MEMORANDUM

TO: Thurston Regional Planning Council
FROM: Clean Energy Transition and Stockholm Environment Institute
RE: Methodology & Assumptions for Carbon Wedge Analysis with Transportation Scenarios
DATE: October 13, 2017

This memo provides background for the Thurston Regional Planning Council (TRPC) staff on the methodology and assumptions that the Clean Energy Transition and Stockholm Environment Institute team used to create TRPC's Carbon Wedge Analysis and Transportation Scenarios, which are designed to help the TRPC staff understand how to achieve meaningful greenhouse gas emissions reductions by 2035 and through 2050.

Carbon Wedge Analysis

The TRPC Carbon Wedge Analysis graphically represents the cumulative carbon dioxide (CO_2) emission reductions that are expected to result from a range of both existing and potential laws and policies that could affect CO_2 emissions in Thurston County. The laws and policies range from national to state to the local level. The effect of each law or policy is represented as a "wedge" of emission reductions, stacked to show each respective contribution to total emission reductions.

Emission reductions are calculated against a baseline, which projects what CO_2 emissions would be in the future if there were no significant policies driving emission reductions (including existing policies). Baseline emissions therefore steadily increased in line with expected population growth for Thurston County. Various existing national, state, and local policies, however, are likely to drive down both the rate of energy consumption for different activities over time (e.g., transportation and building heating/cooling), as well as the CO_2 emissions associated with such energy consumption (e.g., emissions associated with electricity generation and consumption).

In addition, we examine a range of potential policy actions that could further reduce CO_2 emissions. Some of these are fairly discrete (e.g., extension of the Washington State Energy Code to drive further reductions in energy consumption in buildings). Others are more broadly defined. For example, we examine a "deep decarbonization pathway" for Washington's electricity sector that could result from a range of state, regional, and/or national policy actions. We also examine the effects of increased adoption of electric vehicles (EVs), which could be achieved through a similarly broad set of local, state, and national policies and incentives.

Several of the potential policy actions we examine interact with each other and with existing policies. For example, decarbonizing the electricity sector reduces the relative effect on CO_2 emissions of building energy efficiency measures. It also increases the CO_2 reduction potential of EV adoption. Because of these interactions, we have developed several scenarios, showing the relative contributions of different policy actions under different combinations of both electricity sector decarbonization and EV adoption. All told, we examine six different scenarios, showing the effects of different policy actions based on these combinations of electricity and EV policies:

Carbon Wedge Diagram Scenarios

Electricity Emissions	Electric Vehicle Adoption Scenarios
Existing policy electricity mix (assumes Puget Sound Energy follows existing Washington State Renewable Portfolio Standard)	1. Current policy EV adoption
	2. Medium ambition EV adoption policies
	3. High ambition EV adoption policies
Deep decarbonization electricity mix (assumes a combination of policies that drive deep reductions in power sector CO_2 emissions, including for Puget Sound Energy)	4. Current policy EV adoption
	5. Medium ambition EV adoption policies
	6. High ambition EV adoption policies

The remainder of this memo explains how we model carbon wedges reflecting the effects of different policies under each of these scenarios, including the sources and assumptions used to inform our analysis.

General Assumptions for the Baseline

In this analysis, we compare emissions reduction relative to a baseline in which emissions grow along with increased population, but no action is taken to decrease emissions. This baseline is the top line of all of our carbon wedge graphics. In this case:

- ***Building energy usage and VMT grow at the same rate as population growth***
- ***Light-duty and heavy-duty vehicle (LDV and HDV) fuel efficiencies remain at 2015 levels***
- ***Per capita VMT remains at 2015 levels (and therefore VMT grows linearly with population growth)***
- ***The mix of vehicle types over time does not change***
- ***Electricity generation mix over time does not change***

Note that the trends in vehicle and electricity generation mix reflect the effects of some (though not all) existing policies, as well as larger economic forces and technological developments. For the purposes of this analysis, however, we chose not to explicitly break out such policies, and have included these trends in our baseline case.

Electricity Sector Emissions Analysis

We developed a baseline for electricity sector emissions, along with two policy actions: maintaining the existing Washington State Renewable Portfolio Standard, and an assumed general suite of policies that would drive deep decarbonization in Washington's electricity sector, in line with the outcomes modeled in Washington's Deep Decarbonization Pathways study.[1] In all cases, we calculated the carbon emissions per unit of electricity production using average operating heat rates for electricity generation in 2015 from the Energy Information Agency (EIA),[2] fossil fuel combustion emissions factors from EIA,[3] and

[1] Washington State Deep Decarbonization Pathways Analysis by Evolved Energy Research, April 2017 http://www.governor.wa.gov/sites/default/files/DeepDecarbonizationPathwaysAnalysisforWashingtonSt.pdf
[2] EIA Electric Power Annual 2015 Table 8.1, *Average Operating Heat Rate for Selected Energy Sources*, https://www.eia.gov/electricity/annual/html/epa_08_01.html
[3] EIA, *Carbon Dioxide Emissions Coefficients by Fuel*, https://www.eia.gov/environment/emissions/co2_vol_mass.php

average electricity grid loss percentages from the Environmental Protection Agency (EPA)'s eGRID model.[4] Because electricity emissions influence both the effects of building energy efficiency and EV policies, we developed two wedge diagram scenarios based on electricity sector emissions.

