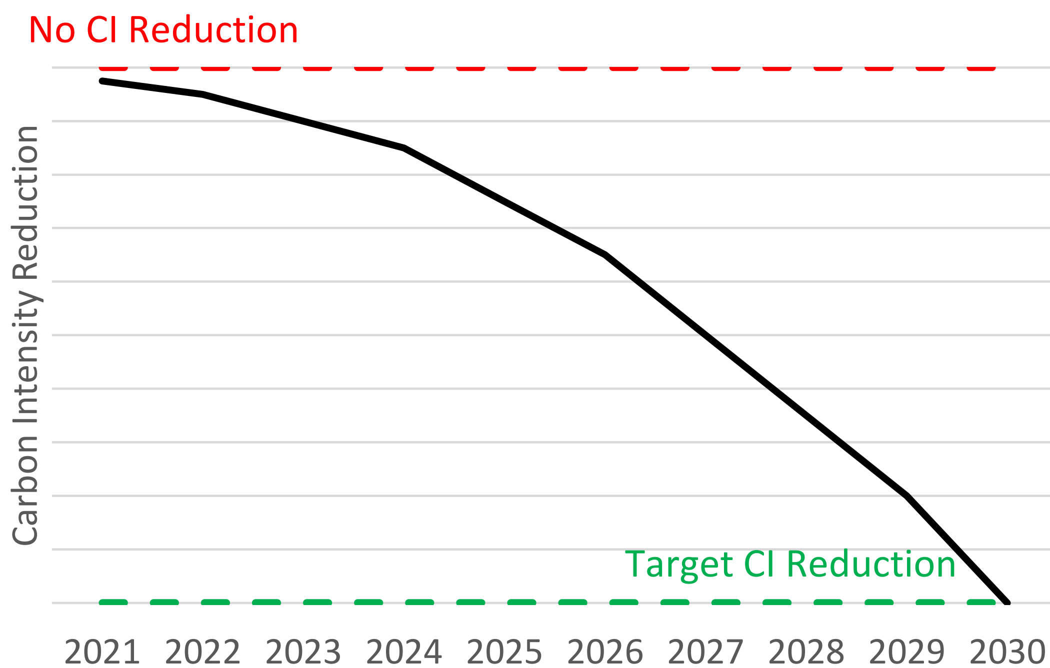
challenges associated with this strategy in the near-term future, but will likely be more viable as the transportation sector is increasingly saturated with RNG.

ICF used the same methodology for credit generation via renewable hydrogen that CARB has developed as part of the LCFS program.

## Carbon Intensity Reductions in Scenario Modeling

ICF implemented a carbon intensity reduction trajectory from 2021 to 2030 similar in shape to the implementation schedule for California's originally implemented LCFS program for 2011 to 2020 and Oregon's implemented CFP for 2016 to 2025 (Figure 6).

Figure 6. Carbon intensity reduction trajectory for proposed CFS in Puget Sound region




The y-axis in the figure above is purposely left blank—because ICF used the same curve, but with different carbon intensity reduction targets in the scenario modeling, as discussed in more detail below. The nominal target intensity in the scenarios is the CI reduction in 2030 -the bottom right point on the curve. The figure illustrates that the target (carbon intensity reduction) path is not linear; it drops more rapidly in the later years than in the earlier years. For the sake of reference, California's program originally had a target of 10% reduction by 2020 (before subsequently revising that target) and Oregon's program has a target of 10% reduction by 2025.

# Overview of Scenarios

ICF modeled four scenarios, as summarized here and in Table 22 below—more details about each scenario are included in the text that follows.

- Scenario A is focused on biofuel blending, and decreases in carbon intensity of those biofuels. The carbon intensity reduction target is set at 10% below 2016 levels by 2030.

- Scenario B is focused on electrification, and has a more rapid increase of EV deployment for both the light- and medium/heavy-duty vehicle sectors than what is included in the reference case or in other cases. The carbon intensity reduction target is set at 10% below 2016 levels by 2030.
- Scenario C is a blend of Scenario A and Scenario B, with a mix of increased biofuel blending, lower carbon intensity biofuels, and electrification. It is also introduces increased penetration of natural gas vehicles using RNG, small volumes of renewable jet fuel, and reduced carbon intensity at refineries through efficiency measures and renewable hydrogen. The carbon intensity reduction target is set at 16% below 2016 levels by 2030.
- Scenario D is meant to capture the upper limit of carbon intensity reduction that ICF viewed as feasible for the Puget Sound region by 2030. This includes more aggressive biofuel blending, lower carbon intensity biofuels, and more aggressive EV deployment in all vehicle segments. It also includes the increased penetration of natural gas vehicles using RNG, more substantial volumes of renewable jet fuel than included in Scenario C, and more aggressive carbon intensity reductions at refineries through efficiency measures and renewable hydrogen. ICF modeled this scenario in two ways with respect to the carbon intensity reduction target: we employed a 20% target by 2030, and then through iterative calculations determined that the effective maximum carbon intensity reduction through this scenario is 26% by 2030.

Table 22. Overview of Puget Sound CFS Scenarios

| Low Carbon Fuel Strategy | Scenario A: Biofuel Blending | Scenario B: Aggressive Elec | Scenario C: Mixed Technology | Scenario D: All-in Max |
|---|---|---|---|---|
| Biofuel Blending | | | | |
| Ethanol | • E15 by 2030 | • E10 | • E15 by 2030 | • E15 by 2030 |
| Biodiesel | • B10.5 by 2030 | • B5 by 2030 | • B20 by 2030 | • B20 by 2030 |
| Renewable diesel | • RD10.5 by 2030 | • RD10 by 2030 | • RD15 by 2030 | • RD20 by 2030 |
| Renewable jet | • n/a | • n/a | • 25 MG by 2030 | • 50 MG by 2030 |
| Vehicle Replacement | | | | |
| EVs / FCVs, LD | • 10% of new sales by 2025 | • 15% of new sales by 2025 | • 14% of new sales by 2025 | • 20% of new sales by 2025 |
| EVs / FCVs, Class 3-6 | • Baseline | • 7% of new sales by 2025 | • 7% of new sales by 2025 | • 7% of new sales by 2025 |
| NG / RNG | • 95% blend of RNG by 2024 | • Baseline | • 95% blend of RNG by 2024<br>• 5% NGVs into Class 7/8 fleet | • 95% blend of RNG by 2024<br>• 7% NGVs into Class 7/8 fleet |
| Refinery Improvements | | | | |
| Renewable $H_2$ | • n/a | • n/a | • 20% penetration | • 40% penetration |
| Refinery investment | • n/a | • n/a | • 5% efficiency improvement | • 10% efficiency improvement |

The results for each scenario are summarized in the sub-sections below.

## Scenario A: Biofuel Blending

Scenario A is focused on modest increases in biofuel blending, which has been the most immediate response to low carbon fuel standards in both California and Oregon. In California, for instance, the diesel market was at about a 5% blend for biodiesel and a 10% blend for renewable diesel. In this scenario, ICF simply increased the biodiesel blend rate and the renewable diesel blend rate on a year-over-year basis. In Scenario A, biodiesel and renewable diesel were both blended at rates of 10.5%. For reference, the majority of on-road diesel engines deployed today are warrantied up to B20, a 20% blend of biodiesel and 80% conventional diesel. Furthermore, biodiesel blended up to 5% of the conventional fuel supply does not even have to be labeled as such—California fuel suppliers, for instance have been blending biodiesel up to the 5% limit for at least the last 12 months as part of their compliance with the LCFS program.[53] Oregon suppliers have surpassed the 5% blend rate and have been blending at around 7% for the last two years.[54] While there are some retail infrastructure constraints associated with blending above 5%, the costs of implementing the infrastructure to do so are modest. Minnesota, for instance, blends between 10% and 20% biodiesel for at least half of the year, but reduces the blend rate for the cold winter months when changes in the viscosity of the fuel (referred to as gelling or waxing) can cause performance problems in engines.[55] The weather conditions in the Puget Sound region should not present the same blending issues as in colder climates like Minnesota when it comes to higher biodiesel blending.

ICF assumed that biodiesel and renewable diesel would have effective carbon intensity values of about 48 g $CO_2$e/MJ, representing a blend of about 40% waste products (e.g., used cooking oil, tallow, corn oil) and 60% virgin oils (e.g., soy oil and canola oil).

ICF also increased the rate at which ethanol is blended into gasoline. The Puget Sound region is an E10 market today; however, there is potential to go to higher blends of ethanol. In May 2019, the EPA approved nationwide, year-round sales of E15, a 15% blend of ethanol with gasoline (or conventional blendstock) for vehicles of model year 2001 or newer. ICF increased the blend rate of ethanol by 0.5% per year, reaching a maximum of 15% by 2030. Similar to higher blends of biodiesel, the main constraint that the market will face with respect to higher blends of ethanol is simply the availability of and willingness to deploy the retail infrastructure to dispense it. The cost of retail dispensing infrastructure is modest and there are examples in other markets that have seen growth in E15. For instance, as of July 2019, there are more than 1,800 stations in 31 states that sell E15 at retail—typically using blender pumps and also selling E85.[56]

ICF also decreased the carbon intensity of ethanol from around 72 g $CO_2$e/MJ to 65 g $CO_2$e/MJ by 2030, representing a 10% reduction over 10 years.

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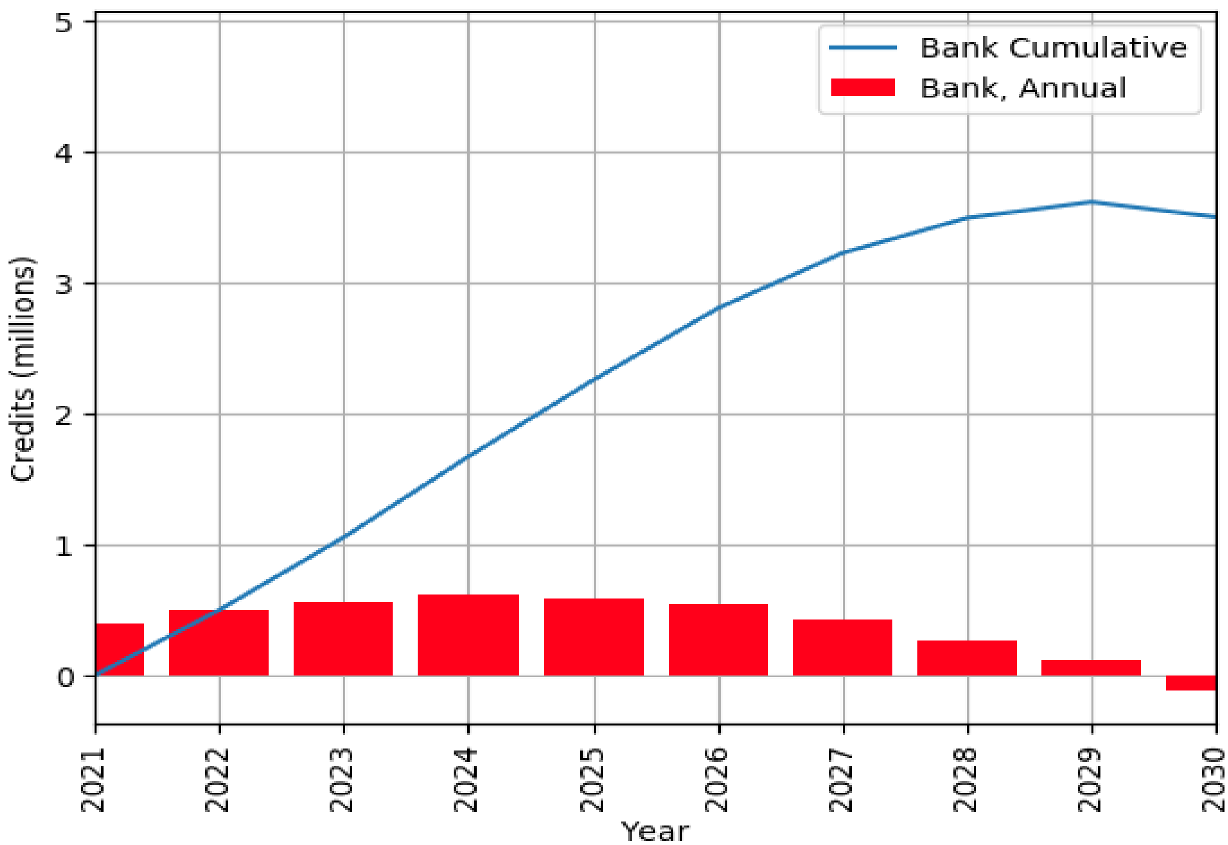
[53] Based on ICF analysis of data reported by CARB, available online at https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm.
[54] Based on ICF analysis of data reported by Oregon DEQ, available online at https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels-Data.aspx.
[55] More information on Minnesota's program can be found in Minnesota's Annual Report on Biodiesel in a Report to the Legislature, with the most recent version from January 2019, and available online at https://www.leg.state.mn.us/docs/2019/mandated/190634.pdf.
[56] Growth Energy, E15 Rapidly Moving Into the Marketplace, August 2019. Available as a fact sheet via Growth Energy at https://growthenergy.org/resources/newsroom/fact-sheets/.

Other than biofuel blends, the scenario includes reference case adoption trends consistent with those included in the Energy Information Administration's Annual Energy Outlook—including about a 15% adoption rate of light-duty EVs by 2030 in the passenger car segment (including BEVs and PHEVs).

**Balance of Deficits and Credits**

Figure 7 below shows the balance of deficits and credits in Scenario A. The red bars show the balance of credits on a year-over-year basis, whereas the blue line shows the bank of credits. As shown in the figure, the positive credits generated year-over-year through 2030 help to build a bank of credits. By 2030, when the program is most stringent, the available supply of low carbon fuels is about equal to the number of deficits generated via the sale of gasoline and diesel. And in that case, this leads to the leveling out of the cumulative bank of credits.

Figure 7. Balance of Credits and Deficits Generated in Scenario A

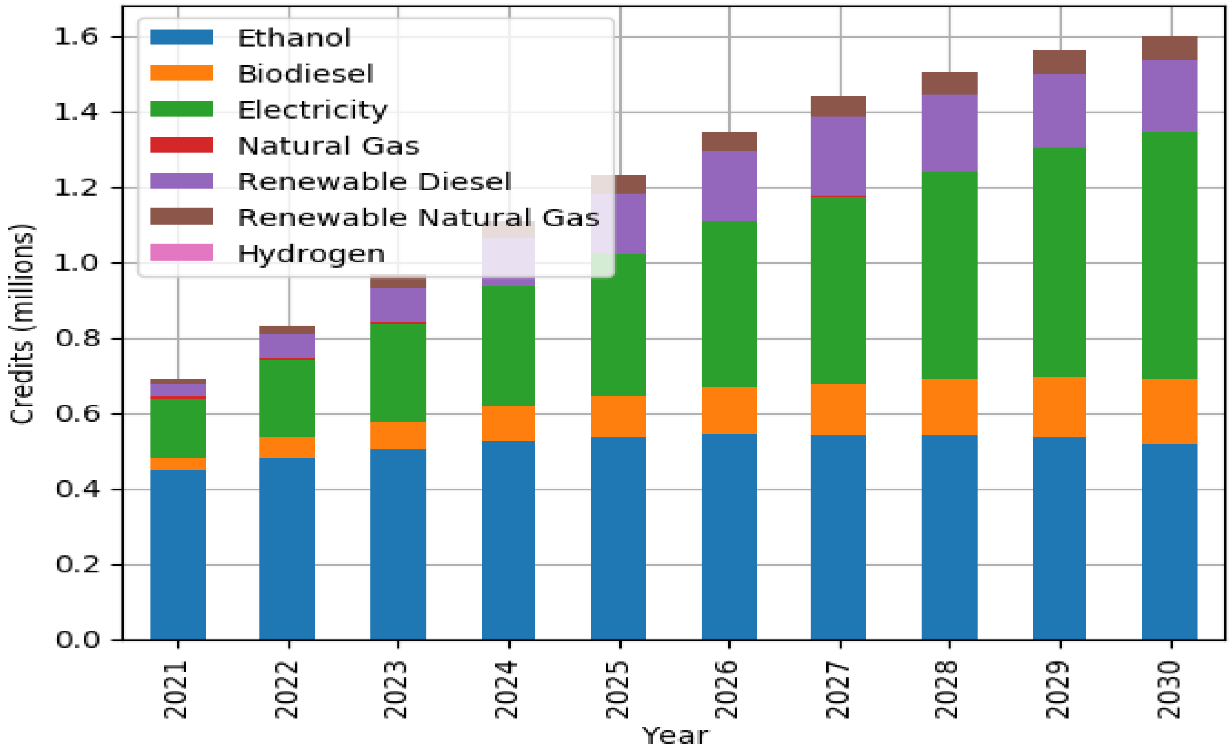



This type of banking activity is to be expected because of the way the program is structured—with a back-loaded compliance curve whereby regulated parties are given a pathway to identify a compliance strategy, and pursue it. The earlier years of the program enable regulated parties to bank credits for later years, and comply as the program becomes more stringent in later years.

**Contributions to Compliance**

Figure 8 below shows the relative contribution to compliance by various fuels—including ethanol, biodiesel, electricity, natural gas, renewable diesel, with the y-axis showing credits generated on a year-over-year basis from each fuel source, and the x-axis representing each year of the Puget Sound region's CFS.

Figure 8. Alternative Fuel Contributions to CFS Compliance in Scenario A




Scenario A is clearly reliant on the blending of biofuels, with ethanol, biodiesel, renewable diesel, and RNG accounting for 70% and 60% of the total credits in 2025 and 2030, respectively. Even though the focus is not on electrification, the decreasing carbon intensity of the electrical grid and the expected uptake of EVs in the Puget Sound region has a substantial impact on the program's compliance outlook.

## Scenario B: Aggressive Electrification

Scenario B is focused on modest increases to EV adoption in multiple market segments, but most notably in the light-duty vehicle market. The scenario still includes modest increases in biodiesel and renewable diesel blending to blending, up to 5% and 10% by 2030, respectively. ICF notes that these are effectively the rates of blending that California and Oregon have achieved in fewer years of the program—and that significant supply of both fuels is available. Furthermore, ICF assumed carbon intensity values of 58 g $CO_2e$/MJ and 48 g $CO_2e$/MJ for biodiesel and renewable diesel, respectively. ICF did not change the rate at which ethanol is being blended into gasoline in Scenario B, nor did we make any changes to the carbon intensity of ethanol over time.

In Scenario B, ICF used a more aggressive EV adoption curve, with EVs representing 25% of new passenger car sales in 2025 and 30% by 2030.[57] For reference, states that have adopted the ZEV program are expected to need to achieve new EV sales of roughly 12-20% of new passenger car sales by 2025 in order to achieve compliance.[58] ICF also increased the rate at which EVs were adopted into the light-duty truck market, representing about 8% of new sales by 2030. ICF also assumed that EVs made advancements in the medium- and heavy-duty market segments (Class 3 through Class 6 vehicles), with a focus on appropriate applications like urban delivery, vans, and other vocations. In these markets, we assumed that EVs would achieve 15% of new sales by 2030.

**Balance of Deficits and Credits**

Figure 9 below shows the balance of deficits and credits in Scenario B. The red bars show the balance of credits on a year-over-year basis, whereas the blue line shows the bank of credits. As shown in the figure, the positive credits generated year-over-year through 2030 help to build a bank of credits. By 2030, when the program is most stringent, the available supply of low carbon fuels is slightly less than the number of deficits generated via the sale of gasoline and diesel. And in that case, this leads to the leveling out of the cumulative bank of credits. Note that the bank of credits year-over-year (the blue line) is lower that compared to Scenario A. This highlights the difference between blending biofuels and electrification: biofuel blending takes advantage of the existing infrastructure, while electrification is dependent on fleet turnover, which is generally slower, but has a longer-term impact. Because the accumulation of credits in this scenario is lower in the earlier years, the balance of supply for credits and deficits is tighter in the last two years, 2029-2030, but the bank of credits is more than sufficient to ensure the 10% standard is met in 2030.

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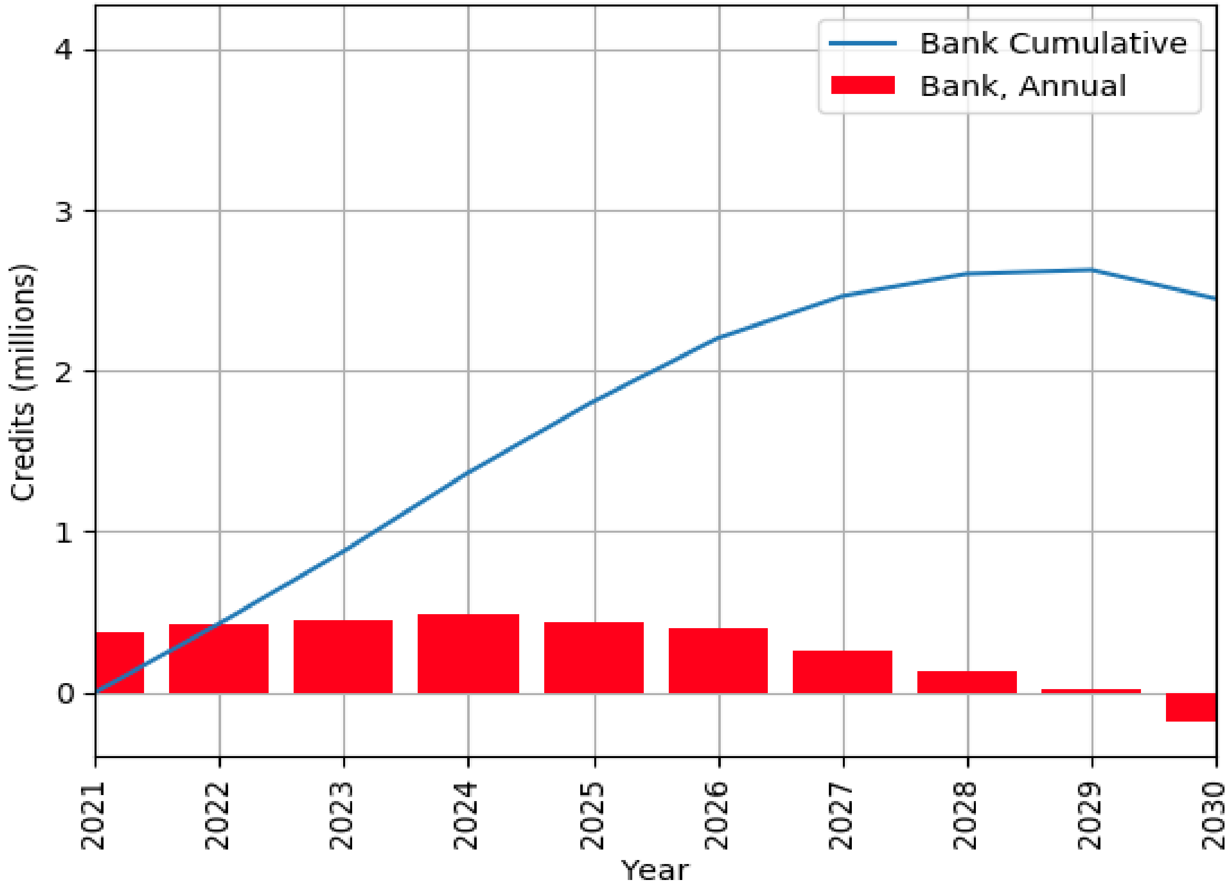
[57] ICF notes that the percentages presented here are for the share of *passenger cars* that are sold as EVs. The numbers presented previously (see Table 22) are for the percentage of total light-duty vehicles, which include passenger cars and light trucks.

[58] ZEV compliance is dependent on a variety of factors, including the range of the ZEV and the number of early compliance credits generated, travel provisions, and other nuanced aspect of the ZEV regulation. Therefore, it is difficult to determine with great specificity the likely ZEV compliance pathway for the automotive industry. The estimate presented here is based on ICF's view of information presented by CARB as part of the 2017 Midterm Review Report for the ZEV Regulation, available online at https://ww2.arb.ca.gov/resources/documents/2017-midterm-review-report. States that have adopted the ZEV program include Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont

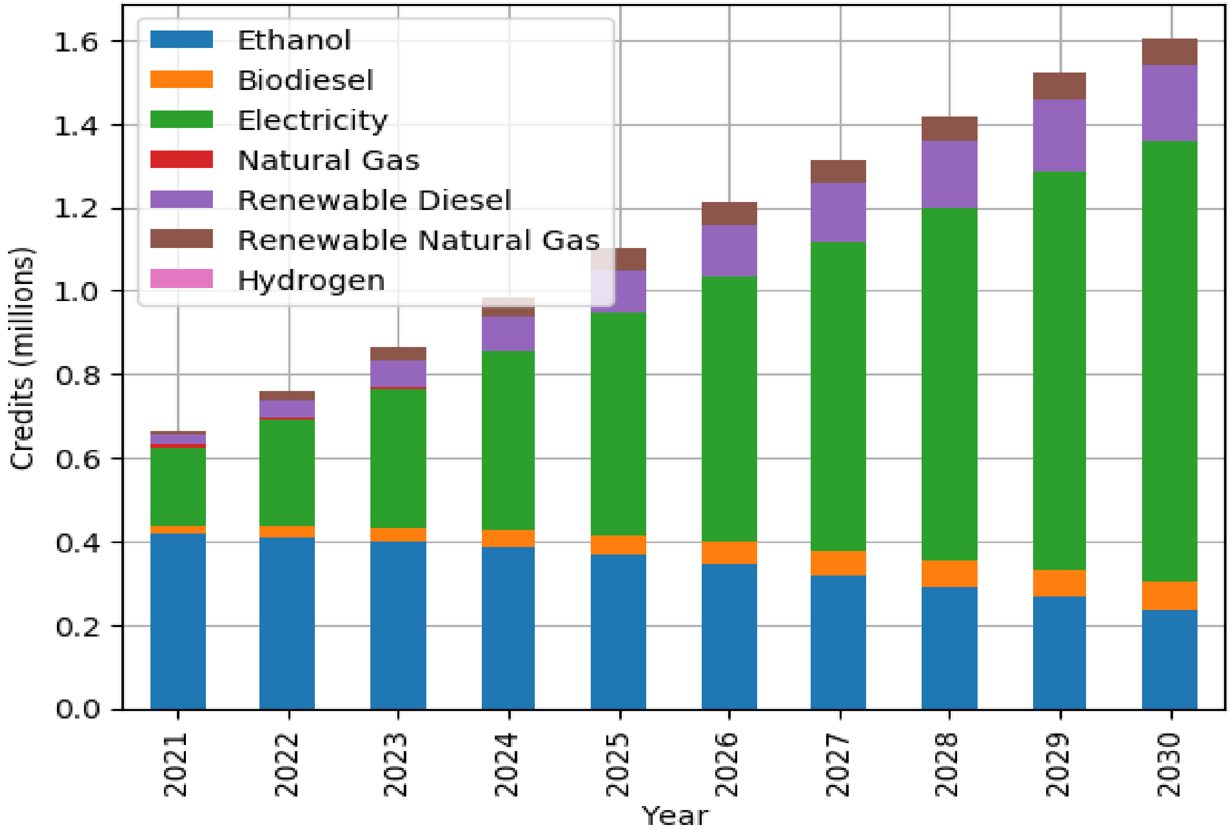
Figure 9. Balance of Credits and Deficits Generated in Scenario B




**Contributions to Compliance**

Figure 11 below shows the relative contribution to compliance by various fuels—including ethanol, biodiesel, electricity, natural gas, renewable natural gas, and renewable diesel.

Figure 10. Alternative Fuel Contributions to CFS Compliance in Scenario B




Scenario B is clearly reliant on electrification, with light- and MD/HD EVs accounting for 50% and 65% of the total credits by 2025 and 2030, respectively. The balance of the program is made up by increased blending of biofuels, with a focus on ethanol and renewable diesel, and to a lesser extent, biodiesel and RNG.

## Scenario C: Mixed Technology

Scenario C is referred to as Mixed Technology because it relies on multiple strategies, rather than just leaning towards biofuels or electrification. Furthermore, with more strategies in consideration, the stringency of the carbon intensity reduction requirement was increased to 16%. To achieve this level of carbon intensity reduction, ICF assumed that biodiesel and renewable diesel would be blended at rates of 20% and 15%, respectively by 2030. Although adequate supply exists, it will be challenging for the Puget Sound region to blend up to 20% biodiesel, given the limited retail fueling infrastructure. For instance, there is more than sufficient biodiesel production capacity at REG's Grays Harbor facility to provide enough biodiesel to the Puget Sound region to meet a 20% biodiesel blend—and this excludes the potential for imports via railcar from other locations. ICF assumed in this scenario that the CFS would provide the price signal to accommodate investment in retail infrastructure to blend higher volumes of biodiesel. With respect to renewable diesel, the California market serves as a useful example for the Puget

Sound region to demonstrate how a low carbon fuel policy can induce higher demand for the fuel with the right market signals in place—California blended renewable diesel at a rate higher than 10% in 2018.[59]

ICF assumed that the supply of biodiesel and renewable diesel would be shifted towards more waste products than assumed in Scenario A, with effective carbon intensity values of 33 and 44 g $CO_2$e/MJ for biodiesel and renewable diesel, respectively. ICF also introduced renewable jet fuel with a carbon intensity of 44 g $CO_2$e/MJ in 2025, increasing to a total volume of 25 million gallons by 2030. ICF also increased the rate at which ethanol is blended into gasoline to 15%, and lowered the carbon intensity of ethanol to 55 g $CO_2$e/MJ by 2030, a 24% reduction over 10 years.

