Oregon Statewide Transportation Strategy

A 2050 Vision for Greenhouse Gas Emissions Reduction

Volume 2

Oregon Sustainable Transportation Initiative (OSTI)

Technical Appendices

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Oregon
Department
of Transportation

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TECHNICAL APPENDIX 1

Statewide Transportation Strategy Analysis Methodology Overview

Introduction

Technical Appendix 1 provides an overview of the methodology used in the analysis of transportation sector greenhouse gas (GHG) emissions reductions for inclusion in the Statewide Transportation Strategy (STS). It contains the following sections:

- **Analysis by Travel Market** – explains why and how the transportation sector was broken out into three distinct travel markets (Ground Passenger and Commercial Services, Freight, and Air Passenger) for the purposes of GHG emissions analysis, and describes the general format of Technical Appendix 2, Technical Appendix 3, and Technical Appendix 4;

- **Transportation Sector GHG Emissions Overview** – provides a brief summary of the relative contribution of different transportation modes and travel markets to overall transportation sector GHG emissions; and

- **Key Transportation Sector Forecast Assumptions** – describes the development and application of four key assumptions used across all travel market GHG emissions analyses.

Technical Appendix 2, Technical Appendix 3, and Technical Appendix 4 contain additional details on data sources, assumptions, and estimation/forecasting techniques used to predict potential GHG emissions reductions by individual travel market. Technical Appendix 3 presents tables of the key recommendations (as further discussed in the STS report), including potential challenges to implementation and possible implementation trajectories.

Analysis by Travel Market

The transportation sector consists of a diverse variety of modes, markets, sensitivities, and interactions. These components of travel are often driven by very different forces, and are therefore impacted by different measures. The STS attempts to explore all aspects of the transportation system, including the movement of both people and goods over short and long distances. Three distinct travel markets are identified for the purposes of analyzing GHG emissions in the development of the STS:

- **Ground Passenger and Commercial Services Travel Market.** This travel market refers to all ground passenger travel on roads and rail, as well as commercial service and delivery travel using vehicles weighing less than 10,000 lb gross vehicle weight (GVW). This includes family and fleet vehicles such as compact cars, SUVs, vans, and pick-up trucks; passenger travel by surface public transportation (e.g. bus and train); and travel by most delivery, service and repair vehicles. For more information on the analysis methods used to estimate Ground Passenger and Commercial Services travel market emissions, see Technical Appendix 2.

- **Freight Travel Market.** This travel market refers to goods movement across all transportation modes (road, air, rail and water) on vehicles greater than 10,000 lb GVW. Freight transportation in this context involves larger, heavier vehicles that usually travel longer distances to serve both regional and national markets. Air freight differs from air passenger travel in terms of travel purpose and other considerations. For more information on the analysis methods used to estimate Freight travel market emissions, see Technical Appendix 3.

- **Air Passenger Travel Market.** This travel market refers to commercial air passenger travel, including aircraft, ground access and support equipment. Air passenger travel moves at much faster speeds and typically over much longer distances than ground passenger travel. In addition, unique fuels are required to propel aircraft. These differences subject air passenger travel GHG emissions to a different set of potential emission reduction actions. For more information on the analysis methods used to estimate Air Passenger travel market emissions, see Technical Appendix 4.

For the most part, these three travel markets will involve unique GHG emissions reduction strategies. However, some actions (e.g., advancements in fuel technologies or deployment of intelligent transportation systems [ITS] technologies) may affect multiple markets. Therefore, the STS presents separate recommendations for each travel market.

In order to conduct the technical analysis for the STS work, the Oregon Department of Transportation (ODOT) developed the GreenSTEP[1] model. This new model estimates and forecasts the effects of various policies and influences on the amount of vehicle travel, types of vehicles and fuels used, and resulting GHG emissions. Technical detail on how GreenSTEP was developed and used is described in these appendices.

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[1] GreenSTEP is an acronym, which originally stood for Greenhouse gas State Transportation Emissions Planning. The meaning of the acronym was changed later to reflect revisions to the model to enable it to be applied at a metropolitan area level and to address a more general set of transportation energy considerations as well as greenhouse gas emissions. The current full name for GreenSTEP is Greenhouse gas Strategic Transportation Energy Planning.

Transportation Sector GHG Emissions Overview

The following figures provide some brief context on the primary contributors to transportation sector GHG emissions.

Figure 1 displays a breakdown of U.S. domestic transportation sector GHG emissions sources by mode of travel. In 2009, light vehicles make up a large majority of transportation sector emissions (65 percent), followed by heavy trucks (21 percent), and aircraft (8 percent). Rail, pipelines and waterborne transportation each represented roughly 2 percent of domestic GHG emissions.[2]

Figure 2 displays the estimated share of Oregon's transportation sector GHG emissions attributable to each of the three travel markets in base year (2010) conditions: Ground Passenger and Commercial Services (48 percent); Freight (41 percent), and Air Passenger (11 percent).[3]

Note: The STS GHG estimates are based on a new approach to accounting for transportation emissions. The STS approach is to estimate the transportation emissions of Oregonians, regardless of where those emissions occur, rather than to estimate the emissions occurring within the boundaries of Oregon. The ground and air passenger estimates include the travel emissions of Oregonians within Oregon and to other states and countries but does not include the emissions of non-Oregonians traveling within or through Oregon. The freight estimates include the emissions from transporting goods that are used by households and businesses in Oregon, regardless of where they come from. These estimates do not include the emissions resulting from the shipment of goods from Oregon or through Oregon because those goods are used by households and businesses located in other states or countries. Consequently, the GHG emissions reported by the STS for each market segment may be different from the GHG emissions reported elsewhere.

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[2] U.S. Environmental Protection Agency. Inventory of US Greenhouse Gas Emissions, 1990 – 2009. Table 3-12.

[3] Reflects research and analysis by ODOT, Cambridge Systematics and Fehr and Peers based on data from the US Environmental Protection Agency (EPA), ODOT, and multiple other sources.

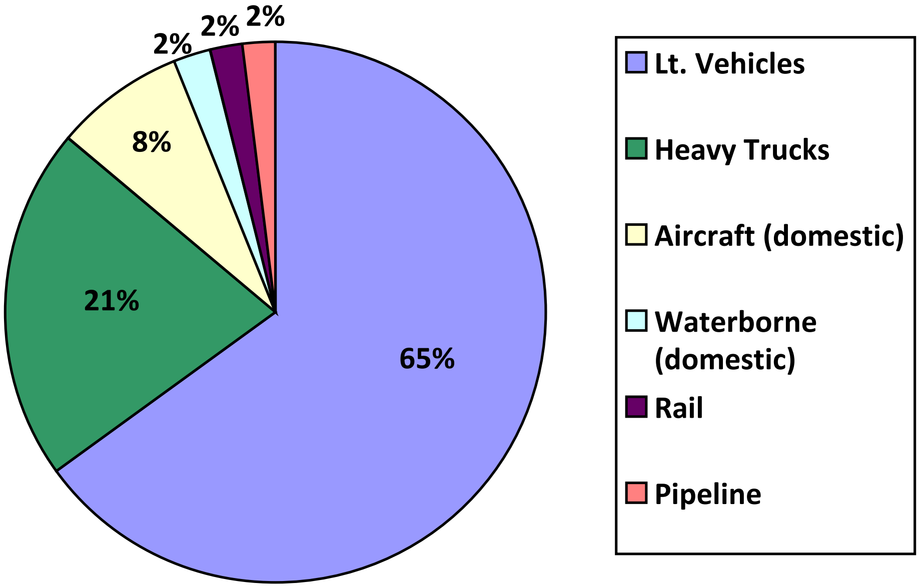

Figure 1. US Domestic Transportation Sector Emissions Sources by Mode of Travel (2009)

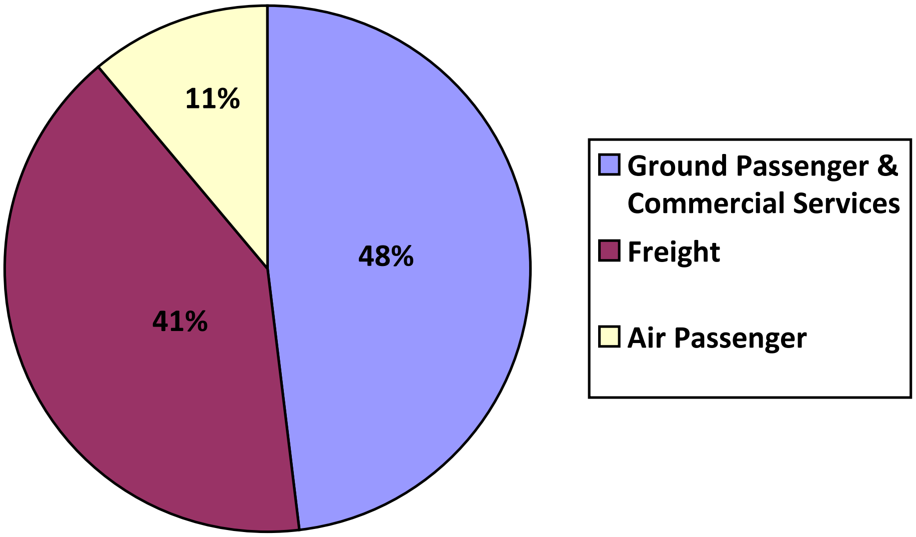

Figure 2. Estimated Share of Oregon Transportation GHG Emissions by Travel Market (2010)

Key Transportation Sector Forecast Assumptions

This section describes the development and application of four key forecasting assumptions used to project potential GHG emissions trends out to 2050 for use in all three travel market analyses:

- Population Growth
- Income Growth
- Fuel Price Growth
- Electrical Power Cost Growth

For other travel market-specific assumptions, see Technical Appendix 2, Technical Appendix 3 and Technical Appendix 4.