Existing Policy: Washington Renewable Portfolio Standard

To estimate emissions from Thurston Country electricity consumption under the existing Washington Renewable Portfolio Standard, we first estimated Puget Sound Energy (PSE)'s electricity generation mix from 2015 through 2035 based on PSE's 2015 Integrated Resource Plan (IRP). At the time of writing, the 2015 IRP was the most recent IRP available, but PSE subsequently released its draft 2017 IRP.[5] The generation mix projections from PSE's 2015 IRP are shown in Figure 1. The "Contracts" in Figure 1 represent purchases from the coal-fired Centralia Power Plant.

Figure 1-5: Annual Energy Position for 2015 IRP Resource Plan in the Base Scenario

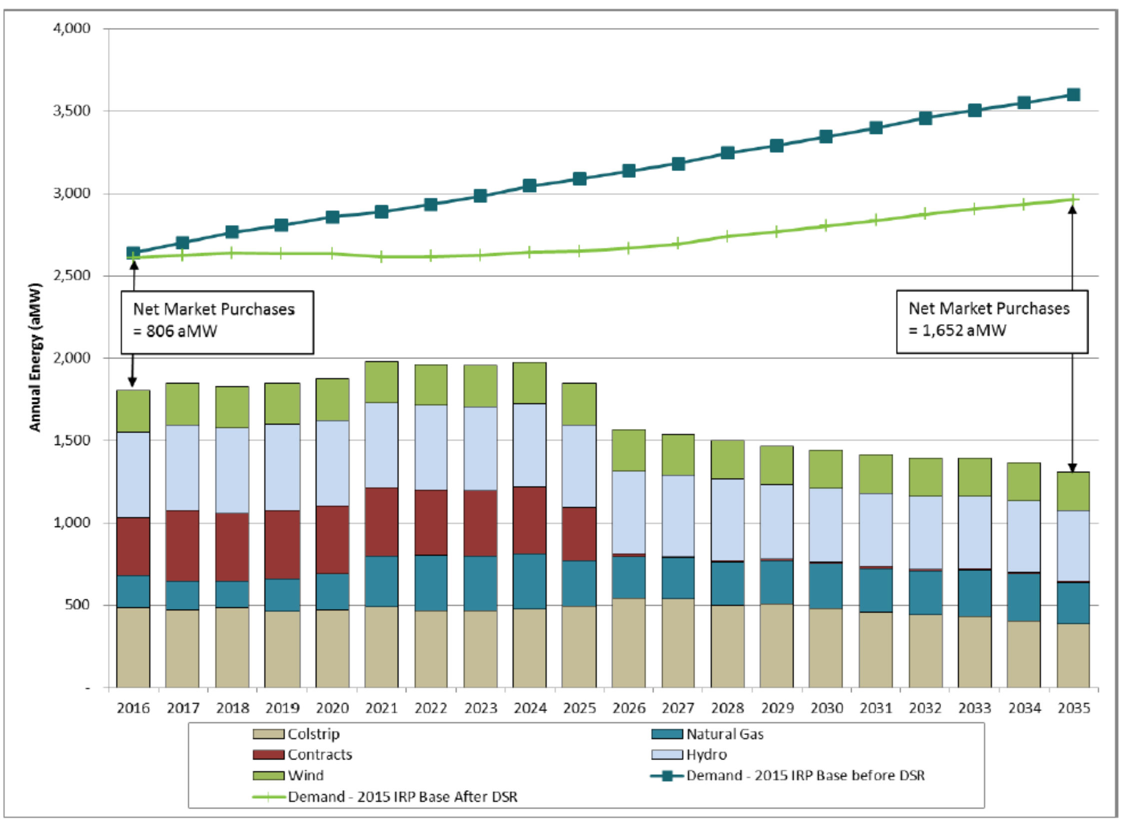

Figure 1. Electricity generation mix projections from PSE's 2015 IRP

[4] 4.79% for the Western region. From EPA *Technical Support Document for eGRID with Year 2014 Data*, https://www.epa.gov/sites/production/files/2017-02/documents/egrid2014_technicalsupportdocument_v2.pdf
[5] We completed our analysis before September 12, 2017, when Puget Sound Energy (PSE) released its draft 2017 Integrated Resource Plan, which offers a less fossil-fuel dependent power mix, as well as the announcement on September 22, 2017 of PSE's settlement with the Utilities and Transportation Commission, which addresses the utility's closure of Colstrip power plant units 1 and 2, and sent a strong signal for an accelerated closure of units 3 and 4. This work should be updated to reflect PSE's new projected portfolio mix.