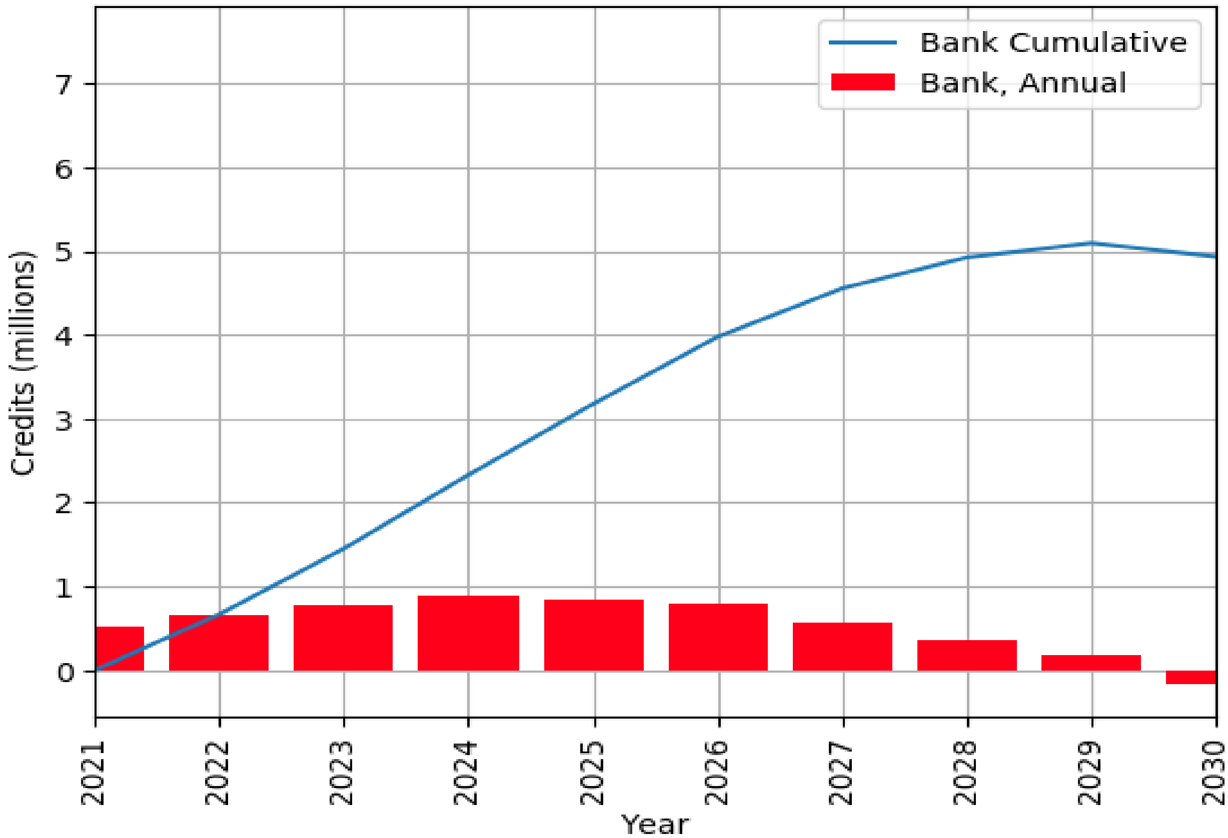
ICF used an EV adoption rate in Scenario C similar to Scenario B, with EVs representing 25% of new passenger car sales in 2025 and 35% by 2030. ICF also increased the rate at which EVs were adopted into the light-duty truck market, representing about 8% of new sales by 2030. ICF assumed that EVs made advancements in the MD/HD market (Class 3 through Class 6 vehicles), with a focus on appropriate applications like urban delivery, vans, and other vocations. In these markets, we assumed that EVs would achieve 15% of new sales by 2030.

**Balance of Deficits and Credits**

Figure 11 below shows the balance of deficits and credits in Scenario C. The red bars show the balance of credits on a year-over-year basis, whereas the blue line shows the bank of credits. As shown in the figure, the positive credits generated year-over-year through 2030 help to build a bank of credits. By 2030, when the program is most stringent, the available supply of low carbon fuels is effectively equivalent to the number of deficits generated via the sale of gasoline and diesel. And in that case, this leads to the leveling out of the cumulative bank of credits. Note the banking behavior included in this scenario is similar to Scenario A—the immediate increases in biofuel blending help to bolster the credit bank (the blue line) in earlier years, putting downward pressure on the supply of credits needed in later years to achieve compliance. This scenario highlights the benefits of strategic planning with regard to CFS compliance: Immediate action in biofuel blending can provide the runway needed to achieve compliance, while allowing electrification and natural gas vehicles, even at modest penetrations into the fleet, to help sustain compliance at more stringent levels in later years.

[59] Based on ICF analysis of data reported by CARB, available online at https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm.

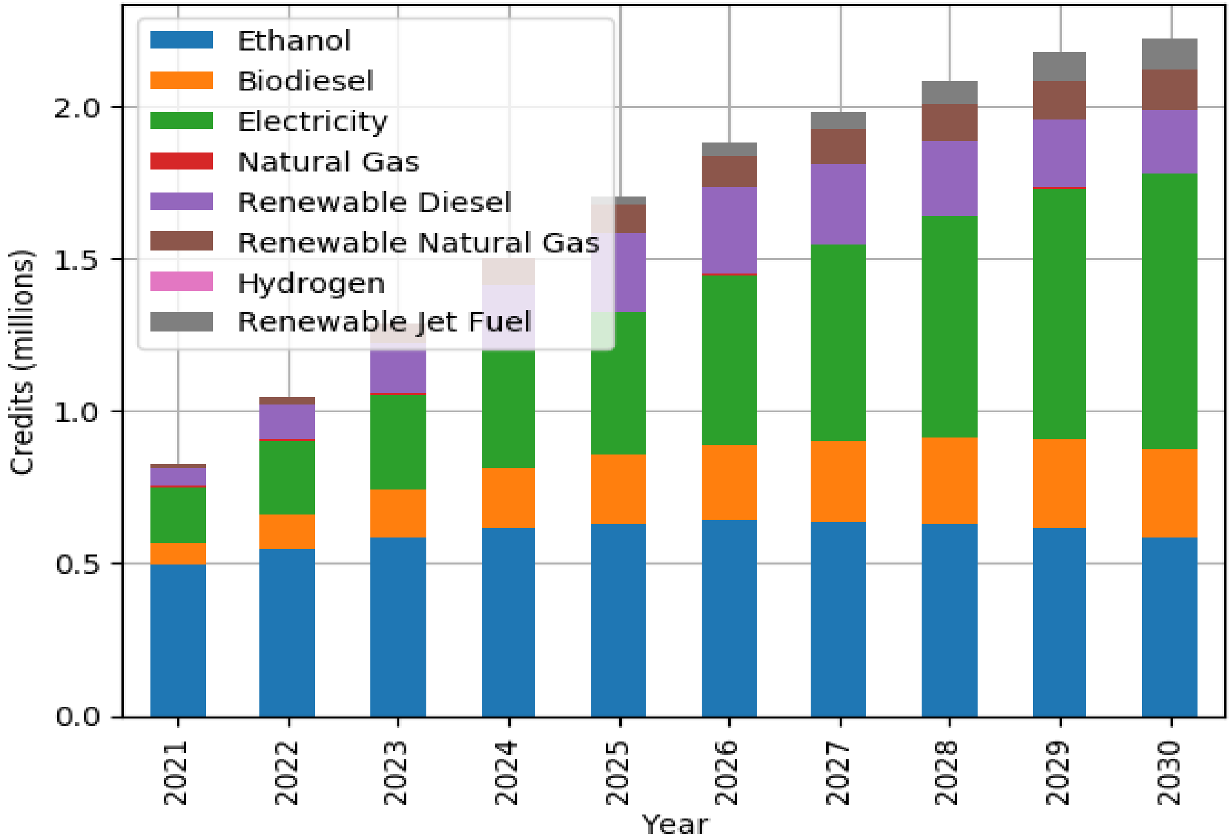
Figure 11. Balance of Credits and Deficits Generated in Scenario C




**Contributions to Compliance**

Figure 12 below shows the relative contribution to compliance by various fuels—note the more equitable distribution of compliance from different low carbon fuel strategies by 2030 compared to Scenario A or Scenario b: Although liquid biofuels account for two thirds of compliance in 2025, the adoption of EVs and decreasing carbon intensity of the grid helps to account for 50% of credits by 2030.

Figure 12. Alternative Fuel Contributions to CFS Compliance in Scenario C




Scenario C is less reliant on any single compliance strategy than the previous scenarios, and demonstrates that an integrated approach to CFS compliance in the Puget Sound region could yield a carbon intensity reduction of 16% by 2030.

## Scenario D: All-In, Maximum Feasible Reduction

Scenario D is designed to characterize the maximum feasible reduction on maximum carrying capacity for low carbon fuels in the Puget Sound region by 2030. It includes aggressive introductions of higher blends of liquid and gaseous biofuels, aggressive reductions in the carbon intensity of these biofuels, more rapid electrification in light-duty vehicles and heavy-duty vehicles (up to Class 6), higher rates of natural gas vehicle penetration in heavy-duty applications (with vehicles using RNG), increased fuel cell vehicle adoption, refinery measures (including efficiency and renewable hydrogen), and renewable jet fuel. ICF incorporated the following assumptions into Scenario D:

- Ethanol: 15% blend of ethanol by 2026, with the carbon intensity of ethanol decreasing to 56 g $CO_2e$/MJ by 2030.
- Biodiesel: 20% blend rate of biodiesel by 2028 with an effective carbon intensity of 26 g $CO_2e$/MJ by 2030, effectively excluding any virgin oil-based biodiesel into the market.
- Renewable diesel: 20% blend rate of renewable diesel by 2028 with an effective carbon intensity of 32 g $CO_2e$/MJ.
- Renewable jet: 50 million gallons of renewable jet fuel by 2028.

- EVs, passenger cars: 28% new sales for EVs in passenger car market by 2025 and 42% by 2030
- Fuel cell vehicles: 5% of new sales in passenger car market and light-duty truck market by 2030
- EVs, Class 3-6: 10% new sales by 2030
- Natural gas vehicles: 7% of new sales in Class 7-8 single unit market by 2030
- RNG: 100% RNG blend by 2023, with 70% of the RNG coming from diary digesters and an overall effective carbon intensity of -180 g $CO_2$e/MJ.
- Refinery improvements: 15% refinery efficiency upgrades and 25% renewable hydrogen displacement

**Balance of Deficits and Credits**

Figure 13 below shows the balance of deficits and credits in Scenario D. The red bars show the balance of credits on a year-over-year basis, whereas the blue line shows the bank of credits. The 26% carbon intensity reduction target in 2030 makes for a very tight program. There is no year in which credit generation exceeds 500,000; furthermore, the program runs small annual deficits in 2029 and 2030, despite the aggressive introduction of lower-carbon fuels. ICF's modeling indicates that these deficits can be more than offset by previously banked credits.

Figure 13. Balance of Credits and Deficits Generated in Scenario D with a 26% CI standard

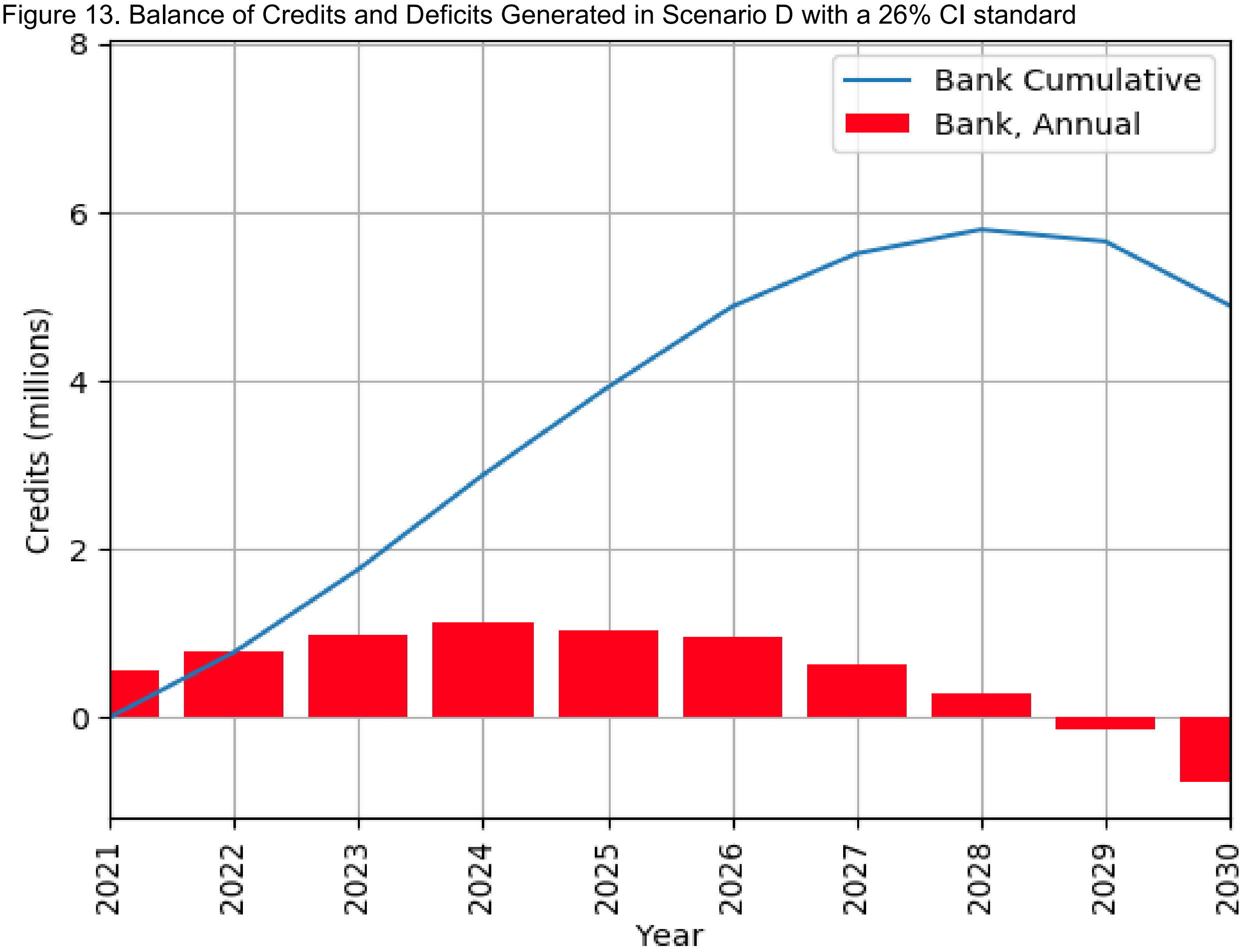
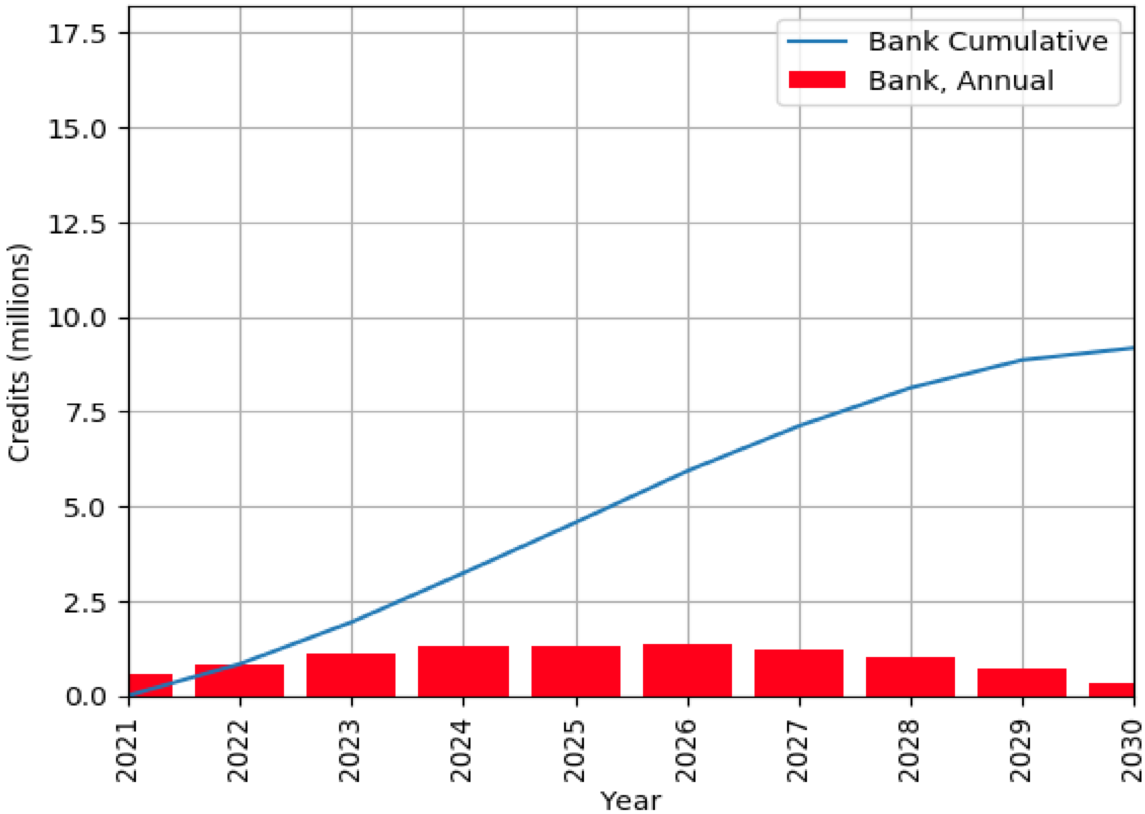


Figure 14 below shows the same scenario as Figure 13 above, but with the carbon intensity reduction target in 2030 reduced from 26% to 20%. This illustrates how even a modest change in the carbon intensity reduction target in 2030 can have a significant impact on the evolution of banked credits and how that impacts compliance. Instead of the program showing an annual deficit starting in 2029, the program remains net credit generating, and builds a bank of about 9 million credits.

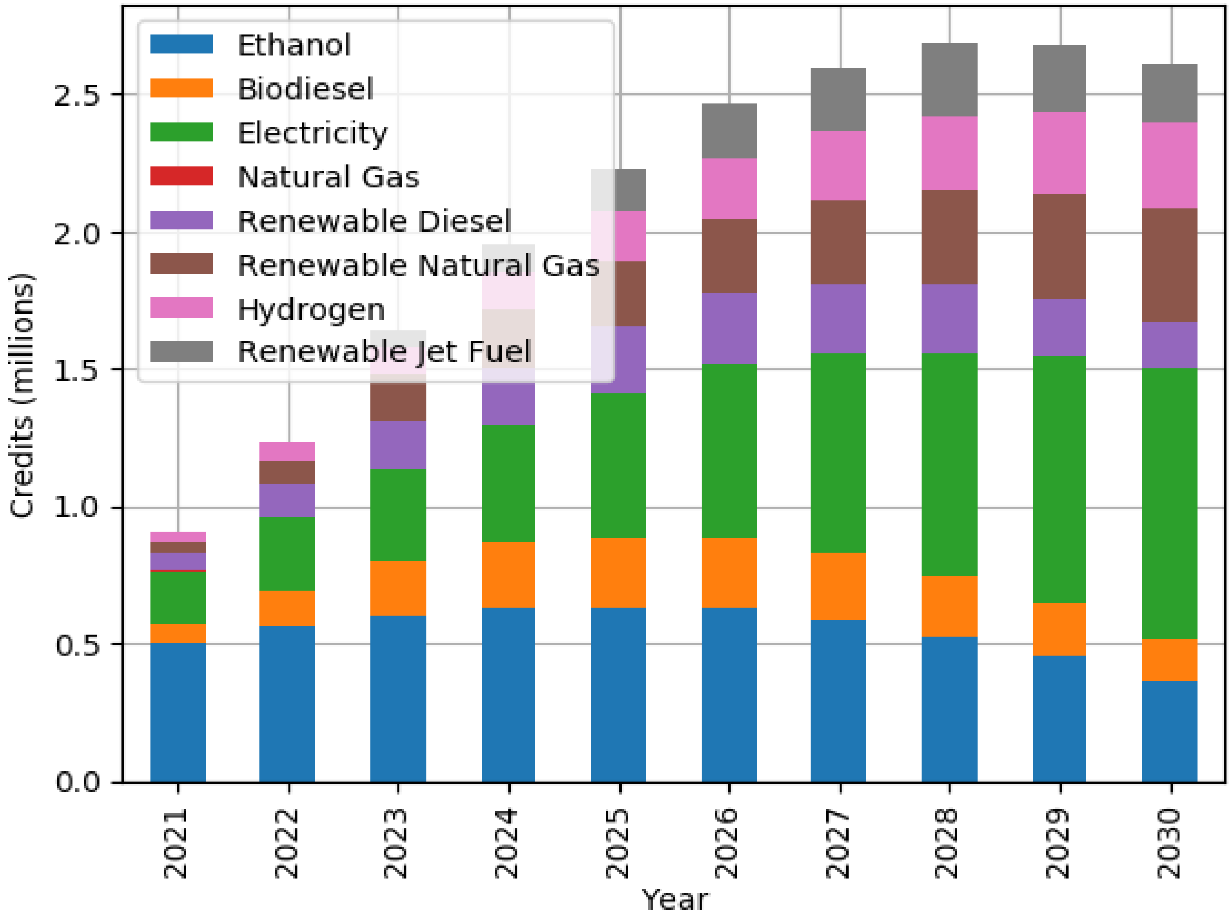
Figure 14. Balance of Credits and Deficits Generated in Scenario D with a 20% CI standard




**Contributions to Compliance**

Figure 15 below shows the relative contribution to compliance by various fuels—note the more evenly-balanced distribution of compliance strategies by 2030 compared to other scenarios, as is expected given the focus on all strategies for Scenario D.

Figure 15. Alternative Fuel Contributions to CFS Compliance in Scenario D with a 26% CI standard



# 4. Economic Impacts of Low Carbon Fuel Deployment

The scenarios outlined in Section 3 will require varying levels of financial investment in alternative fuel production, fueling infrastructure (including delivery and fueling stations), and alternative fuel vehicles. These investments have the potential to drive changes in the Puget Sound region's economy as lower-carbon fuels enter the market. The following sub-sections outline the costs required to bring the alternative fuels to the market for each compliance scenario and the associated macroeconomic impacts of these investments.

## Introduction to REMI Modeling

ICF employed the REMI E3+ Model[60] to measure the wider macroeconomic impacts of the compliance scenarios developed in this study. The REMI model is a well-established, peer reviewed structural economic modeling, forecasting, and policy analysis tool that has been used by numerous national, regional, state, and city governments, as well as universities, nonprofit organizations, public utilities, and private consulting firms since 1980.

The REMI model consists of thousands of simultaneous equations that represent fundamental relationships between key economic and social variables and yield response estimates. The model also contains a five-block structure that represents the entire macro-economy: 1) Output and Demand, 2) Labor and Capital Demand, 3) Population and Labor Supply, 4) Compensation, Prices, and Costs and, 5) Market Shares. REMI is particularly well suited for analyzing the secondary impacts in this study.

The REMI model is capable of producing results on a year-by-year basis throughout the 10 year modeling timeframe in this study. This dynamism is critical to help understand how the various compliance scenarios will have different impacts over time. In addition to being a dynamic modeling framework, another advantage of the REMI model is that it is able to assess distributional impacts. In this case, outputs were reported for various regions. This granularity was particularly useful for this study because it allowed for the analysis of how policies could affect the Puget Sound region. And lastly, the model is flexible enough that it can provide a wide variety of output options for a range of policy scenarios.

In this study, REMI was used to model the macroeconomic and distributional impacts of compliance with a Puget Sound region CFS on different sectors and regions. The model was used to conduct second-stage analysis, using outputs from ICF's analysis of expenditures required to achieve compliance as inputs, which provided projections of the distributional impacts of the compliance scenarios being analyzed. The REMI model provided the ability to forecast impacts over time, across industry sectors, and among regions. In this study, the analysis modeled impacts through 2030 and for five regions: Snohomish County, King County, Pierce County, Kitsap County, and the Rest of Washington.

REMI can produce a wide variety of economic and demographic outputs. Some of the outputs that can be evaluated include overall employment levels, employment by industry sector, value

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[60] See https://www.remi.com/ and http://www.remi.com/wp-content/uploads/2017/10/Model-Equations-v2_1.pdf

added output, output by sector, changes in income, and population or demographic shifts. In this study, the analysis focused on analyzing the impacts to employment and value added output.

Model inputs for each compliance scenario modeled included expenditures for fuel production, distribution infrastructure (including transportation, storage, and retail infrastructure), vehicles, and fuel pricing. These expenditures and investments are discussed in more detail in the next sub-section.

# Investments Required to Achieve Compliance

## Introduction to Investments and Costs Considered

The REMI model is designed to determine the change in macroeconomic activity through parameters such as gross state product and jobs. ICF developed estimates for the investments that would be required to achieve the compliance scenarios outlined in Section 3. ICF considered three broad types of expenditures noted below, with a brief description of the methodology employed to incorporate the costs into the REMI model.

**Fuel production / upstream expenditures**
Many of the alternative fuels included in the compliance scenarios will require investments in low-carbon fuel production, primarily associated with decreasing the carbon intensity profile of alternative fuels. For the most part, ICF assumed that there was already sufficient fuel production capacity, attributable in part to other programs—including the federal Renewable Fuel Standard, California's Low Carbon Fuel Standard, and Oregon's Clean Fuels Program—to comply with the scenarios developed for this analysis. However, we did model the investments that would be required to achieve the carbon intensity reductions assumed in the compliance scenario modeling—specifically for ethanol. Fuel production costs were modeled as a change in exogenous final demand for those industries involved with the fuel production.

**Distribution infrastructure expenditures**
The compliance scenarios include drop-in fuels that are compatible with existing distribution infrastructure, such as renewable diesel and low-level blends of biodiesel, as well as other fuels that require dedicated infrastructure, with a focus on the retail infrastructure space.

Distribution infrastructure costs were modeled as an increase in exogenous final demand for industries involved in equipment manufacturing or building new infrastructure. For specific equipment that was found to be produced primarily outside Washington (i.e., components required for CNG station construction), the increase in exogenous demand was modeled as occurring outside of the regions of interest. Otherwise, the increase in exogenous demand was modeled as occurring in Washington, and the REMI model determines the region of production.

**Vehicle expenditures**
In the case of electricity, hydrogen, and natural gas, new light- and heavy-duty vehicles will need to be purchased to achieve the levels of fuel consumption included in the compliance scenarios. Vehicle expenditures were modeled as a change in exogenous demand for Motor Vehicles, Bodies, and Trailers, and Parts Manufacturing—a sector in the REMI model.

The following subsections provide an overview of the expenditures, broken down by fuel.

## Cost Assumptions

ICF sought to identify reliable and credible estimates for each of the variables and parameters described in the following sub-sections included as an input into the economic modeling. Where there is limited publicly available information regarding costs, ICF relied on best professional judgement and personal communications with industry stakeholders to develop cost assumptions. When there is a broad range of cost estimates in the literature, like for forecasted alternative fuel vehicle pricing, ICF used what we considered more moderate or conservative price and costing assumptions.

### Ethanol

ICF considered fuel production, refueling infrastructure, and fuel pricing expenditures for ethanol consumed as E10 or E15 in the compliance scenarios. No vehicle expenditures were considered because E10 is already consumed in vehicles today and E15 was only assumed to be consumed by approved vehicles (i.e., model year (MY) 2001+).

#### Fuel production

Although the CFS will likely be a driver for lower-carbon ethanol in the Puget Sound region, it is difficult to make the case that the proposed program will be the primary or strongest driver for lower-carbon ethanol production because there is considerably higher demand in California for this product as a result of the LCFS, with similar demand developing in Oregon as a result of the CFP. This makes it challenging to estimate the investments attributable to the proposed low-carbon fuel standard program for an impact assessment.

ICF limited our consideration of fuel production costs from reducing the carbon intensity of ethanol through upstream reductions (i.e., at the farm) and improvements at biorefineries. The primary supply side driver for ethanol production in the United States is and will remain the Renewable Fuel Standard at the federal level. However, ICF attributed the costs of lower-carbon ethanol production that is consumed in the Puget Sound region to the proposed CFS program for the purposes of this analysis. The proposed CFS will provide additional revenue for lower-carbon ethanol producers through credits.

As noted in the compliance scenarios, ICF assumed that the premium on lower carbon intensity ethanol (sugarcane or cellulosic ethanol) would lead to an increased consumption of conventional low CI ethanol (Midwest corn or sorghum). ICF assumed that to achieve a lower carbon intensity for conventional ethanol production, facilities would seek to reduce energy consumption in their operations, increase ethanol yields through process improvements, and switch feedstocks (e.g., to sorghum). ICF assumed that facilities could improve their carbon intensity on average by about 20 percent to achieve the low CI ethanol included in the compliance scenarios. Based on ICF research and stakeholder outreach, we estimate capital investments of $3–$5 million for every 2–4 percent improvement in carbon intensity.

#### Distribution infrastructure

Investments in refueling infrastructure for ethanol in the compliance scenarios were limited to expanded E15 infrastructure. In the case of E15, there are two potential infrastructure investments at fueling stations: fuel dispensers and underground storage tank (UST) upgrades. Compatibility standards and regulations for USTs have not been established for E15. ICF used the infrastructure cost estimates in Table 23.[61]

Table 23. E15 Retail Station Component Costs

| Component(s) | Description | Median Price Reported |
|---|---|---|
| Signage / labeling only | All other components – UST, dispensers, and hanging hardware are compatible | $1,000 |
| UST | One E15 UST system w/ one secondarily contained UST system of similar size | $115,000 per UST |
| Retrofit kit for dispenser, hanging hardware | 2-10 dispensers at typical station | $3,800 per dispenser |
| Retrofit kit for dispenser, no hanging hardware | 2-10 dispensers at typical station | $3,250 per dispenser |
| New dispensers, hanging hardware | | $18,420 per dispenser |
| Stand-alone dispenser | Assumed existing compatible tank | $30,000 |
| New station, virgin land, incremental E15 cost | Cost is increment compared to new E10 station | $10-12,000 per dispenser |
| Source: Adjusted from numbers reported by PEI[61] | | |

There are not reliable data available regarding the number of USTs in the Puget Sound region that are compatible with E15. ICF assumed conservatively that 50% of USTs would need to be replaced; however, we assume that two 10,000 gallon tanks would be replaced with a single 20,000 gallon tank. ICF assumed that 45% of dispenser upgrades would occur with retrofit kits and 45% would require new dispensers and that 10% of new dispensers would be stand-alone equipment.

**Biodiesel**

ICF considered fuel production and fuel pricing expenditures for biodiesel consumed in the compliance scenarios. ICF considered storage infrastructure for biodiesel, however, we limited our fueling infrastructure cost considerations to B20 blends. Although biodiesel is and can be dispensed as B100, ICF only considered blends of B5 and B20 for the purposes of this analysis—B5 is sold in the market as equivalent to conventional diesel, and requires no changes to infrastructure, whereas B20 blends typically represent the upper limit of most engine manufacturer warranties, and B20 blender pumps are deployed in other markets. No vehicle

[61] Scenarios to Determine Approximate Cost for E15 Station Readiness, September 2013. Available online at: http://www.pei.org/portals/0/resources/documents/USDA-letter-e15.pdf

expenditures were considered for biodiesel, with the assumption that the number of OEMs that currently warranty B20 use in engines is sufficient to sustain the projected biodiesel consumption.

### Fuel production

ICF assumed that by 2030 as much as 50 million gallons of biodiesel consumed in the compliance scenarios would be produced in or near the Puget Sound region, effectively half of the statewide production capacity today. Although there is significant import potential for biodiesel, research in other markets that have supply- and demand-side drivers for biodiesel indicates that local and regional production tends to increase investments in production facilities. In other words, despite there being excess capacity in other parts of the US that could be imported into Washington and the Puget Sound region to achieve the volumes assumed in the compliance scenarios, it is likely that regionally produced biodiesel production will satisfy the demand locally.

### Distribution infrastructure

ICF considered refueling facilities for biodiesel as part of the distribution infrastructure expenditures. ICF assumed that there was sufficient terminal storage capacity for biodiesel in the Puget Sound region. As the market for biodiesel expands, modifications will have to be made to the refueling infrastructure to accommodate higher blends of biodiesel, i.e., B20. In each scenario, ICF assumed that the market would achieve a B5 blend rate, which does not require any distribution infrastructure investments, before deploying the capital required to satisfy assumed demand for B20.