Population Growth Projections

GreenSTEP uses population projections by county and age group to create households for modeling purposes. The main data sources for population projections are the Office of Economic Analysis (OEA) of the Department of Administrative Services and the Metro Research Center Projections from the OEA extend to 2040 in 5-year intervals. Projections from the Metro Research Center extend to 2050 in 5-year intervals. Since the GHG emission reduction goals for the STS extend out to 2050, it is necessary to extend the OEA forecasts to 2050. This section describes how these two sets of forecasts were extended to 2050 and then combined.

Data

Metro Research Center staff provided population projections by age cohort for Portland metropolitan area counties (Clackamas, Multnomah and Washington).[4] Age cohort population projections for all other Oregon counties were obtained from the OEA website. Both forecasts were aggregated into six age groups: 0-14, 15-9, 20-29, 30-54, 55-64, and 65+.

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[4] Email communication. Dennis.Yee@oregonmetro.gov to Brian.J.Gregor@odot.state.or.us, 11/17/2010

Methodology

The forecasts were combined and extended to 2050 by the following steps (these steps are described in detail following these summary points):

1. Aggregate the OEA and Metro age cohort forecasts into the age groups listed above.

2. Remove data for Clackamas, Multnomah and Washington counties from OEA data.

3. Calculate OEA totals by forecast year and extend the trend to 2045 and 2050.

4. Calculate OEA age group proportions for 2045 and 2050 using the 2040 age group proportions and the change in age group proportions between 2035 and 2040. Apply the respective age group proportions for 2045 and 2050 to the respective extended OEA forecasts for 2045 and 2050 to produce total non-Metro county forecasts by age.

5. Calculate the non-Metro county proportions of OEA population forecast for each age group in 2040. Apply those proportions to the total non-Metro county forecasts by age to produce forecasts by age and county for non-Metro counties.

6. Combine the Metro forecasts for Clackamas, Multnomah and Washington counties with the OEA forecasts.

Extending the Non-Metro Forecast Total to 2045 and 2050

Figure 3 shows the trend for non-Metro counties. The population growth trend is very close to linear. Figure 4 shows the annual population growth increments. The dashed red line corresponds to the annual increment for the best fit linear model. The dashed blue line shows the mean annual increment for the periods from 2015 to 2040. This mean growth rate is used to extend the population projection to 2050.

Comparison of Statewide Forecasts With and Without Metro County Substitution

The Metro forecasts were substituted for the OEA forecasts for Metro area counties. Figure 5 shows that this substitution changes the statewide forecast totals very little.[5]

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[5] Note: the population forecasts were developed prior to the release of the 2010 Census estimates, which explains why Figure 3 identifies the 2010 values as projections, rather than estimates. The 2010 Census values became available for the final 2010 GreenSTEP model runs and were used for those runs.

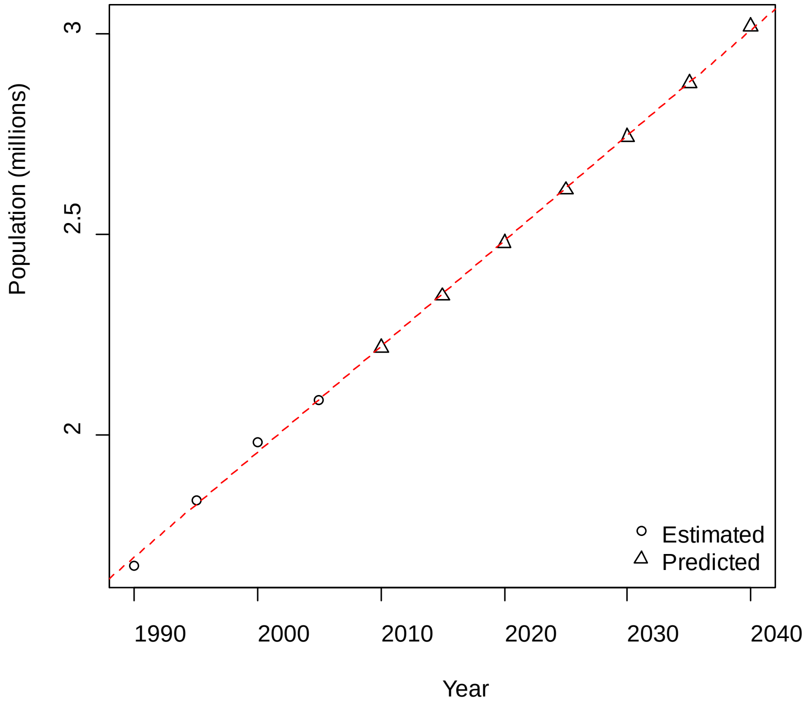

Figure 3. Estimated and Projected Population (Non-Metro Counties)

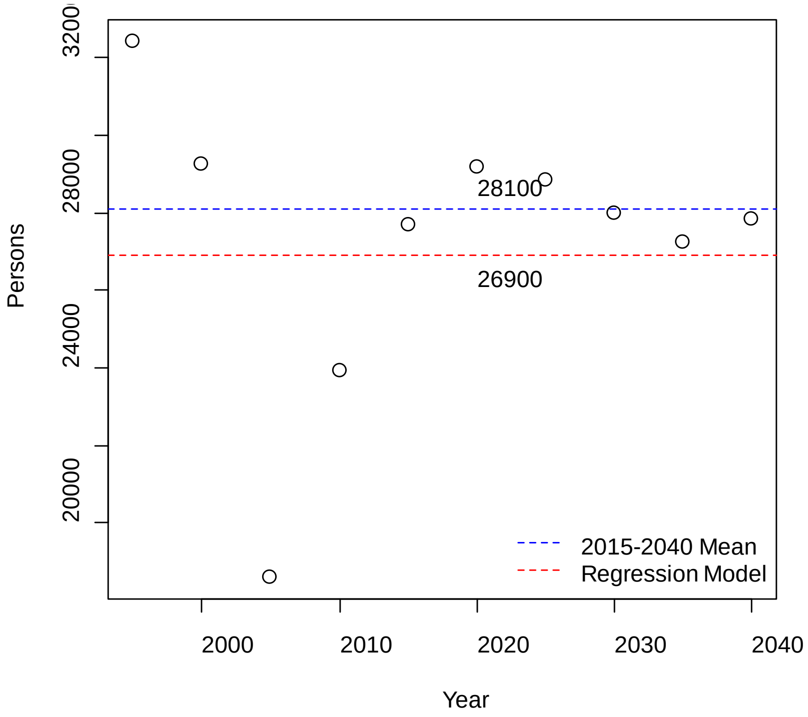

Figure 4. Estimated and Projected Annual Population Growth (Non-Metro Counties)

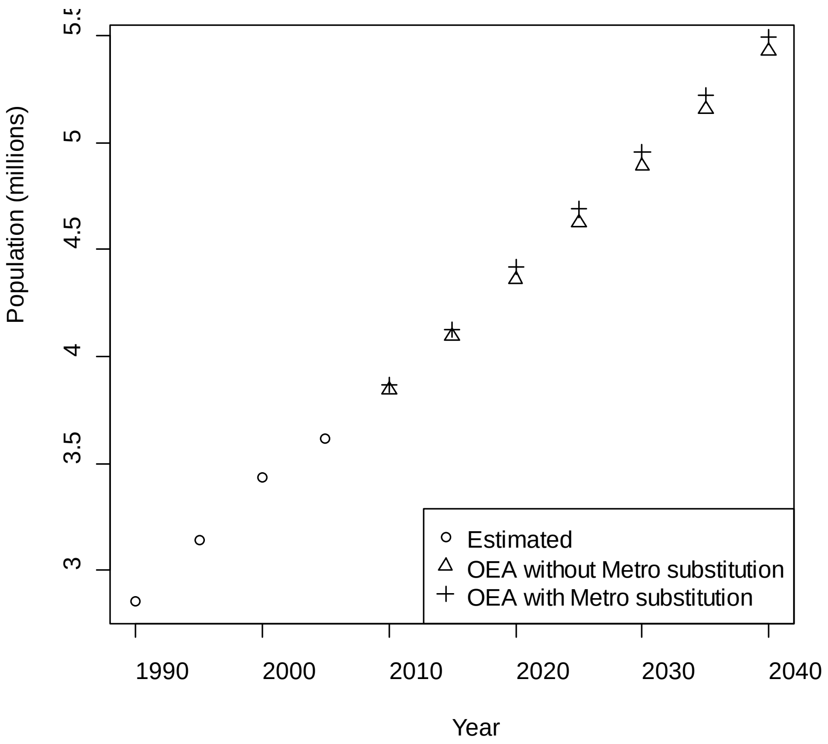

Figure 5. Estimated and Projected Population, 1990-2040 (Metro Counties)

Population Forecast Extension by Age Group

Figure 6 shows the estimated and forecasted percentage proportions of the non-Metro county population in the six age groups used in the GreenSTEP model.