PSE's 2015 IRP did not account for the closure of two generating units at the Colstrip power plant in 2018. To model the effect of the closure of Colstrip, we modified the projections from the IRP to reassign half of the generation capacity from Colstrip to market purchases after 2018. Although the generation capacities of Colstrip units 1 and 2 (the units to be closed in 2018) differ from Colstrip units 3 and 4 (the units to continue operation), about half of PSE's ownership share in Colstrip is in units 1 and 2.[6]

PSE's IRP includes a substantial volume of power from market purchases. We estimated the generation mix for market purchases from PSE's data submitted to the Washington State Department of Commerce's 2015 Fuel Mix Disclosure Report;[7] however, this results in an amount of non-hydro renewable energy that is below Washington's RPS requirements. To calculate the emissions reductions resulting from compliance with the RPS (the RPS wedge in our wedge analysis), we assumed that PSE's market purchases would contain a higher fraction of renewables, sufficient to achieve the RPS's goal of 15% generation from non-hydro renewable sources by 2020 and all years thereafter. (See Figure 2.)

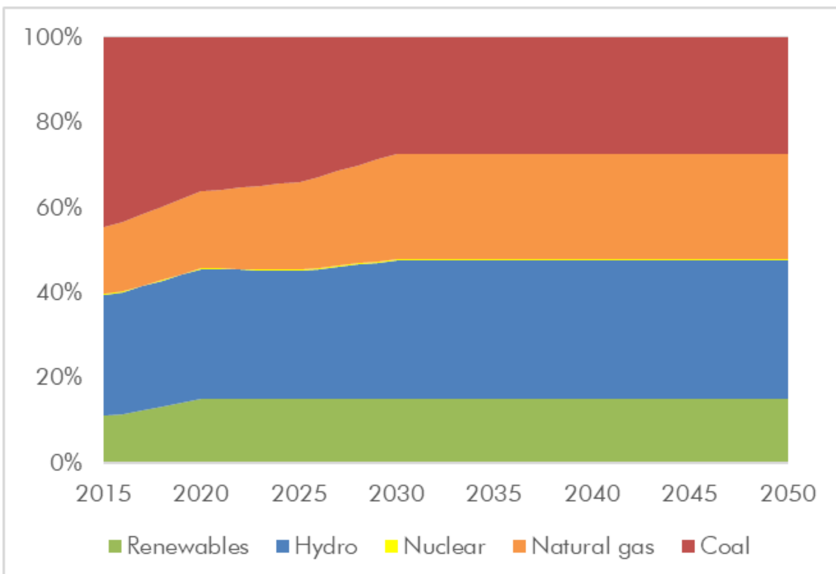

Figure 2. Electricity generation mix under RPS, and reflecting PSE's 2015 IRP assumptions

[6] PSE "Colstrip Generating Station" informational brochure, https://pse.com/aboutpse/PseNewsroom/MediaKit/064_Colstrip.pdf. See also Utilities and Transportation Commission press release https://www.utc.wa.gov/aboutUs/Lists/News/DispForm.aspx?ID=470 and PSE press release https://pse.com/aboutpse/PseNewsroom/NewsReleases/Pages/Settlement-reached-in-PSE-general-rate-case.aspx, concerning the September 24 2017 settlement re: Colstrip units 1-4.

[7] Washington State Department of Commerce 2015 Fuel Mix Disclosure, http://www.commerce.wa.gov/growing-the-economy/energy/fuel-mix-disclosure/

The end result is that the "Washington RPS" wedge indicates expected emission reductions from the baseline due to (1) PSE's expected shift away from coal-fired power (due to Colstrip closure); and (2) PSE's procurement of sufficient renewable energy to meet Washington RPS requirements.

Potential Policy: Deep Decarbonization

We also examine the effects of a presumed suite of policies (at the state, regional, or national level) that would drive deep decarbonization of Washington's electricity sector. This policy wedge is based on Washington's Deep Decarbonization Pathways (DDP) Report.[8] We quantified the percent of total generation for the electricity mix in Washington provided by each source in the DDP report.

We assume that PSE follows its IRP projections through 2020 and then transitions rapidly to achieve the highly decarbonized grid represented in the DDP study by 2030. After 2030, PSE's generation percentage for fossil sources and nuclear follows the statewide average generation mix in the DDP study through 2050.