According to the U.S. Department of Energy's Alternative Fuels Data Center, there are five publicly accessible stations and 26 private stations that currently provide B20 to consumers in the Puget Sound region.[62] ICF assumed a throughput at B20 stations of 350,000 gallons per year per pump, which is equivalent to 70,000 gallons of biodiesel throughput per year per pump.

ICF used the following estimates for the retrofits to existing diesel fuel pumps and the addition of new biodiesel fueling islands:

- For retrofits at existing stations, we assume a cost of $70,000 to $100,000 per station.
- For new stations, we assume a cost $200,000 per station.

We assumed that 90 percent of B20 stations would be conversions and the remaining 10 percent would be new stations.

## Renewable Diesel

ICF assumed that the announced capacity expansions of renewable diesel production would yield sufficient capacity to satisfy the demand assumed in our compliance scenarios. The scenario modeling assumes a maximum demand of about 60 million gallons per year of renewable diesel. This is small compared to the announced capacity expansion and new capacity build projects—including BP's co-processing of biomass at its Cherry Point refinery in Washington, the partnership between REG and Phillips 66 planned for construction adjacent to the Ferndale refinery in Washington, the NEXT biofuels facility in Oregon (~600 million gallons per year), the

[62] National Renewable Energy Laboratory (NREL) Alternative Fuel Station Locator Database. Accessed 8/15/2019. Available at: https://afdc.energy.gov/stations#/find/nearest

Diamond Green expansion in Norco, Louisiana (to ~675 million gallons per year), the Neste facility expansion in Singapore (to ~700 million gallons per year), Marathon's conversion of an existing refinery to produce renewable diesel in North Dakota (~180 million gallons per year), and the planned construction of two renewable diesel facilities by Ryze Renewables in Nevada (combined capacity of ~150 million gallons per year).

### Natural Gas and Renewable Natural Gas

The compliance scenarios only included modest expansion of natural gas as a vehicle fuel in the Puget Sound region—ICF assumed that there is sufficient distribution infrastructure to satisfy the maximum 10-15 million diesel gallon equivalents included in the scenario modeling. The Alternative Fueling Station Locator[63] indicates that there are three (3) public CNG stations in the Puget Sound region and another nine (9) privately accessible stations (typically open to fleet customers, such as waste management fleets). It is conceivable that a small amount of additional retail infrastructure would have to be deployed, but this would only be a small investment, as shown in Table 24 below.

Table 24. Estimated Natural Gas Fueling Station Costs

| Fuel | Capacity | Reported Range | Estimated Cost |
|---|---|---|---|
| CNG | 1.25 million dge, 80% capacity | $675,000 – $3 million depends on variety of factors: slow or fast fill time, virgin land, size of facility, etc. | $2.00 million |

Most facilities with existing biogas capture capabilities are currently sending the fuel to California or Oregon, given the opportunity to claim credits under both the federal Renewable Fuel Standard and the state low-carbon fuel program. ICF analysis of existing and planned projects indicate that about 65-70% of the RNG consumed in the transportation sector is consumed in California and Oregon—and the available supply is growing rapidly. As a result, ICF assumed that there is sufficient RNG production capacity to fulfill the modest 5-15 million DGE of demand in the Puget Sound region.

#### Vehicles

Natural gas vehicles are more expensive than their diesel counterparts primarily because of the additional cost associated with fuel storage. Other components that increase the cost of natural gas vehicles include the additional components (e.g., methane detection, engineering) and the natural gas engine. For the purposes of this analysis, ICF used the incremental costs for CNG vehicles outlined in Table 25 below.

[63] National Renewable Energy Laboratory (NREL) Alternative Fuel Station Locator Database. Accessed 8/15/2019. Available at: https://afdc.energy.gov/stations#/find/nearest

Table 25. Incremental Vehicle Pricing for Natural Gas Vehicles

| Vehicle Type | Fuel | Incremental Vehicle Price | |
|---|---|---|---|
| | | Range Reported | Value for ICF Study |
| Medium-duty, Class 3 | CNG | $9,750–$37,500 | $12,500 |
| Medium Heavy-duty, Class 4-6 | CNG | $30,000–$70,000 | $35,000 |
| Heavy Heavy-duty, Class 7-8 | CNG | $45,000–$90,000 | $60,000 |

The values selected for this study were based on the vehicle classes and applications that are most likely to adopt natural gas vehicles. These vehicle classes and applications were selected based on ICF's market research–including consideration of vehicle miles traveled by application and vehicle sales in each segment.

**Electricity**

ICF considered distribution infrastructure, vehicle, and fuel pricing expenditures for electricity consumed in plug-in electric vehicles for the compliance scenarios.

### Distribution infrastructure

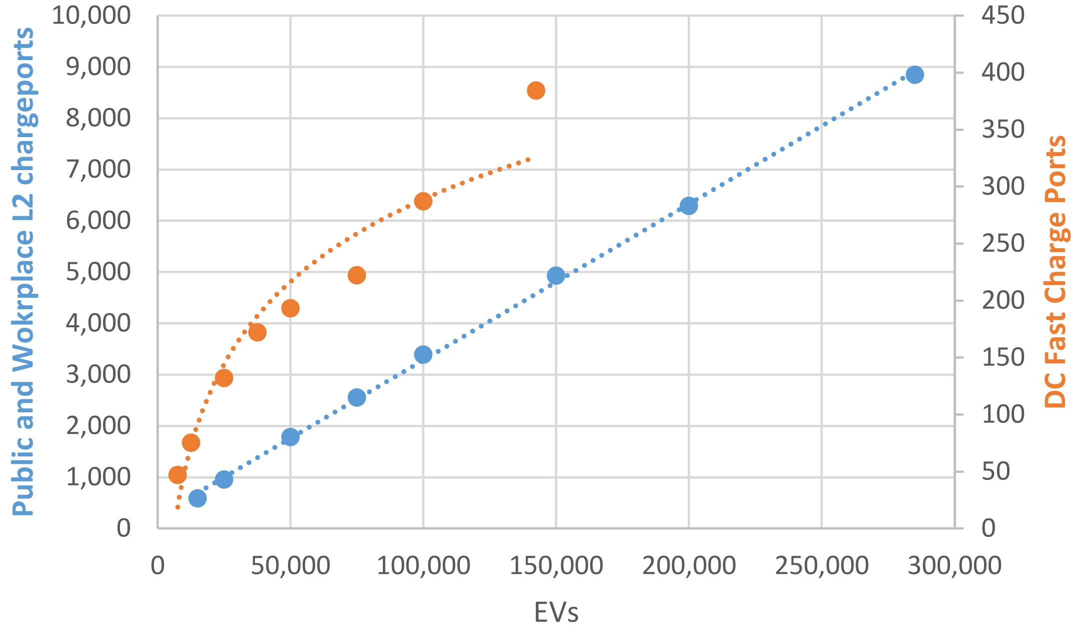
ICF assumed that EV charging infrastructure would have to be deployed to support EVs in the Puget Sound region. We developed assumptions for residential charging and non-residential charging. The former includes Level 2 EV charging infrastructure installations whereas the latter includes Level 2 and DC fast charging (DCFC) installations (for BEVs).

For residential charging, ICF assumed that 50% of EV drivers would install Level 2 charging infrastructure at their homes, with an estimated installed cost of $1,250.

ICF used the EVI-Pro Lite[64] Tool to estimate the amount of EV charging infrastructure that would be required to support anticipated levels of EV deployment. Figure 16 below shows the amount of EV charging infrastructure that is estimated for the EVI-Pro Lite Tool in the Puget Sound region under different EV penetration rates—including Level 2 charging infrastructure (reported as charge ports) at public locations and workplaces, as well as DC fast charging requirements.

[64] Available online at https://afdc.energy.gov/evi-pro-lite.

Figure 16. EV Deployment vs Demand for Charge Ports: ICF Analysis of EVI-Pro Lite Tool Outputs for Puget Sound Region




The blue line (corresponding to the left y-axis) shows the assumed rate of Level 2 charge port adoption as a function of total EVs deployed (shown as total EVs divided by 25,000). The orange line (corresponding to the right y-axis) shows the total DC fast charge ports required to support increased BEV adoption (show as total BEVs divided by 50,000). ICF used a best fit function to characterize the relationship between charging infrastructure and EVs deployed to estimate the amount of Level 2 non-residential charging infrastructure and DC fast charging infrastructure that would be required in each scenario.

ICF assumed a non-residential L2 charging infrastructure cost of $14,500 for a dual port EVSE. The Level 2 charging infrastructure costs were estimated based on ICF research of existing installations, including a report from the DOE[65] and similar installations in other jurisdictions.[66] ICF assumed that DC fast charging infrastructure costs would be about $75,000, consistent with estimates from the DOE[67] and used in other analyses.[68]

For medium- and heavy-duty vehicles, ICF assumed that DC fast charging infrastructure would cost about $225,000 per EVSE and that each EVSE would service 6-10 trucks.

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[65] Costs Associated with Non-Residential Electric Vehicle Supply Equipment, Department of Energy, November 2015. Accessed online via https://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf.
[66] For instance, NYSERDA reports that the average Level 2 EVSE installation ranged from $1,554 to $25,785 with an average cost of $7,435 per station. See Roy, B et al, New York State EV Charging Station Deployment, EVS29 Symposium, June 2016. Accessed online via http://www.mdpi.com/2032-6653/8/4/877/pdf.
[67] Costs Associated with Non-Residential Electric Vehicle Supply Equipment, Department of Energy, November 2015. Accessed online via https://www.afdc.energy.gov/uploads/publication/evse_cost_report_2015.pdf.
[68] For example, Benefit-Cost Analysis of Electric Vehicle Deployment in New York State, 2019. Available online at https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Transportation/19-07-Benefit-Cost-Analysis-EV-Deployment-NYS.pdf.

### Light-duty Vehicles

Electric vehicles currently have a higher purchase price than their internal combustion engine (ICE) vehicle counterparts, although their operational and maintenance costs are lower. The primary reason that EVs have a higher purchase price than conventional vehicles is due to the cost of the battery, with the cost of the drivetrain also influencing the price to a lesser extent. ICF used projections for future EV pricing, consistent with those used in a recent study for NYSERDA.[69] ICF's estimates were developed for a PHEV with 50 miles of all-electric range and a BEV with 200 miles of range. ICF's assumptions yielded battery sizes of 16 kWh for the PHEV and 65 kWh for the BEV, using an efficiency of about 0.275 kWh per mile for the vehicle, 90% depth of discharge, and 5% degradation of the battery over the life of the vehicle. Table 26 illustrates the assumed incremental EV pricing used in this analysis, which takes into account both battery and drivetrain costs. Incremental pricing reflects how much more a PHEV or BEV is expected to cost than a comparable vehicle with an internal combustion engine only.

Like other parameters considered in the economic modeling, there are a range of EV price projections in the literature. For instance, Bloomberg New Energy Finance (BNEF) publishes an annual EV Outlook—in 2017, BNEF reported that price parity between internal combustion engine vehicles and battery electric vehicles would occur in 2026, and then in 2018 reported that it could be achieved as early as 2024. Most recently, BNEF has asserted that by 2022, large electric vehicles in Europe will reach price parity with their conventional counterparts, with parity reached in other markets and other vehicle classes in the mid to late 2020s.[70] Conversely, the EIA reports incremental EV pricing of $13,100 for a midsize BEV with a 200-mile range compared to a similar internal combustion engine vehicle in 2030. EIA reports similar incremental pricing across multiple vehicle segments.[71] In other words, while some estimates are showing price parity within five years, others are showing persistently higher pricing. Clearly, this range of incremental EV pricing in the literature presents a challenge to analysts, especially when considering aggressive electrification pathways in a scenario analysis, with the upfront and incremental price of the vehicle having a significant impact on the results. As noted previously, ICF sought to identify reliable and credible estimates for each variable included as an input into the economic modeling, and we generally err on the side of more moderate or conservative pricing projections across the board. ICF used the incremental EV purchase price projections shown in Table 26. ICF did not include consideration of tax credits or other incentives, meaning that the prices shown might be higher than what consumers would actually pay out-of-pocket.

Table 26. Assumed Incremental EV Purchase Pricing in LD BEV and PHEVs. ($2019)

| Vehicle Segment | 2021 | 2025 | 2030 |
|---|---|---|---|
| LDV, BEV | $6,950 | $4,650 | $2,000 |
| LDV, PHEV | $7,150 | $4,500 | $1,200 |

[69] Ibid.
[70] Bullard, N, Bloomberg Opinion, Electric Car Price Tag Shrinks Along With Battery Cost, April 2019, available online at https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost
[71] EIA, AEO2019 National Energy Modeling System, Table of New Light-Duty Vehicle Prices, available online at https://www.eia.gov/outlooks/aeo/data/browser/#/?id=114-AEO2019&cases=ref2019&sourcekey=0.

ICF applied these vehicle price premiums to light-duty vehicles out to 2030 based on the EV sales estimated in our compliance scenarios.

### Medium- and Heavy-Duty Vehicles

ICF included medium-duty (MD) and heavy-duty segments (HD) of the market for EV deployment. Although there are limited EV offerings in the Class 3-6 market segments today, these market segments will likely have multiple market entries over the next 2-5 years, especially as battery prices are expected to fall. Urban delivery use of medium-duty EVs will be particularly attractive in the near-term future, as they offer stable and fixed routes between 50 and 100 miles per day, and because vehicles tend to return to the same location. Table 27 below includes ICF's assumed EV price trajectory for vehicles in the various market segments.[72] This analysis did not include Class 7-8 electric trucks, for which the market is less mature and for which there are fewer projections of future price trends. Such uncertainty would make the inclusion of these vehicles classes in the modeling speculative. Nonetheless, there are some forecasts that these segments should see substantial reductions in marginal cost through 2030 and some heavy duty vehicles are currently being tested and deployed.[73]

Table 27. Assumed Incremental EV Purchase Pricing in Medium- and Heavy-Duty Sectors ($2019)

| Vehicle Segment | 2025 | 2030 |
|---|---|---|
| Light-medium (Class 2b-3) | $22,600 | $17,600 |
| Medium (Class 4-6) | $74,200 | $58,000 |

**Hydrogen**

Fuel cell vehicles (FCVs) use electricity to power the wheels, however, rather than using electrical energy from a battery, the energy is produced using a fuel cell powered by hydrogen. Hydrogen fuel cell vehicles are more expensive than their ICE vehicle counterparts, and require new retail fuel distribution infrastructure.

### Distribution infrastructure

ICF assumed that hydrogen refueling infrastructure would have to be deployed to support FCVs in Puget Sound region. ICF assumed that each station would cost approximately $2.0-3.2 million with a capacity to deliver about 120-350 kilograms per day of hydrogen.[74]

### Light-duty vehicles

The primary reason that FCVs have a higher purchase price than conventional vehicles is because of the fuel cell and the corresponding components. ICF used pricing consistent with the EIA's Annual Energy Outlook for light-duty cars and trucks, as summarized in Table 28 below.

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[72] These numbers are consistent with those used in a forthcoming ICF report prepared for the California Electric Transportation Coalition regarding the potential for medium- and heavy-duty vehicle electrification.
[73] For example, Freightliner announced 2021 production of its electric semi, with a 250 mile range and 80% recharge in 90 minutes. https://freightliner.com/e-mobility/.
[74] Based on information reported by the California Fuel Cell Partnership online at https://h2stationmaps.com/costs-and-financing.

Table 28. Incremental Hydrogen FCV Pricing

| Light-duty vehicles | 2025 | 2030 |
|---|---|---|
| Passenger cars & Light Trucks | $23,200 | $16,700 |

**Refinery Impacts**

Compliance with the proposed Puget Sound CFS yields varying levels of decreases in gasoline and diesel consumption in the Puget Sound region. Although the reduction of petroleum consumption will have positive impacts via reduced emissions, improved energy security and increased fuel diversity, it will also have direct negative impacts on the refining industry—in the same way that the investments in low carbon fuels will yield positive impacts in the corresponding industries. ICF treated the reduction in gasoline and diesel consumption in the modeling as follows:

- ICF assumed that there were lost margins on 50% of those crude volumes that are assumed to be displaced entirely as a result of modeled compliance with the Puget Sound CFS. These margins were estimated based on an ICF analysis of the "3-2-1 crack spread"[75] for West Coast refineries at $15/barrel.
- ICF assumed that the remaining 50% of crude volumes displaced by reduced gasoline and diesel consumption in the Puget Sound region are exported, rather than displaced entirely. For these exports, ICF assumed a decrease in revenue of $5/barrel due to increased freight costs.

**Refinery Credits**

ICF included the expenditures required to improve refinery efficiency and expand the use of renewable hydrogen.

### Refinery Efficiency

The economics of refinery efficiency improvement via mitigation technologies and practices were developed by applying the mitigation technologies to emissions sources according to levels of applicability identified through research and supplemented by ICF's expert judgment. For example, it was assumed that for boiler emissions, first a steam balance reduction measure would be applied, then potential combined heat and power (CHP) opportunities, and then finally a set of further boiler-specific mitigation options. At each level, the boiler emissions baseline was carefully considered and adjusted based on the subsequent level of applicability. The output was the cost and volume of abatement by emissions source.

### Renewable Hydrogen

Renewable hydrogen is produced from the reformation of renewable natural gas (referred to as steam methane reforming, SMR); ICF assumed that no additional infrastructure would be

[75] The crack spread measures the difference between the purchase price of crude oil and the selling price of finished products such as gasoline or diesel. The 3-2-1 crack spread approximates the product yield at a typical refinery, assuming that for every three barrels of crude oil the refinery processes, it makes two barrels of gasoline and one barrel of distillate fuel or diesel.

required to increase refinery renewable hydrogen use, as refineries already have SMR units in place, but that there was an incremental cost of using renewable natural gas over fossil natural gas. ICF assumed that the price signal in the Puget Sound CFS, as well as the price signals in other environmental commodity markets (e.g., the federal RFS market or California's LCFS) would favor the use of landfill gas or wastewater treatment gas for renewable hydrogen production. ICF estimated the incremental cost of transporting RNG from landfills to the refinery compared to pipeline natural gas. ICF analysis indicates that RNG from landfills is available in the range of $8 to $12 per MMBtu compared to geological or fossil natural gas in the range of $2 to 4 per MMBtu over the course of the analysis.

## Compliance Costs and CFS Credit Pricing

One of the limitations of REMI is that it is not explicitly an energy model. Most notably, the model is not designed to predict changes in demand and supply for fuels, or the impacts on fuel pricing. As a result, these aspects were determined exogenously through ICF analysis via consideration of fuel pricing and credit distribution.

ICF considered several components of fuel pricing as inputs into the REMI modeling. We sought to capture the likely impacts on fuel pricing as a result of compliance with the proposed Puget Sound CFS. This analysis was initiated by considering fuel pricing forecasts from the EIA for fuels including: gasoline, diesel, electricity, and natural gas.

To estimate the compliance costs, ICF developed estimates for potential credit pricing. In principle, the credit price should be equivalent to the cost of the marginal unit of GHG emission reductions through low-carbon fuel deployment in the transportation sector. The abatement cost of deploying alternative fuels and technologies should include fuel production, infrastructure, vehicle expenditures, and other costs required to achieve GHG reductions. For the proposed program, however, it is difficult to use standard dollar per ton ($/ton) pricing and a simple supply/demand elasticity in a model to predict what the credit price will be. The primary reason for this is that only a single entity can directly earn the credit—despite multiple investments generally required to abate carbon in the transportation sector.

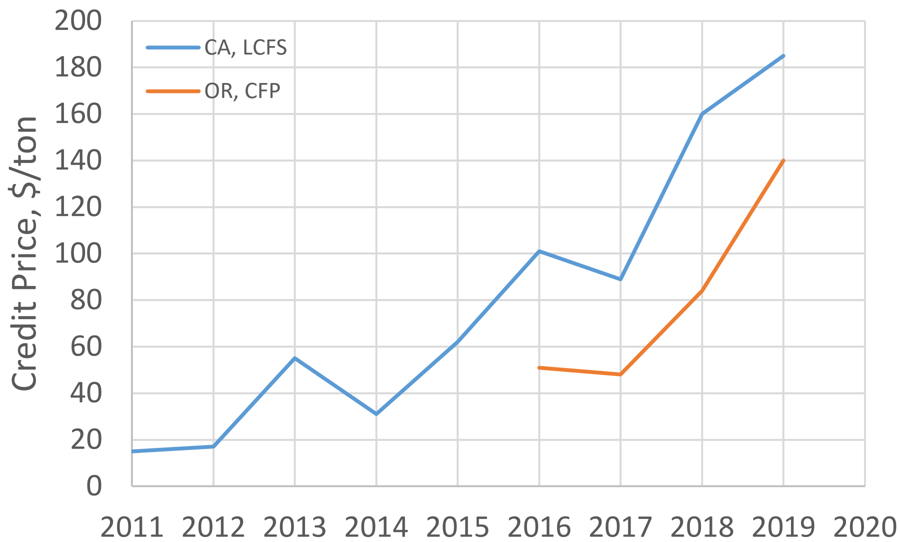
ICF developed an illustrative credit price trajectory for the Puget Sound region CFS by reviewing credit prices in other carbon constrained markets, and then using a low and a high scenario to illustrate the compliance cost impacts.

### Review of current credit prices in low carbon fuel standard markets

Figure 17 below includes the pricing history for California's LCFS program and Oregon's CFP.[76]

[76] Based on ICF analysis of credit transfer data reported by CARB (https://ww3.arb.ca.gov/fuels/lcfs/credit/lrtcreditreports.htm) and Oregon's DEQ (https://www.oregon.gov/deq/aq/programs/Pages/Clean-Fuels-Data.aspx).

Figure 17. Credit Price History in California's LCFS and Oregon's CFP




These credit price curves illustrate what one would expect from both markets: The increasing demand for low carbon fuels (tied to the stringency of each program) has led to increased credit pricing. Both the California LCFS and Oregon CFP are structured similarly—compliance is meant to be easier in the earlier years of the program, and allow regulated parties to increase their bank of LCFS credits.

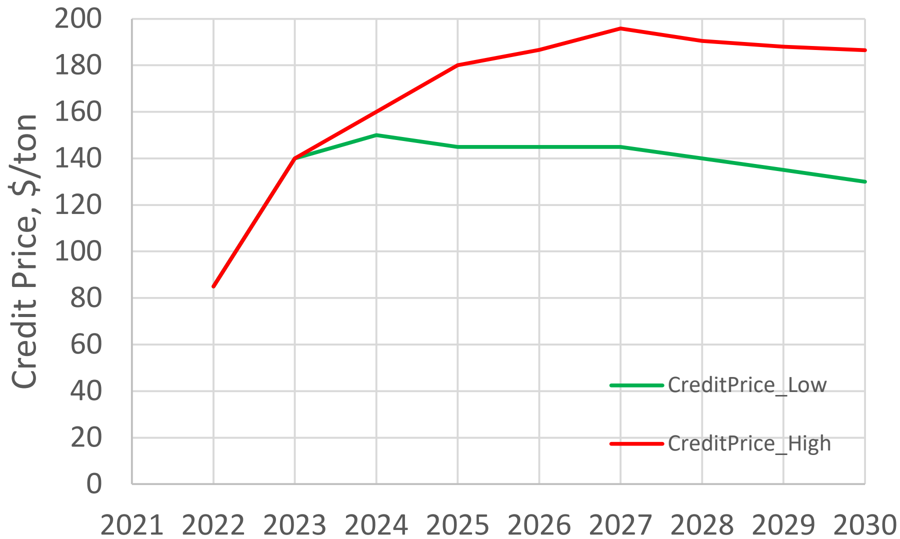
## Estimating compliance costs

ICF assumed that regulated parties (e.g., refiners) will seek to pass along the costs of compliance to the consumer. In a competitive market, refiners will compete on pricing. In some cases, this competition will manifest itself by refiners absorbing the costs of compliance and reducing profit margins. However, this analysis assumes that refiners will seek to maintain current profit margins and will not take active measures to reduce their cost of compliance (e.g., through refinery project credits or co-processing biomass). Refiners and wholesalers will have to consider the impacts of passing along compliance costs on a case-by-case basis, and so to estimate how individual refiners will comply is speculative for this economic modeling exercise. One challenging aspect to predict, for instance, will be competition with lower-carbon fuels like natural gas or electricity that are already cheaper on a per gallon basis than diesel. If retail prices of gasoline or diesel increase too high as a result of blending biofuels as a compliance strategy, then this will simply accelerate the deployment of vehicles that use other, cheaper low-carbon fuels like electricity or natural gas. This, in turn, could decrease demand for fossil fuels, and have some secondary effects on their pricing.

In each year of compliance, ICF used the estimated average credit price to estimate the impact on fuel prices. The number of deficits generated in each year as a function of conventional gasoline before oxygenate blending (CBOB) and ultra-low sulfur diesel (ULSD) consumption was assumed to be offset by the credits generated in each year.

ICF used the credit price curves in Figure 18 below, shown in real dollars (for year 2019) per metric ton. ICF notes that the first year of the program, as proposed by the Agency is a reporting year only, and there is not a corresponding credit price in that year.

Figure 18. Assumed Credit Pricing for Puget Sound Region CFS ($2019/ton)




ICF assumed that the credit price trajectory for the Puget Sound Region CFS would track Oregon's CFP market in the early years, with credits trading in the $80 to $100 per ton range. However, due to competition with Oregon's CFP and California's LCFS program, the credit price would need to increase in later years, as well as when the proposed Puget Sound CFS becomes more stringent. Oregon's and California's programs will have a 5-year and 10-year head start on the proposed Puget Sound CFS, and will be considerably further along their respective compliance curves by 2022, when the proposed Puget Sound CFS is expected to have its first enforceable CI target. ICF assumes that credit prices will have to increase rapidly to keep up with the stringency of other markets, and that the demand for low-carbon fuels across the three programs will have already exceeded the supply at $80-$100/ton, thereby pushing the credit prices higher. In the low case, ICF envisions a future where EVs (which can help keep costs down in clean fuels programs) and other technological advancements (e.g., expanded renewable diesel production and refinery improvements) have the potential to put some downward pressure on credit prices. In the high case, ICF models a future wherein there are consistently high prices for credits across multiple programs because of the supply constraints on low-carbon fuels, keeping credit prices above $180/ton after 2025.

The precise impact on fuel prices is difficult to predict because of the range of factors that affect fuel price—including but not limited to crude oil prices, regional demand, other regulatory policies in place—and the context in which transportation costs exist (driving habits, fuel economy, (in)elasticity of demand, fuel octane switching, etc). From a broad perspective, pump prices (driven largely by the price of crude oil) have varied considerably over the past 15 years with a range of around $2.00 per gallon, and as much as $0.50 per gallon in a single year. There is also a large range in predictions for future crude oil and gas and diesel prices, including modest decreases to a significant increase.[77] Thus, gas and diesel consumers already face a future with substantial uncertainty in their per-mile costs. But, for the purpose of simplifying our assessment of the incremental impact of a regional CFS, we can assume a baseline flat cost per gallon (or cost for crude oil) and consider future fleet fuel needs. If fleet average fuel economy increases consistent with the current light-duty vehicle standards (which would yield about a 20%-25% improvement in fuel economy[78]), the 2030 cost-per-mile for conventional vehicles using gasoline would still be the same as or less than today, even under a CFS with a maximum target (CI reduction target of 26%) and worst-case marginal compliance cost per gallon ($0.22-$0.57 per gallon). For diesel fuel, the worst-case marginal compliance cost per gallon would be about $0.24-$0.63 per gallon in 2030 for CI targets of 10%-26%. This can also be considered on a per-mile basis. For medium and heavy-duty diesel vehicles, there will also be an improvement in fleet average fuel economy of about 15% by 2030.[79] This will make the cost-per-mile the same or less than before, even under worst-case marginal compliance cost for CI reduction targets up to 20%. Under the worst-case marginal compliance cost for a 26% CI reduction target, heavy duty diesel vehicles could see an increase of about $0.01-$0.02 per-mile in 2030, which is about 0.5-1%.

## Modeling Compliance Costs in REMI

The final step in our consideration of compliance costs is translating them into REMI model inputs. ICF's approach to fuel price expenditures has multiple aspects, including changes in consumer spending and lost sales for the refining industry.

- For compliance costs, modeled as fuel price expenditures, we assumed an increase in consumer, commercial, and industrial sector spending on fuels equal to the incremental amount of spending on all fuel—this spending was equivalent to the compliance costs of the Puget Sound CFS, modeled as a complete pass-through. We also assumed a corresponding decrease in spending on all other goods, equal to the incremental amount of spending on all fuel.
- For the refining industry, we modeled the decrease in exogenous final demand for Petroleum and Coal Products Manufacturing in the region equal to the change in CBOB and diesel sold (using wholesale spot pricing for both fuels). This is a conservative assumption and may over-state the losses by the refining industry because refiners may have the opportunity to export gasoline and diesel that would have been otherwise consumed in Washington, Oregon, or California.

It is important to note that the compliance costs in the proposed Puget Sound CFS are mirrored by benefits to other industries that are producing eligible low-carbon fuels. The flow of credits is a critical aspect of the program.

[77] https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf
[78] ibid
[79] ibid

- For entities that sell the credits or credit generators—such as ethanol producers, biodiesel producers, and natural gas refueling infrastructure owners—ICF modeled the credit value as a decrease in production costs.
- ICF modeled credit purchases (made by entities producing or importing CBOB and diesel) as an increase in production costs.
- In the case of credits generated through the use of electricity as a transportation fuel in the light-duty sector, ICF assumed that the value of the credit would be passed to the consumer, assuming that the Puget Sound CFS would be implemented with similar regulatory structure as California's LCFS and Oregon's CFP. There are provisions in those programs for entities other than utilities to earn credits for the use of electricity as a transportation fuel in the light-duty sector; however, we made a simplifying assumption that the utilities would earn all of the credits in that sector.[80] In the event that there is a significant shift away from at-home charging, then less value would be passed through to consumers. ICF anticipates that this would decrease the positive economic impacts associated with EV adoption because this value would be re-directed to sectors that have deployed charging infrastructure and are earning credits; and those credits would likely go towards offsetting the costs of owning and/or maintaining EV charging infrastructure.
- In the case of credits generated through the use of electricity as a transportation fuel in the medium- and heavy-duty sectors, ICF assumed that the value of the credit would be passed to the commercial and industrial sectors in REMI, representing the likely market segments that would deploy those vehicles.