The percentage proportions vary over the time period (1990-2040) with no consistent pattern over the whole time period. Because of this, the moderate changes in percentages from 2035 to 2040 were used to adjust the 2040 proportions to calculate the splits for 2045 and 2050. The resulting population forecasts by age group for the non-Metro counties are shown in Figure 7.

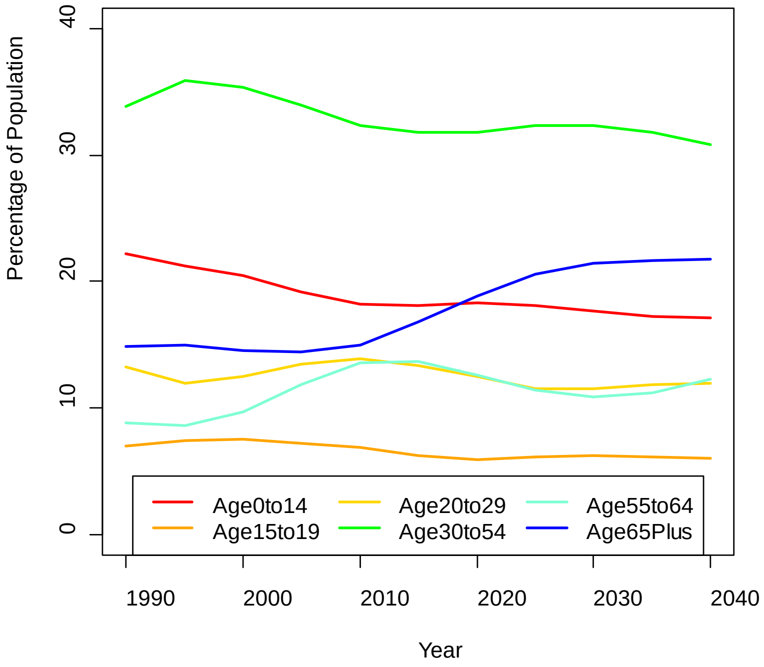

Figure 6. Percentage of Population by Age Group, 1990-2040 (Non-Metro counties)

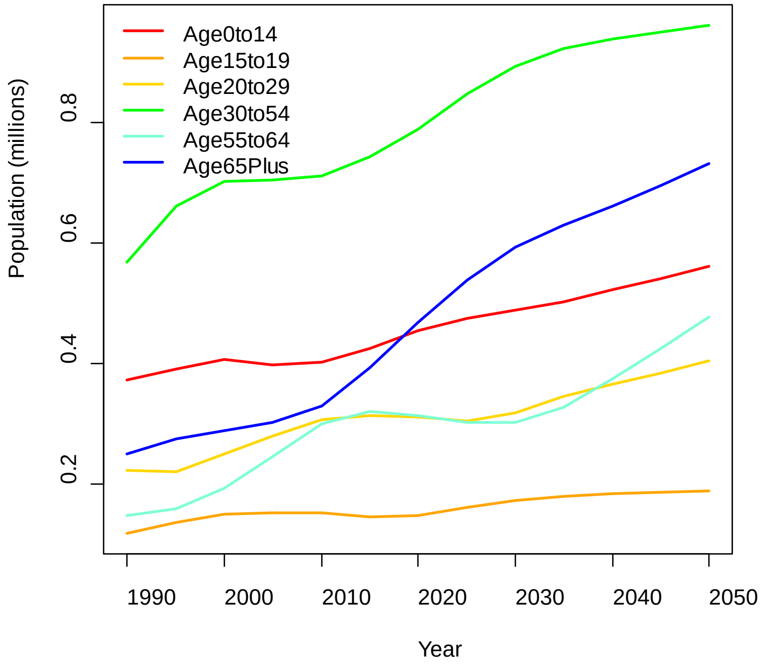

Figure 7. Estimated and Projected Population by Age Group, 1990-2050 (Non-Metro counties)

Projecting Population by County

Figure 8 shows how the county proportions of the total non-Metro county population in each age group vary over the period from 1990 to 2040. There are no consistent patterns over the entire time period. In addition, some of the changes from one 5-year period to the next are fairly large. Therefore, the percentages for 2040 were used to split the projections of population by age for 2045 and 2050 into county shares.

Combining the OEA and Metro Population Forecasts

The extended forecasts for the non-Metro counties are combined with the Metro forecasts. The results are shown in Figure 9.

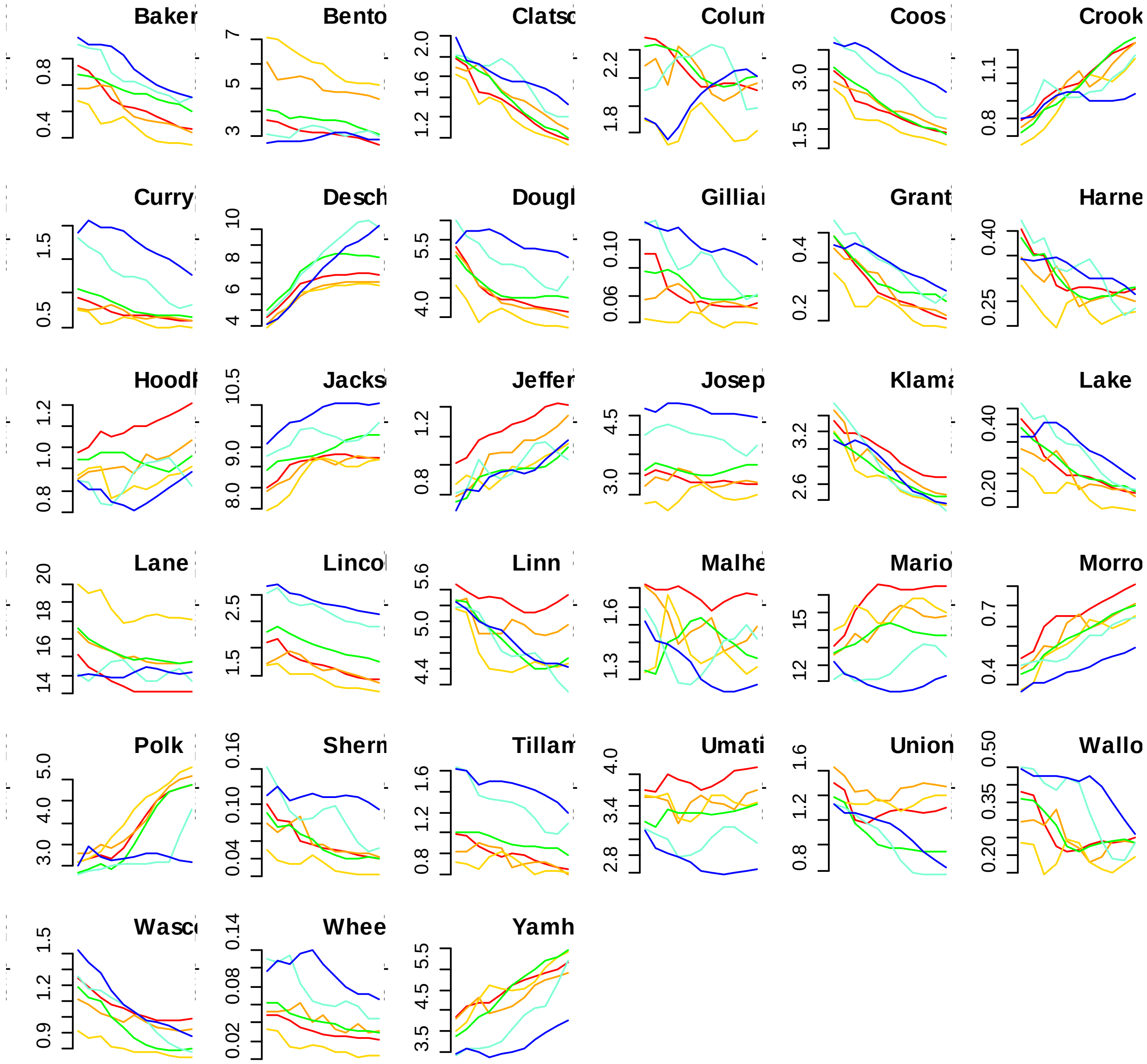

Figure 8. Percentage of Non-Metro County Population in Age Group, by County, 1990-2040[6]

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[6] Line colors correspond to the age group legend in Figure 6.

