How to cut pollution and achieve our *climate goals* in Washington and Oregon

TRANSFORMING TRANSPORTATION

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Stay Healthy Streets (shown above)

The City of Seattle initiated Stay Healthy Streets in 18 city locations at the beginning of the COVID-19 pandemic to give people sufficient space for walking, rolling, biking, and playing as streets were closed to pass through traffic. The goal was to open up more space for people rather than cars as a way to improve community and individual health. The program is ongoing as of December 2021.

EXECUTIVE SUMMARY

Decarbonizing the Pacific Northwest's largest source of greenhouse gas emissions, the transportation sector, is not only possible but will provide deep benefits beyond climate change mitigation.

This research details the pathways that will achieve our climate goals. Different combinations of vehicle electrification and levels of vehicle miles traveled yield varied results for our climate, health, public and personal spending, electricity sector, and more. Ultimately, the greatest climate, economic, and social benefits would be achieved by a combination of electrifying nearly all vehicles on the road and reducing vehicle miles traveled through expanded transit, micromobility options, and safer, convenient ways to get around by walking or bicycling.

At the core of achieving near-zero carbon emissions by 2050 is the need for a rapid and substantial increase in electric passenger, freight, and transit vehicles. In order to meet our climate goals, we must electrify nearly all vehicles on the road. Such a strategy will improve our health, particularly in low-income communities and communities of color that have been overburdened by pollution, as well as reduce personal transportation costs. It will also necessitate an increase in clean electricity sources, public chargers, and a rapid turnover from fossil fuel-powered vehicles to electric ones. Transportation electrification is key to decarbonization, but even more significant social benefits, such as improved safety, greater personal financial savings, and greater near-term health benefits, can be achieved by cutting emissions through a combination of electrification and reducing reliance on personal vehicles and expanding transit, thereby reducing vehicle miles traveled.

INTRODUCTION

Transportation is the single largest source of climate pollution in the Pacific Northwest, and we must cut these emissions to near-zero by 2050 in order to maintain a stable climate.

Air pollution from this sector also harms our health, while disproportionately burdening low-income and BIPOC (Black, Indigenous, and people of color) communities due to racist public policies such as redlining and inner-city highway construction.[1] We need to clean up the fuels we use to get around through rapid transportation electrification, and to reduce our reliance on driving, shifting to higher transit use, walking, bicycling, and other non-vehicle options.

With new research, Climate Solutions, Hovland Consulting, and E3 evaluate options to meet our climate goals in Washington and Oregon, cutting carbon from our transportation system by electrifying our vehicles and by changing how many miles we drive. We examine how different pathways will impact our health, safety, spending, transportation infrastructure, and electricity grid, and how impacts vary for different areas and communities that have been overburdened by pollution.

Many studies have analyzed the impacts of transportation electrification[2] on decarbonization, but fewer have included analyses of how the level of vehicle miles traveled (VMT) affects outcomes. One project that did was the Institution for Development & Transportation Policy and UC Berkeley's Three Revolutions in Urban Transportation which examined the carbon impacts of electrification, automation, and sharing. Their research found that electrification, paired with automation, reduced emissions from a business as usual case, but including sharing reduced emissions significantly further as well as cut the cost of vehicles, infrastructure and transportation system operation by more than 40%.[3]

Similarly, America's Zero Carbon Action Plan, published shortly after the modeling for this research was completed, concluded that electrifying surface vehicles is key to decarbonizing transportation, but when paired with reducing vehicle use, we see significant economic, health, land use, and social equity benefits.[4]

This research is, to our knowledge, the first decarbonization analysis that models the impacts and interaction of electrification and VMT in Washington and Oregon.

While it analyzes our pathways to achieve transportation decarbonization and their various impacts, this research does not evaluate individual policies and how they would contribute to the outlined pathways. Rather, the model sets a trajectory for transportation electrification and VMT but does not specify how these levels would be achieved.

We found it is possible to decarbonize through rapid transportation electrification powered by a clean grid. Doing so will benefit our health and lead to lower personal transportation costs. If we rapidly electrify and reduce VMT, shifting to transit, walking, biking, and micromobility options, we will see more health benefits in the near-term, additional safety benefits, and greater financial savings. Thus, the optimal decarbonization pathway pairs transportation electrification with a reduction in VMT.

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METHODOLOGY

Climate Solutions worked with researchers at Hovland Consulting and E3 to develop three core scenarios reflecting varying levels of VMT in a decarbonized future. In addition to a reference case assuming business as usual transportation electrification and VMT levels, the core scenarios seek to evaluate the impacts, benefits, and expense of decarbonizing our transportation system by a minimum of 95% compared with 1990 levels with low VMT growth where transit and other modes replace many drive-alone trips, business as usual VMT growth where mobility patterns don't change from today, and a high VMT scenario that may result from underfunding transit, poor land use planning, automation or other causes.

In addition to the core scenarios, the project included a variety of sensitivities pertaining to different electricity resource mixes, demand response, and varying degrees of uptake of vehicle electrification and VMT reduction.

General Structure

In order to discern the impact of varying levels of transportation electrification and VMT, we created an Excel-based model. For passenger VMT levels, we are able to input changes compared to a 2050 business as usual baseline for four different geographical groupings in each state: urban, suburban, small town, and rural.

- Passenger miles traveled
- Bus/transit mode use
- Micromobility (for example, shared scooters or bicycles) mode use
- Walking, biking, and trip elimination

The model also accepts changes in freight VMT compared to a 2050 baseline.

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For electrification levels, the model accepts varying levels of electrification by 2050 for the following vehicle classes:

- Cars (passenger)
- Light duty trucks (passenger)
- Buses
- Light duty trucks (freight)
- Medium duty trucks (freight)
- Heavy duty trucks (freight)

In addition to modulating the rate of uptake (percentage growth in electric vehicles by class that results in a given vehicle share by 2050), the model is able to delay the adoption curve by five, ten, or fifteen years.