## REMI Modeling Results

The Puget Sound region is expected to experience continued growth in population, employment, and economic output through 2030. Baseline economic growth assumptions indicate that between 2018 and 2030, about an additional 330,000 new jobs will be created in the Puget Sound region along with a net 13% increase in Gross Regional Product (GRP) by 2030 based on a forecast from the WA Office of Financial Management (OFM) and the Puget Sound Regional Council. The REMI modeling assessed the marginal difference that the policies make on the baseline that exists in the REMI reference case projection of economic growth. Differences between REMI baseline economic growth and the OFM forecast of economic growth have little impact on the marginal difference and thus little impact on the analysis or overall conclusions. In this work the total employment in the 2030 REMI reference case is about 2.9 million jobs, and the total GRP is about $450 billion. The economic impacts discussed in the following sub-sections would then be on top of the baseline growth trajectory—including employment and output. Consider, for instance, the economic modeling yielding a reported employment impact of +/-1,000 jobs. That result means employment growth would change from 330,000 additional jobs to

[80] Generally speaking, most analyses assume about 80% of EV charging will occur at home. However, this may decrease over time as EV ownership increases and driving and charging behaviors change over time. The impact of this assumption is dependent on the extent to which one believes the EV charging service provider or site host would be willing to pass along the CFS credit to the entity using the EV charging. Regardless, unless there is a dramatic shift in charging behavior, as measured in the percentage of electricity delivered via home charging compared to non-residential charging, ICF anticipates that this assumption has a negligible impact.

+331,000 additional jobs (in the case of +1,000 jobs) or 329,000 additional jobs (in the case of -1,000 jobs) in 2030. In the tables below, the % change is with respect to the REMI assumed baseline. The WA OFM/PSRC projection is also provided for context.

## Scenario A: Biofuel Blending

Scenario A includes a 10% carbon intensity standard by 2030 and focuses on biofuel blending and a modest adoption of battery electric trucks in the medium- and heavy-duty trucking sectors. The economic results, presented in Table 29 are small and positive in the early years of the low credit variant of Scenario A, with the four-county region gaining an additional 150 jobs and $7.5 million in gross regional product (GRP). However, after 2025 the impact switches to reduced growth, showing about 2,800 fewer jobs added to the economy by 2030 and reduced GRP growth of -$409 million. The county with the largest employment benefit is King County, which sees, in the low variant, positive impacts of 329 additional jobs and $50.7 million in additional GRP growth in 2025. However, the King County job impact transitions to slowed growth by 2028, with 1,084 fewer jobs added by 2030 and $138.8 million less GRP growth than the baseline.

The differences between the low credit price and high credit price variants of Scenario A are small and the four-county job impacts differ by less than 30. In general, under the high credit price variant, when the economic results are positive beyond baseline, they are less positive than the low credit price variant, and when negative below baseline, they are more negative.

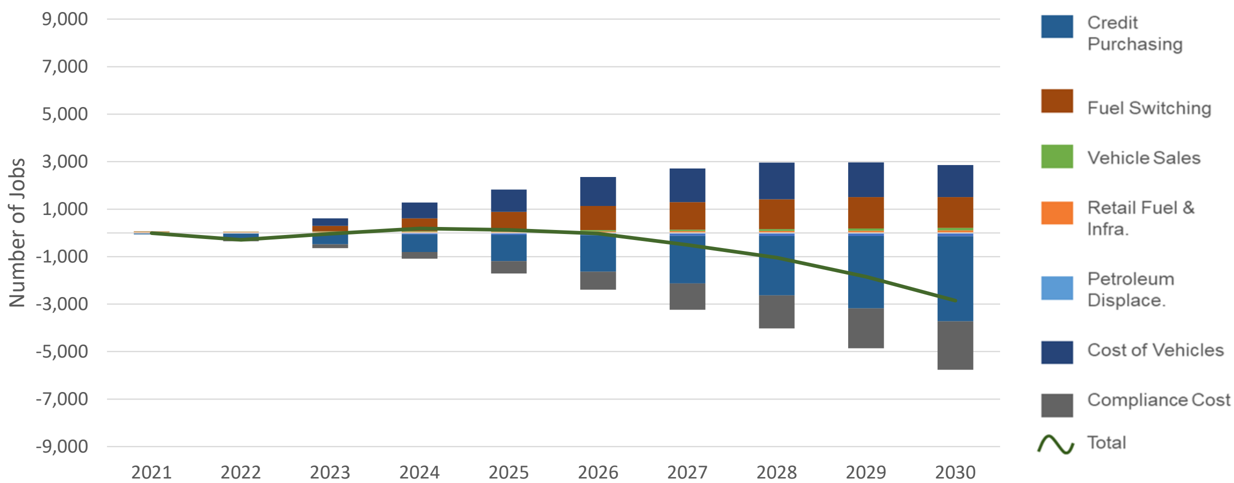
Overall the economic impacts of the CFS in this scenario are very small, never exceeding a 0.1% change in the region's employment or GRP in any year in either the positive or negative direction. This reflects the fact that is the proposed CFS program impacts just one part of a large and diversified regional economy.

Table 29. Scenario A - Summary of Economic Impacts

| **Region / County** | | **Low Credit Price** | | | | **High Credit Price** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Employment (# of Jobs)** | | **GRP (Millions 2018$)** | | **Employment (# of Jobs)** | | **GRP (Millions 2018$)** | |
| | | **2025** | **2030** | **2025** | **2030** | **2025** | **2030** | **2025** | **2030** |
| *Rest of Washington* | | *123* | *75* | *$122.8* | *$74.8* | *133* | *139* | *$133.1* | *$139.1* |
| *Total Washington* | | *273* | *-2,756* | *$130.3* | *-$334.4* | *256* | *-2,711* | *$138.5* | *-$275.9* |
| Snohomish | | -36 | -609 | -$4.3 | -$67.8 | -43 | -637 | -$4.9 | -$71.3 |
| King | | 329 | -1,084 | $50.7 | -$138.8 | 318 | -980 | $50.1 | -$115.1 |
| Pierce | | -107 | -903 | -$37.7 | -$188.1 | -114 | -990 | -$38.4 | -$213.8 |
| Kitsap | | -35 | -235 | -$1.2 | -$14.5 | -38 | -244 | -$1.3 | -$14.7 |
| **Total 4-County Region** | **Net change** | **150** | **-2,831** | **$7.5** | **-$409.2** | **123** | **-2,850** | **$5.5** | **-$414.9** |
| | **% Change (wrt REMI)** | **0.005%** | **-0.099%** | **0.002%** | **-0.090%** | **0.004%** | **-0.099%** | **0.001%** | **-0.091%** |
| **OFM/PSRC Total Jobs (#) or GRP (millions)** | | 2,400,000 | 2,500,000 | $425,000 | $450,000 | 2,400,000 | 2,500,000 | $425,000 | $450,000 |

To understand what is driving the economic results for Scenario A, we present Figure 19, which shows how different categories of impacts are driving the economic results for the high variant. See Appendix B for further description of the individual impacts. The graph for the low variant is nearly identical, and is found in Appendix B along with the full set of results tables. Each bar of the graph represents the individual employment impact of each category of input.

Figure 19. Scenario A - High | Four-County Region Employment Results




**Factors Contributing to Enhanced Economic Growth**

The two main drivers of positive economic impacts are from credit purchasing and fuel switching. Credit purchasing impacts tend to be positive despite consisting entirely of transfer payments. This is because the increase in production costs at refineries that buy credits does not have impacts that stay entirely in the region, as they are able to sell products outside of the four-county region. In addition, the refinery sector is relatively small. Using the assumption that utilities are required to pass through the benefits of credits to EV owners results in significant positive benefits, which outweigh the refinery cost increases, resulting in overall positive impacts from credit purchasing. The other large positive impact of fuel switching occurs as vehicles reduce gasoline and diesel consumption for less expensive fuels like electricity. This results in fuel savings which drive increased economic activity in the region.

There are small benefits from investments in fueling and charging infrastructure resulting from purchases of equipment as well as employing people to install the chargers and fueling infrastructure. Under scenario A, these benefits occur from installation of E15 and B20 fueling infrastructure.

**Factors Contributing to Reduced Economic Growth**

There are two impacts causing slower job growth in the results. The first, and largest, is the economic impact of purchasing more expensive MD/HD trucks. This increases the cost of MD/HD trucking and results in a relatively larger economic impact. This is likely an over-estimate of the economic impact of this cost as it assumes that entities purchasing MD/HD trucks are facing a production cost increase that represents the entire difference in cost between an electric MD/HD truck and its alternative. In reality, they may be able to minimize impacts to production costs through financing and other mechanisms. The second cause of slower job growth in this scenario is the pass-through of compliance costs associated with the program to consumers via higher fuel prices.

**Overall Economic Impacts**

The result of all of these impacts is a net annual effect close to zero through 2026, after which the continued cost of purchasing more expensive vehicles, combined with increasing compliance costs, begins to outweigh the benefits of credit purchasing and fuel switching. As a result, the slowed growth impacts become larger in magnitude through 2030.

## Scenario B: Aggressive Electrification

Scenario B includes a 10% carbon intensity standard by 2030 and focuses on electrification with lower levels of biofuel blending compared to Scenario A. As a result, there is significant adoption of battery electric vehicles, plug-in hybrid electric vehicles, and battery electric MD trucks. This drives larger fuel switching benefits than Scenario A, resulting in vehicle fuel savings and leading to less-negative economic results. The economic results, presented in Table 30, are small and positive in the early years of the low credit variant of Scenario B with the four-county region seeing positive impacts of 675 additional jobs and $63.5 million in additional GRP in 2025. The employment impact shifts to reduced growth in 2026 and reaches 1,693 fewer jobs created by 2030, with about $300 million less growth in GRP by the same year (relative to a baseline of 330,000 jobs added, and $50 billion in GRP growth). The county with the largest employment benefit is King County, which sees, in the low variant, positive impacts of 585 additional jobs in 2025 and $81.5 million in additional GRP growth. That job impact shifts to reduced growth by 2029, decreasing to 492 fewer additional jobs by 2030, alongside a decreased GRP growth of -$69.7 million.

The differences between the low credit price and high credit price variants of Scenario B are very small. In Scenario B, the high credit price variant shows smaller additional growth in jobs and reduced growth in the GRP relative to the low credit price variant. Under this scenario Pierce County shifts from a small increase in additional jobs in 2025 under the low credit price variant, to a small decrease in additional jobs in 2025 under the high credit price variant. Pierce County, as home to a refinery, faces some more reduced growth potential than other counties under high credit prices, as well as under scenarios with higher carbon intensity standards. This is because of the increased costs for refineries purchasing credits and losses in some demand for gasoline and diesel.

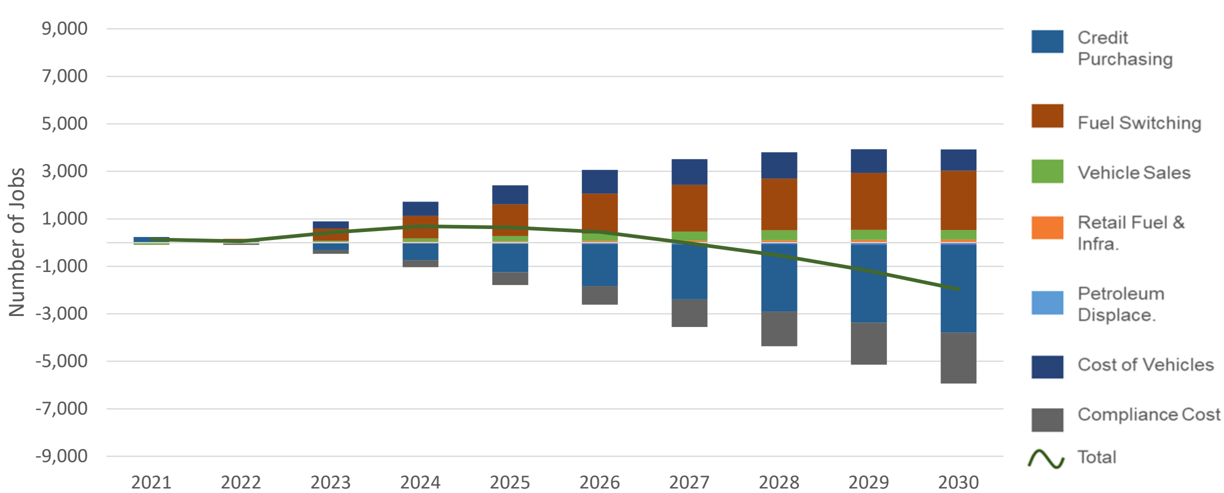
Overall, the economic results of Scenario B are very small. The maximum additional growth is less than 0.022% for jobs and GRP, and the reduction of growth in employment and GRP is never more than -0.077%. This is on top an expected growth of about 13% in employment and GRP.

Table 30. Scenario B - Summary of Economic Impacts

| Region / County | | Low Credit Price | | | | High Credit Price | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Employment (# of Jobs) | | GRP (Millions 2018$) | | Employment (# of Jobs) | | GRP (Millions 2018$) | |
| | | 2025 | 2030 | 2025 | 2030 | 2025 | 2030 | 2025 | 2030 |
| *Rest of Washington* | | *145* | *93* | *$145.4* | *$92.5* | *154* | *110* | *$153.7* | *$110.5* |
| *Total Washington* | | *820* | *-1,600* | *$208.9* | *-$207.9* | *787* | *-1,858* | *$213.2* | *-$242.3* |
| Snohomish | | 80 | -352 | $5.9 | -$44.0 | 72 | -399 | $5.2 | -$50.2 |
| King | | 585 | -492 | $81.5 | -$69.7 | 565 | -559 | $79.4 | -$76.5 |
| Pierce | | 3 | -698 | -$25.3 | -$177.8 | -7 | -848 | -$26.3 | -$216.5 |
| Kitsap | | 6 | -150 | $1.4 | -$8.9 | 4 | -164 | $1.3 | -$9.6 |
| **Total 4-County Region** | **Net change** | **675** | **-1,693** | **$63.5** | **-$300.4** | **633** | **-1,969** | **$59.6** | **-$352.8** |
| | **% Change (wrt REMI)** | **0.022%** | **-0.053%** | **0.014%** | **-0.061%** | **0.022%** | **-0.069%** | **0.014%** | **-0.077%** |
| **OFM/PSRC Total Jobs (#) or GRP (millions)** | | 2,400,000 | 2,500,000 | $425,000 | $450,000 | 2,400,000 | 2,500,000 | $425,000 | $450,000 |

To understand what is driving the economic results for Scenario B we present Figure 20, which shows how different categories of impacts are driving the economic results for the high variant. The graph for the low variant is nearly identical, and is found in Appendix B along with the full set of results tables. Each bar of the graph represents the individual employment impact of each category of input. For a full discussion of how the broad categories of inputs drive the economic impacts see the discussion under Scenario A. Below we discuss differences in those impacts under Scenario B.

Figure 20. Scenario B - High | Four-County Region Employment Results




**Factors Contributing to Enhanced Economic Growth**

The positive impacts for Scenario B are the same as the positive impacts for Scenario A. Under this scenario the fuel switching benefits are larger and continue to slightly grow through 2030, whereas under Scenario A they remained relatively flat after initial growth. Another difference in this scenario is the larger benefit from vehicle sales. This is because, unlike Scenario A, there are light duty BEV and PHEV sales which increase economic activity through dealerships and other local economic impacts from consumers purchasing trucks compared to MD/HD electric trucks that are purchased by businesses. Again the credit purchasing impacts are a net benefit for reasons discussed under Scenario A. Under Scenario B, infrastructure benefits are from installation of L2 residential and public charging stations, DCFC stations, and MD/HD truck charging stations.

**Factors Contributing to Reduced Economic Growth**

The reduced growth impacts for Scenario B are the same as the reduced growth impacts under Scenario A. The total expenditure on vehicles is a bit greater as more EVs are purchased, resulting in a higher cost for businesses purchasing MD electric trucks as well as some declines in household spending as they decide to purchase more expensive EVs instead of alternative goods and services in the local economy. The compliance cost impact in Scenario B results in slightly reduced economic growth relative to Scenario A.

**Overall Economic Impacts**

Overall Scenario B has less reduction in growth than Scenario A, primarily driven by the larger fuel switching benefits from greater EV adoption as well as some increased local benefits from consumer purchases of BEVs and PHEVs. The overall pattern to this scenario is similar to Scenario A, but with additional growth extending to 2027, after which there is some decline in employment growth through 2030.

## Scenario C: Mixed Technology

Scenario C includes a 16% carbon intensity standard by 2030 which results in a larger demand for low-carbon fuels than Scenarios A or B. As a result, there is more electrification and focus on biofuel blending. Of importance to the economic results is an even more significant adoption of EVs in all market segments. This yields greater fuel switching benefits compared to Scenario A or Scenario B. The economic results, presented in Table 31, are predominantly positive (additional growth), and shift to slightly reduced growth only in the years close to 2030 for the low credit variant of Scenario C. The four-county region sees additional growth of 720 jobs and $66.7 million in GRP in 2025. The employment impacts shift to reduced growth in 2029 with 979 fewer additional jobs in 2030 and reduced GRP growth of about $210 million. The results show that King County sees the most significant growth in employment, in the low variant, with an additional 712 jobs in 2025 and an additional $107.4 million in GRP growth. For King County, the economic impact remains positive through 2030 but this additionality decreases to 58 jobs by 2030 and $34 million in GRP.

The differences between the low credit price and high credit price variants of Scenario C are very small in magnitude. Unlike prior scenarios, the high credit price variant shows mixed results when compared to the low credit price variant. Overall, there is slight additional growth through about 2028, shifting to slightly reduced growth by 2030. Under this scenario, most of the reduced growth is in Pierce County. As described under Scenario B, Pierce County is home to a refinery, and thus faces more impacts than other counties under high credit prices, as well as under scenarios with higher carbon intensity standards. This is because of the increased costs for refineries purchasing credits and losses in some demand for gasoline and diesel. And, it assumes that the refinery doesn't adapt its process to generate credits through biofuel production or co-processing.

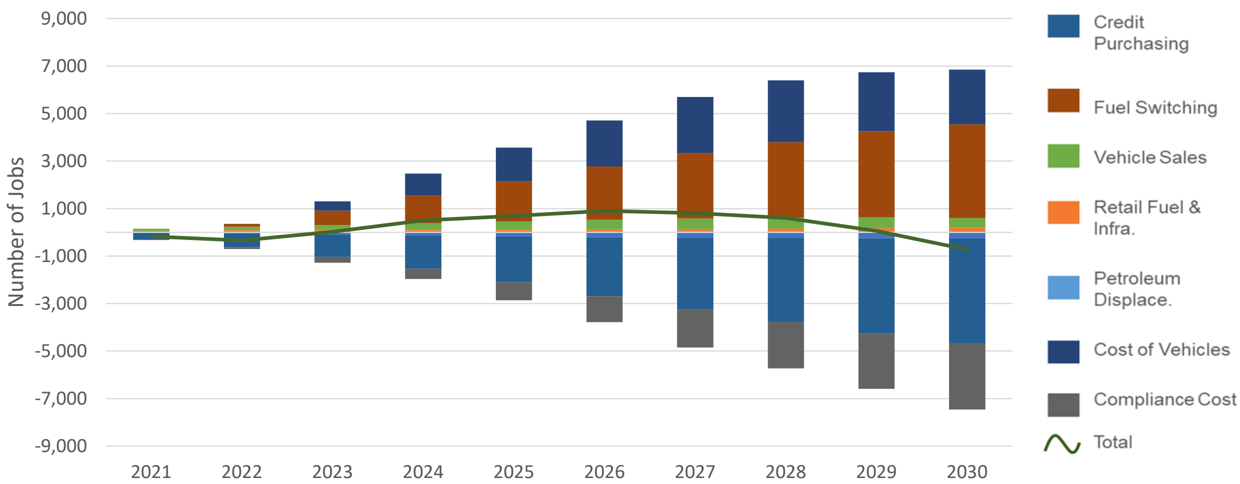
Overall, the economic results are very small. The four-county region impacts range from less than a -0.05% reduced growth in employment and GRP, to an additional increase in employment of just over 0.02% and additional GRP growth of just over 0.01%.

Table 31. Scenario C - Summary of Economic Impacts

<table>
<tr><th colspan="2" rowspan="3">Region / County</th><th colspan="4">Low Credit Price</th><th colspan="4">High Credit Price</th></tr>
<tr><th colspan="2">Employment<br>(# of Jobs)</th><th colspan="2">GRP<br>(Millions 2018$)</th><th colspan="2">Employment<br>(# of Jobs)</th><th colspan="2">GRP<br>(Millions 2018$)</th></tr>
<tr><th>2025</th><th>2030</th><th>2025</th><th>2030</th><th>2025</th><th>2030</th><th>2025</th><th>2030</th></tr>
<tr><td colspan="2">Rest of Washington</td><td>144</td><td>74</td><td>$144.2</td><td>$73.9</td><td>161</td><td>180</td><td>$160.8</td><td>$180.2</td></tr>
<tr><td colspan="2">Total Washington</td><td>865</td><td>-905</td><td>$210.9</td><td>-$136.8</td><td>848</td><td>-550</td><td>$225.8</td><td>$11.4</td></tr>
<tr><td colspan="2">Snohomish</td><td>72</td><td>-239</td><td>$6.1</td><td>-$30.9</td><td>62</td><td>-253</td><td>$5.4</td><td>-$32.4</td></tr>
<tr><td colspan="2">King</td><td>712</td><td>58</td><td>$107.4</td><td>$34.1</td><td>701</td><td>375</td><td>$107.1</td><td>$97.7</td></tr>
<tr><td colspan="2">Pierce</td><td>-64</td><td>-690</td><td>-$47.8</td><td>-$207.9</td><td>-73</td><td>-737</td><td>-$48.3</td><td>-$228.3</td></tr>
<tr><td colspan="2">Kitsap</td><td>1</td><td>-107</td><td>$1.0</td><td>-$5.9</td><td>-3</td><td>-115</td><td>$0.9</td><td>-$5.8</td></tr>
<tr><td rowspan="2">Total 4-County Region</td><td>Net change</td><td>720</td><td>-979</td><td>$66.7</td><td>-$210.6</td><td>687</td><td>-730</td><td>$65.0</td><td>-$168.8</td></tr>
<tr><td>% Change (wrt REMI)</td><td>0.025%</td><td>-0.036%</td><td>0.016%</td><td>-0.046%</td><td>0.024%</td><td>-0.025%</td><td>0.016%</td><td>-0.037%</td></tr>
<tr><td colspan="2">OFM/PSRC Total Jobs (#) or GRP (millions)</td><td>2,400,000</td><td>2,500,000</td><td>$425,000</td><td>$450,000</td><td>2,400,000</td><td>2,500,000</td><td>$425,000</td><td>$450,000</td></tr>
</table>

To understand what is driving the economic results for Scenario C we present Figure 21, which shows how different categories of impacts are driving the economic results for the high variant. The graph for the low variant is nearly identical, and is found in Appendix B along with the full set of results tables. Each bar of the graph represents the individual employment impact of each category of input. For a full discussion of how the broad categories of inputs drive the economic impacts see the discussion under Scenario A, below we discuss differences in those impacts under Scenario C compared to the previous scenarios.

Figure 21. Scenario C - High | Four-County Region Employment Results




**Factors Contributing to Enhanced Economic Growth**

The positive impacts for Scenario C are the same as the positive impacts under the previous scenarios. Under this scenario the fuel switching benefits are larger than either Scenario A or Scenario B. In Scenario C these benefits grow significantly all the way through 2030 as electrification of vehicles increases and fuel savings accumulate for households and businesses. Compared to the previous scenarios, the credit purchasing impacts also grow through 2030, resulting in an extended additional positive overall economic impact through 2029. Under Scenario C, infrastructure benefits are realized from the deployment of E15 and B20 fueling infrastructure as well as Level 2 residential and public charging stations, DCFC stations, and MD truck fast charging stations.

**Factors Contributing to Reduced Economic Growth**

The reduced growth impacts for Scenario C are the same as under the previous scenarios. The total expenditures on vehicles is greater as more EVs are purchased, resulting in a higher up-front cost for businesses purchasing MD/HD electric trucks as well as some declines in household spending as they decide to purchase more expensive EVs instead of alternative goods and services in the local economy. It is worth noting, however, that EVs have a lower total cost of ownership than ICEVs, resulting in long-term consumer savings (post-2030) as a result of EV purchases that are not reflected in this analysis simply because it ends in 2030. The compliance cost impact is greater than either Scenario A or Scenario B, reflecting the increased costs associated with the more stringent scenario.

**Overall Economic Impacts**

Overall Scenario C has positive economic results relative to baseline for the majority of the 2021-2030 time period. This is primarily driven by the large fuel switching benefits from EV adoption as well as the increased credit purchasing benefits as payments for electricity credits are passed through to consumers. There are some small initial negative impacts as fuel switching benefits and credit purchasing benefits take a few years to accrue, whereas the costs begin accruing quickly.

## Scenario D: All-In, Maximum Feasible Reduction

Scenario D includes a 26% carbon intensity standard by 2030 which results in the largest demand for low-carbon fuels of all the scenarios. As a result, there is a large amount of electrification and focus on biofuel blending. This results in an even more significant adoption of battery electric vehicles, plug-in hybrid electric vehicles, and battery electric MD trucks, which drives large fuel switching benefits. The economic results, presented in Table 32, are different from previous scenarios as 2025 shows generally slightly reduced growth and 2030 shows generally enhanced growth. The four-county region sees a reduction of 18 additional jobs and a reduction in additional growth of -$68.1 million in GRP in 2025. Jobs turn positive relative to baseline growth in 2026 and increase to 495 jobs in 2030. As in prior scenarios, King County shows the largest enhanced growth with, in the low variant, additional growth of 346 jobs in 2025 and $61.2 million in GRP. For King County, the economic impact remains positive through 2030 increasing to 905 additional jobs by 2030 and $148 million in additional GRP growth.

The differences between the low credit price and high credit price variants of Scenario D are very small in magnitude. As with Scenario A and B the high credit price variant shows more reduction in growth than the low credit price variant. As seen with Scenario C, under this scenario the reduced growth is driven by Pierce County. As described in the summary of results from Scenario B, Pierce County is home to a refinery, and thus faces more impacts than other counties under high credit prices, as well as under scenarios with higher carbon intensity standards. This is because of the increased costs for refineries purchasing credits and losses in some demand for gasoline and diesel.

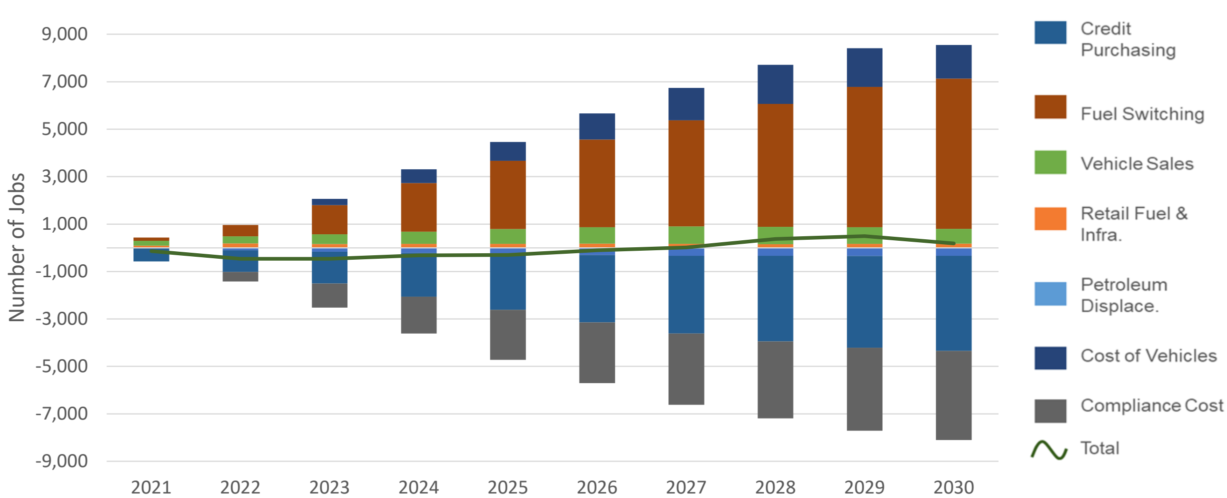
Overall the economic results are very small. The four-county region impacts range from a decrease in growth of -0.04% (on top of a projected growth of 13%) to an additional 0.02% in the region’s employment and GRP. The high credit price variant of Scenario D shows additional positive employment benefits beginning in 2026 and extending through 2030 (the full set of annual results is in Appendix B). However, GRP in the high credit price variant is reduced from the baseline growth throughout the timespan. This result is occurring because high value-added and capital-intensive industries, such as those related to fossil fuels, are facing most of the costs. The positive economic benefits are primarily accruing to consumers and businesses who end up with more money to spend from fuel savings and the pass-through of credits generated from the use of electricity as a transportation fuel. As a result, they spend this extra money in the local economy on labor-intensive industries such as retail and dining, resulting in positive employment impacts.

Table 32. Scenario D - Summary of Economic Impacts

| Region / County | | Low Credit Price | | | | High Credit Price | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Employment (# of Jobs) | | GRP (Millions 2018$) | | Employment (# of Jobs) | | GRP (Millions 2018$) | |
| | | 2025 | 2030 | 2025 | 2030 | 2025 | 2030 | 2025 | 2030 |
| *Rest of Washington* | | *40* | *-174* | *$40.2* | *-$173.9* | *56* | *-213* | *$55.9* | *-$212.6* |
| *Total Washington* | | *22* | *321* | *-$28.0* | *-$291.0* | *-245* | *-31* | *-$41.3* | *-$374.4* |
| Snohomish | | 58 | 173 | $2.8 | $7.4 | 10 | 86 | -$1.4 | -$2.3 |
| King | | 346 | 905 | $61.2 | $148.1 | 185 | 915 | $42.6 | $164.9 |
| Pierce | | -443 | -651 | -$133.6 | -$277.9 | -501 | -855 | -$138.8 | -$327.9 |
| Kitsap | | 20 | 68 | $1.5 | $5.3 | 5 | 35 | $0.5 | $3.6 |
| **Total 4-County Region** | **Net change** | **-18** | **495** | **-$68.1** | **-$117.1** | **-301** | **181** | **-$97.2** | **-$161.7** |
| | **% Change (wrt REMI)** | **-0.001%** | **0.017%** | **-0.016%** | **-0.026%** | **-0.011%** | **0.006%** | **-0.023%** | **-0.035%** |
| **OFM/PSRC Total Jobs (#) or GRP (millions)** | | 2,400,000 | 2,500,000 | $425,000 | $450,000 | 2,400,000 | 2,500,000 | $425,000 | $450,000 |

To understand what is driving the economic results for Scenario D we present Figure 22 which shows how different categories of impacts are driving the economic results for the high credit price variant. The graph for the low credit price variant is relatively similar and is found in Appendix B, along with the full set of results tables. The low credit price variant graph shows a net job impact that becomes positive earlier than the high credit price variant graph below. Each bar of the graph represents the individual employment impact of each category of input. For a full discussion of how the broad categories of inputs drive the economic impacts, see the discussion under Scenario A. Below, we discuss differences in those impacts under Scenario D compared to the previous scenarios.

Figure 22. Scenario D - High | Four-County Region Employment Results




### Factors Contributing to Enhanced Economic Growth

The positive impacts for Scenario D are the same as the positive impacts under the previous scenarios. Under this scenario the fuel switching benefits are the largest of all the scenarios. In

Scenario D these benefits are greater than other scenarios, and grow significantly all the way through 2030 as electrification of vehicles increases and fuel savings accumulate. Compared to the previous scenarios, the credit purchasing impacts also grow through 2030, resulting in an extended positive net overall economic impact through 2030. Under Scenario D, infrastructure benefits are from the installation of E15 and B20 fueling infrastructure as well as Level 2 residential and public charging stations, DCFC stations, and MD/HD electric truck charging stations.