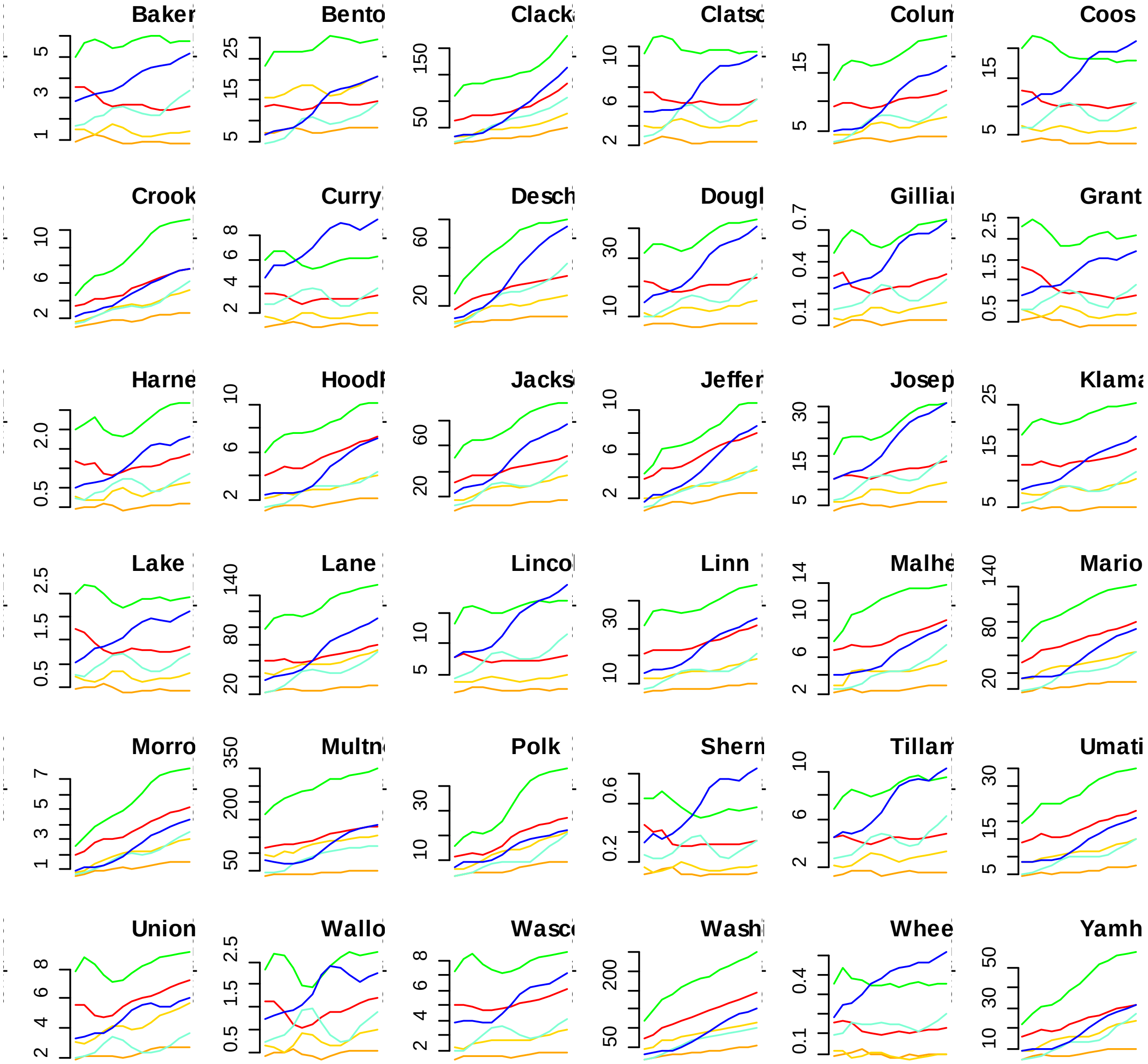

Figure 9. Estimated and Projected Population by Age Group by County, 1990-2050[7]

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[7] Line colors correspond to the age group legend in Figure 6.

Income Growth Projections

The GreenSTEP Model uses the inflation-adjusted state average per capita income as an input to the household income model (year 2005 dollars). The following section describes the method used to predict the required input, and results.

Data

State income and employment summary data for Oregon from the Regional Economic Information System of the Bureau of Economic Analysis (Table SA04) was the source of average Oregon per capita income for the years 1929 to 2009. Income was adjusted to year 2005 dollars using the annual Portland-Salem OR-WA Consumer Price Index (CPI) reported by the Bureau of Labor Statistics for the years 1929 to 2009. The adjustment factor was calculated by dividing the CPI for each year into the CPI for 2005.

Data Analysis

Figure 10 shows average real per capita income from 1929 to 2009. Several smoothed trend lines are overlaid. The light dashed line shows the results of local regression with a period of 20 years while the heavier dashed line shows local regression results over a 40-year period.

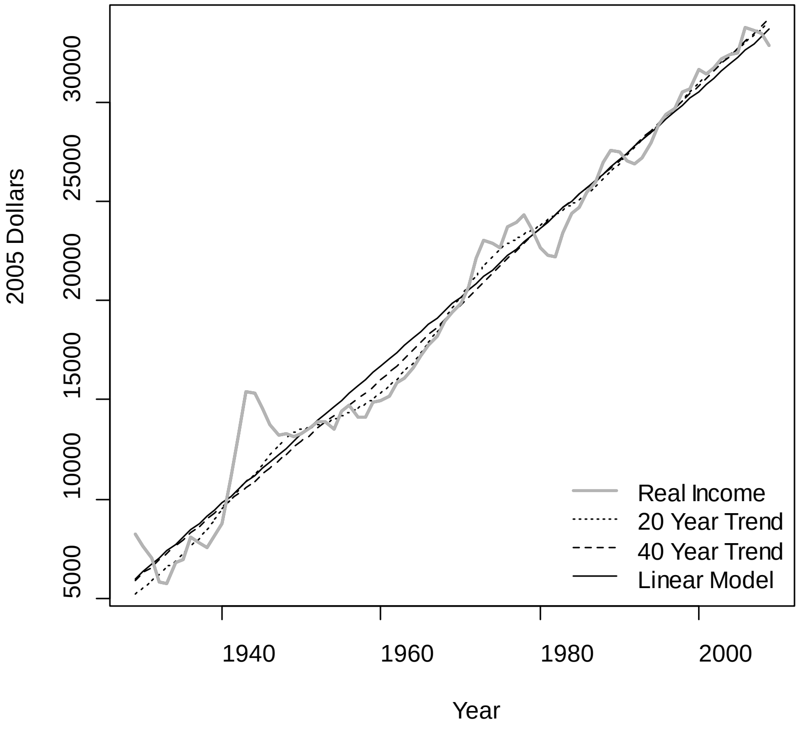

Figure 10. Oregon Real Average Per Capita Income, 1929-2009

The local regression lines illustrate that when short-term fluctuations in income (due to business cycles, war, and other events) are smoothed out, the underlying long-range trend is nearly linear. The solid black line in the figure shows a linear model fitted to the trend. Table 1 summarizes the model.

Table 1. Linear Model of Oregon Real Average Per Capita Income

```
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -6.610e+05  1.253e+04  -52.76   <2e-16 ***
Year         3.458e+02  6.362e+00   54.35   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1339 on 79 degrees of freedom
Multiple R-squared: 0.974,    Adjusted R-squared: 0.9736
F-statistic:  2954 on 1 and 79 DF,  p-value: < 2.2e-16
```

Figure 11 shows the annual changes in per capita income and the annual changes in the local and linear regression trends. Both the average annual change and year-to-year variation have declined over time.

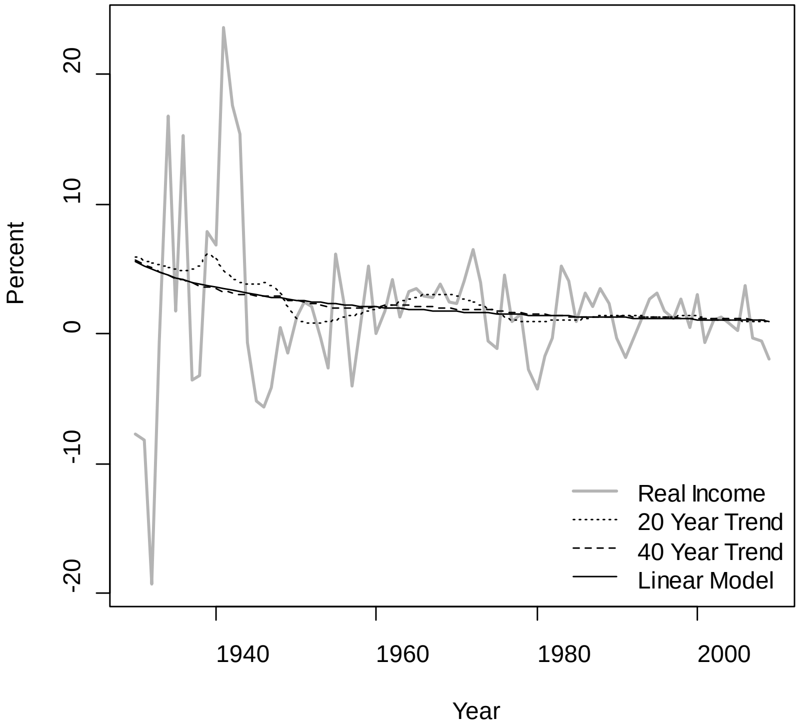

Figure 11. Annual Changes in Oregon Real Average Per Capita Income, 1929-2009

Projecting the Rate of Income Growth

A linear model of real average per capita income provides a good basis for projecting future income given the nature of the underlying growth trend and the stability of the trend over a long period of time. Figure 12 shows the projection of the trend to 2050.