Although PSE purchases electricity generated in other states, we assume that in a deep decarbonization scenario, all states in the region would be acting together to reduce emissions, and so power purchases from other states would come from a similarly decarbonized grid. Because the DDP scenario shows no growth in hydroelectric capacity and because all capacity from existing hydroelectric facilities would be accounted for in a regional decarbonization scenario, we assume that the percentage of hydroelectric generation in PSE's mix follows their 2015 IRP projections.

We assume that the utility will meet its remaining capacity demands with non-hydro renewable sources. This growth in non-hydro renewables is consistent with the statewide growth in non-hydro renewable generation capacity forecast in the DDP study. (See Figure 3.)

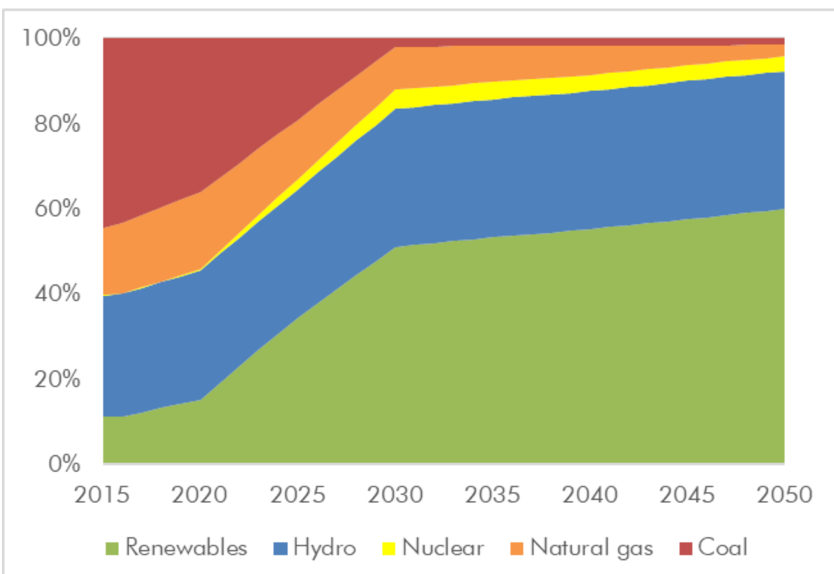

Figure 3. Electricity generation mix in electricity generation DDP scenario

[8] Deep Decarbonization Pathways Analysis for Washington State, Evolved Energy Research, December 16, 2016 http://governor.wa.gov/issues/issues/energy-environment/deep-decarbonization; http://www.governor.wa.gov/sites/default/files/Deep_Decarbonization_Pathways_Analysis_for_Washington_State.pdf

Electricity Scenarios

The sets of carbon wedge diagrams we developed are based on two different electricity sector scenarios. For one set of diagrams (Scenarios 1-3), we examine how different building energy code and EV policies would affect CO_2 emissions assuming only that Washington's Renewable Portfolio Standard is followed.

For the second set of diagrams (Scenarios 4-6), we examine the effects of these policies assuming that the "deep decarbonization" policy scenario is adopted. These two scenarios represent different levels of electricity generation from renewable sources. Increased renewables mean that fewer reductions are associated with building energy efficiency improvements. Conversely, an increase in renewables improves the emissions performance of EVs, leading to greater CO_2 reductions from higher EV adoption.

Building Energy Usage Analysis

We developed a baseline for building energy usage, along with two policy actions: continued implementation and enforcement of Washington's existing building energy codes through 2030, and extension and deepening of these energy codes beyond 2030. We did not develop separate scenarios around building energy usage.

Existing Policy: Washington State Building Code

The Washington Energy Code requires a 70 percent improvement in the energy use for new buildings relative to 2006 by 2031.[9] We assume this code would be fully enforced, and that building energy use for new buildings decreases linearly between 2015 and 2030 to meet this goal.

We also assume that existing buildings are replaced at a constant rate and that new buildings that replace existing buildings also meet the Washington state energy code requirements. We assume an average building lifetime of 80 years, so that 1/80th of the building stock is replaced annually.[10] From the standpoint of energy use, the same reduction in building energy use could be achieved through deep energy retrofits of existing buildings if those retrofits were sufficient to bring existing buildings into compliance with the state energy code.

Potential Policy: Washington State Building Code Extension

In our work for the City of Olympia, we had modeled aggressive fuel-switching in the residential sector from natural gas to high-efficiency electric heat pumps. Encouraging residents to switch to electric heat was presented as a policy option that Olympia could pursue to meet its carbon reduction goals. However, projections for residential and commercial energy use in the base case of the EIA's Annual Energy Outlook 2017 (AEO)[11] do not show evidence of widespread fuel switching.