**Factors Contributing to Reduced Economic Growth**

The reduced growth impacts for Scenario D are the same as under the previous scenarios. The total expenditure on vehicles is greater as more electric vehicles are purchased, resulting in a higher cost for businesses purchasing MD trucks as well as some declines in household spending as they decide to purchase more expensive electric vehicles instead of alternative goods and services in the local economy. These costs continue to increase through 2030 as large numbers of electric vehicles are deployed. As noted in previous scenarios, EVs have a lower total cost of ownership than ICEVs, so long-term consumer savings (post-2030) as a result of EV purchases are not reflected in this analysis simply because it ends in 2030. The compliance cost impact is greater than previous scenarios reflecting the increased costs associated with the more stringent scenario.

**Overall Economic Impacts**

Overall, the Scenario D high credit price variant has slightly reduced growth results between 2021 and 2026. Beginning in 2027 the employment results turn positive through the end of the modeling period. This upswing is primarily driven by the large fuel switching benefits from electric vehicle adoption as well as the increased credit purchasing benefits as payments for electricity credits are passed through to consumers. In the low credit price variant, the reduced employment growth impacts only occur between 2021 and 2024 and become positive beginning in 2025. Not shown in the graph are the GRP impacts which, unlike other scenarios, do not follow the employment trends. As discussed previously, the employment impacts and GRP impacts follow a different trend due to the larger impacts occurring to different areas of the economy under Scenario D.

# 5. Air Quality and Health Impacts of Low Carbon Fuel Deployment

ICF worked together with the Agency to characterize the air quality and health impacts of the compliance scenarios developed (see Section 3). ICF's analysis focused solely on the air quality and public health impacts of changes in tailpipe (downstream) $PM_{2.5}$ emissions resulting from each scenario. ICF's modeling considered the entire region, rather than individual "hotspots." ICF notes that no "upstream" emission sources were included, such as any potential, new biofuel production facilities in the region that may be built as a consequence of this regulation, as these were considered too speculative to be estimated reliably. Only PM-related health effects from direct emissions of $PM_{2.5}$ are included. ICF based the air quality impacts on a screening level modeling approach relying on the C-LINE[81] model. The remainder of this section describes ICF's approach and results of the air quality and health impact analysis.

ICF implemented the analysis in two steps:

- Estimated changes in $PM_{2.5}$ concentrations from implementing the CFS. These reductions are reported at the Census Block Group (CBG) level and at suitable resolution to quantify human health benefits associated with $PM_{2.5}$ reductions (see below).
- Quantified human health benefits associated with the $PM_{2.5}$ reductions using EPA's Benefits Mapping and Analysis Program (BenMAP)[82] to estimate reduction in adverse health impacts and the monetary value of human health benefits from implementation of low carbon fuel standards in each of the four affected counties. This analysis was limited to mortality, which drives the majority of associated costs.

These two steps were implemented for each of the four scenarios as described below for a single year, 2030.

## Concentration Analysis

### Modeling Approach

This analysis focused exclusively on the changes to $PM_{2.5}$ concentrations from vehicle tailpipe emissions in the region resulting from CFS compliance scenario modeling, via Scenarios A-D. ICF used the Community LINE Source (C-LINE) Model to estimate the air pollutant concentrations that BenMAP requires to estimate the effect on public health. C-LINE computes dispersion and concentrations of primary mobile source pollutants on major roadways in a selected area.[81] Its computations are based on the analytical version of R-LINE, a model EPA intends to integrate into its preferred regulatory model, AERMOD.[83,84]

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[81] https://www.cmascenter.org/c-tools/
[82] https://www.epa.gov/benmap.
[83] EPA White Papers on Planned Updates to AERMOD Modeling System. Memorandum from Tyler Fox, Group Leader-Air Quality Modeling Group, to EPA Regional Modeling Contacts, September 19, 2017. Available at: https://www3.epa.gov/ttn/scram/models/aermod/20170919_AERMOD_Development_White_Papers.pdf.
[84] The fully integrated version used for regulatory purposes could differ from the analytic version included in C-LINE. Thus, this analysis should not be considered regulatory.

The primary advantage of using C-LINE is its simplicity. It is accessed through a web-based interface. It produces short- (1-hour) and long-term (annual) average concentrations of several pollutants, including $PM_{2.5}$, along a predetermined array of receptors and automatically produces averages at the community block group (CBG) level. It automatically populates background concentration and meteorological conditions with pre-programmed values, with the option to select and use data from other stations. However, the model is somewhat opaque and rigid. It is unclear exactly how many years of meteorology are used to create the “annual average” (rather than the more correct “period” average), and what monitors are used for background if no or multiple stations appear in the modeling domain. It is a screening-level model.

Emissions in C-LINE are estimated using a simplistic approach, by combining traffic volume (using annual average daily traffic, AADT) with fleet mix and MOVES-2014[85] emissions factors, all from the 2011 National Emissions Inventory (NEI). Some customization is allowed for control runs, but is generally targeted at changes for certain road segments, including modifying the emissions for one or more roads by changing the traffic composition via the fleet mix, the speed, and/or the AADT by applying multipliers to selected roads, and/or by applying a “MPH change”.

## Modeling Domains

The C-LINE model domain size is limited. The model User Guide[86] provides no guidance on the maximum domain size but, at a certain zoom level individual roadways are no longer included. Similarly, zooming in does not appear to increase receptor resolution beyond a minimum threshold. The model domain size is fixed by the screen resolution used to setup a simulation and the corresponding receptor grid appears to be similarly fixed with a resolution that decreases (receptor spacing increases) by doubling (80, 160, 320 m spacing) as the domain changes beyond a fixed threshold.

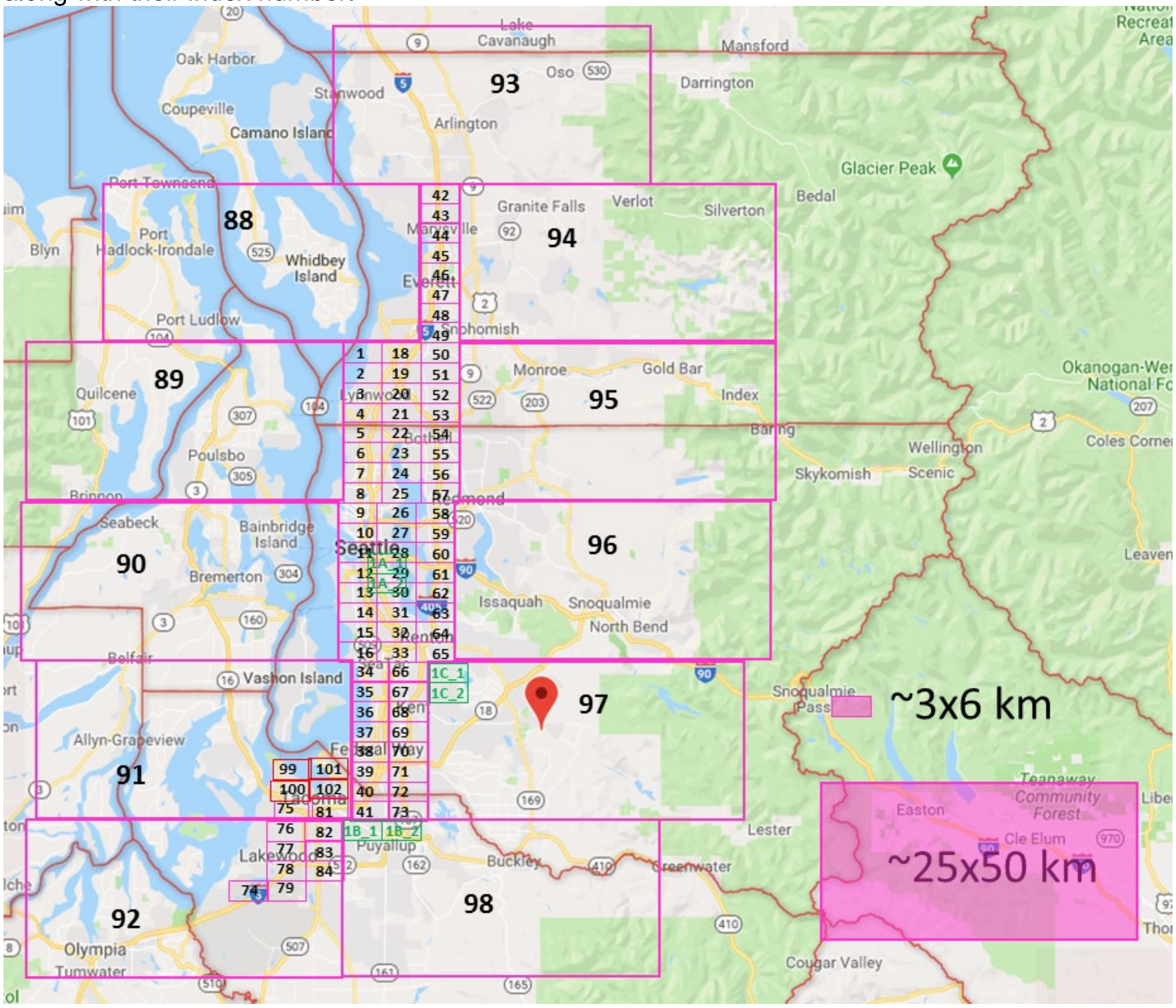
ICF’s concentration analysis is based on C-LINE model outputs for long-term average tailpipe $PM_{2.5}$ concentrations for each census block group (CBG) across the entire four-county area. To do this, ICF performed a suite of C-LINE simulations covering the entire region with individual domains and stitched the results together to form a continuous regional concentration surface.

To balance the need to capture the impact of steep concentration gradients on some key, near-road CBGs while covering the entire region efficiently with as few simulations as possible, we used a combination of two modeling domain sizes: The smaller sized domain is roughly 3km x 6km and represents the largest domain we were able to obtain with the smallest receptor spacing in the model (approximately 80m). The larger domain is roughly 25km x 50 km is the biggest we could obtain with the model and corresponds to the largest receptor spacing in the model (640m).

Figure 23 below illustrates the final array of modeling domains used to capture baseline conditions for near-road, directly-emitted $PM_{2.5}$ across the region. This distribution was settled in coordination with the Agency to balance the total number of model simulations with capturing the near road gradients on major roads with significant populations and areas of particular air quality concern.

[85] https://www.epa.gov/moves.
[86] User’s Guide for C-LINE: Community Line Source Model, Version 5.1, May 3, 2018.

Figure 23. C-LINE Modeling Domains. County borders are shown in brown; domains are shown in pink, along with their index number.




In total, ICF simulated 103 distinct C-LINE model domains; 92 of these were for the smaller domain size.

## C-LINE Modeling Outputs

Model outputs include average $PM_{2.5}$ concentration in each partial or whole CBG in each modeling domain across the four counties. We created a continuous air quality surface for the baseline conditions from these individual CBG-average concentrations, using an unweighted averaging approach to combine all partial and whole values reported for any CBG in the modeled area.[87]

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[87] A potential improvement to this approach would be to first remove overlapping receptors by selecting the most appropriate in cases where multiple domains cover the area (considering both receptor location and sources included in the C-LINE modeling domain), mapping the remaining receptor set to CBGs, then determining CBG-average concentrations from the combined receptor set. This would be more robust than combining the CBG-average

Note that the modeled area does not include all of the four-county domain. Twelve CBGs in the four county area are not included in the baseline air quality surface. Note also that PSCAA opted to hold the future background concentration constant to simplify the analysis. Thus the same background reported by C-LINE was used to determine total $PM_{2.5}$ concentrations for the baseline and all future year scenarios.

The output of this processing was the CBG-average concentration for the baseline conditions based on the C-LINE outputs. The concentration surface for the business as usual and four scenarios were defined by scaling the baseline CBG-average concentrations by the scenario-specific scale factors discussed below and shown in Table 33.

## Modeled Scenarios

ICF developed air quality concentration surfaces for the four compliance scenarios described in Section 3, as well as two other scenarios referred to as Baseline and Business-As-Usual (BAU or Reference) scenarios.

As discussed above, the baseline scenario characterizes existing conditions, circa 2011. C-LINE calculates concentrations of total $PM_{2.5}$ directly emitted from the road network embedded in the model, with activity values derived from the 2011 NEI and corresponding factors from the MOVES emissions model. ICF used the C-LINE model to simulate total $PM_{2.5}$ annual average, both with and without background emissions for all CBGs in the region to produce the baseline air quality surface. This baseline scenario is the only scenario that was modeled directly with the C-LINE model.

The BAU scenario represents 2030 conditions without implementation of any of the considered scenarios. We determined the total $PM_{2.5}$ concentrations for the 2030 BAU case from the 2011 baseline concentration surface by applying a scaling factor uniformly to the modeled annual, CBG-average $PM_{2.5}$ concentrations from the 2011 baseline scenario. Concentrations of directly-emitted pollutants scale linearly with emissions, so we determined the scale factor by performing MOVES emission modeling for the region.

ICF obtained 2011, 2017, and 2030 MOVES inputs used by the Puget Sound Regional Council (PSRC). ICF simulated annual total emissions of $PM_{2.5}$ (exhaust, brake, and tire wear) for King County for 2011 and 2030.[88] ICF created the 2011 and 2030 King County MOVES simulations for baseline and BAU conditions, respectively, from available input files and databases including for vehicle speeds, regional distribution of traffic, and available fuels. The only baseline or BAU inputs that are not consistent with PSRC values are vehicle population and vehicle miles traveled (VMT). Because PSRC uses an “emissions rate” approach in their MOVES modeling, they include only dummy values for these inputs. To fill this gap, ICF extracted, processed, and included in our MOVES simulations vehicle population and VMT by vehicle type from the same

concentrations from the individual model simulations, but significantly more time consuming than the current schedule and budget allowed.

[88] ICF limited our consideration to King County for this step for simplicity, and because it represents about half of the population of the Puget Sound region, and we assume that the fleet in King County is sufficiently representative of the entire region.

vehicle fleet modeling used to develop the compliance scenarios. This approach provided the best available, locally specific projections for the study region.

ICF used the ratio of the county-wide total $PM_{2.5}$ emissions between 2011 and 2030 to determine the BAU-to-Baseline scaling factor. We then applied this scale factor uniformly to all CBGs in the four-county region to scale baseline to BAU $PM_{2.5}$ concentrations. This is a straightforward approach approximating the natural changes in fleet, fuels, and VMT in the region based on local data.

The vehicle and fuel modeling framework that ICF used in this analysis is focused on energy consumption and GHG emissions; it does not calculate criteria air pollutant emissions. To estimate the $PM_{2.5}$ concentration changes attributable to the four scenarios, ICF implemented a similar approach to that for the BAU. For each case, we determined scale factors relative to the baseline conditions with MOVES modeling for King County for year 2030. However, for the scenarios, additional factors were included to approximate the effect on direct $PM_{2.5}$ emissions from the changes in the vehicle fleet and engine technology driven by implementation of each scenario. The vehicle population and VMT by vehicle type were taken from the modeling outputs as described above for the BAU case. For each of the four scenarios we also determined and included the age and vehicle technology distribution from each scenario. These changes were included in the MOVES model through the SourceTypeAgeDistribution and AVFT input database tables. In cases where there is not a perfect match between VISION and MOVES vehicle or technology types, best engineering judgment was applied to capture the expected changes in PM emissions.

Table 33 shows the countywide total $PM_{2.5}$ emissions and resulting scale factors used for each scenario. Figure 24 represents the vehicle and technology distribution from ICF's modeling used in each MOVES scenario.

Table 33. Countywide Emissions and Scale Factors for each Scenario

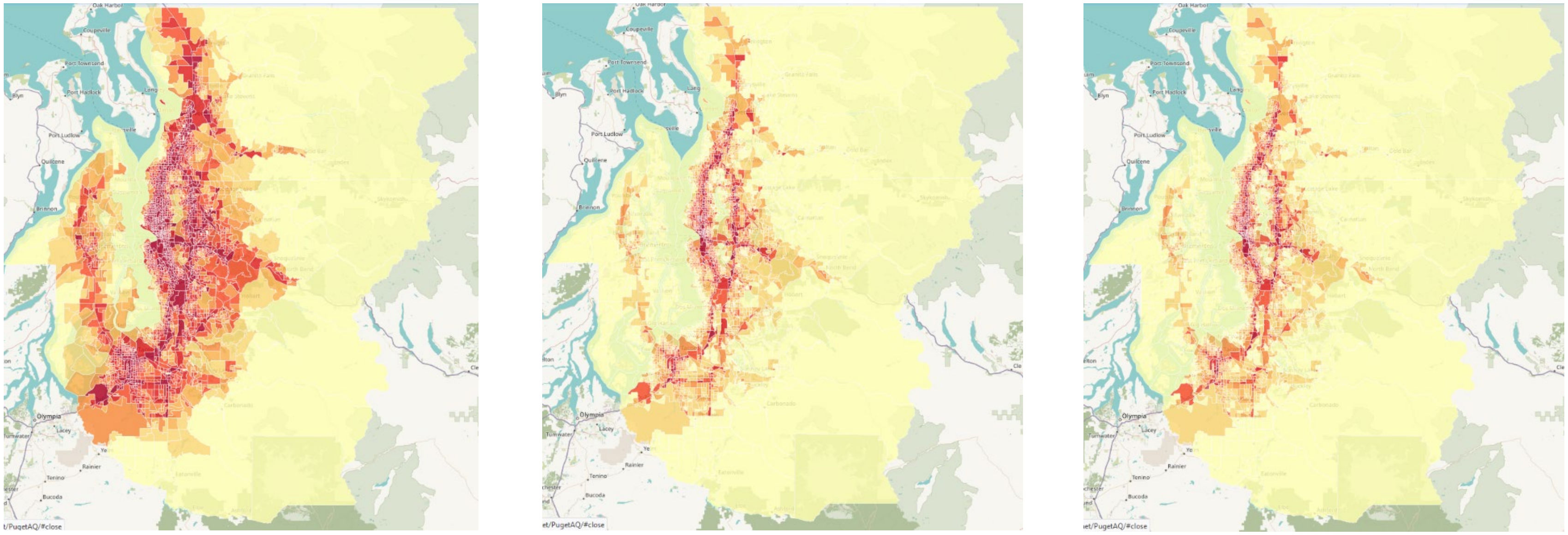
| Scenario | Total $PM_{2.5}$ (metric tons) | Scale Factor |
|---|---|---|
| Baseline (2011) | 1442 | 1.0000 |
| BAU (2030) | 463 | 0.3214 |
| Scenario A (2030) | 441 | 0.3056 |
| Scenario B (2030) | 437 | 0.3034 |
| Scenario C (2030) | 438 | 0.3037 |
| Scenario D (2030) | 430 | 0.2982 |

Figure 24. Vehicle and Technology Distributions by Scenario


## Air Quality Results by Scenario

Figure 25 shows the annual, CBG-average $PM_{2.5}$ concentration for the baseline in 2011, BAU in 2030, and under implementation of Scenario A in 2030. $PM_{2.5}$ levels declined significantly from 2011-2030 BAU, mainly as a result of federal vehicle standards reducing $PM_{2.5}$ emissions. The additional reductions from the proposed CFS (Scenario A) are small in comparison to the anticipated reductions from federal vehicle standards. As the main goal of the CFS is to reduce GHG emissions, the reductions in $PM_{2.5}$ are considered a co-benefit. The figure does not reflect reductions in other tailpipe emissions beyond $PM_{2.5}$. Other scenarios are not included in Figure 25 since the differences are difficult to discern visually.

Figure 25 Annual average $PM_{2.5}$ Concentration distribution by CBG under baseline (left), BAU (center), and Scenario A conditions



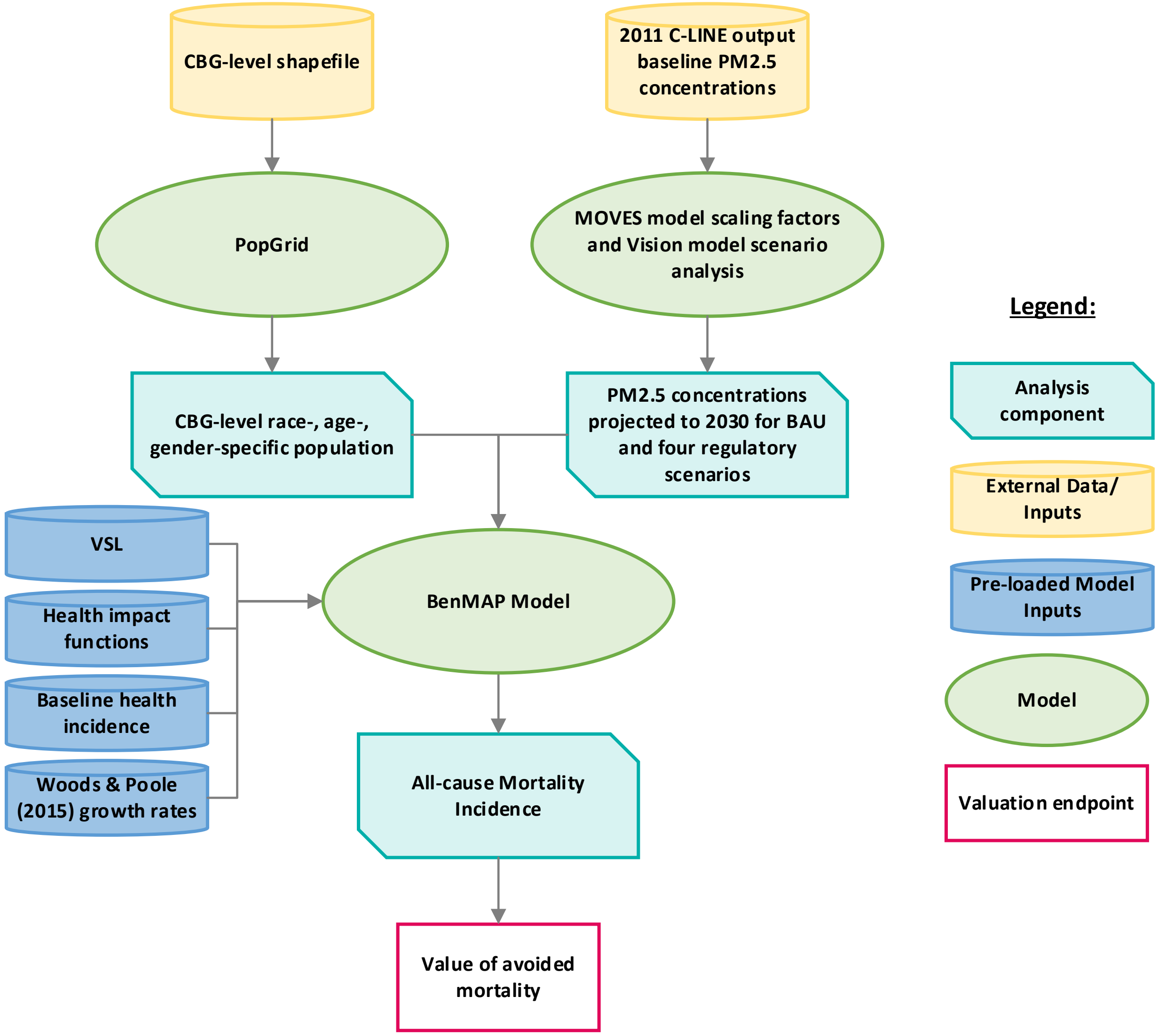
## Estimating Health Benefits from Air Pollution Reductions

To estimate human health benefits from reductions in air pollution following implementation of any of the considered CFS compliance scenarios, ICF input the estimated $PM_{2.5}$ concentrations relevant to baseline conditions and regulatory policy scenarios for each census block group into BenMAP. BenMAP is a Windows-based computer program that estimates the health impacts and accompanying economic benefits associated with changes in air quality. BenMAP runs health impact functions to estimate human health impacts and associated economic values of changes in ambient air pollution. Health impact functions (HIF) relate a change in the concentration of a pollutant with a change in the incidence of a particular health endpoint, such as human mortality and morbidity.

An important caveat is that this air quality impacts analysis is addressing solely human mortality due to cardiovascular impacts of fine particles. Of all known air quality impacts, human mortality from fine particles is the best documented, causes the majority of the loss of economic value, and is obviously the most severe type. The full scope of air pollution impacts includes additional pollutants (such as air toxics and ozone precursors) and multiple other health endpoints (such as asthma attacks, lost work and school days, respiratory infections, non-fatal heart attacks, cancer risk, and potentially more). Some of these pollutants and endpoints have sufficient data and evidence to allow for impacts to be estimated from simple emissions changes. Others have more complicated relationships with emissions, or have weaker evidence for the impacts. So, this calculation, while likely capturing a majority of the lost economic value does not capture the full range of human health impacts.

Figure 26 below illustrates the general approach for quantifying and valuing the benefits of reducing $PM_{2.5}$ concentrations under the four regulatory scenarios. The analysis entails the use of EPA's PopGrid program to determine age-, race-, and gender-specific population data at the CBG level and the C-LINE, MOVES, and vehicle/fuel modeling described above to determine $PM_{2.5}$ concentrations projected to 2030 BAU conditions and the four regulatory scenarios. These inputs are used in BenMAP, along with pre-loaded datasets representing valuation functions, health impact functions, baseline health incidence rates, and population growth rates from Woods & Poole (2015). The BenMAP model outputs the change in all-cause mortality incidence for the four regulatory scenarios and the accompanying value of avoided mortality.

Figure 26. Overview of Analysis of Human Health Benefits of Altering Roadway Emissions




Notes:
CBG = census block group; C-LINE = community line source model; MOVES = motor vehicle emission simulator; PM2.5 = particulate matter with diameter less than 2.5; VSL = value of a statistical life

## BenMAP Inputs

BenMAP relies on a number of inputs to estimate health impacts and potential associated costs from changes in exposures to air pollution. The inputs include the estimated baseline and post-compliance (i.e., scenario-specific) air quality data, baseline health statistics for each health outcome of interest, health impact functions derived from epidemiological studies, data on the population exposed to air quality changes, and valuation functions to quantify potential costs associated with each health outcome. In developing BenMAP inputs for this analysis, we used data specific to the four-county Puget Sound region (King, Pierce, Snohomish, and Kitsap Counties) as well as pre-loaded datasets included within the BenMAP interface.

## Baseline and Post-Compliance Air Quality Scenarios

We used the 2030 modeled concentration of $PM_{2.5}$ for the BAU and each of the four scenarios described above as inputs to BenMAP to determine changes in health impacts.

## Health Impact Functions

BenMAP has several pre-loaded health impact functions that estimate the impact of a change in air pollution on adverse health effects. We used health impact functions based on epidemiological studies to assess the impact of $PM_{2.5}$ reductions on all-cause mortality incidence. BenMAP includes five health impact functions for premature mortality from annual exposure to $PM_{2.5}$.[89] Each function was developed based on data from cohort studies performed in various locations throughout the U.S. and uses different formulas and coefficients. The applicable ages for each health impact function reflect the age groups examined in the cohort studies.[90] We chose the health impact functions utilized in the air quality benefits analyses for the National Ambient Air Quality Standards (NAAQS) Regulatory Impact Analysis[91] and the Clean Power Plan (CPP) Final Rule,[92] and compared functions for adults, and used a separate estimate for children under age 1. Table 34 below summarizes the formulas and applicable ages for these health impact functions.

Table 34. Selected All-Cause Mortality Health Impact Functions

| Author(s) | Year | Applicable Ages | Health Impact Function [a] |
|---|---|---|---|
| Krewski et al.[93] | 2009 | 30-99 | (1-(1/EXP(Beta*DeltaQ)))*Incidence*POP |
| Lepeule et al.[94] | 2012 | 25-99 | (1-EXP(-Beta*DeltaQ))*Incidence*POP |
| Woodruff et al.[95] | 2006 | <1 | (1-(1/((1-Incidence)*EXP(Beta*DeltaQ)+Incidence)))*Incidence*POP |

[a] Health impact function variables are defined as follows: Beta = coefficient representing the mean value of the Beta (normal) distribution; DeltaQ = the difference between the baseline and scenario concentrations; Incidence = baseline mortality incidence rate; POP = population.

[89] U.S. EPA. 2018. Environmental Benefits Mapping and Analysis Program – Community Edition. BenMAP-CE User's Manual. Updated for BENMAP-CE Version 1.4.8. BenMAP also includes functions for assessing changes in acute and chronic bronchitis incidence resulting from changes in annual exposures to $PM_{2.5}$.

[90] BenMAP does not include all-cause mortality health impact functions applicable to people between the ages of one and 25.

[91] U.S. EPA. 2012. Regulatory Impact Analysis for the Final Revisions to the National Ambient Air Quality Standards for Particulate Matter. Office of Air Quality Planning and Standards. Health and Environmental Impacts Division. Research Triangle Park, NC 27711. EPA-452/R-12-005.

[92] U.S. EPA. 2015. Regulatory Impact Analysis for Review of the Clean Power Plan Final Rule. U.S. Office of Air and Radiation. Office of Air Quality Planning and Standards. Research Triangle Park, NC 27711. EPA-452/R-15-003. Other health impact functions for all-cause mortality available in BenMAP include Laden et al. (2006) and Pope et al. (2002).

[93] Krewski, D., et al. 2009. Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality. HEI Research Report, 140, Health Effects Institute, Boston, MA.

[94] Lepeule, J., et al. 2012. Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. Environmental health perspectives 120.7: 965-970.

[95] Woodruff, T. J., et al. 2006. Fine particulate matter (PM2.5) air pollution and selected causes of post-neonatal infant mortality in California. Environmental Health Perspectives. Vol. 114: 786-790.

## Baseline Health Incidence Data

To estimate the absolute change in annual incidence of mortality using pre-loaded health impact functions, BenMAP requires data on the baseline incidence rate of mortality. The baseline incidence rate is an estimate of the average number of people who die in a given population over a specified period of time (i.e., incidence per 100,000 per year). BenMAP includes pre-loaded age-, cause-, and county-specific mortality rates for the United States in five-year increments, from years 2000 to 2060. We use pre-loaded all-cause mortality incidence rates for the end year of the potential policy implementation, or 2030. The product of the baseline incidence rates and the exposed population provides the total baseline incidence per year in the study region – a necessary input for the health impact functions (see Table 34).

## Exposed Population

The exposed population is the number of people affected by the reduction in $PM_{2.5}$ levels resulting from the low carbon fuel standards policy scenarios. In this analysis, the exposed population includes residents living in the four-county Puget Sound region.[96] To support analysis of distributional impacts of the implementation of low carbon fuel standards, we perform the analysis at the CBG level. BenMAP includes pre-loaded population data based on 2010 U.S. Census data at the county and CMAQ[97] 12-km levels, but not at the CBG level. ICF used EPA's PopGrid program to allocate 2010 U.S. Census population data by gender, age group, and race/ethnicity to the CBG-level grid in BenMAP.[98] Of the 2,647 CBGs in the four-county Puget Sound region, seven had no data on 2010 adult population and 18 had no data on 2010 infant population. As result, these CBGs were excluded from the analysis.