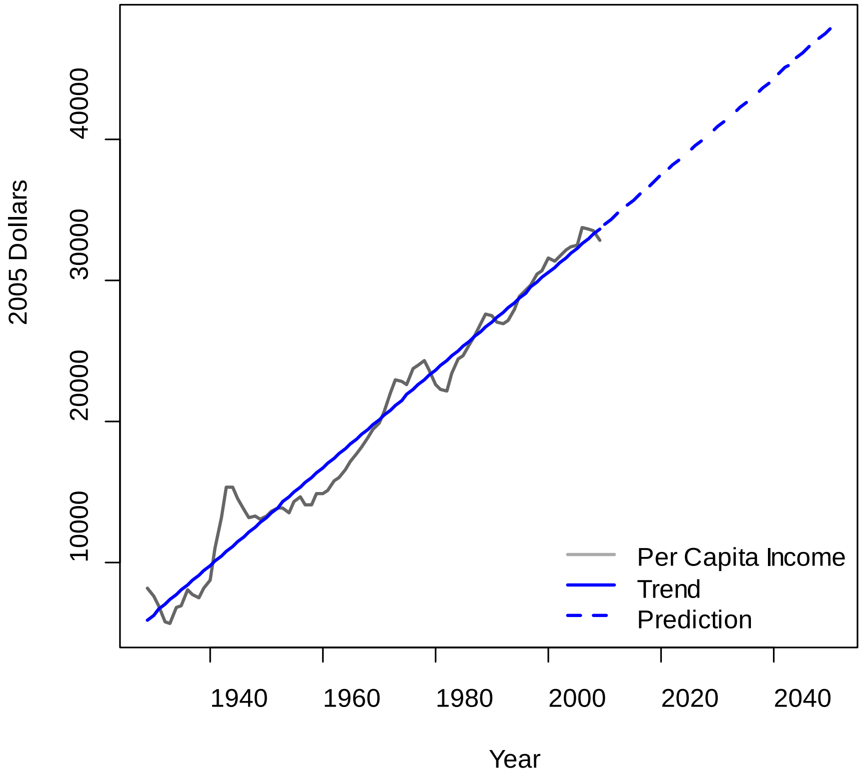

Figure 12. Projection of Oregon Real Average Per Capita Income (1929-2050)

Given the strength of the linear growth trend, it was used as the basis for the prediction of future average per capita income, with some adjustments to account for the current economic recession as shown on the following page.

To forecast per capita income after 2010, the 2050 prediction from the linear model is assumed_as correct, with values between 2010 and 2050 interpolated linearly. Table 2 shows the results.

Table 2. Estimated and Forecast Statewide Average Per Capita Income

Year	Income (2005 dollars)
1990	27,531
1995	28,826
2000	31,622
2005	32,515
2010	31,565
2015	34,709
2020	36,584
2025	38,459
2030	40,334
2035	42,209
2040	44,084
2045	45,959
2050	47,834

According to this forecast, future average per capita income will grow at an average rate of about 0.9% per year. This trend is shown in Figure 13.

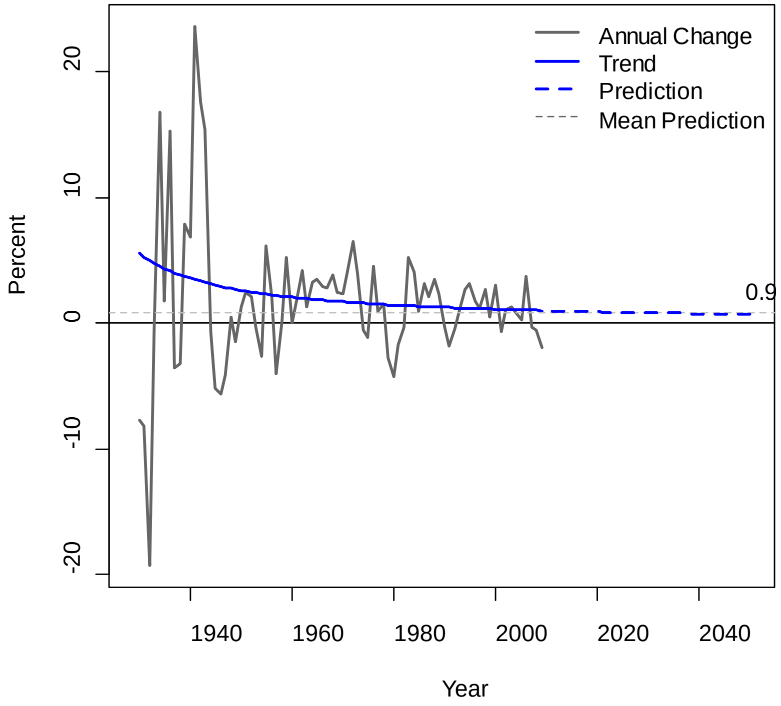

Figure 13. Trend for Average Per Capita Income Growth Rate (1929-2050)

Fuel Price Growth Projections

The GreenSTEP Model uses average gasoline costs (in 2005 dollars) to calculate the fuel cost for driving light duty vehicles powered by gasoline or other hydrocarbon fuels. This section describes the method used for developing long-range fuel cost assumptions. These costs do not include fuel taxes, since fuel taxes are calculated and applied separately.

Data from the U.S. Energy Information Agency (EIA) was used to provide estimates of average annual gasoline retail fuel price from 1990 to 2010.[8] Table 3 shows the price estimates.

Table 3. Nominal and Real (2005) Gasoline Prices for Oregon (Excluding Taxes) 1990 – 2010

Year	Nominal Dollars Per Gallon	Consumer Price Index	Deflator	Real Price 2005_Dollars Per Gallon
1990	0.95	127.4	1.707	1.63
1995	0.83	153.2	1.420	1.17
2000	1.21	178.0	1.222	1.47
2005	1.91	196.0	1.110	2.12
2010	2.43	217.5	1.000	2.43

Forecasts of future gasoline prices were developed from the Reference Case and the high price forecasts published by the EIA in its Annual Energy Outlook 2010.[9] Figure 14 shows the EIA forecasts of retail gasoline prices for these two scenarios (Reference Case, High Price). The figure also shows the net price after gasoline taxes are removed. The EIA forecasts extend out to 2035.

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[8] U.S. Energy Information Administration, Petroleum Marketing Annual (for the years 1995, 2000, 2005, 2008, 2009), Table 31. Motor Gasoline Prices by Grade, Sales Type, Petroleum Administration for Defense (PAD) District, and State, (Cents per Gallon Excluding Taxes)", Oregon All Grades, Sales to End Users Through Retail Outlets.

The annual value for 2010 was calculated based on the reported monthly prices and quantities sold for January through November as reported in the following tables:

- U.S. Energy Information Administration, Petroleum Marketing Monthly, Table 31 "Refiner Motor Gasoline Prices by Grade, Sales Type, PAD District, and State (Cents per Gallon Excluding Taxes)", Oregon All Grades Sales to End Users Through Retail Outlets.
- U.S. Energy Information Administration, Petroleum Marketing Monthly, Table 39 "Refiner Motor Gasoline Volumes by Grade, Sales Type, PAD District, and State (Thousand Gallons per Day)", Oregon All Grades Sales to End Users Through Retail Outlets.