Instead, we chose to model a more general reduction in building energy use via an extension of the state's building energy code. Under this extension, building energy use continues to decline after 2030

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[9] Frankel, Mark and Edelson, Jim, *Washington State Energy Code Roadmap*, New Buildings Institute, 2015. https://fortress.wa.gov/ga/apps/SBCC/File.ashx?cid=5623

[10] Based on the central value for building stock lifetime for residential and commercial buildings in Philibert, Cédric and Jonathan Pershing, *Beyond Kyoto – Energy Dynamics and Climate Stabilization*, OECD/IEA, 2002.

[11] U.S. Energy Information Administration Annual Energy Outlook 2017, https://www.eia.gov/outlooks/aeo/

at the same rate as is achieved under the Code between 2015 and 2030, achieving net-zero energy for new buildings by approximately 2050. (See Figure 4.)

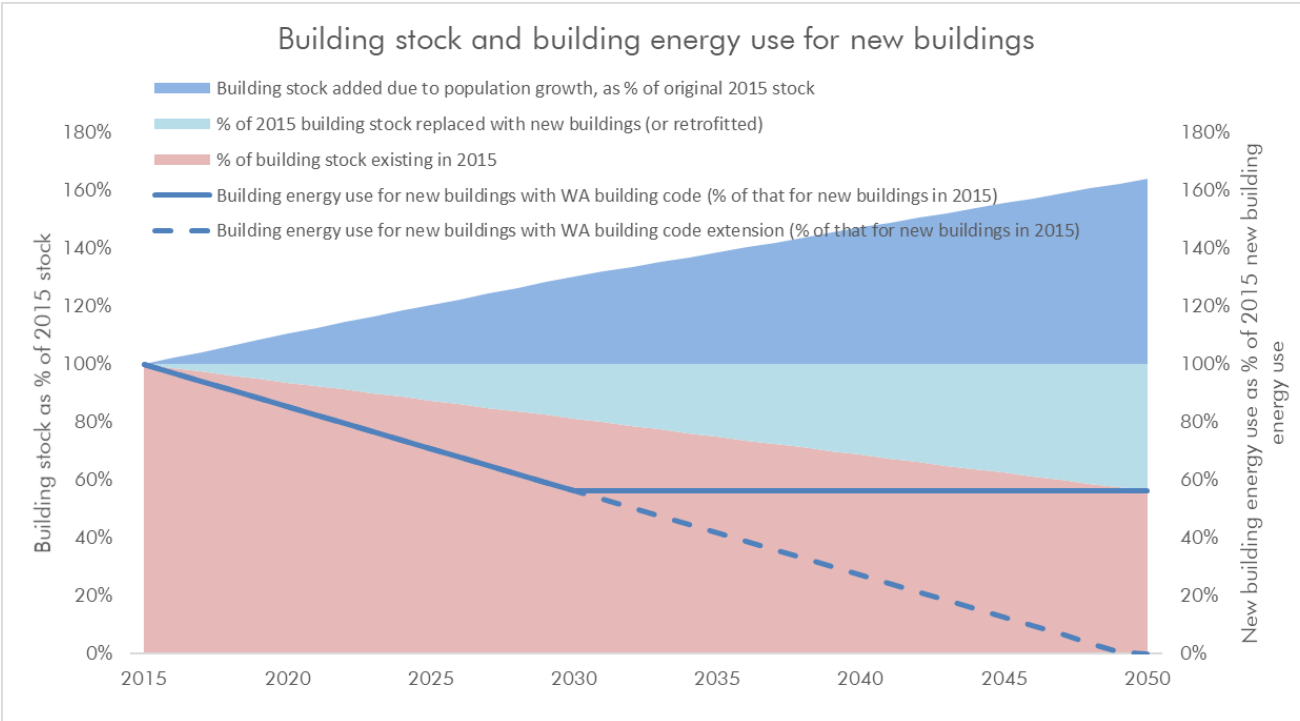

Figure 4. Building stock and new building energy use

Transport Emissions Analysis

We modeled a baseline for Thurston County vehicle emissions, along with five policy actions: (1) the continuation and successful achievement of existing federal CAFE standards; (2) new local VMT reduction policies; (3) adoption of a new low-carbon fuel standard (CFS) for Washington State; and new (4) medium- and (5) high-ambition EV adoption policies (considered two different policy actions).

Since the EV adoption policies amount to different versions of the same types of policies (with differing levels of ambition)—and because EV adoption rates affect how much a CFS would independently contribute to emission reductions—we present different EV adoption rates in separate scenarios, linked to the two electricity sector scenarios.