Based on the above input variables, the model then produces values for the following outputs, all of which can be individually viewed for Washington and Oregon and further split by urban (Seattle or Portland), suburban, small city, and rural geographies from 2020-2050 over five-year increments:

- Carbon-equivalent emissions
- Social cost of carbon
- Electrical power need
- Number of chargers needed
- Cost of chargers needed
- Crash fatalities
- Number of electric vehicles
- Number of people walking, biking, and using micromobility
- Number of people taking transit
- Public road spending
- Public transit spending
- Personal spending on transportation

In order to understand the health impacts of various scenarios, we combined the Excel-based model with the Environmental Protection Agency's COBRA (Co-Benefits Risk Assessment) Tool. The Excel-based model provides outputs for three pollutants—fine particulate matter (PM 2.5), nitrogen oxides (NOx), and volatile organic compounds (VOCs)—which are input into the

COBRA model. Using these, COBRA produces a number of health-related metrics at the county level out until 2028. These metrics were then scaled based on population growth in the Excel-based model to produce 2050 results for the following outputs:

- Total health benefits ($), low - high
- Hospital admits ($), all respiratory
- Work loss days ($)
- Minor restricted activity days ($)
- Asthma exacerbation
- Work loss days
- Minor restricted activity days

As described above, the model is able to differentiate certain inputs and outputs based on geography. Using the geographic outputs from COBRA, in combination with census tract data, the model is then able to estimate proportionate health impacts on people of color and hispanic populations (per census definitions and reporting) and low-income populations (defined by either <185% of the poverty line or 80% of area median income).

In partnership with E3, the project modeled the electricity sector pathways for serving the region's transportation electrification loads. E3's RESOLVE model optimizes investments and operations of the electricity system across a Core NW region that includes Oregon and Washington, and considers resource additions under a set of user defined constraints, including policy requirements, resource availability, operational needs, and reliability metrics. The model used for this research builds on and incorporates the results of previous E3 Pacific Northwest modeling projects, including their 2019 resource adequacy analysis. To evaluate the impacts of shifting charging behavior, annual loads developed under the VMT model were shaped using the Electric Vehicles Load Shift Tool (EVLST), which allowed for sensitivities evaluating demand response opportunities.

Assumptions

This model makes a number of assumptions in order to build out a BAU pathway and other scenarios. These include:

- The use of population growth scenarios from the Oregon Department of Administrative Services[5] and the Washington Office of Financial Management[6] without changes in geographic population distribution by income and race
- No impact from vehicle automation in the BAU or core scenarios
- Linear, correlated relationships between most input variables and outputs (such as VMT and deadly crashes)
- 30% of public EV charging is done at fast chargers (impacts cost range calculations)
- Set both Oregon and Washington on a carbon reduction trajectory consistent with Washington's Clean Energy Transformation Act, requiring 100% clean electricity by 2045. Achieving decarbonization targets was not possible without this policy.

Limitations

There were additional items that were not included in this research due to data and resource constraints and bear further investigation in future efforts. These are listed below:

- Job and local economic impacts
- Land use inputs
- Scope 3 (full lifecycle) emissions
- Non-tailpipe pollution impacts, such as particulate from tire wear
- Traffic congestion impacts and the resulting impacts on travel time
- Inclusion of biofuels or hydrogen-based fuels
- Impact of automation

REFERENCE SCENARIO
BUSINESS AS USUAL

As a reference case, this research models a Business as Usual (BAU) pathway to 2050.

Under this scenario, we see a 30% increase in VMT by 2050 due to a growing population. Personal (per capita) miles traveled do not change, nor do transportation modes selected. Freight miles traveled increase by 45% over the same period of time due to population growth and based on economic projections[7]. We do not consider any new policies to spur transportation electrification, and the model does not include state or federal policies passed after 2019, including Washington's Clean Fuel Standard or the increased Oregon Clean Fuels Program. The policy baseline does include federal Corporate Average Fuel Economy (CAFE) Standards, but does not assume they are extended beyond model year 2026.

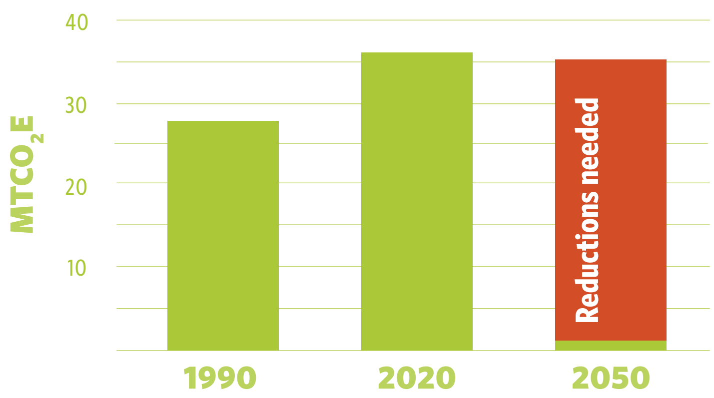
This scenario also assumes low transportation electrification uptake based on Northwest Power and Conservation Council's Seventh Power Plan, which is consistent with previous Pacific Northwest electric sector studies. This results in only 11% of the passenger fleet electrifying by 2050. Thanks to existing commitments and early action from transit agencies, 23% of buses are electrified by 2050. Freight does not electrify.

Adequate decarbonization of the transportation sector was not possible without the region transitioning to a fully zero-carbon electricity supply. Both states were modeled to comply with Washington's Clean Energy Transformation Act requirement of 100% clean power by 2045. Since the research was completed, Oregon has adopted a similar requirement targeted at 2040 instead.