[9] U.S. Energy Information Administration, Annual Energy Outlook 2010, Table A-12, Scenario aeo2010r (reference case), Datekey d111809a, Release Date December 2009

- U.S. Energy Information Administration, Annual Energy Outlook 2010, Table 112. Components of Selected Petroleum Product Prices, hp2010.d011910a

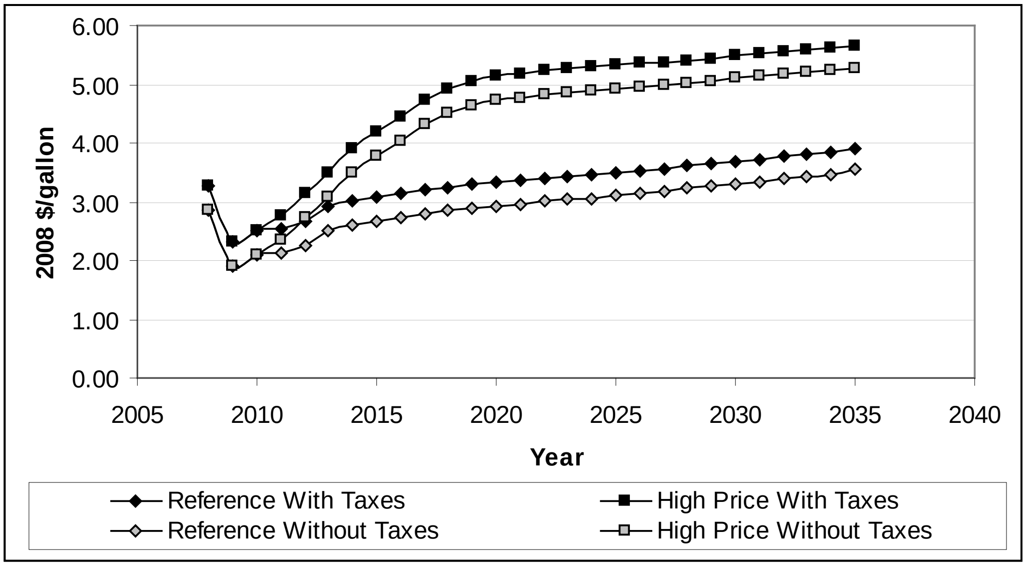

Figure 14. U.S. EIA Reference Case and High Gasoline Price Forecasts

The EIA forecasts were extended out to 2050 by assuming that prices after 2035 will increase at an annual rate identical to the average annual rate forecasted for the 2030 to 2035 period.

The Reference Case projection was used for most scenario model runs. The High Price projection was used in sensitivity testing of scenarios in later rounds of modeling. A third projection was developed for the final scenario modeling efforts to investigate doubts about the realism of the Reference Case scenario. This third “Composite Scenario” projection follows a trajectory between the two scenarios but rises to approach the high price scenario prices in later years. The three projections are shown in Figure 15. Forecast values were deflated to 2005 dollars for use in modeling.

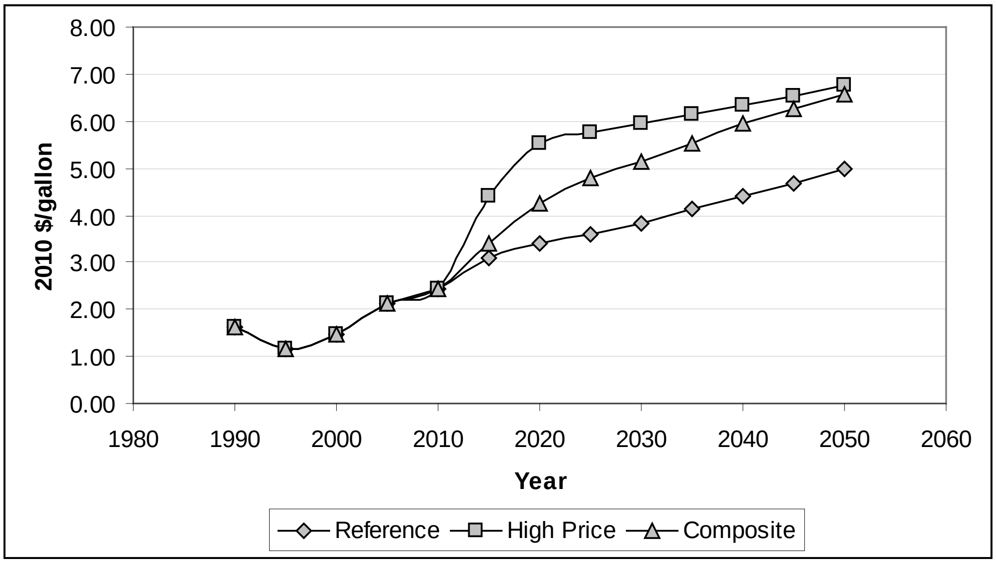

Figure 15. STS Fuel Price Forecast Scenarios (excluding taxes)

Electrical Power Cost Growth Projections

The GreenSTEP Model uses the average residential retail cost of electrical power to calculate the power cost for electric vehicle usage. This section describes a method used for developing the long-range power cost assumptions.

Data from the EIA provides estimates of average annual nominal retail price of electricity from 1990 to 2010.[10] These data were adjusted to 2005 dollars using the CPI for the Portland-Salem OR-WA metropolitan area published by the U.S. Bureau of Labor Statistics. Table 4 shows the price estimates.

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[10] U.S. Energy Information Administration, Electric Power Annual 2009 - State Data Tables, 1990-2009 Average Price by State by Provider (EIA-861), https://www.eia.gov/electricity/data/state/

U.S. Energy Information Administration, Electric Power Monthly with data for October 2010, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Table 5.6.B. (includes data for 2010 through October), https://www.eia.gov/electricity/monthly/

Table 4. Average Annual Nominal and Real (2005) Residential Retail Power Prices for Oregon (1990 – 2010)

Year	Nominal Cents Per Kilowatt Hour	Consumer Price Index	Deflator	Real Price (2005) Cents Per Kilowatt Hour
1990	4.73	127.4	1.54	7.28
1991	4.81	133.9	1.46	7.04
1992	4.93	139.8	1.40	6.91
1993	5.02	144.7	1.35	6.80
1994	5.33	148.9	1.32	7.02
1995	5.49	153.2	1.28	7.02
1996	5.69	158.6	1.24	7.03
1997	5.56	164.0	1.20	6.64
1998	5.82	167.1	1.17	6.83
1999	5.75	172.6	1.14	6.53
2000	5.88	178.0	1.10	6.47
2001	6.29	182.4	1.07	6.76
2002	7.12	183.8	1.07	7.59
2003	7.06	186.3	1.05	7.43
2004	7.18	191.1	1.03	7.36
2005	7.25	196.0	1.00	7.25
2006	7.48	201.1	0.97	7.29
2007	8.19	208.6	0.94	7.70
2008	8.49	215.4	0.91	7.73
2009	8.68	215.6	0.91	7.89
2010	8.85	217.5	0.90	7.97

The Base Case wholesale power price forecast in the Northwest 6th Power Plan[11] was used to calculate electrical power price forecast growth rates to 2030. These growth rates were used to forecast future retail power prices. Table 5 shows Base Case wholesale electricity price forecast and the annual rate of growth.

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[11] Northwest Power and Conservation Council, 6th Northwest Conservation and Electric Power Plan, February 2010, Appendix D, Table D-6, p. D-31.

Table 5. Base Case Forecast of Average Annual Wholesale Electrical Power Prices (2006 dollars/MWh) (2010 – 2030)

Year	Base Case Price	Annual Increase
2010	30	
2011	34	13.3%
2012	40	17.6%
2013	45	12.5%
2014	50	11.1%
2015	54	8.0%
2016	57	5.6%
2017	59	3.5%
2018	60	1.7%
2019	62	3.3%
2020	63	1.6%
2021	65	3.2%
2022	66	1.5%
2023	68	3.0%
2024	69	1.5%
2025	70	1.4%
2026	71	1.4%
2027	72	1.4%
2028	73	1.4%
2029	73	0.0%
2030	74	1.4%

The growth rates in Table 5 were applied to the 2010 residential retail power price to forecast future retail power prices to 2030 for the STS Reference Case and most other scenarios. The average annual growth rate for the last 2 years (0.7 percent) was used to project prices beyond 2030.

Additional forecast assumptions were developed for a lower GHG scenario that reflected the assumption that the electric power sector reduces GHG emissions by 75 percent from 1990 levels by 2050. This assumption was found to be necessary in order to achieve a 75 percent reduction in GHG emissions from the Ground Passenger and Commercial Services travel market.

Electricity prices for this scenario were calculated by pivoting off the STS Reference Case prices using the ratio of the 2030 wholesale price forecast for the 6th Power Plan “High CO_2” (prices) sensitivity test and 2030 Base Case price forecast.[12] The 6th Power Plan forecasts that, with the addition of a $100/metric ton carbon price, electricity prices will increase rapidly at first and then stabilize by 2030 and additional low-carbon resources will be deployed. This pivot approach was used rather than the price forecast for the "High CO_2" sensitivity test, because the purpose of adjusting the price is to reflect the added cost of greater amounts of renewable power production, not to reflect the effect of additional carbon prices assumed by the sensitivity test. Carbon pricing in this STS scenario is timed differently than in the 6th Power Plan. The two forecasts are compared in Figure 16.