In general, to estimate CO_2 emissions, we combined the VMT projections that TRPC provided with data on the national vehicle fleet from EIA's AEO. We calculated transport emissions using the formula:

Emissions = *VMT* x *mode share* x *energy intensity* x *emissions factor*

VMT values were provided to us from TRPC. We calculated mode share for different types of light-duty vehicles (LDV) and heavy-duty vehicles (HDV) using data from the AEO.[12] We also calculated the energy intensity of travel (energy use per mile) for each vehicle type in the AEO's classification.[13] We used emissions factors for fossil fuel consumption from EIA, as mentioned previously.

Because of the small amount of ethanol use projected in the transport sector through 2050 (generally 0% to 1% of total transport energy use between 2015 and 2050 in our base case), and because of uncertainty about the method of production for ethanol consumed in the future, we have assumed that the carbon intensity of ethanol consumption is zero. This is consistent with the methodology employed in the EIA's AEO, which assumes ethanol emissions are carbon neutral.

Also, for simplicity, we have assigned the very small amount VMT driven by non-gasoline fossil-powered vehicles, such as those powered by compressed natural gas or propane, to gasoline or diesel Internal Combustion Engines (ICE) for LDVs and HDVs, respectively.[14]

Existing Policy: Federal CAFE Standards

Corporate Average Fuel Economy (CAFE) standards will affect vehicle fleet energy consumption and emissions in two ways: (1) by improving the fuel efficiency of different classes of new vehicles; and (2) by shifting demand for new vehicles to different vehicle types. We assume full implementation of the CAFE standard. The EIA predicts that the U.S. vehicle fleet will achieve an average vehicle fuel efficiency of 27.3 miles per gallon in 2030 under current CAFE standards.

For vehicle mix, we follow the mode share assumptions from EIA's AEO 2017, which incorporates the effects of CAFE standards (and other factors) on consumer vehicle choice. In this scenario, LDV VMT driven by electric vehicles increases from less than 1% in 2015 to approximately 6% by 2050 (see Figure 5). For simplicity, we attribute this increase to the federal CAFE standards policy wedge.

In March 2017 the Trump Administration announced that it would review current CAFE standards, which could make the CAFE standard less stringent than shown in our analysis.

[12] Based on data from AEO's reference case for "Light-Duty Vehicle Miles Traveled by Technology Type", https://www.eia.gov/outlooks/aeo/data/browser/#/?id=51-AEO2017&cases=ref2017, and "Freight Transportation Energy Use," U.S. Energy Information Administration Annual Energy Outlook 2017, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=58-AEO2017&cases=ref2017

[13] Based on data from AEO's reference case for "Light-Duty Vehicle Energy Consumption by Technology Type and Fuel Type", https://www.eia.gov/outlooks/aeo/data/browser/#/?id=58-AEO2017&cases=ref2017, combined with the AEO data sources mentioned previously.

[14] These vehicle types combined account for less than 0.5% of transport energy used in EIA's reference case.

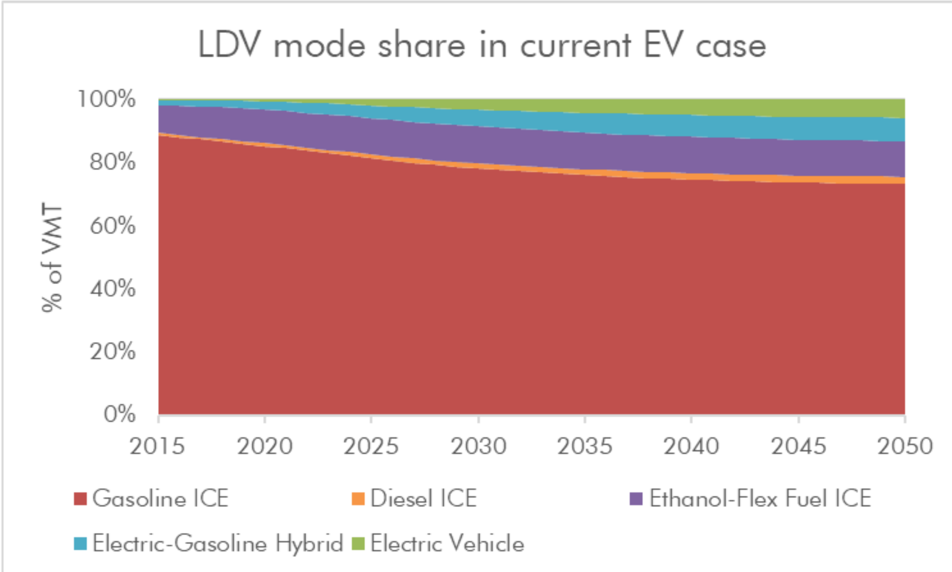

Figure 5. LDV mode share under federal CAFE standards

Potential Policy: VMT Reduction

We modeled VMT reduction in Thurston County consistent with the goals provided by TRPC staff, and calculated the emissions reduction associated with these goals relative to our baseline scenario in which VMT increase with population growth. We achieved TRPC's VMT reduction goals by reducing VMT specifically for LDVs, assuming no change in VMTs for medium- or heavy-duty trucks.