BenMAP also includes a pre-loaded dataset of county-level population growth rates developed by Woods and Poole.[99] These growth rates are age-, race-, and gender-specific. To estimate the affected population in 2030, ICF used the 2010 U.S. Census population data obtained from PopGrid for each CBG in conjunction with the Woods and Poole county-level population growth rates. We use the Woods and Poole growth rates instead of state-level growth rates provided by the Washington State Office of Financial Management because growth rates at the county level are more granular and provide a more accurate representation of the expected changes in population for the four-county Puget Sound region. On average, the predicted adult population increase from 2010-2030 based on Woods and Poole growth rates is within 3% of the predicted statewide average population increase for all ages from 2010-2030 based on Washington State Office of Financial Management growth rates (e.g., a 35% increase for all ages vs. a 32% increase for adults ages 25-99 and a 35% increase for adults ages 30-99).

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[96] Of the 2,647 CBGs in the four-county Puget Sound region, 12 CBGs were outside of the domain modeled using C-LINE and 22 CBGs had no air quality concentrations. The BenMAP model assigns no $PM_{2.5}$ concentrations to these CBGs and the accompanying populations are not included in the exposed population.

[97] Refers to the Community Multiscale Air Quality Modeling System

[98] The PopGrid program in its current iteration only provides age-, race-, and gender-specific populations for a user-defined grid based on 2010 U.S. Census data.

[99] Woods & Poole Economics Inc. 2015. Complete Demographic Database. Washington, DC. http://www.woodsandpoole.com/index.php.

## Valuation Functions

The final step in the analysis is to estimate the economic value of avoided health impacts. BenMAP includes several pre-loaded valuation functions for health endpoints associated with $PM_{2.5}$ concentrations. Following EPA's guidance for economic analysis,[100] ICF relies on the value of a statistical life (VSL; $8,705,114 in 2015$) to estimate the value of avoided mortality.[101] Within BenMAP, we specify an income growth year of 2030 and a dollar value year of 2019 such that the valuation estimates reflect income levels in 2030 but present estimates in the current year (2019) dollars.

Mortality is typically found to be the driver for valuation given the magnitude of the VSL. ICF was not able to consider additional health endpoints, such as emergency room visits for cardiovascular disease, hospital visits for pneumonia, and asthma-related effects that relied on shorter term exposure which was not characterized in our original C-LINE simulations under this contract.

## Health Impact Assessment Results

We estimated the number of avoided premature mortality cases and the monetary value of benefits of reducing long-term (annual) $PM_{2.5}$ levels from the 2030 BAU Scenario to the four scenarios. These results are summarized in Table 35 below. The estimated avoided mortality incidence and monetary values of benefits reported in Table 35 represent the sum of avoided mortality incidence or monetary benefits for each CBG. Because a dollar today is worth more than a dollar in 2030, the table provides the present value of benefits incurred in 2030, using a 3% discount rate.

As shown in Table 35, the total number of avoided all-cause mortality cases (including adults and infants) from changes in $PM_{2.5}$ levels resulting from the implementation of the Puget Sound CFS range from about one to six cases per year, depending on the scenario.[102] The present value of benefits from a reduction in $PM_{2.5}$ levels in 2030 ranges from $13.8 million to $45.7 million in 2019$, depending on the analyzed scenario and health impact function (i.e., Krewski et al., 2009 or Lepeule at al., 2012).

U.S. EPA rulemakings, such as the NAAQS and Clean Power Plan rules, report estimates of the potential benefits from reducing $PM_{2.5}$ levels as a range, with the lower range of estimates based on the Krewski et al. (2009) function and the higher range of estimates based on the Lepeule et al. (2012) function. Following the EPA methodology, we present benefits from both health impact functions as a range.

[100] U.S. EPA. 2010. Guidelines for Preparing Economic Analyses. EPA 240-R-10-001.
[101] U.S. EPA. 2018. Environmental Benefits Mapping and Analysis Program – Community Edition. BenMAP-CE User's Manual. Updated for BENMAP-CE Version 1.4.8.
[102] To put these results into perspective, according to Centers for Disease Control (CDC) mortality rates, there were 4,182 all-cause mortality cases for adults ages 25-99 in the four-county Puget Sound region in 2017 (CDC, 2019). The avoided mortality cases under Scenario D make up about 0.13% of all deaths in the region in 2017. Similarly, there were 513 mortality cases for adults ages 25-99 attributed to diseases of the circulatory system in the four-county Puget Sound region in 2017 (CDC, 2019). The avoided mortality cases under scenario D make up about 1% of these deaths.

Table 35. Annual Benefits of Avoided All-Cause Mortality Resulting from Reductions in Roadway $PM_{2.5}$ Concentrations in 2030 by Policy Scenario (2019$)

| Scenario | Avoided Mortality Incidence (No. Cases Avoided)[a] | Present Value Benefits, 3% Discount [a,b] |
|---|---|---|
| A | 1.6 to 3.6 | $13,800,000 to $31,100,000 |
| B | 1.8 to 4.1 | $15,700,000 to $35,400,000 |
| C | 1.8 to 4.0 | $15,500,000 to $34,800,000 |
| D | 2.4 to 5.3 | $20,300,000 to $45,700,000 |

[a] The number of avoided mortality cases and benefits are presented as a range, with the lower value representing infants and adults ages 30-99 based on Woodruff et al. (2006) and Krewksi et al. (2009) and the upper value representing infants and adults ages 25-99 based on Woodruff et al. (2006) and Lepeule et al. (2012).

[b] The present value of the 2030 benefits is determined assuming a 3% discount rates. The 3% discount rate reflects society's valuation of differences in the timing of benefits.

As summarized in Table 35, Scenario D shows the greatest potential reduction in mortality incidence and the highest accompanying benefits resulting from implementation of a low carbon fuel standard, followed by Scenario B, Scenario C, and Scenario A. Variation in the potential benefits from reducing $PM_{2.5}$ levels is fairly limited across the four scenarios, especially for Scenarios B and C, which yield very similar benefits

## Limitations and Uncertainties

Table 36 summarizes principal limitations and sources of uncertainty associated with the estimated reduction in incidence of all-cause mortality and the economic value of benefits resulting from changes in $PM_{2.5}$ emissions in the four-county Puget Sound region. Uncertainties and limitations associated with the development of $PM_{2.5}$ concentration surfaces are discussed previously in the Concentration Analysis sub-section. The key uncertainties presented here are related to population estimates, health impact functions, and valuation functions used in the benefits analysis.

Table 36. Limitations and Uncertainties in the Analysis of Human Health Benefits from Changes in $PM_{2.5}$ Concentration Levels

| Uncertainty/Assumption | Effect on Benefits Estimate | Notes |
|---|---|---|
| ***Population Data and Growth Rates*** | | |
| The analysis relies on the PopGrid program to estimate age-, race-, and gender-stratified population totals for each CBG. The program is constrained to estimate population based on the 2010 U.S. Census. | Uncertain | The PopGrid program is a BenMAP tool that allocates the 2010 U.S. Census population to a user-defined grid, producing a population file that is ready for input into BenMAP. The population growth rates used in BenMAP rely on age-, race-, and gender-specific population totals from 2010 to estimate future year populations. Applying growth rates to populations from 2010, rather than more recent population totals, likely to result in a higher degree of uncertainty in future populations estimates. |

| Uncertainty/Assumption | Effect on Benefits Estimate | Notes |
|---|---|---|
| The PopGrid program estimated zero population for seven CBGs and, thus, these CBGs were excluded from the benefits analysis. | Underestimate | Based on a shapefile input of CBGs in the four-county Puget Sound region, the PopGrid program estimated zero population for seven CBGs. We compared the 2010 PopGrid output for these seven CBGs to population estimates from the U.S. Census Bureau American Community Survey (ACS) population totals for 2010 and 2017 (U.S. Census Bureau, 2017) and found that two out of the seven CBGs had nonzero populations in both datasets (the remaining five CBGs had zero population in both 2010 and 2017). The ACS population totals for the two CBGs make up 0.04% of the total population for the four-county Puget Sound region. The exclusion of these two CBGs in our analysis may result in a slight underestimate of benefits. |
| The analysis relies on county-level growth rates within BenMAP based on Woods & Poole (2015). | Uncertain | Because the analysis focuses on four counties within Washington, we used Woods & Poole (2015) county-level growth rates to estimate total population in 2030. We compared the growth rates for the BenMAP output from 2010-2030 for age groups used in adult health impact functions (25-99 and 30-99) to the all ages state-level growth rate from 2010-2030 provided by PSCAA and found that, on average, the BenMAP population growth rate is within 3% of the state-level rate. Woods & Poole (2015) population projections are based on income levels, earnings by industry, employment by industry, inflation, projected migration rates, and other variables. Inherent limitations to Woods and Poole (2015) growth rates may include events that could not be foreseen based on analysis of historical data, such as abrupt economic shifts, changing patterns in migration, displacement due to natural disasters, etc. |
| U.S. Census data from 2010-2017 suggest a smaller growth rate for some CBGs than implemented in BenMAP using Woods and Poole (2015) growth rates. | Overestimate | The BenMAP model predicted that populations age 25-99 would increase by more than 100% from 2010-2030 for ten CBGs. The 2030 population estimates for these CBGs make up 0.57% of the total 2030 population assessed in BenMAP. We examined ACS population totals from 2010-2017 (U.S. Census Bureau, 2017) and found that three of the ten CBGs actually experienced reductions in population and an additional three CBGs showed modest growth during this period. |
| Exposure does not include commuting impacts. | Underestimate | The modeling approach assumes that the CBG population is only exposed to $PM_{2.5}$ levels modeled within its particular CBG and does not consider different exposure levels for those who commute or travel regularly to other locations within the four-county Puget Sound region. The modeling approach also does not account for populations who live outside of and commute to locations within the four-county Puget Sound region. This may result in an underestimate of benefits. |

| Uncertainty/Assumption | Effect on Benefits Estimate | Notes |
|---|---|---|
| The analysis is limited to populations ages 25-99 and infants. | Underestimate | The health impact functions available in BenMAP for the all-cause mortality are applicable to only infants and adults ages 25-99. Populations between the age of one and 24 are thus excluded from the analysis. This may result in an underestimate of benefits. |
| ***Health Impact and Valuation Assessment*** | | |
| The analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality and does not consider other health outcomes. | Uncertain | $PM_{2.5}$ varies considerably in composition across sources (U.S. EPA, 2015). Although $PM_{2.5}$ can be linked with multiple health effects, our analysis does not differentiate the chemical constituents or sources that might result in other health outcomes. |
| The analysis assumes that health impact functions based on national or regional studies are representative of exposure and population characteristics in the four-county Puget Sound region. | Uncertain | BenMAP does not include health impact functions specific to the four-county Puget Sound region. Instead, we rely on health impact functions from Krewski et al. (2009) – based on 116 U.S. cities, Lepeule et al. (2012) – based on 6 Eastern cities, and Woodruff et al. (2006) – based on 204 counties. Mortality estimates from Lepeule et al. (2012) tend to be higher than estimates from Krewski et al. (2009). Although the Lepeule et al. (2012) approach is based on data from the Eastern U.S., we use it to represent a high-end estimate of health impacts in the Puget Sound region. |
| The analysis assumes that the health impact functions for fine particles are log-linear without a threshold. | Uncertain | Benefits estimates under the four regulatory scenarios include benefits from reductions in fine particles in areas with varied levels of $PM_{2.5}$ concentrations, including areas that meet $PM_{2.5}$ air quality standards and areas that do not. |
| The VSL used in this analysis is the mean of a distribution fitted to 26 VSL estimates in the economic literature. | Uncertain | The VSL reflects the amount that individuals are willing to pay to incrementally reduce their risks of death from adverse health conditions resulting from environmental pollution. The VSL value does not distinguish among people based on the age at their death or the quality of their lives and is applied to all premature deaths. |

# 6. Conclusions

ICF's analysis of a Puget Sound CFS is informed by scenario modeling considering various low-carbon fuel strategies, a consideration of limitations in the Puget Sound transportation fuels market, economic impact modeling using the REMI model, and a health impact analysis based on changes in air quality pollutant emissions. The following are the primary conclusions from ICF's analysis.

**ICF's analysis indicates that the Puget Sound region has a significant carrying capacity for low carbon fuels, and the deployment of other low carbon fuel strategies.** California's LCFS and Oregon's CFP have demonstrated that the right price signal can induce low carbon fuel deployment—and ICF's analysis assumes that the Puget Sound region would presumably benefit from some of the induced investment from these other programs, and help to ensure sufficient demand for the low-carbon fuels produced. There are several relevant aspects of the Puget Sound region with respect to low-carbon fuel deployment:

- The region currently has low-level blends of biodiesel and renewable diesel—both of which would likely be consumed in the region at considerably higher volumes with even a modest price signal from a CFS. ICF scenario modeling suggests that the near-term deployment of liquid biofuels could help a proposed Puget Sound CFS develop an adequate bank of credits to help offset the potential stringency of a CI target in the later years of the program. The potential to blend higher volumes of biofuels is bolstered by the proximity to several existing and planned regional projects that produce or will produce biodiesel and renewable diesel.
- The Puget Sound region already has a strong demand for EVs based on adoption to date; ICF assumes that the introduction of a regional CFS has the potential to accelerate that trend. The potential value of increased electricity consumption in light-, medium-, and heavy-duty vehicles is boosted by the low carbon intensity of electricity generation in the region.
- The Puget Sound region has a small natural gas footprint in the transportation sector, but has significant domestic RNG resources that have the potential to be developed to displace geologic or fossil natural gas rapidly.
- The Puget Sound region includes a refinery, and is in close proximity to another four refineries. There is significant potential for refinery carbon intensity improvements—including through efficiency projects and renewable hydrogen deployment.

**The Puget Sound region can achieve a 10%-16% carbon intensity reduction by 2030 with only modest changes to the transportation fuel supply.** Scenario A and Scenario B in ICF's analysis focused on modest changes to biofuel blending and more aggressive assumptions regarding electrification, focusing primarily on light-duty fleets. Similarly, ICF's analysis of a 16% carbon intensity reduction by 2030 can be achieved with feasible changes to the transportation fuel supply—assuming that the price signal from the program is strong enough to attract lower-carbon liquid biofuels and RNG, and that the credits generated from the program can help to defray the costs of purchasing more expensive vehicles like EVs, hydrogen FCVs, and NGVs.

**ICF estimates that the maximum achievable carbon intensity reduction in the Puget Sound region is 26% by 2030.** ICF assumes that this can be achieved via the aggressive implementation of low carbon fuel strategies, including but not limited to increased liquid biofuel blending (for ethanol, biodiesel, and renewable diesel), increased natural gas vehicle deployment (with those vehicles using RNG), accelerated EV deployment in light-, medium- and heavy-duty applications, renewable jet fuel blending, refinery efficiency improvements, and renewable hydrogen use at refineries.

**Compliance with a proposed Puget Sound CFS will require a range of investments in low carbon fuel production, retail distribution infrastructure, and advanced vehicle technologies.** There are several hundred million dollars of investment required by 2030 to support the deployment of lower-carbon fuel production, and another $600 million to $1.6 billion on light-duty vehicle expenditures, depending on the scenario. These investments are critical to enabling a low-carbon future in the Puget Sound region's transportation sector—and can help to realize net positive economic impacts through fuel savings and job growth in domestic expansion of low-carbon fuel production.

**The modeled economic impacts of compliance with a Puget Sound CFS are small, and have a negligible impact on forecasted growth in the region.** ICF's analysis using the REMI model shows results ranging from -0.099% to +0.017% for employment and -0.091% to -0.026% for GRP in 2030. In other words, ICF's analysis indicates that the economic impacts across all four scenarios considered yield employment and GRP impacts less than 0.1%. The trends revealed from the economic impact modeling indicate that greater fuel diversification—including through increased use of electricity and natural gas as transportation fuels—can help increase GRP and employment in the region, with the most diverse scenario D yielding the most positive (albeit small) economic impact results. The increased costs of advanced vehicle technologies, most notably EVs, and the assumed pass-through of compliance costs contribute to negative impacts in the modeling.

**ICF's analysis of the air quality implications of the compliance scenarios indicates positive health impacts associated with the implementation of the Puget Sound CFS**. ICF estimated changes in $PM_{2.5}$ concentrations from implementing the CFS, and subsequently quantified human health benefits associated with those reductions using the BenMAP model. ICF reports one to six avoided all-cause mortality cases per year (including adults greater than 25 years old and infants under one year old) from changes in $PM_{2.5}$ levels resulting from the implementation of the Puget Sound CFS. The present value of benefits from a reduction in $PM_{2.5}$ levels in 2030 ranges from $13.8 million to $45.7 million. These results do not include all $PM_{2.5}$ health endpoints, nor do they include health co-benefits from other tailpipe emissions reduced as a result of a CFS.

# Appendix A: Carbon Intensity Analysis

## WA-GREET Methodology

A Washington-specific GREET model was developed by Life Cycle Associates in 2013 that was based on the Argonne National Laboratory (ANL) GREET model version GREET1_2013. ICF and the Agency agreed that this model is outdated with assumptions and data from prior to 2013. Instead of using the 2013 model, ICF recommended modifying the California Air Resources Board's (CARB) CA-GREET3.0 model. It was agreed this would be the most relevant and expedient solution to developing a current, Washington-specific GREET model. CA-GREET3.0 is currently used for fuel pathways in California's Low Carbon Fuel Standard (LCFS) and would allow for consistency in overall assumptions and modeling framework between a Washington model and the LCFS. The modifications of the CA-GREET3.0 to develop a WA-GREET are summarized in the following sections.

### Electricity Grid Mix Update

ICF updated the Electricity Generation Mixes with EPA's Emissions & Generation Resource Integrated Database (eGRID) 2016 data[103]. Since it is unlikely to be used, ICF replaced the user's option for Hawaii HICC Miscellaneous eGRID subregion with a Washington State option. ICF replaced all HICC data with Washington State data. This includes regional combustion technology shares, regional power plant energy conversion efficiencies, and the electric generation mix of the state of Washington.[103] ICF compared the generation mix of the utilities serving the Puget Sound counties[104] with the Washington State average. Due to Puget Sound Energy's significant use of coal generation, the carbon intensity of electricity from utilities in the four county Puget Sound region was calculated to be over two times greater than the Washington State average. Table 37 and Table 38 below provide a comparison of the electricity mixes in Puget Sound versus the Washington average. Table 37 does not include a few smaller utilities serving communities in Pierce County. Since the service areas of these utilities would only be a small fraction of the total service area in Puget Sound (less than 5%), they were excluded. They are conceptually represented by Lakeview and Peninsula. The excluded utilities are Fircrest, Milton, Elmhurst Mutual, Parkland, Ruston, and Steilacoom.

103 US EPA, Emissions and Generated Resource Integrated Database 2016. Available at: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid; released 2/15/2018

104 Puget Sound Clean Air Agency, Greenhouse Gas Emissions Inventory, Tables 5 & 6, 2018. Available at: http://www.pscleanair.org/DocumentCenter/View/3328/PSCAA-GHG-Emissions-Inventory

Table 37: Reported Fuel Mix of Electric Utilities in PSCAA Region, 2017[104]

| Fuel | Puget Sound Energy[105] | Seattle City[106] | Snohomish[107] | Tacoma[108] | Peninsula[109] | Lakeview[110] | Weighted Average |
|---|---|---|---|---|---|---|---|
| Residual Oil/Fossil fuels | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0% |
| Natural gas | 21.0% | 1.0% | 0.4% | 1.0% | 1.0% | 0.9% | 10% |
| Coal | 38.0% | 1.0% | 0.4% | 1.5% | 1.0% | 2.4% | 17% |
| Nuclear | 0.6% | 4.0% | 9.0% | 6.1% | 8.0% | 10.2% | 4% |
| Biomass | 0.3% | 1.0% | 0.2% | 0.2% | 0.0% | 0.2% | 0% |
| Hydroelectric | 33.0% | 91.0% | 90.0% | 84.0% | 83.0% | 86.3% | 65% |
| Geothermal | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0% |
| Wind | 6.0% | 1.0% | 0.0% | 7.0% | 7.0% | 0.0% | 4% |
| Solar PV | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0% |
| Others (purchased) | 1.0% | 1.0% | 0.0% | 0.2% | 0.0% | 0.1% | 1% |
| Proportion Based on kWh Consumed | 43.58% | 25.06% | 17.04% | 12.09% | 1.54% | 0.69% | |
| GREET CI [g $CO_2e$/MJ] | 150.47 | 4.90 | 2.00 | 6.27 | 4.75 | 8.76 | 68.03 |
| **Pathway CI for LD BEV[111]** | **44.3** | **1.44** | **0.59** | **1.84** | **1.40** | **2.58** | **20.0** |

[105] Accessed via https://www.pse.com/pages/energy-supply/electric-supply
[106] Accessed via http://www.seattle.gov/light/FuelMix/
[107] Accessed via https://www.snopud.com/PowerSupply.ashx?p=1105
[108] Accessed via https://www.mytpu.org/tacomapower/about-tacoma-power/dams-power-sources/
[109] Accessed via https://www.penlight.org/energy-services/power-resources/
[110] Accessed via https://lakeviewlight.com/wp-content/uploads/LLP-Spring-2017-Newsletter_Final_Production-Ready.pdf
[111] This is the estimated pathway for a light-duty BEV accounting for the Energy Economy Ratio (EER) of 3.4.

Table 38: Washington State Average Electricity Generation Mix and CI

| Fuel | % Generation Mix |
|---|---|
| Residual Oil/Fossil fuels | 0% |
| Natural gas | 10% |
| Coal | 4% |
| Nuclear | 8% |
| Biomass | 2% |
| Hydroelectric | 69% |
| Geothermal | 0% |
| Wind | 7% |
| Solar PV | 0% |
| Others (purchased) | 0% |
| **GREET WA CI [g $CO_2$e/MJ]** | **28.8** |

As an alternate scenario, ICF projected Puget Sound's electricity grid mix carbon intensity to 2030 assuming major changes to Puget Sound Energy's generation mix. Table 39 provides the estimated generation mix for Puget Sound Energy based on the following assumptions:

- 2025: Assumed that coal generation is replaced entirely by natural gas
- 2030: 60% of total generation from renewable sources
    - Natural gas is replaced by renewable sources
    - Type of renewable sources grow proportionally to the current mix

Table 39 presents the carbon intensity of the PSCAA jurisdiction's electricity generation resulting from these changes to PSE's mix. The carbon intensity values of the other utilities are not projected to change due to their already high rates of renewable generation. The values in Table 40 are calculated based on the assumption that the relative demand for electricity from each utility remains consistent with 2017 demand. By 2030, the carbon intensity of the PSCAA's counties drop to the current CI of the state of Washington. Taking into account Puget Sound Energy's agreement to permanently retire a portion of the coal generation mix by July 1, 2022 and shut down another coal plant in 2025[112], ICF used the Washington State Mix in the fuel pathway analysis. While it is beyond the time horizon of this analysis, it is worth noting that the CI of electricity will continue to decrease under a state law passed in 2019—with a goal of being carbon-free in 2045.[113]

[112] http://www.seattleweekly.com/news/puget-sound-energy-to-retire-some-coal-fired-power/ ; https://www.pse.com/pages/carbon-reduction-plan

[113] Washington State Legislature. SB5116 2019. https://app.leg.wa.gov/billsummary?BillNumber=5116&Year=2019.

Table 39: Puget Sound Energy Generation Mix and Carbon Intensity Projection

| Fuel | 2017 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Nonrenewable Sources | 60.0% | 60.0% | 50.0% | 40.0% |
| Residual Oil/Fossil fuels | 0.1% | 0.1% | 0.1% | 0.1% |
| Natural gas | 21.0% | 35.3% | 49.0% | 39.0% |
| Coal | 38.0% | 23.8% | 0.0% | 0.0% |
| Nuclear | 0.6% | 0.6% | 0.6% | 0.6% |
| Biomass | 0.3% | 0.3% | 0.3% | 0.3% |
| Renewable Sources | 40.0% | 40.0% | 50.0% | 60.0% |
| Hydroelectric | 33.0% | 33.0% | 41.3% | 49.5% |
| Geothermal | 0.0% | 0.0% | 0.0% | 0.0% |
| Wind | 6.0% | 6.0% | 7.5% | 9.0% |
| Solar PV | 0.0% | 0.0% | 0.0% | 0.0% |
| Others (purchased) | 1.0% | 1.0% | 1.2% | 1.5% |
| **PSE GREET CI [g $CO_2$e/MJ]** | **150.47** | **128.27** | **75.83** | **60.4** |

Table 40: Projected PSCAA-area Electricity Generation Mix and CI

| Fuel | 2017 | 2020 | 2025 | 2030 |
|---|---|---|---|---|
| Residual Oil/Fossil fuels | 0% | 0% | 0% | 0% |
| Natural gas | 10% | 16% | 22% | 18% |
| Coal | 17% | 12% | 1% | 1% |
| Nuclear | 4% | 4% | 4% | 4% |
| Biomass | 0% | 0% | 0% | 0% |
| Hydroelectric | 65% | 64% | 67% | 71% |
| Geothermal | 0% | 0% | 0% | 0% |
| Wind | 4% | 4% | 4% | 5% |
| Solar PV | 0% | 0% | 0% | 0% |
| Others (purchased) | 1% | 0% | 1% | 1% |
| **GREET CI [g $CO_2$e/MJ]** | **68.03** | **58.4** | **35.5** | **28.8** |

## Refining Efficiency Update

The WA-GREET model can be used to calculate the carbon emissions from crude refining and transport, based on an assumed value for refining efficiency. The GREET model computes a refining efficiency based on the crude API gravity and sulfur content. API gravity is an index of density created by the American Petroleum Institute. [114] ICF estimated crude API gravity and sulfur content based on the 2015 crude slate to Washington refineries. For each crude identifier, the API gravity was assumed to be consistent with values used as OPGEE inputs for the CA-

[114] https://www.mckinseyenergyinsights.com/resources/refinery-reference-desk/api-gravity/

LCFS Crude Oil Lifecycle Assessments.[115] The API gravity and sulfur content (wt %) were determined based on a weighted average, as seen in Table 41. The resulting refining efficiencies of Washington gasoline and diesel are presented in Table 42.

Table 41: API Gravity and Sulfur Content of Washington Crude

| Crude Source | % of Crude Slate | API Gravity | S Content (wt %) |
|---|---|---|---|
| Canadian Oil Sands Bitumen | 6% | 20.9 | 3.58% |
| Canadian SynCrude | 5% | 32 | 0.38% |
| Canadian Conventional Light | 25% | 30 | 0.65% |
| Bakken Crude | 24% | 40 | 0.19% |
| Alaska North Slope | 38% | 28.3 | 0.19% |
| Other foreign imports | 2% | 30.7 | 0.96% |
| **Average Washington Crude** | | **30.75** | **0.81%** |

Table 42: GREET Calculated Refining Efficiencies for WA Crude

| | |
|---|---|
| Gasoline Refining Efficiency | 89.0% |
| Diesel Refining Efficiency | 91.2% |
| Jet Fuel Refining Efficiency | 95.7% |

## Finished Fuel Transport Assumptions

The transport assumptions for fuel from the Washington refineries to the petroleum terminal and refueling stations are shown in Table 43 below, as assumed in the 2013 WA- GREET model developed by Life Cycle Associates, LLC.[116] The total can be over 100% because some of the fuel is transported by multiple transportation modes.

Table 43: Washington Gasoline & Diesel GREET Transportation and Distribution Assumptions

| T& D Inputs | WA Product | |
|---|---|---|
| | Share | Miles |
| Tanker | 0% | 0 |
| Barge | 11% | 200 |
| Pipeline | 99% | 82 |
| Rail | 0% | 0 |
| Truck | 100% | 76 |

[115] CARB. Low Carbon Fuel Standard. OPGEE Model and Supporting Information, MCON Inputs Spreadsheet for Crude Lookup Table. Available at: https://www.arb.ca.gov/fuels/lcfs/crude-oil/lookup_table_mcon_inputs_opgee_v2.0_2018-0306.xlsm

[116] Life Cycle Associates, LLC. A Clean Fuel Standard in Washington State Revised Analysis with Updated Assumptions, Table 3-8. 2014. https://ofm.wa.gov/sites/default/files/public/legacy/reports/Carbon_Fuel_Standard_evaluation_2014_final.pdf

## Washington Crude Carbon Intensity

To calculate the upstream carbon intensity of gasoline and diesel produced in Washington, ICF utilized the OPGEE results from California's LCFS Crude Oil Life Cycle Assessments[117]. ICF estimated a Washington Crude Oil Production and Transport CI by using the average LCFS reported crude carbon intensities, weighted by the proportion of each source. The upstream gasoline and diesel CI is estimated to be 12.96 g $CO_2$e/MJ, as shown in Table 44.