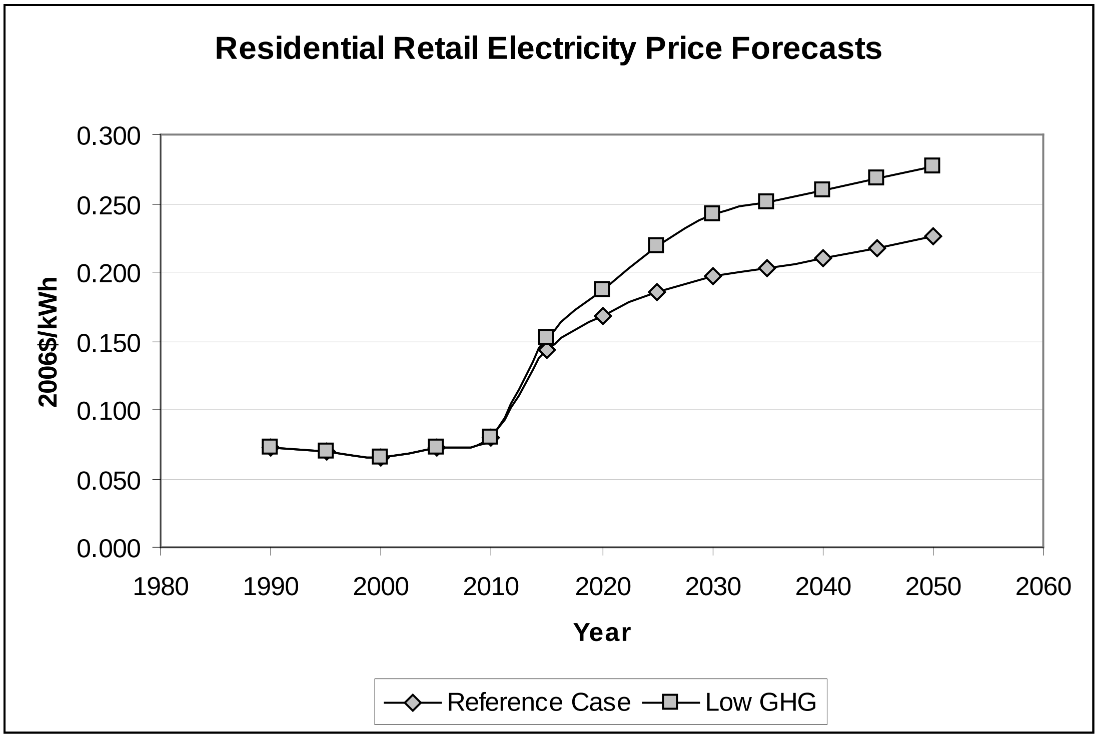

Figure 16. STS Reference Case and Low GHG Electrical Power Residential Retail Price Forecasts

This provides an overview of the methodology used in the analysis of transportation sector GHG emissions reductions. Technical Appendix 2, Technical Appendix 3, and Technical Appendix 4 contain additional details on data sources, assumptions, and estimation/forecasting techniques used to predict potential GHG emissions reductions by individual travel market. Technical Appendix 5 presents tables of the key recommendations.

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[12] Northwest Power and Conservation Council, 6th Northwest Conservation and Electric Power Plan, February 2010, pp. 2-12 to 2-16.

TECHNICAL APPENDIX 2

GROUND PASSENGER AND COMMERCIAL SERVICES TRAVEL MARKET ANALYSIS METHODOLOGY

TECHNICAL APPENDIX 2

Ground Passenger and Commercial Services Travel Market Analysis Methodology

Introduction

The Ground Passenger and Commercial Services travel market segment includes passenger travel using light duty vehicles (e.g., automobiles, pickup trucks, sport utility vehicles, vans) and commercial service travel using light duty vehicles. It also includes travel by modes that provide alternatives to light duty vehicles, such as public transportation, bicycling (and other light weight vehicles), and walking. Light duty vehicles produce the majority of greenhouse gas (GHG) emissions from the Ground Passenger and Commercial Services travel market.

This travel market segment does not include passenger travel by airplanes (see Technical Appendix 4) or the movement of goods by medium or heavy duty trucks, rail, air, barge, or any other freight mode. (see Technical Appendix 3).

This appendix describes various technical aspects pertinent to the development of the vision and recommendations for this market segment including:

- Factors affecting greenhouse gas (GHG) emissions from this market segment;
- Analytical methods and tools used to estimate potential effects of transportation changes on GHG emissions;
- An evaluation framework used for comparing scenarios;
- An overview of the scenario development and analysis process and results; and,
- Final results.

Factors Affecting Greenhouse Gas (GHG) Emissions

GHG emissions from light duty vehicles are fundamentally the product of 1) the number of vehicle miles traveled, and 2) the average emissions rate per vehicle mile traveled. These considerations are in turn affected by a large number of factors that are listed below in six general categories:

- Land use and transportation infrastructure;
- Transportation system management;
- Travel demand and vehicle use management;
- Vehicle and fuel technologies;
- Vehicle fleet characteristics; and
- Pricing.

Land Use and Transportation Infrastructure

This category is composed of factors that impact GHG emissions primarily by affecting the number of vehicle miles traveled using light duty vehicles. The factors in this category relate to how towns and cities grow and are served by transportation systems. They are foundational in many respects and have long-lasting effects, but also tend to be costly and change slowly. Examples include:

- **Amounts of population growth occurring in urban and rural areas**. Average travel distances are different for households living in urban and rural areas of differing sizes. In addition, these areas have differing capabilities for being served by public transportation and other modes of transportation.

- **Growth rates of urban land areas**. A city that grows more slowly in area than in population will become denser over time. Households and the places that people go to in the city would be located closer together on average. This will decrease average trip lengths and increase the likelihood that people will walk or bicycle to destinations. In larger cities, this results in more people being served by public transportation.

- **Compact, mixed-use neighborhoods**. Residents of compact, mixed-use neighborhoods can more easily attend to their needs without driving, or by driving shorter distances. These neighborhoods most often have a well-connected street network that makes walking and bicycling more accessible and more attractive modes of transportation.

- **Public transit system growth**. The amount of public transportation service (service area and frequency) affects both the amount of travel by public transportation and the amount of travel by light duty vehicles.

- **Road system growth and layout**. The extent and design of the road system affects the amount of light duty vehicle travel and GHG emissions in a number of ways. The expansion of freeways generally increases average travel speeds and distances (because drivers can go farther in the same amount of time). Freeways can also act as travel barriers to other modes of transportation. The expansion of other roads does not have the same effect, but how those roads are laid out affects trip distances and the amount of walking and bicycling that occurs. Road layout may become more important in the future as new light weight and low carbon modes of transportation such as electric bicycles become more prevalent. Road system growth and layout also impact GHG emissions by affecting congestion and vehicle fuel economy.

Transportation System Management

This category is composed of factors that affect the efficiency of transportation system operations and the effectiveness with which transportation systems provide services to travelers. These factors impact both the amount of light duty vehicle travel and the average emissions rates per mile of travel. Compared to land use and transportation system infrastructure, many transportation system management actions can be put into practice relatively quickly and at lower cost. However, the extent and effectiveness of transportation system management depends on the development and deployment of information technologies. While many system management actions can occur today, many of the gains will occur in the future as technologies develop further. Examples include:

- **Traffic management**. The management of roadway traffic affects roadway congestion and traffic flow. If management of the roadways can be improved, average fuel economy can be improved, by reducing the amount of extra fuel consumed through idling, acceleration, and deceleration. Traffic management also affects the frequency of crashes and other incidents and the amount of wasted time and fuel consumption that occurs while capacity is being restored. Some traffic management actions such as ramp metering, incident management (detection and clearance), coordinated traffic signalization, and access management are relatively common and accepted by drivers.

  More advanced traffic management systems, such as speed harmonization using variable speed limits and variable priced lanes, would require more extensive technology deployment and increased driver-acceptance and familiarity. In the future, vehicles might communicate with each other via computers, with computers managing transportation infrastructure to smooth out traffic flows and minimize incidents. However, if traffic management actions increase average vehicle speeds rather than just reducing the traffic speed fluctuation, some of these gains could be diminished.

- **Traveler information**. Information on travel conditions, available route and mode alternatives, and the consequences of travel choices can influence how and when people choose to drive or use other modes of transportation. This in turn affects GHG emissions. Examples include roadway congestion information (helps drivers plan departures and routes), and public transit scheduling and routing information (makes it easier to get around using public transportation). More advanced traveler information systems such as real-time notification of park-and-ride lot availability could enable even more efficient travel choices. With further improvements to information technology and traveler services, it may be possible for travelers to easily set up travel itineraries that effectively coordinate multimodal trips involving transit, bike-sharing, car-sharing, and other modes. Finally, research has shown that simply informing travelers about the GHG emissions consequences of their travel decisions can influence the choices they make.

Travel Demand and Vehicle Use Management

The travel demand and vehicle use management category refers to programs that actively seek to influence decisions about how people use their vehicles. These actions can take longer to gain acceptance and be deployed. However, they are similar to transportation system management enhancements in that they affect travel efficiency and emissions by influencing travel choices, and feature relatively low capital requirements and the potential for rapid deployment. Examples include:

- **Employer-based travel demand management (TDM) programs**. These are programs sponsored by employers to reduce the use of light duty vehicles for commuting to work. Examples of employer-based TDM programs include providing free transit passes, offering carpool and vanpool matching services, enabling flexible work schedules (e.g. allowing employees to work 4, 10-hour days), and allowing telecommuting.