We note that we did not model an increase in HDV emissions associated with increased transit use to facilitate this drop in LDV use. However, depending on the policies implemented to pursue TRPC's VMT reduction goals, some rebound in HDV VMT may be expected.

TRPC's VMT reduction goals are as follows:

Decrease annual per capital vehicle miles traveled in the Thurston Region to:

- 1990 levels by 2020
- 30% below 1990 by 2035
- 50% below 1990 by 2050

Potential Policy: Clean Fuel Standard

We modeled a 10% reduction in transport fuel carbon intensity over 10 years, which is what the Washington State Clean Fuel Standard (CFS)[15] would likely have achieved had it been enacted. We

[15] A Clean Fuel Standard in Washington State Final Report LCA 8056.98.2014, Life Cycle Associates LLC, December 12, 2014 http://ofm.wa.gov/reports/Carbon_Fuel_Standard_evaluation_2014_final.pdf

assumed passage of the CFS in the 2018 legislative session with implementation through 2028.[16] We assume no further emissions reductions from the carbon intensity of gasoline and diesel after 2028.

We assume that the CFS can be met through a combination of reduction in gasoline and diesel emission intensity and also through increasing use of electric vehicles. Under California's CFS, for example, electricity providers that power electric vehicles can earn credits for emissions avoided with electricity as a transportation fuel rather than gasoline or diesel. Thus, we factor EV penetration rates (under each of the EV policy scenarios described below) into our calculations of how much transportation fuel carbon intensities would need to decrease to meet a 10% reduction goal.

Under our high EV use policy scenario (described below), the requirements of the CFS are completely met through electric vehicle use. Thus, in those scenarios, there is no additional emissions reduction from the CFS.

Potential Policy: Medium-Ambition EV Adoption

Our medium-ambition EV adoption scenarios assumes a suite of policies consistent with analysis provided in an Electric Vehicle Cost-Benefit Analysis[17] by M.J. Bradley & Associates. Under these assumed policies, LDV VMT driven by EVs rises from EIA's 2015 projection to 20% in 2050. We assume that the increase in EV LDV VMT occurs at the expense of gasoline ICE VMT. We assume no change in HDV mode share relative to our base EV case, i.e. we assume no electrification of the HDV fleet. (See Figure 6.)

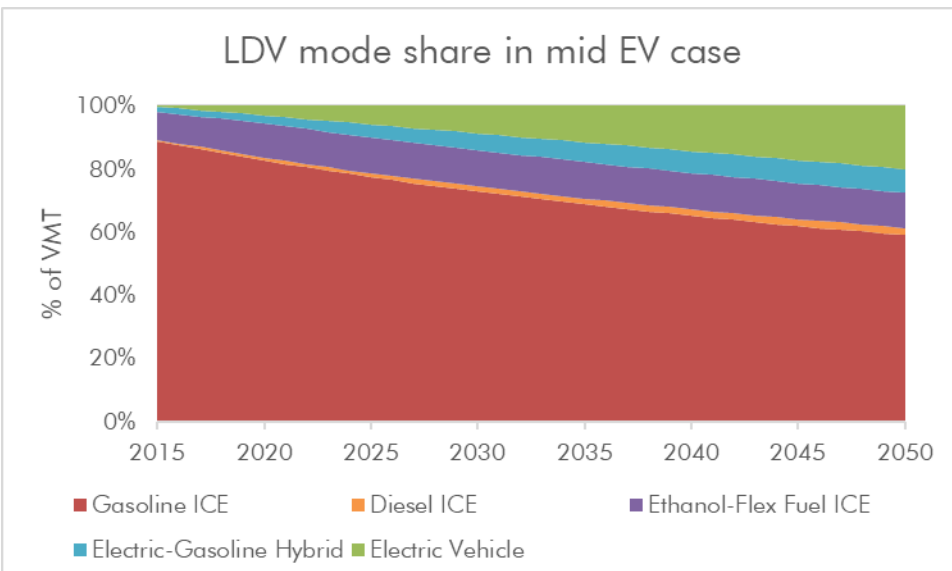

Figure 6. LDV mode share in the mid EV case, reaching 20% of LDV VMT driven by EVs in 2050

[16] Modeling the CFS is purely for illustrative purposes at this time since there is no indication in September 2017 that Washington State will be implementing a CFS at this time. A change in the representation of the Washington State legislature could result in this policy being revisited at some future time, hence we wanted to see how it might affect Thurston's transportation emissions.