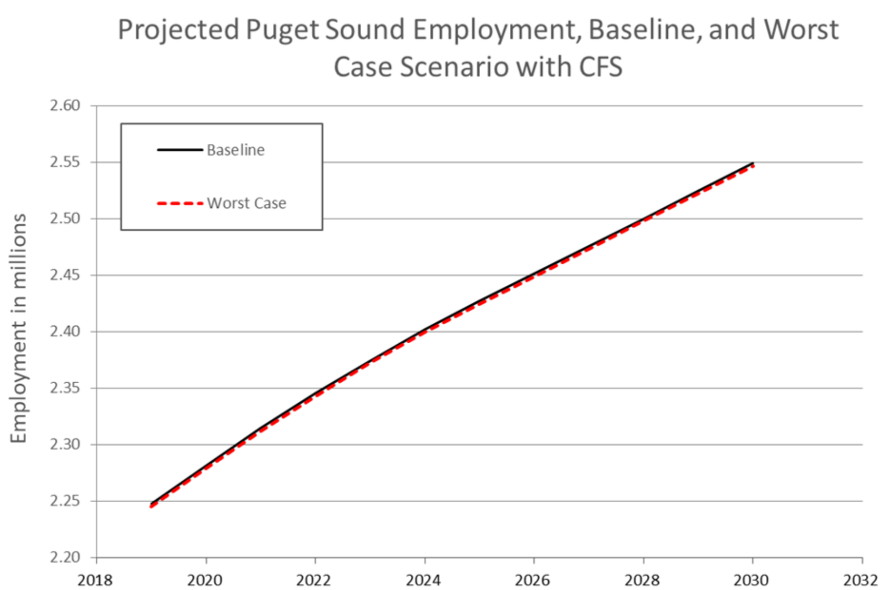
Table 44: Washington Crude Oil Production and Transportation Carbon Intensity

<table>
<tr><th>Crude Source</th><th>LCFS Crude Identifier</th><th>LCFS CI [g $CO_2$e/MJ]</th><th>Average CI</th><th>% WA Crude Slate</th></tr>
<tr><td rowspan="2">Canadian Oil Sands Bitumen</td><td>Christina Dilbit Blend</td><td>12.71</td><td rowspan="2">14.56</td><td rowspan="2">6%</td></tr>
<tr><td>Statoil Cheecham Dilbit</td><td>16.41</td></tr>
<tr><td rowspan="9">Canadian SynCrude</td><td>Albian Heavy Synthetic (all grades)</td><td>23.68</td><td rowspan="9">29.64</td><td rowspan="9">5%</td></tr>
<tr><td>CNRL Light Sweet Synthetic</td><td>25.27</td></tr>
<tr><td>Hardisty Synthetic</td><td>32.66</td></tr>
<tr><td>Long Lake Light Synthetic</td><td>40.12</td></tr>
<tr><td>Premium Albian Synthetic</td><td>29.49</td></tr>
<tr><td>Premium Synthetic</td><td>27.38</td></tr>
<tr><td>Shell Synthetic (all grades)</td><td>29.49</td></tr>
<tr><td>Suncor Synthetic (all grades)</td><td>27.09</td></tr>
<tr><td>Syncrude Synthetic (all grades)</td><td>31.62</td></tr>
<tr><td>Canadian Conventional Light</td><td>Canadian Conventional Light</td><td>8.11</td><td>8.11</td><td>25%</td></tr>
<tr><td>Bakken Crude</td><td>US North Dakota Bakken</td><td>9.73</td><td>9.73</td><td>24%</td></tr>
<tr><td>Alaska North Slope</td><td>Alaska North Slope</td><td>15.91</td><td>15.91</td><td>38%</td></tr>
<tr><td>All foreign imports</td><td>Weighted Average of all others</td><td>12.96</td><td>12.96</td><td>2%</td></tr>
<tr><td colspan="3">WA Crude Mix CI</td><td>13.13</td><td></td></tr>
</table>

[117] CARB Low Carbon Fuel Standard Final Regulation Order, Table 9: Carbon Intensity Lookup Table for Crude Oil Production and Transport. 2018. Available at: https://www.arb.ca.gov/regact/2018/lcfs18/frolcfs.pdf?_ga=2.246951810.766619030.1548198089-546402948.1536794631

# Appendix B: Full Results for Economic Impact Modeling

For context, as discussed in the REMI Modeling Results, the employment and GRP impact values reported are on top of (in addition to) the regional growth. From 2018 to 2030, the region is forecast to have a roughly 13% increase in GRP – (about $50 billion) reaching about $450 billion, and a growth of 330,000 jobs, reaching about 2.6 million jobs.[118] The results for each Scenario in the tables and plots below are added or subtracted to these baseline values. As shown in the figure below, even the worst case value from the modeling (-0.1%) is difficult to distinguish from




the baseline and is within the uncertainty of the modeling work (GRP is similar).

The projected employment in 2030, broken down by county, was estimated by projecting current employment estimates (proportioned from regional employment by current county population)[119] and a linear extrapolation to projected employment extracted from REMI. It is shown in the table below:

[118] Estimated from https://www.ofm.wa.gov/sites/default/files/public/dataresearch/pop/stfc/stfc_2018.pdf
[119] https://www.psrc.org/sites/default/files/economicanalysiswithcover.pdf

| County | 2016 | 2030 Projected |
|---|---|---|
| Kitsap | 151,000 | 180,000 |
| Snohomish | 409,000 | 480,000 |
| King | 1,140,000 | 1,350,000 |
| Pierce | 452,000 | 540,000 |
| Region | 2,150,000 | 2,550,000 |

The employment impact results for each scenario are presented in a series of tables and graphs in the sub-sections below; in each figure, there are seven categories or factors that are plotted to what drives the overall trend. The table below lists the categories and provides a brief description of what each category represents.

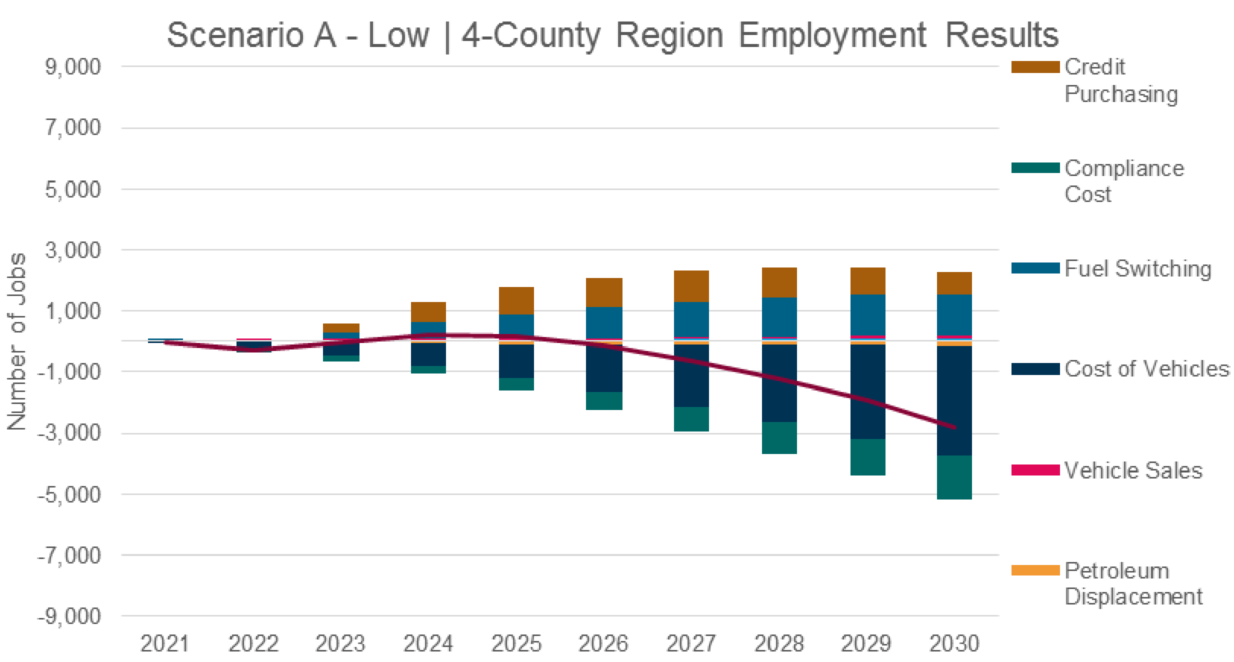
| Impact Category | Description |
|---|---|
| Credit Purchasing | • Reflects the increased revenue to low carbon fuel providers based on the value of credits generated via the deployment of the lower carbon fuels in the Puget Sound region. |
| Compliance Cost | • Accounts for the assumption that the compliance cost (i.e., purchasing credits) will be passed through to consumers. |
| Fuel Switching | • Low carbon fuels like electricity and natural gas have a lower price than petroleum-based fuels, yielding a lower total cost of ownership. These lower fuel costs are reflected in this category. |
| Cost of Vehicles | • Alternative fuel vehicles, like EVs and NGVs, tend to be more expensive than their conventional counterparts that use combustion engines. As a result, there are increased expenditures by consumers and commercial and industrial sectors that for light-duty vehicles and MD/HD vehicles, respectively. ICF assumed that EV pricing over time, but even |
| Vehicle Sales | • The increased costs of alternative fuel vehicles also yields increased investment by the vehicle manufacturing sector, thereby increasing economic activity in the sector and associated economic sectors. |
| Petroleum Displacement | • The implementation of a Puget Sound CFS will reduce the amount of petroleum consumed in the region, thereby decreased regional demand for petroleum. This will have a negative impact on the refining industry—and this category reflects the decrease in revenue to refineries as a result of either displaced product, or higher transportation costs to export the product out of the region. |
| Retail Fuel and Charging Infrastructure | • Low carbon fuels will require investment in new or modified retail fueling infrastructure—these investments include converting existing petroleum-based fueling infrastructure to accommodate higher biofuel blends to providing and deploying EV charging infrastructure. |

# Scenario A: Biofuel Blending

## Scenario A, Low Credit Price

| Employment Impact (# of Jobs) - Scenario A - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -3 | -50 | -23 | -6 | -36 | -102 | -201 | -316 | -450 | -609 |
| King | 0 | -155 | 64 | 289 | 329 | 230 | 13 | -261 | -621 | -1,084 |
| Pierce | -5 | -68 | -57 | -60 | -107 | -202 | -333 | -495 | -683 | -903 |
| Kitsap | -4 | -19 | -17 | -19 | -35 | -62 | -98 | -139 | -184 | -235 |
| Rest of Washington | 3 | -25 | 25 | 84 | 123 | 141 | 148 | 142 | 116 | 75 |
| Total Washington | -9 | -317 | -8 | 288 | 273 | 5 | -472 | -1,069 | -1,823 | -2,756 |
| Total 4-County Region | -12 | -292 | -33 | 204 | 150 | -135 | -620 | -1,210 | -1,939 | -2,831 |

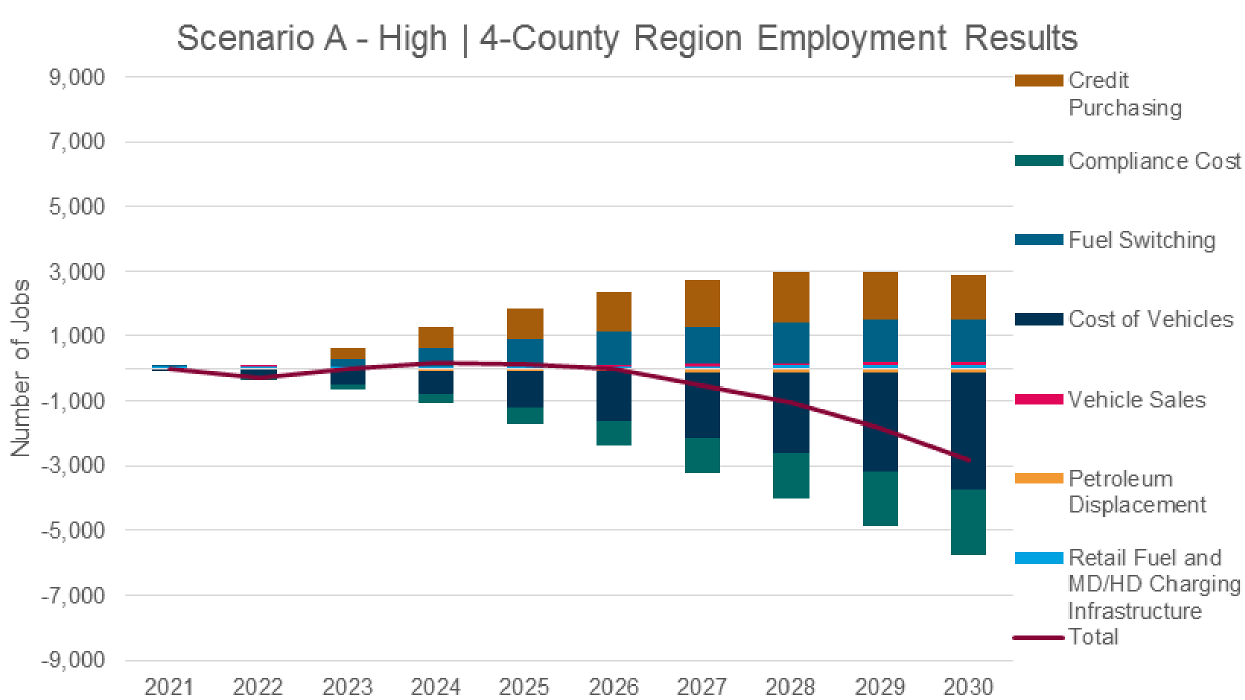
| GRP Impact (Millions 2018$) - Scenario A - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | 0.0 | -4.1 | -2.1 | -1.0 | -4.3 | -11.2 | -21.8 | -34.6 | -49.8 | -67.8 |
| King | 0.6 | -17.6 | 10.9 | 41.9 | 50.7 | 41.0 | 14.9 | -21.2 | -71.8 | -138.8 |
| Pierce | -0.4 | -10.4 | -15.1 | -24.2 | -37.7 | -57.9 | -82.9 | -113.4 | -148.7 | -188.1 |
| Kitsap | -0.2 | -1.2 | -0.7 | -0.4 | -1.2 | -2.7 | -5.0 | -7.6 | -10.7 | -14.5 |
| Rest of Washington | 2.9 | -25.1 | 25.0 | 83.7 | 122.8 | 140.8 | 147.6 | 141.6 | 116.0 | 74.8 |
| Total Washington | 2.8 | -58.4 | 18.0 | 99.9 | 130.3 | 110.0 | 52.9 | -35.3 | -165.0 | -334.4 |
| Total 4-County Region | -0.1 | -33.3 | -7.0 | 16.2 | 7.5 | -30.8 | -94.8 | -176.9 | -281.0 | -409.2 |



## Scenario A, High Credit Price

| Employment Impact (# of Jobs) - Scenario A - High | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -3 | -50 | -23 | -8 | -43 | -94 | -198 | -310 | -459 | -637 |
| King | 0 | -155 | 64 | 279 | 318 | 325 | 132 | -77 | -468 | -980 |
| Pierce | -5 | -68 | -57 | -62 | -114 | -202 | -345 | -515 | -734 | -990 |
| Kitsap | -4 | -19 | -17 | -19 | -38 | -61 | -99 | -139 | -188 | -244 |
| Rest of Washington | 3 | -25 | 25 | 84 | 133 | 179 | 204 | 216 | 188 | 139 |
| Total Washington | -9 | -317 | -8 | 273 | 256 | 147 | -306 | -825 | -1,660 | -2,711 |
| Total 4-County Region | -12 | -292 | -33 | 189 | 123 | -32 | -510 | -1,041 | -1,848 | -2,850 |

| GRP Impact (Millions 2018$) - Scenario A - High | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | 0.0 | -4.1 | -2.1 | -1.2 | -4.9 | -10.5 | -21.5 | -34.2 | -51.0 | -71.3 |
| King | 0.6 | -17.6 | 10.9 | 40.7 | 50.1 | 55.5 | 34.6 | 9.6 | -43.2 | -115.1 |
| Pierce | -0.4 | -10.4 | -15.1 | -24.3 | -38.4 | -60.0 | -88.4 | -123.8 | -166.1 | -213.8 |
| Kitsap | -0.2 | -1.2 | -0.7 | -0.5 | -1.3 | -2.5 | -4.8 | -7.3 | -10.7 | -14.7 |
| Rest of Washington | 2.9 | -25.1 | 25.0 | 84.0 | 133.1 | 179.4 | 204.4 | 216.2 | 187.9 | 139.1 |
| Total Washington | 2.8 | -58.4 | 18.0 | 98.6 | 138.5 | 161.9 | 124.3 | 60.6 | -83.1 | -275.9 |
| Total 4-County Region | -0.1 | -33.3 | -7.0 | 14.7 | 5.5 | -17.5 | -80.1 | -155.7 | -271.0 | -414.9 |

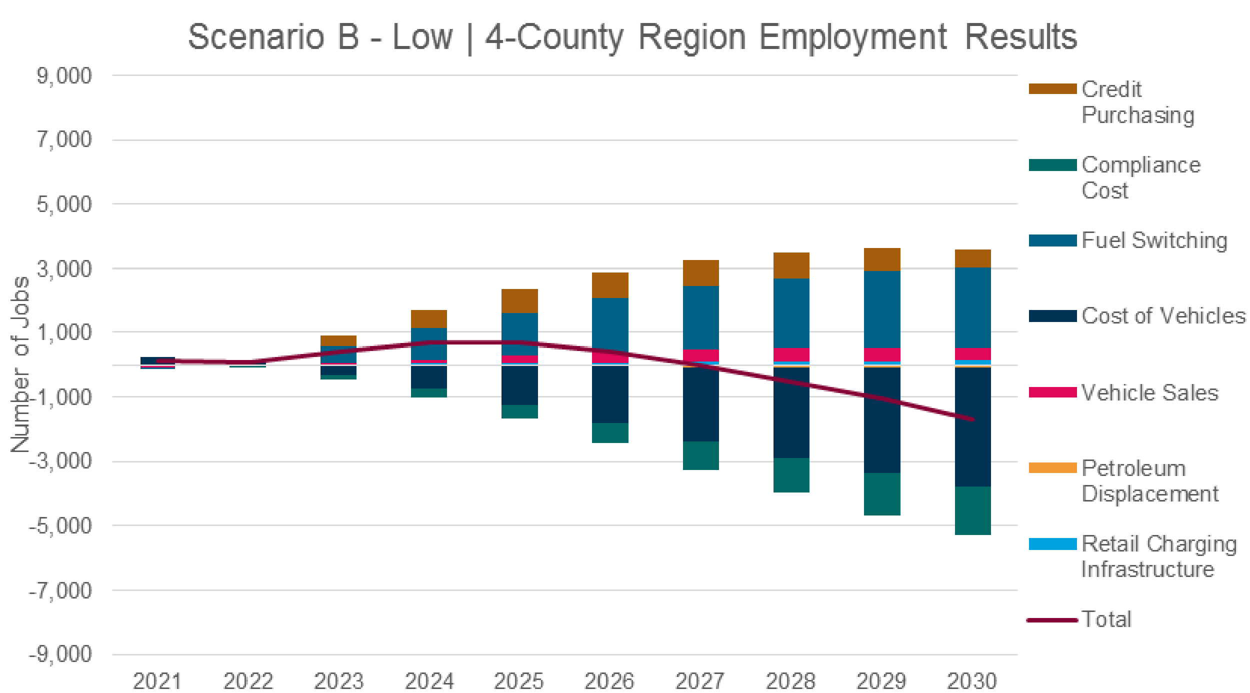


# Scenario B: Aggressive Electrification

## Scenario B, Low Credit Price

| Employment Impact (# of Jobs) - Scenario B - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | 21 | 8 | 59 | 95 | 80 | 28 | -51 | -141 | -237 | -352 |
| King | 85 | 45 | 311 | 547 | 585 | 485 | 294 | 70 | -175 | -492 |
| Pierce | 26 | 7 | 39 | 46 | 3 | -90 | -212 | -362 | -520 | -698 |
| Kitsap | 6 | 1 | 12 | 17 | 6 | -15 | -44 | -77 | -111 | -150 |
| Rest of Washington | 14 | 7 | 62 | 115 | 145 | 154 | 154 | 142 | 122 | 93 |
| Total Washington | 151 | 68 | 483 | 820 | 820 | 562 | 140 | -368 | -921 | -1,600 |
| Total 4-County Region | 138 | 61 | 421 | 704 | 675 | 408 | -14 | -510 | -1,043 | -1,693 |

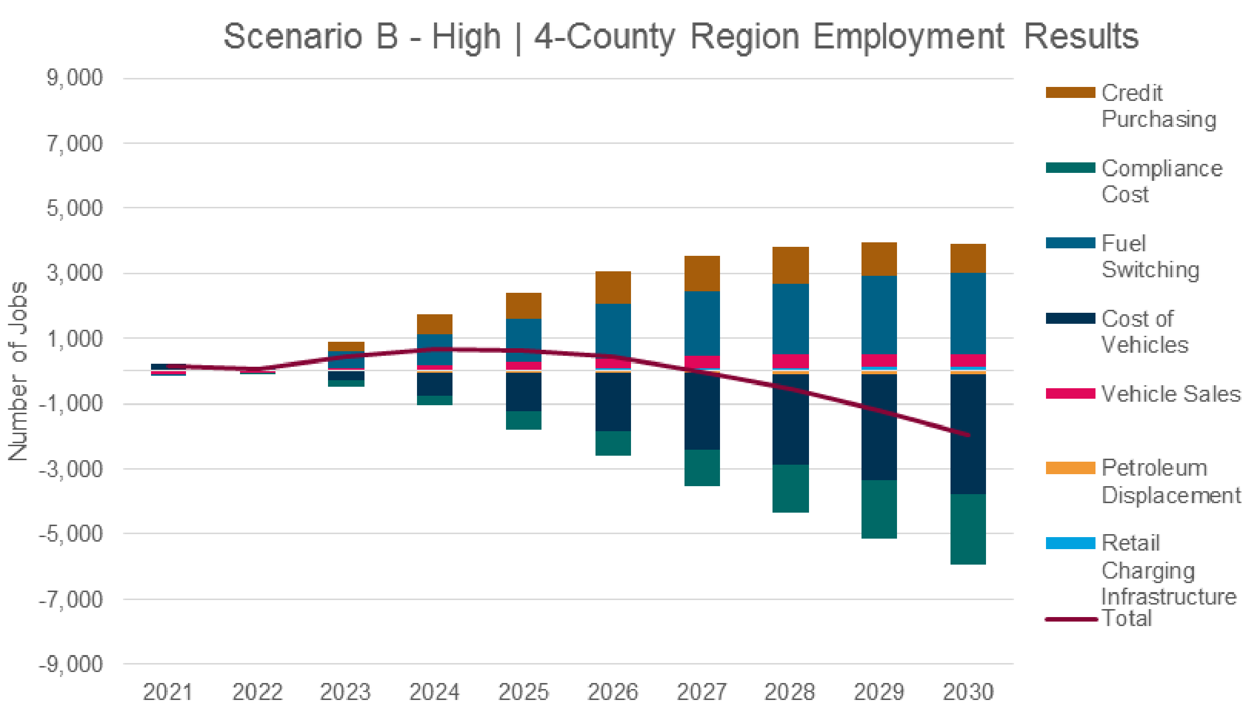
| GRP Impact (Millions 2018$) - Scenario B - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | 1.7 | 0.7 | 4.9 | 7.7 | 5.9 | 0.2 | -8.4 | -18.8 | -30.3 | -44.0 |
| King | 9.0 | 5.3 | 40.4 | 73.0 | 81.5 | 70.9 | 47.0 | 15.6 | -21.0 | -69.7 |
| Pierce | 2.4 | -1.4 | -3.4 | -11.6 | -25.3 | -46.3 | -72.0 | -104.6 | -139.8 | -177.8 |
| Kitsap | 0.4 | 0.2 | 1.1 | 1.8 | 1.4 | 0.2 | -1.6 | -3.7 | -6.0 | -8.9 |
| Rest of Washington | 13.8 | 6.8 | 61.6 | 115.4 | 145.4 | 153.6 | 154.3 | 141.8 | 121.9 | 92.5 |
| Total Washington | 27.4 | 11.6 | 104.7 | 186.3 | 208.9 | 178.7 | 119.4 | 30.3 | -75.2 | -207.9 |
| Total 4-County Region | 13.6 | 4.8 | 43.1 | 70.9 | 63.5 | 25.1 | -34.9 | -111.4 | -197.1 | -300.4 |



## Scenario B, High Credit Price

| Employment Impact (# of Jobs) - Scenario B - High | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | 21 | 8 | 59 | 92 | 72 | 32 | -57 | -150 | -263 | -399 |
| King | 85 | 45 | 311 | 537 | 565 | 536 | 328 | 116 | -179 | -559 |
| Pierce | 26 | 7 | 39 | 43 | -7 | -103 | -251 | -428 | -625 | -848 |
| Kitsap | 6 | 1 | 12 | 16 | 4 | -15 | -47 | -80 | -119 | -164 |
| Rest of Washington | 14 | 7 | 62 | 116 | 154 | 181 | 190 | 182 | 153 | 110 |
| Total Washington | 151 | 68 | 483 | 804 | 787 | 631 | 163 | -360 | -1,033 | -1,858 |
| Total 4-County Region | 138 | 61 | 421 | 688 | 633 | 449 | -27 | -542 | -1,185 | -1,969 |

| GRP Impact (Millions 2018$) - Scenario B - High | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | 1.7 | 0.7 | 4.9 | 7.5 | 5.2 | 0.4 | -9.3 | -20.4 | -34.0 | -50.2 |
| King | 9.0 | 5.3 | 40.4 | 71.8 | 79.4 | 78.6 | 53.2 | 24.0 | -19.3 | -76.5 |
| Pierce | 2.4 | -1.4 | -3.4 | -11.7 | -26.3 | -50.4 | -81.9 | -122.9 | -167.8 | -216.5 |
| Kitsap | 0.4 | 0.2 | 1.1 | 1.7 | 1.3 | 0.4 | -1.6 | -3.7 | -6.4 | -9.6 |
| Rest of Washington | 13.8 | 6.8 | 61.6 | 115.7 | 153.7 | 181.2 | 190.3 | 181.9 | 152.8 | 110.5 |
| Total Washington | 27.4 | 11.6 | 104.7 | 185.0 | 213.2 | 210.2 | 150.7 | 58.9 | -74.6 | -242.3 |
| **Total 4-County Region** | **13.6** | **4.8** | **43.1** | **69.3** | **59.6** | **28.9** | **-39.6** | **-123.0** | **-227.4** | **-352.8** |

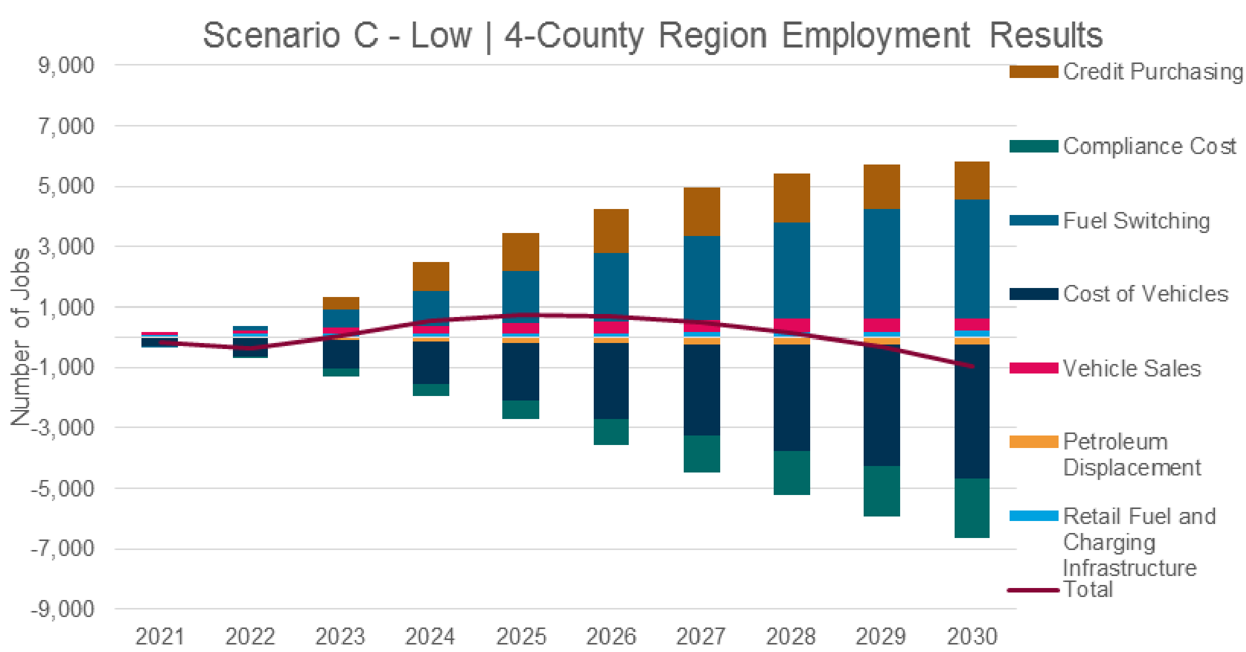


# Scenario C: Mixed Technology Scenario

## Scenario C, Low Credit Price

| Employment Impact (# of Jobs) - Scenario C - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -28 | -51 | -4 | 58 | 72 | 53 | 7 | -58 | -134 | -239 |
| King | -97 | -180 | 112 | 513 | 712 | 762 | 719 | 581 | 379 | 58 |
| Pierce | -36 | -91 | -73 | -48 | -64 | -133 | -223 | -357 | -509 | -690 |
| Kitsap | -11 | -20 | -10 | 2 | 1 | -9 | -27 | -49 | -74 | -107 |
| Rest of Washington | -13 | -44 | 12 | 90 | 144 | 168 | 187 | 174 | 135 | 74 |
| Total Washington | -185 | -386 | 36 | 616 | 865 | 841 | 664 | 291 | -203 | -905 |
| Total 4-County Region | -172 | -342 | 25 | 526 | 720 | 673 | 477 | 117 | -338 | -979 |

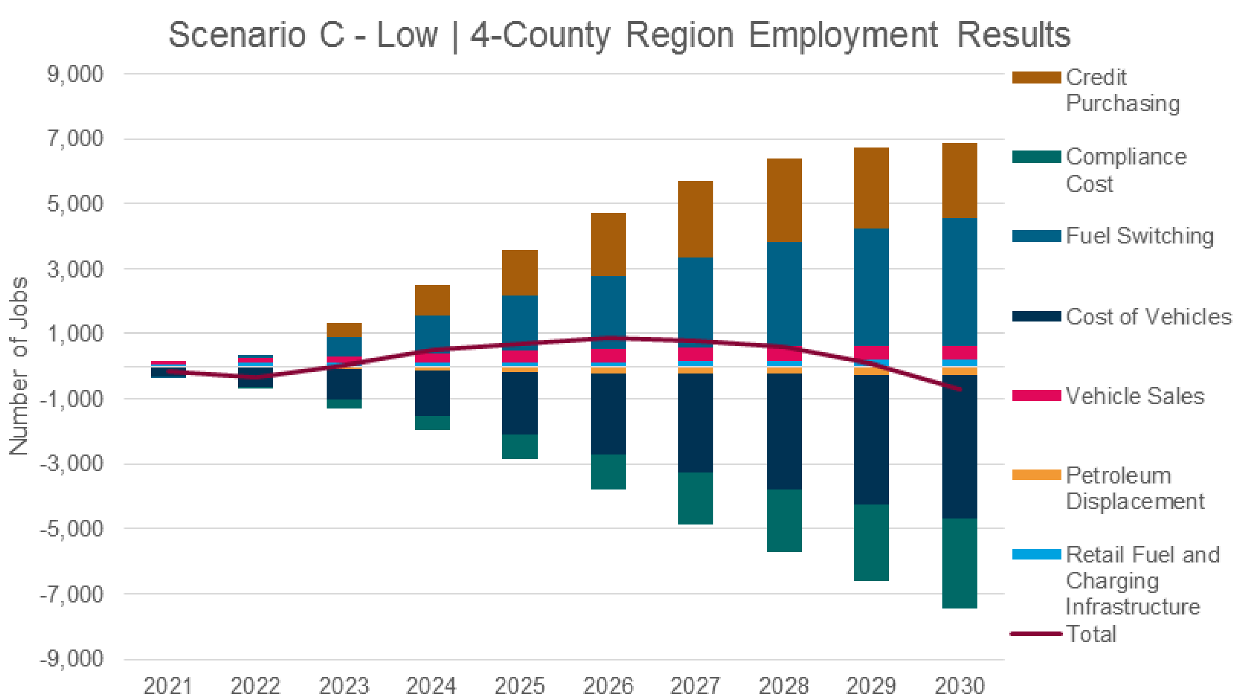
| GRP Impact (Millions 2018$) - Scenario C - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -2.1 | -4.1 | -0.2 | 5.1 | 6.1 | 3.9 | -1.2 | -8.9 | -18.3 | -30.9 |
| King | -10.0 | -19.7 | 19.3 | 74.8 | 107.4 | 120.5 | 121.6 | 107.0 | 80.2 | 34.1 |
| Pierce | -3.4 | -16.9 | -23.7 | -33.7 | -47.8 | -70.2 | -94.1 | -127.9 | -166.0 | -207.9 |
| Kitsap | -0.7 | -1.3 | -0.4 | 0.8 | 1.0 | 0.6 | -0.3 | -1.7 | -3.5 | -5.9 |
| Rest of Washington | -12.8 | -43.9 | 11.7 | 89.6 | 144.2 | 167.7 | 187.4 | 173.7 | 134.7 | 73.9 |
| Total Washington | -28.9 | -85.9 | 6.6 | 136.6 | 210.9 | 222.5 | 213.3 | 142.1 | 27.2 | -136.8 |
| Total 4-County Region | -16.2 | -42.0 | -5.0 | 47.0 | 66.7 | 54.8 | 25.9 | -31.6 | -107.5 | -210.6 |