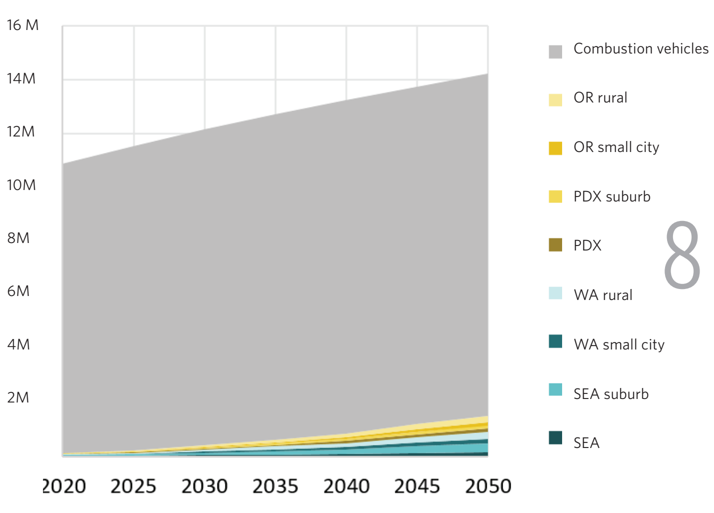
Even without increased transportation electrification loads, Oregon and Washington deploy a substantial amount of new clean electricity to support their phase out of current coal and gas use. The region builds more than 22 GW of new resources by 2050, approximately three quarters of which are solar, wind, and combined cycle gas power plants fitted with carbon capture and storage (CCS) with a 100% capture rate. Also built in meaningful quantities are peaker plants (all gas plants without CCS are run with biogas post-2045), battery storage and demand response. Hydropower remains the dominant source of electricity in this scenario, providing 64% of energy needs, followed by wind generation at 16%. Electricity rates in 2050 average $0.102/kWh.

Under this BAU scenario, we only see a 4% reduction in carbon emissions by 2050—far short of the 95% reduction needed at minimum.

Emissions vs. reductions needed



EVs - Passenger + Freight



CORE SCENARIOS

The core scenarios modeled result in carbon emissions reductions of at least 95% from 2020 levels by 2050. These reductions align with the Washington Deep Decarbonization Pathways and the Clean Energy Transition Institute's Pathways study for the Northwest and are within the range projected to limit global warming to 2 degrees Celsius or below.

Given the need to achieve near-100% transportation electrification to meet pathway goals, core scenarios hold this variable constant, thereby examining the different outcomes associated with different levels of VMT when paired with this level of electrification.

Nearly all vehicles must be electric by 2050:

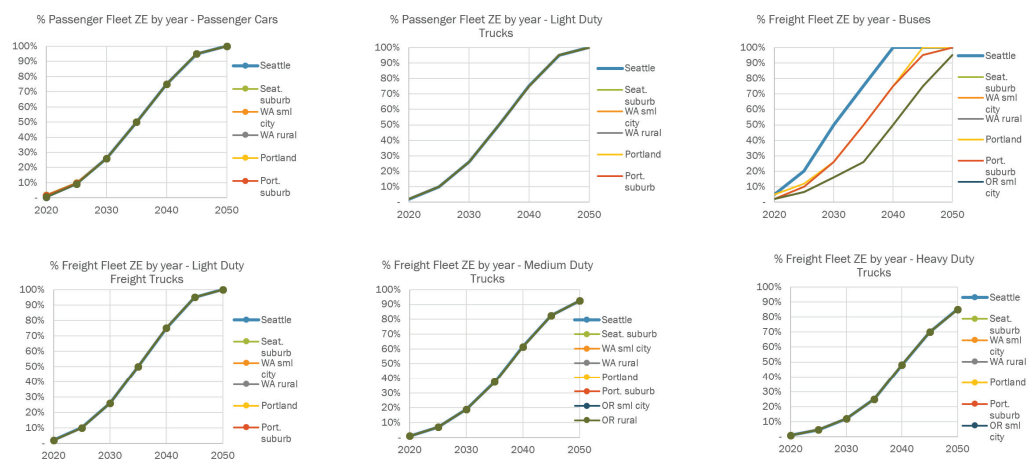
100% of passenger and light duty vehicles

98% of buses

93% medium duty trucks

85% heavy duty trucks

Near 100% electrification by vehicle type (below)



SCENARIO 1:
Electrification + VMT Reduction

- Near 100% electrification of all vehicle types
- 27% VMT reduction

SCENARIO 2:
Near 100% electrification

- Near 100% electrification of all vehicle types
- No change in VMT compared to BAU

SCENARIO 3:
Electrification + VMT Increase

- Near 100% electrification of all vehicle types
- 21% VMT increase

SCENARIO 1: ELECTRIFICATION + VMT REDUCTION

This scenario represents the optimal pathway, contributing the greatest health, safety, and financial benefits on top of achieving our decarbonization goal.

In this scenario, VMT is reduced by 27% by 2050 compared to BAU. This level of VMT necessitates Seattle and Portland reducing their VMT by 47%, which is lower than that of New York City and would be about the same as London. VMT in small cities would need to be the same as the New York state average, which is the state with the lowest VMT. Freight VMT is reduced by 15%. These VMT reductions are paired with the near-100% electrification shared across the core scenarios.

Though the VMT reductions compared to BAU are significant, they still represent similar levels of VMT and vehicles on the road when compared to today. This is due to population growth and the BAU case representing an absolute increase in VMT and vehicles due to our growing population and a projected increase in freight miles.

This pathway results in carbon pollution dropping to 97% below 2020 levels by 2050. This averts 475 million metric tons of greenhouse gas

Health benefits of Scenario 1 vs. BAU

	2025	2050 (Adjusted for population)
$ Total Health Benefits (low-high)	$30 - $68 M	$278 - $ 626 M
$ Hospital Admits reduced, All Respiratory	$20 k	$186 k
$ Work Loss Days avoided	$83 k	$764 k
$ Minor Restricted Activity Days avoided	$210 k	$1941 k
Mortality avoided (low-high)	3 - 6	28 - 62
Asthma Exacerbation avoided	95	875
Work Loss Days avoided	460	4,265
Minor Restricted Activity Days avoided	2,700	25,100

*Team analysis using EPA's COBRA model

emissions by 2050, which translates to saving $41 billion in the social cost of carbon compared to business as usual.