[17] Electric Vehicle Cost-Benefit Analysis, M. J. Bradley & Associates, August 2017 http://mjbradley.com/sites/default/files/MI_PEV_CB_Analysis_FINAL_03aug17.pdf

New Policy: High-Ambition EV Adoption

Our high-ambition EV scenarios are also drawn from the M. J. Bradley & Associated' Electric Vehicle Cost-Benefit Analysis, as well as Bloomberg New Energy Finance's Long Term Electric Vehicle Outlook.[18] Under the assumed high-ambition policy suite, LDV VMT driven by EVs rises from EIA's 2015 projection to 60% in 2050. As in the medium ambition EV case, we assume that the increase in EV LDV VMT occurs at the expense of gasoline internal combustion engine VMT. As with the medium ambition EV case, we assume no electrification of the HDV fleet. (See Figure 7.)

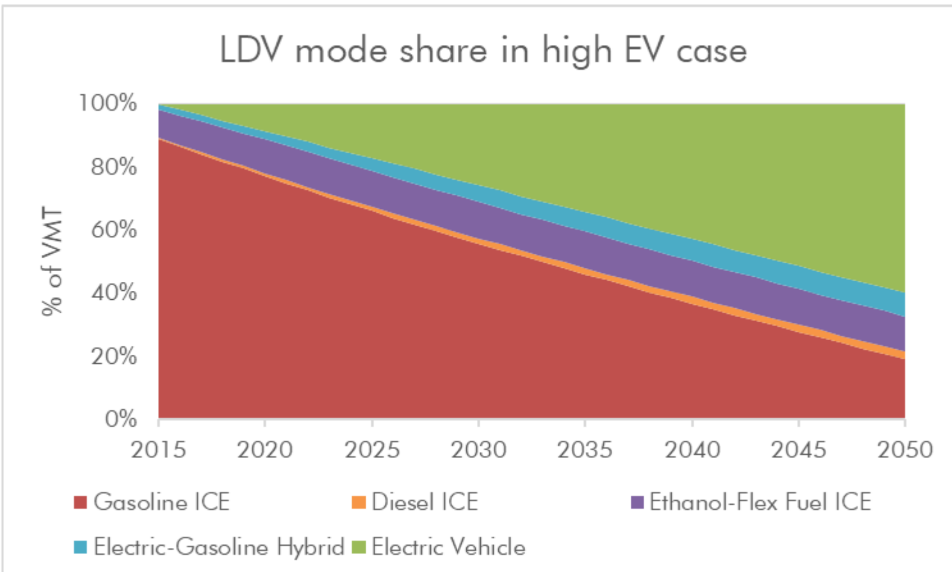

Figure 7. LDV mode share in the high EV case, reaching 60% of LDV VMT driven by EVs in 2050

Electric Vehicle Scenarios

For scenarios 1-3 and 4-6, we present three different alternatives related to EV adoption: expected EV adoption under existing CAFE standards, EV adoption under medium-ambition policies, and EV adoption under high-ambition policies.

Note that EV adoption rates can play a large role in achieving a CFS policy (based on how such a policy currently works in California). As noted above, in the high-ambition EV case, a 10% carbon-intensity reduction for transportation fuels would be met entirely through EV adoption, which is why the CFS policy wedge does not appear in Scenarios 3 and 6.

Summary of Findings

Achieving Washington State's Deep Decarbonization Pathways targets alone is enough to meet Thurston region's goal to reduce emissions to 30% of 1990 levels by 2035. Scenarios 1-3 make clear how critical it is to decarbonize the grid. EVs without a clean grid do not get Thurston to its targets. The region will

[18] Bloomberg New Energy Finance's Long Term Electric Vehicle Outlook https://about.bnef.com/electric-vehicle-outlook/

want to advocate for the successful decarbonization of Washington's electricity grid to meet its emissions goals.

There are challenges with continuing reductions between 2035-2050, since even with the highest Electric Vehicle scenario (Scenario 6), Thurston will not meet its 2050 goal. However, several opportunities present themselves:

- Heavy-Duty Vehicles: Emission reduction potential exists for HDVs since reductions for them were excluded in this analysis.
- Buildings: Natural gas fuel-switching and further energy efficiency are possible.
- Technologies: Technologies in development today but likely deployed before 2035 will help achieve targets.
- VMT: It is possible that additional VMT reductions could help Thurston County achieve its goal, but we have not done the analysis to ascertain whether additional VMT reduction is realistic.

Conclusion

Clean Energy Transition and Stockholm Environment Institute are grateful for the opportunity to model different transportation scenarios to examine the impact of Puget Sound Energy's IRP assumptions on the overall carbon emissions trajectory for Thurston County, and to assume aspects of the Washington State Deep Decarbonization Pathways study in our work for the Thurston Regional Planning Council. The more precision we can bring to the assumptions we make, the better our work product, so we thank you for being willing to push our analysis beyond what we have produced to date for other communities.