## Scenario C, High Credit Price

| Employment Impact (# of Jobs) - Scenario C - High | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -28 | -51 | -4 | 54 | 62 | 71 | 28 | -25 | -121 | -253 |
| King | -97 | -180 | 112 | 498 | 701 | 951 | 1,002 | 1,003 | 767 | 375 |
| Pierce | -36 | -91 | -73 | -51 | -73 | -115 | -201 | -329 | -512 | -737 |
| Kitsap | -11 | -20 | -10 | 1 | -3 | -6 | -24 | -44 | -75 | -115 |
| Rest of Washington | -13 | -44 | 12 | 90 | 161 | 236 | 294 | 312 | 264 | 180 |
| Total Washington | -185 | -386 | 36 | 592 | 848 | 1,137 | 1,099 | 917 | 322 | -550 |
| Total 4-County Region | -172 | -342 | 25 | 502 | 687 | 901 | 805 | 605 | 59 | -730 |

| GRP Impact (Millions 2018$) - Scenario C - High | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -2.1 | -4.1 | -0.2 | 4.8 | 5.4 | 5.8 | 1.2 | -5.3 | -16.7 | -32.4 |
| King | -10.0 | -19.7 | 19.3 | 73.0 | 107.1 | 149.1 | 167.1 | 176.4 | 149.3 | 97.7 |
| Pierce | -3.4 | -16.9 | -23.7 | -33.9 | -48.3 | -70.2 | -95.7 | -132.6 | -177.7 | -228.3 |
| Kitsap | -0.7 | -1.3 | -0.4 | 0.7 | 0.9 | 1.1 | 0.2 | -0.8 | -2.9 | -5.8 |
| Rest of Washington | -12.8 | -43.9 | 11.7 | 90.0 | 160.8 | 235.9 | 294.0 | 312.3 | 263.8 | 180.2 |
| Total Washington | -28.9 | -85.9 | 6.6 | 134.7 | 225.8 | 321.6 | 366.9 | 350.0 | 215.8 | 11.4 |
| Total 4-County Region | -16.2 | -42.0 | -5.0 | 44.6 | 65.0 | 85.8 | 72.9 | 37.7 | -47.9 | -168.8 |

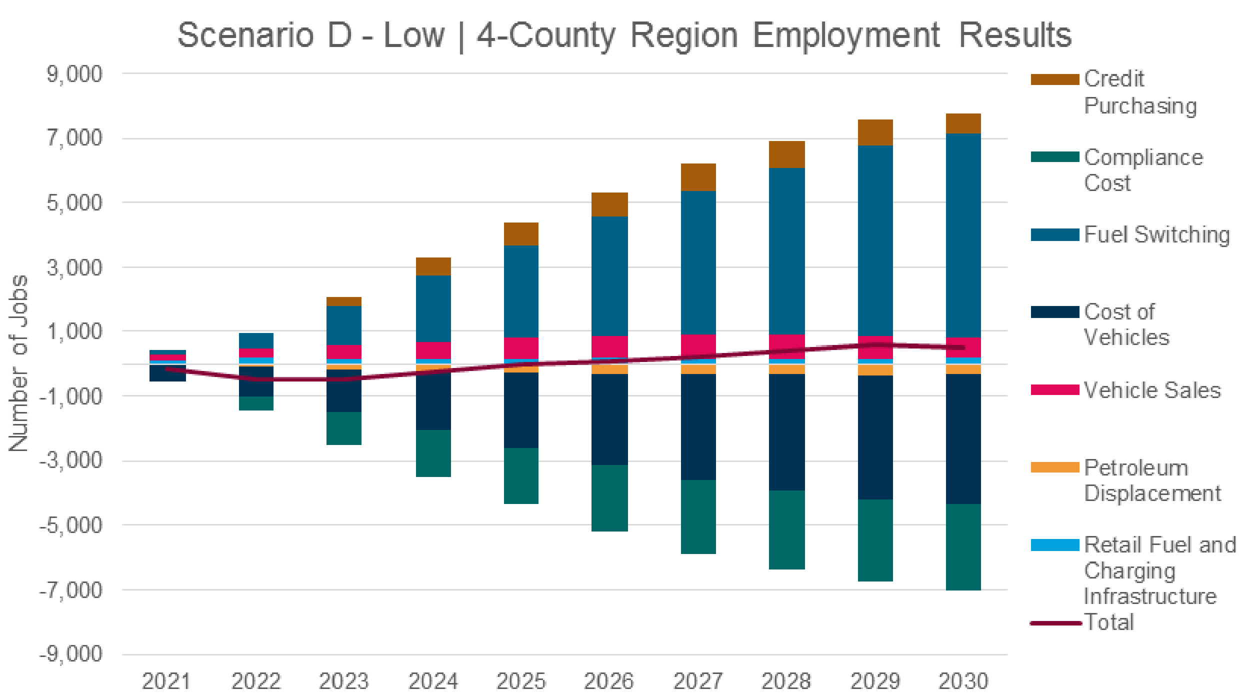


# Scenario D: All-In, Maximum Feasible Reduction

## Scenario D, Low Credit Price

| Employment Impact (# of Jobs) - Scenario D - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Snohomish | -16 | -51 | -38 | 10 | 58 | 83 | 113 | 149 | 187 | 173 |
| King | -79 | -263 | -174 | 101 | 346 | 478 | 628 | 801 | 957 | 905 |
| Pierce | -34 | -133 | -241 | -353 | -443 | -524 | -574 | -590 | -596 | -651 |
| Kitsap | -7 | -17 | -11 | 4 | 20 | 31 | 44 | 58 | 72 | 68 |
| Rest of Washington | -14 | -56 | -13 | 34 | 40 | 15 | -20 | -57 | -102 | -174 |
| Total Washington | -151 | -520 | -478 | -204 | 22 | 83 | 191 | 361 | 519 | 321 |
| Total 4-County Region | -136 | -463 | -465 | -238 | -18 | 69 | 211 | 418 | 620 | 495 |

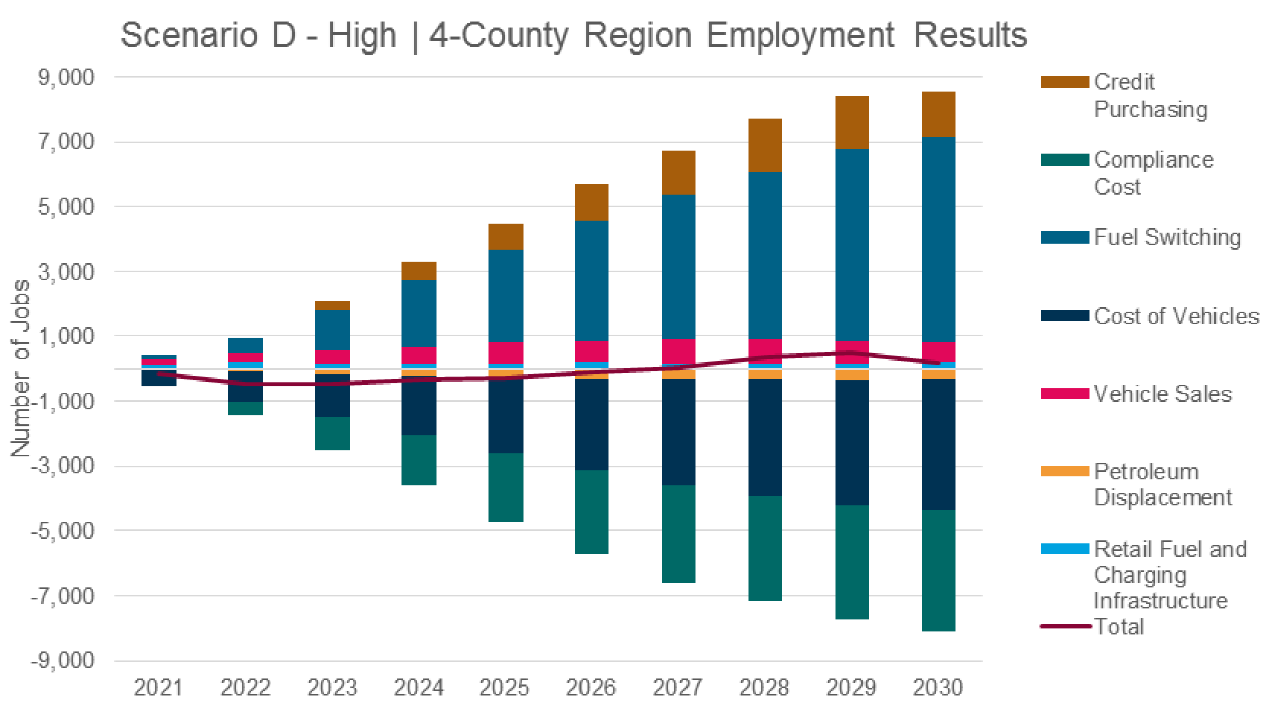
| GRP Impact (Millions 2018$) - Scenario D - Low | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | -0.8 | -3.5 | -3.0 | -0.1 | 2.8 | 3.9 | 5.4 | 7.6 | 10.2 | 7.4 |
| Snohomish | -6.5 | -26.1 | -11.6 | 26.2 | 61.2 | 82.7 | 107.1 | 133.8 | 156.9 | 148.1 |
| King | -3.3 | -26.3 | -53.0 | -92.6 | -133.6 | -171.1 | -203.6 | -229.2 | -251.8 | -277.9 |
| Pierce | -0.5 | -1.3 | -0.9 | 0.2 | 1.5 | 2.3 | 3.3 | 4.4 | 5.5 | 5.3 |
| Kitsap | -14.4 | -56.4 | -13.2 | 33.9 | 40.2 | 14.7 | -19.7 | -56.9 | -101.5 | -173.9 |
| Rest of Washington | -25.6 | -113.5 | -81.8 | -32.4 | -28.0 | -67.5 | -107.5 | -140.2 | -180.8 | -291.0 |
| Total Washington | -11.2 | -57.2 | -68.6 | -66.3 | -68.1 | -82.3 | -87.8 | -83.4 | -79.2 | -117.1 |
| Total 4-County Region | -0.8 | -3.5 | -3.0 | -0.1 | 2.8 | 3.9 | 5.4 | 7.6 | 10.2 | 7.4 |



## Scenario D, High Credit Price

| Employment Impact (# of Jobs) - Scenario D - High | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| Snohomish | -16 | -51 | -38 | -4 | 10 | 45 | 62 | 110 | 130 | 86 |
| King | -79 | -263 | -174 | 47 | 185 | 439 | 617 | 933 | 1,060 | 915 |
| Pierce | -34 | -133 | -241 | -366 | -501 | -605 | -689 | -709 | -748 | -855 |
| Kitsap | -7 | -17 | -11 | 0 | 5 | 17 | 25 | 41 | 48 | 35 |
| Rest of Washington | -14 | -56 | -13 | 35 | 56 | 63 | 37 | 2 | -81 | -213 |
| Total Washington | -151 | -520 | -478 | -288 | -245 | -41 | 53 | 377 | 408 | -31 |
| Total 4-County Region | -136 | -463 | -465 | -323 | -301 | -104 | 15 | 375 | 489 | 181 |

| GRP Impact (Millions 2018$) - Scenario D - High | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|
| Snohomish | -0.8 | -3.5 | -3.0 | -1.3 | -1.4 | 0.2 | 0.4 | 3.4 | 3.9 | -2.3 |
| King | -6.5 | -26.1 | -11.6 | 19.9 | 42.6 | 81.7 | 112.7 | 162.3 | 184.6 | 164.9 |
| Pierce | -3.3 | -26.3 | -53.0 | -93.3 | -138.8 | -185.0 | -226.5 | -259.4 | -290.6 | -327.9 |
| Kitsap | -0.5 | -1.3 | -0.9 | 0.0 | 0.5 | 1.5 | 2.3 | 3.7 | 4.4 | 3.6 |
| Rest of Washington | -14.4 | -56.4 | -13.2 | 35.3 | 55.9 | 63.3 | 37.1 | 1.5 | -80.9 | -212.6 |
| Total Washington | -25.6 | -113.5 | -81.8 | -39.4 | -41.3 | -38.3 | -74.1 | -88.5 | -178.7 | -374.4 |
| Total 4-County Region | -11.2 | -57.2 | -68.6 | -74.7 | -97.2 | -101.5 | -111.2 | -90.1 | -97.8 | -161.7 |



# Appendix C: Supplemental Data Available

The following data and files have been supplied to PSCAA to support this project:

- WA-GREET
- C-LINE run output and receptor concentrations
- Population and BenMAP results
- AQ Data layers

# Appendix D: Erratum

November 7, 2019

Subsequent to the release of the final report:

ICF discovered that there was an error in the code that was used to develop the compliance scenario model used in the analysis as part of the work for the Puget Sound Clean Air Agency. The error was linked to the increased use of natural gas (primarily renewable) as a transportation fuel in heavy-duty trucks (Class 7-8). In short, as natural gas consumption increased, the model included a displacement of conventional diesel at a rate that was inconsistent with (greater than) what should be considered. This error manifested itself when natural gas as a transportation fuel consumption was modeled to increase over baseline usage—which was most significant in Scenario D, with small increases in Scenario C. There was no increase in the use of natural gas above baseline in Scenario A nor Scenario B. For Scenario C and D, this error led to less-than-anticipated diesel consumption. After fixing this error, ICF identified the following high-level impacts on our results, with a focus on the compliance curve and potential economic impacts.

- **There is no discernable impact on ICF's modeled compliance.** After correcting for the error regarding diesel consumption, there were an increased number of deficits calculated. However, both biodiesel and renewable diesel are calculated as a percent blend in the model (as opposed to a fixed volume to prevent blending at a rate too high over time). In other words, as the diesel volumes were corrected, increased volumes of biodiesel and renewable diesel effectively offset the deficit generation with credit generation.
- **ICF estimates no discernable impact on the economic modeling results.** As noted throughout the report, the economic modeling results are small across all scenarios. There are several reasons for our estimates that there are no impacts on the modeling results.
  - **Small change in the compliance cost pass-through (compliance cost).** ICF models the compliance cost to consumers as a full pass-through of the compliance cost associated with illustrative credit price curves used in the analysis. This pass-through cost is modeled as the cost of all deficits. The compliance cost is calculated as the product of the sum of all deficits generated in a given year and the credit price in that year. After correcting for the error, more deficits were generated, but the impact is spread over a larger volume of fuel. On a net basis, the compliance cost pass-through assumption increases, but the per gallon change is unaffected. Impact: small negative economic impacts.
  - **Small change to refinery impacts (petroleum displacement).** As noted in the report, ICF accounts for displaced diesel (and gasoline) as a net negative impact to the refining industry—by displacing half the product and assuming the other half is shipped out of the region at a higher cost. Our modeling over-stated diesel displacement and as a result over-states the impacts on the refining industry. Impact: small positive economic impacts.
  - **Small change to biofuel impacts (credit purchasing).** Both renewable diesel and biodiesel are linked as a percentage blend to total diesel consumption in our modeling. As a result, when the diesel volumes were too low, the amount of renewable diesel and biodiesel blended was also too low. When correcting the

error, both volumes increased, as did credit generating activity for both fuels. ICF links the value generated by those credits back to the corresponding low carbon fuel industry, so there would be increased flow of that revenue in the corrected model. Impact: small positive economic impacts.

- **No other change.** There are no other anticipated changes in the economic modeling results, as the corrected change has no impact on vehicle sales or cost of vehicles, infrastructure investments, or fuel switching.

**Summary.** The identified error has no impact on ICF conclusions regarding the carbon intensity reduction of 26% achieved in Scenario D. Further, ICF estimates that there will be no discernible change to economic modeling results as a result of fixing the identified error in the scenario modeling analysis because the two small positive impacts outlined above are expected to offset the small negative impact.

The error also has no impact on the air quality analysis because that analysis was derived from the projected vehicle fleet composition, activity, and emission factors, not the total fuel volumes.

The following, corrected figures replace Figures 11-15 (on pages 38-42). For a quantitative comparison, the corrected (and old) Cumulative Credit Bank values in 2030 are:

- for Scenario C, 5.22 (4.93) million credits
- for Scenario D (with a 26% CI reduction target), 5.24 (4.89) million credits
- for Scenario D (with a 20% CI reduction target), 9.76 (9.01) million credits

Figure 27 Replaces Figure 11: Balance of Credits and Deficits Generated in Scenario C

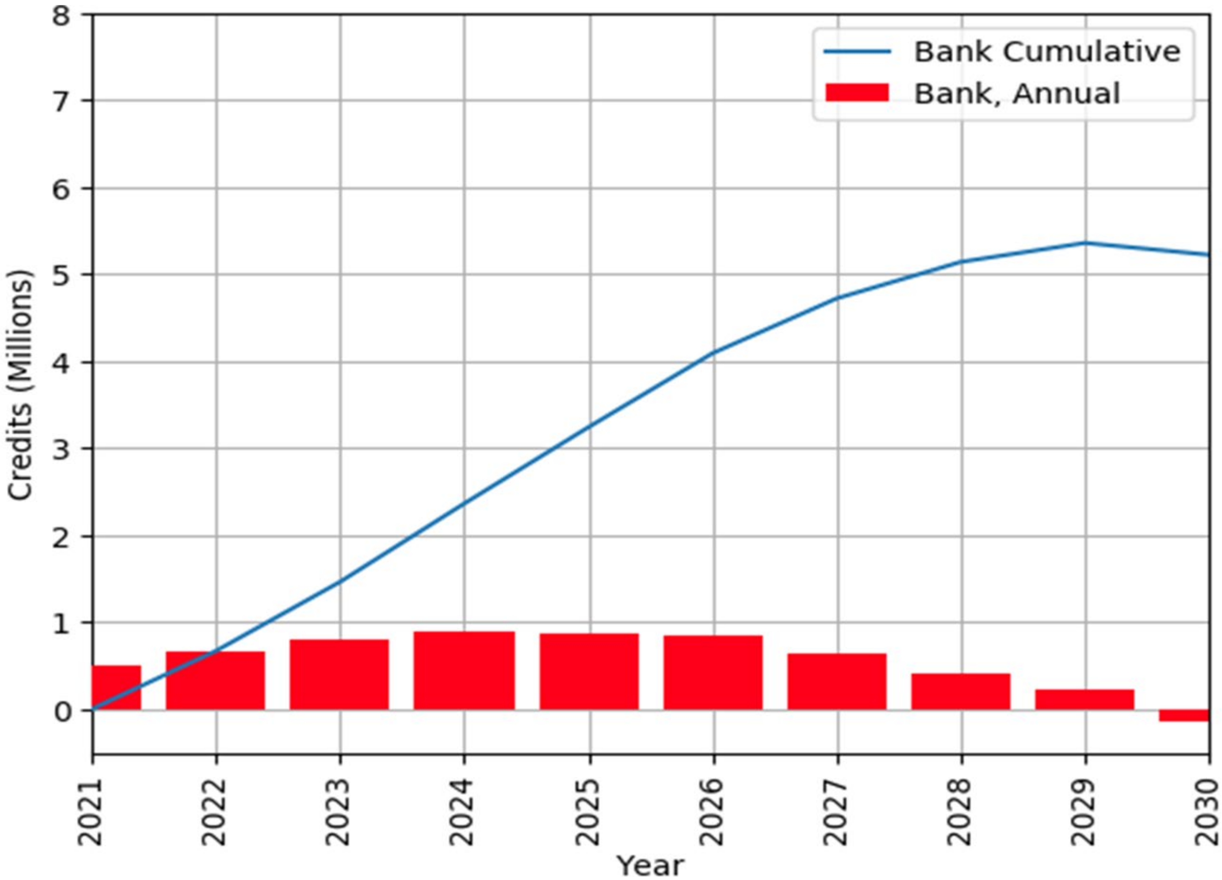


Figure 28 Replaces Figure 12 Alternative Fuel Contributions to CFS Compliance in Scenario C

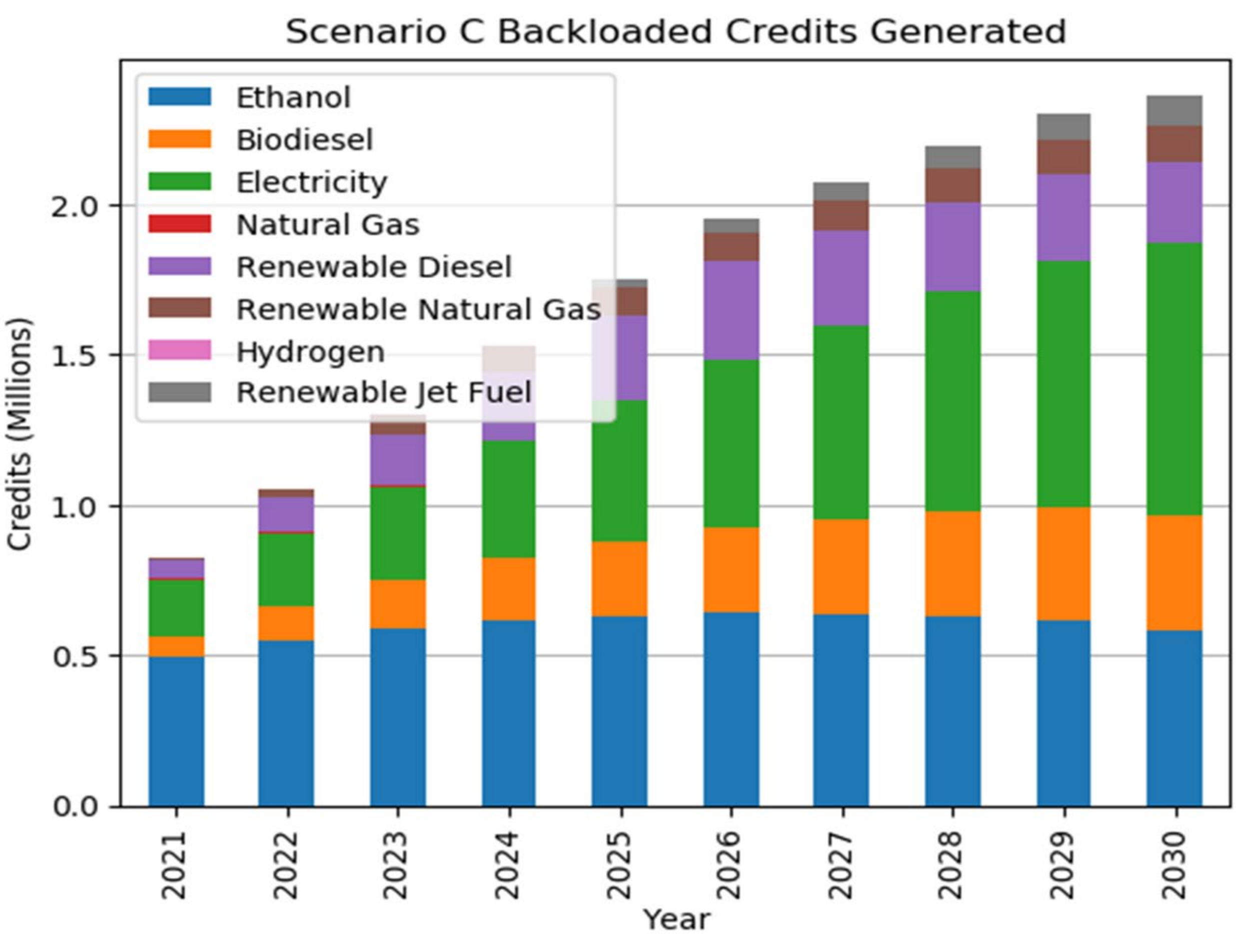


Figure 29 Replaces Figure 13  Balance of Credits and Deficits Generated in Scenario D with a 26% CI standard

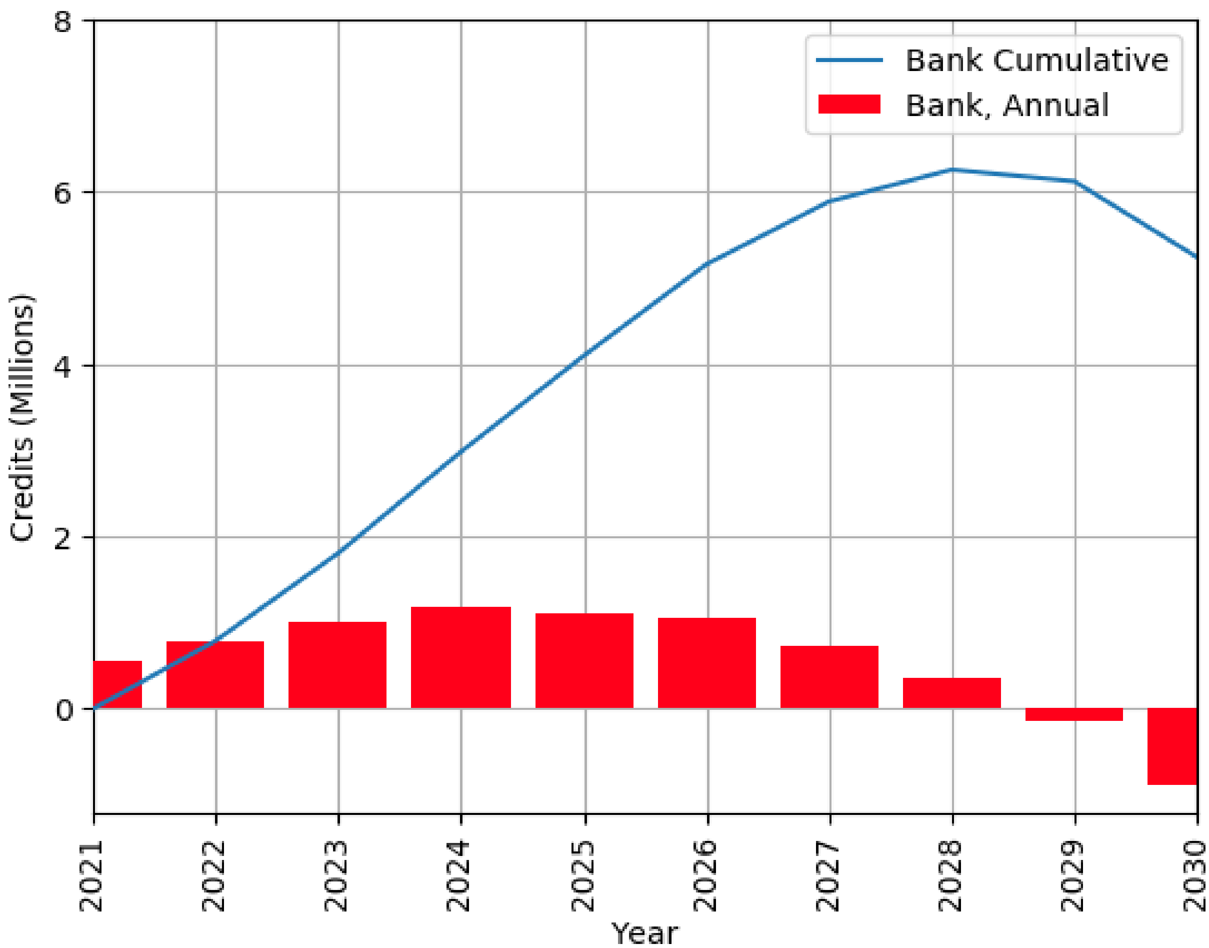


Figure 30 Replaces Figure 14 Balance of Credits and Deficits in Scenario D with a 20% CI standard

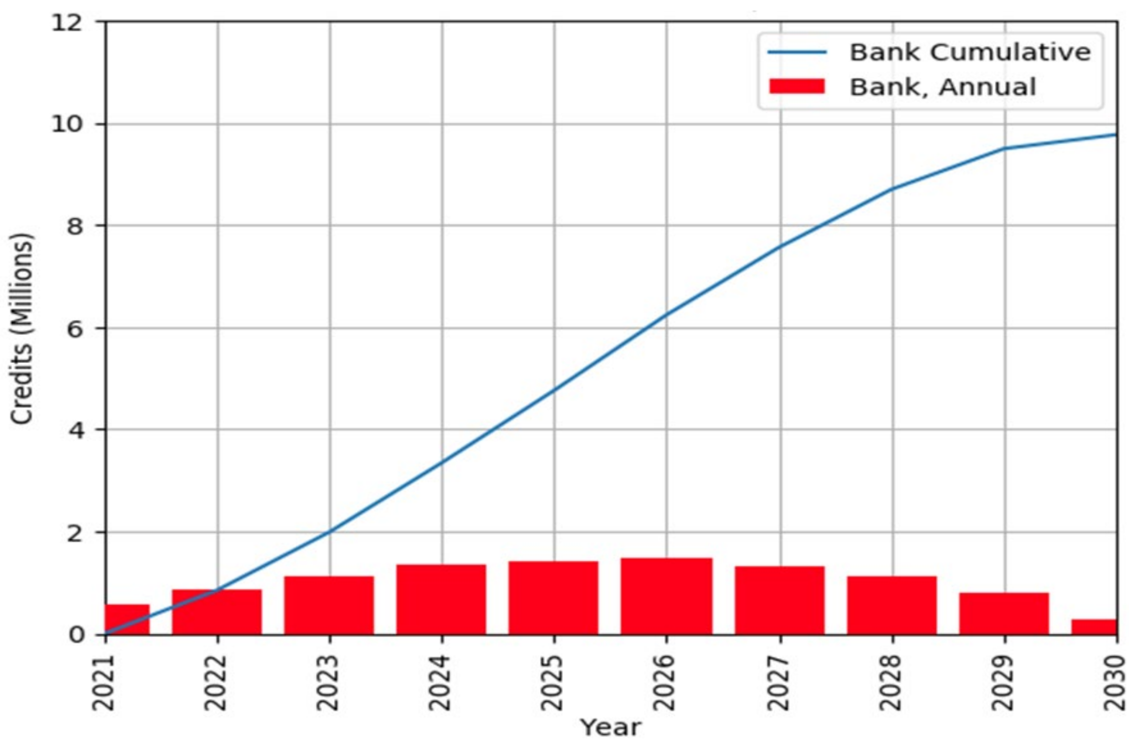


Figure 31 Replaces Figure 15  Alternative Fuel Contributions to CFS Compliance in Scenario D with a 26% CI standard