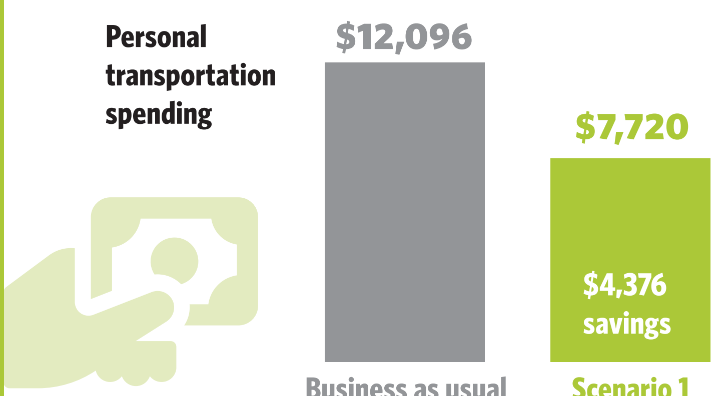
The reduction in tailpipe emissions that comes from reducing VMT and transportation electrification results in massive health benefits which also translate to monetary savings of up to $626 million annually by 2050. For people of color in Seattle alone, this amounts to, at minimum, $88 million in avoided health costs by 2050 and 176 fewer asthma attacks, due to the fact that people of color are disproportionately burdened by air pollution.

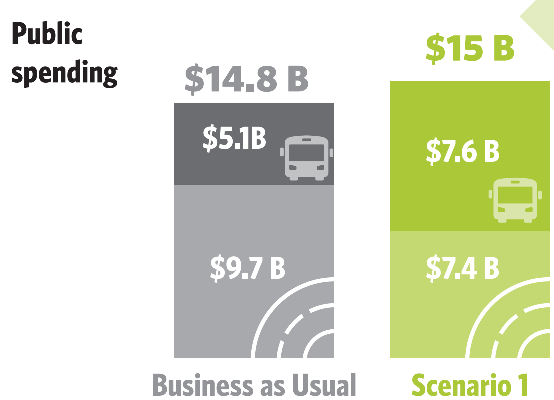
In addition to reducing deaths caused by pollution, reducing VMT will also reduce deaths caused by vehicle crashes. Under this scenario, 205 lives will be saved in 2050.

Owning an electric vehicle is cheaper than owning a gas-fueled vehicle, and reducing the frequency of driving or opting out of owning a vehicle entirely is cheaper yet. While the cost of electricity in this scenario increases from $0.102/kWh to $0.110/kWh, under this scenario, thanks to the combination of electrification and reducing the need to drive, the average person will save around $4,370 annually when compared with business as usual.

To support this amount of electric vehicles, we will need 750,000 public chargers ($1.2-2.4 billion total cost). We will also need to significantly invest in transit to achieve a shift from driving alone in personal vehicles, spending $2.5 billion more in public transit investments (with farebox recovery accounted for) than under business as usual. However, we will need to spend much less on roads—$2.3 billion less. Together, this amounts to $200 million more than business as usual.

Total electricity load in this scenario increased by 16% or 39 TWh, and with annual peak climbing by approximately 12% or 4.9 GW. To serve this increased demand, the region procures an additional 10.2 GW of electric resources, including nearly doubling the amount of wind and battery storage. Substantial capacity needs in this scenario also lead to a near doubling of new peakers run with biogas and combined cycle gas plants run with CCS. Solar construction does not substantially increase due to its poor alignment with projected vehicle charging times. Hydropower represents a lower share of total generation, though still a clear majority at 54%, and wind contributes an increased 19% of all energy needs.





Overall, Scenario 1 is our socially-optimal pathway for achieving our decarbonization goals in the transportation sector. It will require investments in clean electricity, transportation electrification infrastructure, and transit, but it will improve our health, cut personal transportation costs, and save lives.

SCENARIO 2: ELECTRIFICATION ONLY

This scenario combines the near 100% electrification of the previous scenario with no changes to per capita VMT. People's travel patterns do not change, but nearly all of the vehicles on the road are electric by 2050.

This pathway achieves our emissions reductions goal, with carbon pollution dropping to 96% below 2020 levels by 2050. This averts 435 million metric tons of greenhouse gas emissions by 2050, which translates to saving $38 billion in the social cost of carbon compared to business as usual. However, this scenario results in more cumulative emissions than the optimal pathway.

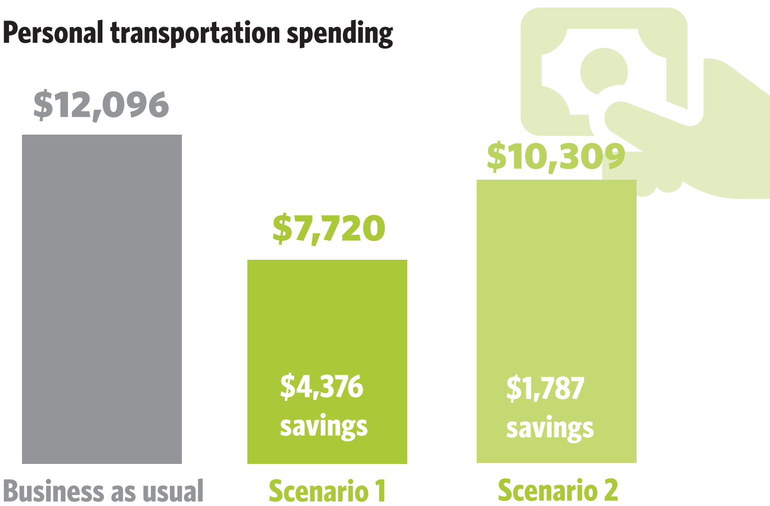
Reducing tailpipe emissions results in substantial health benefits, and both this scenario and Scenario 1 produce similar outcomes by 2050. However, the health savings do not accrue as quickly in this scenario, with $10-$24 million fewer in health-related savings in 2025 due to more miles being traveled by vehicles that are not yet electrified. Near-term benefits under this scenario are smaller for communities of color and low-income communities as well for the same reason. Benefits remain, but they are not as significant as in Scenario 1.

Because travel patterns remain the same as business as usual, we do not see increases in active transportation or decreases in crash deaths under this scenario.

Since electric vehicles are cheaper to fuel than gas-powered vehicles, individuals will save about $1,780 annually compared with the status quo. However, they will not save as much as they would under the scenario where electrification is paired with VMT reductions. In this scenario, electricity rates increase to $0.113/kWh, or a nearly 60% sharper climb compared to a scenario that prioritized greater mass transit and lower drive-alone behavior.

As this scenario does include any reduction in VMT, it requires 3.8 million more electric vehicles and 190,000 more public chargers than the previous scenario.

Personal transportation spending



Health benefits of Scenarios 1 & 2 vs. BAU

2050 shown unless otherwise specified	Change from reduced VMT	Electrification + VMT reduction	Electrification only
Cumulative CO_2 emissions 2020-2050	40 Mt more	515 Mt	555 Mt
Social cost of carbon, 2020-2050	$3 B more	$37 B	$40 B
Electrical power need	11 TWh more	42 TWh	53 TWh
Chargers	190 k more	750 k	940 k
$ for chargers (cumulative, low-high range)	$300-700 M more	$1.2-2.4 B	$1.6-3.2 B
Annual crash fatalities in 2050 (2030)	205 (42) more	874 (863)	1,070 (904)
Electric vehicles	3.8 M more	10.4 M	14.2
People walking, biking, or micro-mobility	250k fewer	700k	450k
People using buses	1 M fewer	2 M	1 M
Annual public road (no transit) spending in 2050 (2030)	$2.1 ($0.5) B more	$7.4 ($7.3) B	$9.5 ($7.8) B
Annual transit expenditures* in 2050 (2030)	$2.5 ($1.5) B less	$7.6 ($5.6) B	$5.1 ($4.1) B
Annual per person transport spending in 2050 (2030)	$2,600 ($1,000) more	$7,700 ($10,800)	$10,300 ($11,800)**
Total annual personal transport spending in 2050 (2030)	$40 ($14) B more	$119 ($143) B	$159 ($157) B

*Includes fare recovery

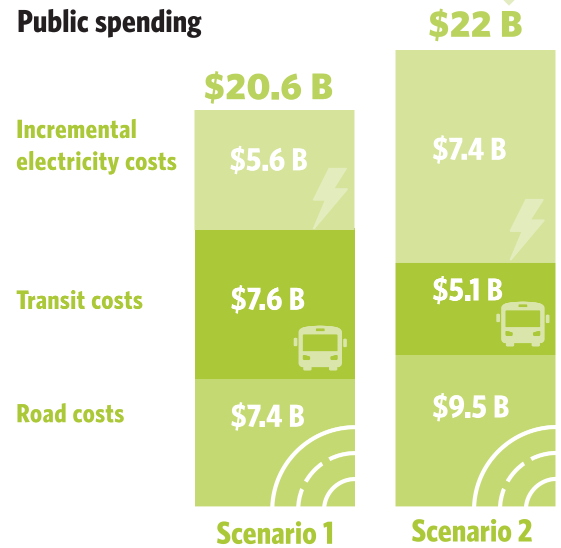
**Down from $12,350 in 2020

The 59 TWh increase in energy needs represents a 23% increase compared to business as usual, with a comparable increase in peak loads. At these load levels, the electricity system has largely reached saturation of variable renewable energy long ago—for example, Scenario 1 which centered VMT reduction alongside electrification saw an increase in solar and wind deployment compared to business as usual of 45%, equal to an extra 5 GW of installations. This scenario, which includes much higher load needs, sees a further increase in wind and solar installs of just 400 MW, or about 3% extra. The declining effective load-carrying capacity of these resources at very high levels of deployment leads the model to select ever-increasing amounts of dispatchable peak-contributing resources instead of continued solar and wind. Compared to the reference case, battery storage capacity triples from 758 MW to 2,116 MW; construction of biogas peakers and CCS-enabled combined cycle gas plants climbs from over 6.5 GW to 14.3 GW.

When we combine road, transit, and incremental electricity costs, this scenario is $1.4 billion more expensive than Scenario 1. Scenario 1 has higher transit spending, but it requires less road spending and has fewer electricity costs.

This scenario achieves the level of transportation decarbonization necessary and will result in significant additional benefits, but these benefits are not as significant, and accrue more slowly, than in the previous scenario.

This demonstrates that electrifying our transportation is foundational to decarbonization, but is more socially beneficial and presents cost savings when paired with VMT reductions.



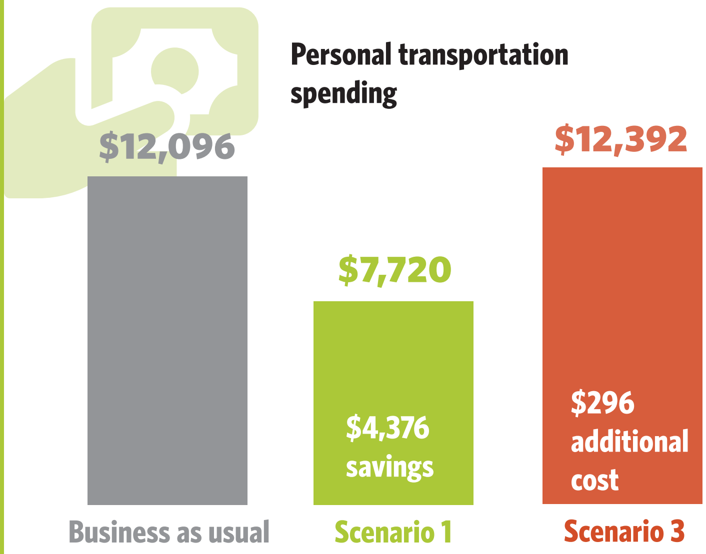
SCENARIO 3: ELECTRIFICATION + VMT INCREASE

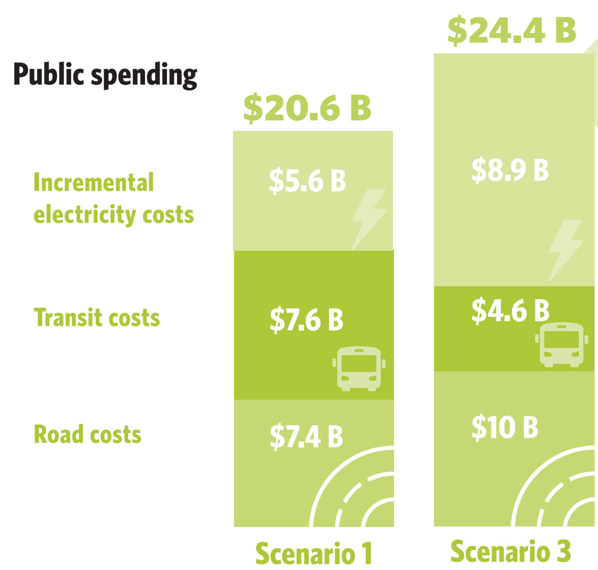
This scenario, which combines near-100% electrification with an increase in personal and freight vehicle miles traveled relative to BAU, achieves our greenhouse gas reduction goal but at higher financial and social costs.

In this case, VMT increases 21% by 2050 compared to the reference case. Rural VMT increases more than urban and suburban VMT, with rural areas matching the mileage of the average North Dakotan today. This increase in VMT could be the result of a combination of poor land use practices, unregulated vehicle automation, and a decrease in transit funding.

Due to the increase in VMT, this scenario presents the most cumulative carbon emissions: 30 MMT more than Scenario 2, translating to $3 billion more in the social cost of carbon. Just as emissions reductions do not occur as quickly as in Scenario 1, nor do health benefits. Without VMT reductions, Scenario 3 also does not produce any safety benefits—compared to Scenario 1, Scenario 3 results in 425 more crash fatalities in 2050.

Personal costs are higher in this scenario. Though increased electrification yields lower fuel costs, total transportation costs exceed BAU by approximately $296 annually. Public costs are higher than both Scenarios 1 and 2 as well: Scenario 3 requires $0.6-1.2 billion more in spending on public chargers than Scenario 1 and $8.85 billion more in electric system costs to build an additional 59 TWh of load and meet an additional 9.9 GW of peak capacity. In sum, the greater road costs and incremental electricity costs of this scenario outweigh its lower transit costs, resulting in $3.8 billion of additional direct annual public costs when compared with Scenario 1.





SENSITIVITIES

We also analyzed additional scenarios to better understand the impacts of different levels of electrification and vehicle miles traveled which emphasized:

We cannot delay or slow down the rate of electrification and we cannot achieve our goals through VMT reductions alone. We must rely on a combined strategy of transportation electrification and VMT reductions.

In order to achieve the deep decarbonization we need and achieve our goals, we cannot delay the rapid uptake of transportation electrification even by five years, regardless of whether electrification is paired with VMT reductions. Therefore, it is critical that we work on policies that will support transportation electrification in the near term.

Even if we reduce VMT by 27% (per Scenario 1) and slow electrification so that 80% of cars, 90% of buses, 75% of medium-duty freight, and 72% of heavy-duty freight are electrified by 2050, we would still fall 15% short of our carbon reduction goal.

If we rely only on reducing VMT and do not electrify further than BAU, we will fall far short of our climate goals. Even if we match urban and small city VMT to be at or below that of Paris and suburban VMT matches London's—a 55% reduction overall—we would still be 50% short of our goal.

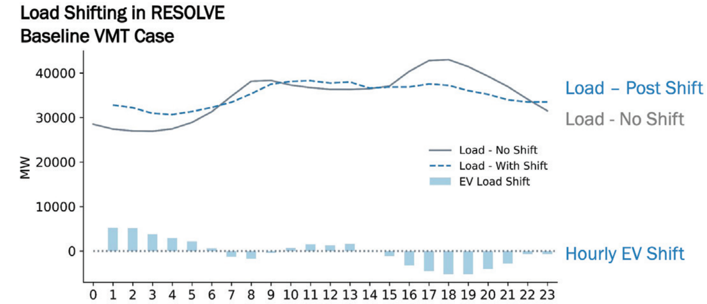
If we pair these deep VMT reductions with the least amount of electrification possible, we still find that we need about 97% of cars and light duty trucks, 96% of buses, and 85% of medium and heavy duty freight to be electrified in 2050. Anything less and we will not meet our decarbonization goals. However, combining deep VMT reductions with electrification leads to significant benefits, building on those outlined in Scenario 1.

Additional modeling of the electricity sector analyzed the impact of shifting the charging load of electric vehicles to different times of day in order to reduce costs, assuming the shift is reducing capacity requirements of the NW electricity system. Using parameters that assumed no change in driving patterns, load could be shifted 8%. This reduces the system cost by $600 million and requires 3 GW less of peak capacity when compared to the baseline, near-100% electrification pathway of Scenario 2.

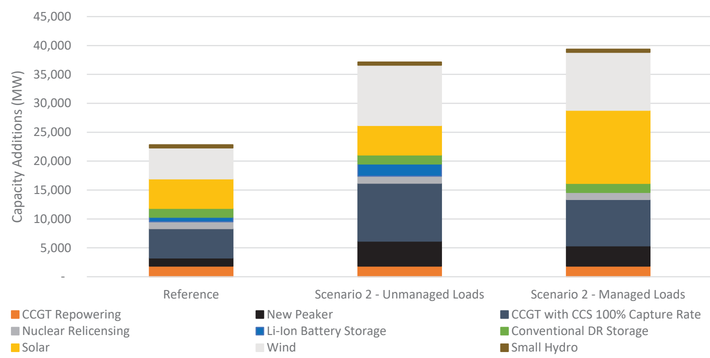
Managing loads is more cost-effective than battery storage deployment, so the model eliminates all such installations when it's allowed to adjust load shapes. Loads are shifted into the midday time period and into the night, when resources are less stretched. Wind installations in this scenario remain largely unchanged; however, the increased ability to capture mid-day, low-cost solar installations increases these deployments by nearly 150% from 5.1 GW to 12.6 GW. Biogas peaker and CCS (carbon capture and storage) combined cycle plant builds fall by 20%. Coupling load management with VMT reductions contained in Scenario 1 reduces peaker and combined cycle deployment by an additional 16%, saves an additional $1.6 billion annually, and yields the lowest rate impacts of just $0.108/kWh.

This shift in electric load from EV charging emphasizes the need to ensure that people have access to charging in the very middle of the day, likely necessitating more charging capacity at workplaces.

Load Flexibility



Electric Sector Capacity Additions in a Low Carbon Future



WHAT ABOUT NUCLEAR?

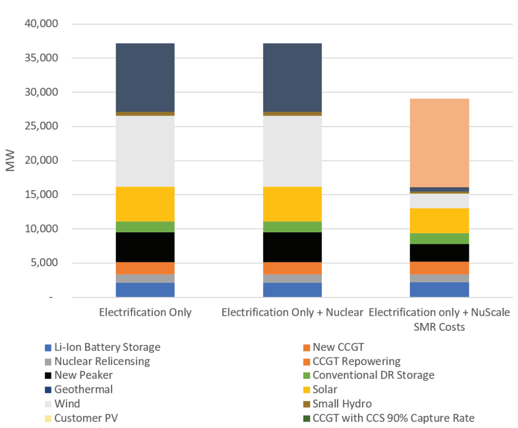
No Washington or Oregon utilities currently envision deploying new nuclear power as part of their transition to 100% clean electricity, though this could change over time, especially as electricity demand grows to catch up with widespread electrification in the transportation and buildings sectors. To evaluate whether nuclear can play a cost-effective role in a low carbon transportation and electricity future, we evaluated two electric sector sensitivities on Scenario 2 (high electrification, BAU VMT).

The first of these relied on the same cost estimates and projections that we used for renewable electricity—NREL's Annual Technology Baseline. We ran an additional sensitivity where these nuclear costs were substituted for NuScale's "nth of a kind" cost projection. Both of these cost families aligned with assumptions used in previous research[8] commissioned by Energy Northwest and carried out by E3.

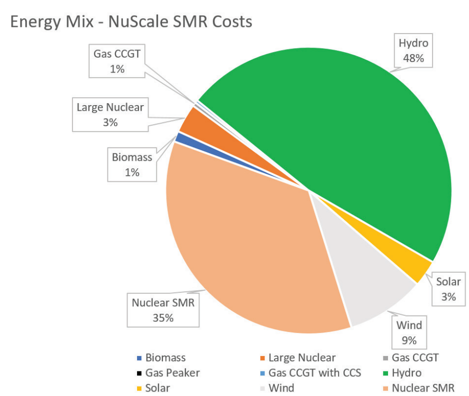
Using NREL's cost, we found that the model yielded a result identical to the original Scenario 2 result even with no additional nuclear deployment. Small modular reactors (SMR) are just not cost-effective in the Pacific Northwest at these costs, and the electrical system's need for clean firm resources in this scenario continue to be provided by a combination of natural gas plants with CCS and biogas plants.

The deep cost reductions associated with NuScale's projections, however, led to a substantial amount of nuclear deployment—a total of nearly 13 GW of new small modular reactors deployed across the region. In this case, nuclear SMR becomes the second largest source of energy after hydropower and provides 35% of total load in the region.

Resource Builds 2050



Energy Mix



DISCUSSION

Like many previous research projects, these scenarios demonstrate that a clean transportation future is within our grasp and provides deep benefits, especially for low-income communities and communities of color that are most burdened by the current system. Maximizing those benefits requires a multi-pronged approach that includes reducing driving dependence while decarbonizing the transportation system through electrification. Electrification provides substantial benefits in a variety of ways—elimination of tailpipe emissions, substantial reductions in transportation fuel costs, and, in combination with a zero-carbon grid, elimination of greenhouse gases from transportation. Ultimately, this research concludes that decarbonizing the transportation sector simply isn't possible without electrification at the pathway's core. Policy solutions must both accelerate electrification and support lowering VMT.

Reducing auto-dependence is important and provides many benefits, discussed below. When it is viewed solely as a carbon mitigation strategy, though, it is very expensive, emphasizing the need to evaluate climate policy within a broader context and the importance of examining climate, social, and economic benefits together. In Scenario 1, VMT reduction is responsible for 115 million tons in aggregate carbon emission reductions (just over 24% of the total reduced) over the study period. The marginal abatement cost over the study period of these reductions is equal to $221/ton[9]. Other analyses find even higher marginal abatement costs, including one completed by King County Metro examining reduction strategies associated with both fuel conversions and service expansion. Metro found that expansion of service on low-performing routes could yield additional carbon reductions, but at exceedingly high direct costs that could reach $5,000/ton[10]. Their higher estimate does not consider savings opportunities on road construction and electricity as this research does, but does show the very high direct costs associated with these strategies to those agencies charged with carrying them out, while savings may accrue elsewhere in the economy. In comparison, the marginal abatement cost for Scenario 2, which includes BAU VMT and relies solely on deep electrification, totals $190/ton. Electrification is cheaper and a more comprehensive decarbonization strategy. It's also more scalable—the marginal abatement cost for VMT reductions is likely to grow if VMT reduction is required to achieve even deeper cuts, as indicated by the King County Metro analysis.

It's essential, given this comparison, to place these costs in context. While electrification is principally a pollution reduction strategy, with substantial benefits to health and climate, VMT reduction is better suited to address a variety of societal ills, with climate change mitigation being only one of a range of other benefits. Most of these benefits are only partially captured in this research, if at all, including those pertaining to climate change. A proper case for VMT reduction through expanded transit, bicycle and pedestrian infrastructure, and land use regulations resulting in adequate housing near jobs and services cannot rest principally on the need to mitigate climate change because it is far from the most cost-effective method of pursuing these carbon reductions on a cost per ton basis. It is nonetheless essential to acknowledge that a future that combines VMT reductions and electrification costs less than an electrification only approach.

Other essential benefits of VMT reduction:

- A variety of health and safety improvements in aggregate over the time period. This includes air pollution benefits in the interim years that are ultimately fully realized through electrification in 2050.
- A range of other pollution benefits not evaluated in this research, including particulate matter associated with tire wear and resuspension from roads.
- Reduced costs for non-transportation electricity use, which will especially benefit those car-free households that don't financially benefit from a transition away from gasoline. Because under most typical rate designs, electricity load costs are socialized to all customers, regardless of whether they're contributing

to the particular segment of load in question, reducing unnecessary vehicle electrification benefits everyone, and especially those that don't themselves contribute to transportation loads. Because the entire electricity system is built on these kinds of cross-subsidies (for example, rural customers are subsidized by urban customers) out of a recognition that democratic access to energy is a social good, it is reasonable to assume that this practice will largely persist. Nonetheless, at 2019 average household electricity usage rates[11], a low-VMT, managed load future will save a Washington household $58.40/year on non-transportation electricity costs compared to Scenario 2, a number that is even higher for all-electric customers that don't also rely on natural gas. Oregon households would save $54.67/year.

- Avoided embodied carbon emissions associated with the production of electric vehicles, which are more carbon intensive than internal combustion engine varieties, and from road expansion.
- Basic livability improvements, including less congestion, more pleasant and walkable neighborhoods, safety and fewer vehicle crashes, improved community feeling, and much more.

A thoroughgoing transition to a low carbon future should include these wide range of considerations. Rebuilding our society in a sustainable way should serve not only carbon reductions but social good, and regardless of the specific dollars and cents of decarbonization alone, this comprehensive suite of benefits should be incorporated into transition strategies. The least-cost low carbon transportation future includes expensive components, but ultimately yields the greatest benefits to the widest share of our population.

CONCLUSION

It is possible to decarbonize our transportation sector while shifting to a 100% clean electricity grid, but we need to act quickly by reducing vehicle miles traveled and electrifying all vehicles still on the road. The rate of transition to an electric transportation system must be rapid and occur without delay to align with our need to decarbonize. In addition to mitigating the climate crisis, electrifying transportation and reducing VMT will also lead to improved equitable outcomes including substantially better health and air quality, and a reduction in how much money we spend to get around compared to business as usual. While we can meet our decarbonization goals by focusing only on transportation electrification, we see even more holistic health, safety, and economic benefits when paired with increasing transit use, walking, and biking. We must support an equitable array of bold policies that will lead to rapid transportation electrification; invest more in transit, active transportation infrastructure, and other ways to reduce vehicle trips; improve our land use policies to make it safer and easier to walk, bike, and use transit to get around; and, integrate an emphasis on improved health, safety, and equity into all policy.

PC: SDOT via Flickr

PC: Trimet via Flickr

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[9] This is somewhat of an overestimate of the marginal abatement cost for a variety of reasons, including that the investments included in these cost estimates will continue reducing emissions outside of the study period, the avoided road construction will reduce embodied carbon and other factors. Nonetheless, this figure provides a sense of scale.

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DATA SOURCES

VMT: Bureau of Transportation Statistics, Local Area Transportation Characteristics for Households (LATCH) plus Federal Highway Administration

Note: For VMT and PMT by census tract, estimated from model using 2012-2016 American Community Survey 5-year estimate tract data

Freight activity: FHWA/DOT Freight Analysis Framework

Fuel economy: U.S. Energy Information Administration & Alternative Fuel Data Center

Criteria pollutants and greenhouse gases: Argonne National Laboratory & Environmental Protection Agency

Safety/crashes: Bureau of Transportation Services & Oregon DOT & Reason Foundation

Health: COBRA EPA Model

Road infrastructure spending: 2017 Census of Governments, State and local government finances, Federal Highway Administration & Transportation by the Numbers

Electrical grid: Pacific Northwest Low Carbon Scenario Analysis & Resource Adequacy in the Pacific Northwest

Charging infrastructure costs: Federal Highway Administration & BTS Transportation by the Numbers

Household spending: Consumer Expenditure Survey, U.S. Bureau of Labor Statistics, September, 2019 , Eno Center for Transportation, Federal Highway Administration, ITDP & Bureau of Transportation Statistics

Demographics and population: Census Tiger data, Oregon Department of Administrative Services, Washington Office of Financial Management & U.S. Census Data

Transportation emissions: Oak Ridge National Lab DARTE & New York Times

Pathways references: US Energy Information Administration's Annual Energy Outlook 2020 & IEA Energy Technology Pathways