- **Household-based TDM programs**. Unlike employer-based TDM programs, household-based TDM programs are relatively new. Such programs typically use direct marketing approaches to influence household travel decisions. Readily available information is provided to households ~~to~~ about available transportation choices, including rideshare programs, public transit, and non-motorized modes. Feedback is encouraged to help identify transportation facility and service improvements that might make these other transportation options more attractive and accessible.

- **Eco-driving**: While TDM programs aim to reduce the amount of light duty vehicle travel, eco-driving and vehicle use optimization programs encourage drivers to conserve fuel as they drive. Drivers can do this by choosing more fuel-efficient vehicles, by properly servicing and maintaining vehicles to achieve maximize fuel economy, and by driving in a manner that reduces idling and overly rapid acceleration and deceleration. Traffic management can help by providing the information drivers need to reduce idling. As with TDM programs, the marketing of eco-driving can vary from broad dissemination of information to targeted and individualized efforts. Newer vehicles that provide real-time feedback on fuel economy help promote eco-driving behavior.

Vehicle and Fuel Technologies

Vehicle and fuel technologies have the greatest effect on the rate of GHG emissions per mile of travel. However, the effects of these technologies are limited by the pace of certain changes within the industry including technological improvements, the rate at which manufacturers incorporate improvements into their products, and the rate at which consumers replace older vehicles with newer ones. Examples include:

- **Vehicle powertrain**. The internal combustion engine (ICE) continues to be the dominant source of power for motor vehicles, but newer powertrains have entered the fleet as a result of technological advances and stricter pollution regulations. Hybrid electric vehicles (HEV) combine ICE engines and electric motors to increase efficiency and boost fuel economy. Plug-in hybrid electric vehicles (PHEVs) are HEVs with bigger batteries and electric motors, so that a portion of their use may be powered solely by electricity. Electric vehicles (EV or BEV for battery electric vehicle) are powered solely by electric motors. Fuel cell vehicles (FCV) are powered by electric motors, but the electricity is produced by on-board fuel cells from hydrogen and oxygen. Some combination of these newer vehicle powertrains are likely to dominate the market for light duty vehicles in the coming decades because vehicles propelled by electric motors are much more energy efficient than ICE vehicles and are more conducive to the use of cleaner fuels.

- **Fuel economy**. Though substantial advancements in ICE engine efficiency have been made over the past several decades, these gains have accommodated increased engine power and vehicle size/weight, and thus the gains have been offset to some degree. As some vehicle manufacturers have shown, substantial increases in average fuel economy can be achieved by applying available engine technology on achieving higher fuel economy while reducing vehicle weight and friction.[13]

- **Battery range and power efficiency**. The potential for replacing gasoline and other hydrocarbon fuels with electricity depends on the

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[13] Both friction from tires rolling on pavement, and friction from air flowing around a moving vehicle (drag) have been measurably reduced through design improvements.

amount of electricity that can be stored in the vehicle's battery and how far the vehicle can travel on a charge. For PHEVs, this affects the proportion of the vehicles' travel that is powered solely by electricity. For EVs this affects the market potential of the vehicles. A similar issue exists for FCVs because hydrogen is a fuel with a low energy density.

- **Carbon intensity of vehicle fuels**. Different types of fuels produce different levels of GHG emissions per unit of energy they contain. This is called the carbon intensity of the fuel. For example, compressed natural gas (CNG) produces less GHG emissions per unit of energy than gasoline. The carbon intensity of fuels may be calculated considering only the combustion of the fuel itself, or by considering the GHG emissions required to produce the fuel as well, for example, through extraction and refining. The analysis for the STS takes the latter approach because the GHG emissions from production of-some fuels can make up a substantial portion of the total emissions resulting from use of the fuels.

- **GHG emissions from electrical power production**. Although GHG emissions are not directly produced by EVs and PHEVs running on stored electricity, those emissions are produced when the electricity is initially generated. The amount of GHG emissions per unit of electrical energy (kilowatt-hour or kWh) depends on how the electricity is generated. For example, coal-fired power plants produce more GHG emissions per kWh than natural gas-fired power plants.

Vehicle Fleet Characteristics

Technology, while very important, is not the only characteristic of light duty vehicles affecting GHG emissions. The number, type (e.g. auto or light truck) and age of vehicles affect GHG emissions as well. Fleet characteristics can also impact the relative effectiveness of advancements in vehicle and fuel technology. Examples include:

- **Vehicle ownership**. The number of vehicles owned by a household has a significant effect on its vehicle miles traveled (VMT). Vehicles' high costs create a strong incentive to drive them once purchased. Vehicle ownership is influenced by a number of factors including household income, the cost of ownership, and the availability of alternatives. Car-sharing is a relatively new alternative to vehicle ownership that provides many of the benefits of car ownership and reduces "excess" driving. Car-sharing can be formally organized as a business through which subscribers can reserve and rent a car as needed, or less formally in which individuals or groups of individuals share cars amongst themselves.

- **Vehicle type proportions**. The size and weight of vehicles have a significant effect on fuel economy and GHG emissions. The type and fuel economy of vehicles in the fleet can be influenced by incentive and disincentive programs including rebates, gas-guzzler taxes, and "feebates" (a revenue neutral program where rebates on more fuel efficient vehicles are paid for with fees on less fuel efficient vehicles).[14]

- **Rate of fleet turnover**. The rate at which vehicles are retired and replaced by newer vehicles affects the rate at which new vehicle technologies reduce GHG emissions. Programs that encourage people to retire old vehicles and buy new fuel-efficient vehicles can increase the rate at which fleet fuel economy is improved.

Pricing

Economic studies have demonstrated that prices are an important mechanism for efficiently allocating resources. However, in order for prices to be efficient, they must reflect the true cost of providing those resources. This does not occur when there are significant externalities, or hidden costs to market transactions (e.g. pollution). In those circumstances, resources are over-consumed and costs are incurred by persons who are not responsible for them, including future generations. Various aspects of transportation can be priced and each pricing approach has a different relationship to GHG emissions. Examples include:

- **Fuel use and emissions pricing (gas tax, carbon tax)**. Although fuel taxes have been the principle funding source for the maintenance, operation and construction of the road system, such taxes only approximate the effect that users have on the roadway system because of significant differences in vehicle fuel economy. A driver of a small, fuel efficient sedan will pay substantially less fuel tax per mile than the driver of a high-powered SUV or light-duty truck. The strength of the association between fuel taxes and road use will further weaken as fuel economy increases and more and more vehicles are powered by electricity. Although the relationship between fuel taxes and road use is weakening due to changes in vehicle efficiency and power source, the relationship between fuel taxes and GHG emissions is strong because there is a very high correlation between the amount of conventional fuel used and the amount of GHG emissions produced. The one limitation of fuel taxes in this respect is that GHG emissions vary by fuel type. Carbon taxes have the strongest relationship to GHG emissions because the taxes reflect the types of fuels consumed (e.g., the carbon content of the specific fuel) and they also account for the GHG emissions of electric power production.

- **Vehicle travel pricing.** Many vehicle travel pricing mechanisms are available:

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[14] Green, David L., Philip D. Patterson, Margaret Singh, Jia Li., Feebates, rebates and gas-guzzler taxes: a study of incentives for increased fuel economy. Energy Policy 33 (2005) 757-775.

  - Mileage taxes, in the form of weight-mile taxes, are currently the primary user charge for heavy trucks in Oregon; there is a federal fuel tax as well. Given inevitable increases in fuel economy and an increasing share of electric vehicles, it is becoming increasingly likely that the fuel tax for light-duty vehicles will need to be replaced at least in part by a mileage tax (e.g., VMT tax) as well. Mileage taxes have a strong relationship to the amount of vehicle use, but the relationship to GHG emissions is weaker than for fuel or carbon taxes because vehicles vary in their fuel economy and types of fuel used. Mileage taxes are also related to other impacts of motor vehicle travel such as traffic congestion and air, water and noise pollution.

  - Congestion pricing is a variant of a mileage tax where the amount of the tax varies with the amount of road congestion. Although fuel economy is reduced at slower travel speeds, congestion pricing has a fairly weak relationship to total GHG emissions because many travelers will shift to unpriced roads or travel times in response to congestion pricing. Total VMT could decrease or increase from congestion pricing because some drivers may take longer routes to avoid the charges. The amount of slower speed travel may increase as well because some travelers will avoid the charges by driving on unpriced, slower speed roads. As advanced technology vehicles become a larger share of the vehicle fleet, congestion pricing will become a less effective strategy for reducing GHG emissions Improvements to the fuel economy of ICE vehicles will also reduce the slow speed fuel economy penalty.

  - Pay-as-you-drive (PAYD) insurance is included in this category as well, although it is not an added cost to drivers (on average). Rather, it changes the way that vehicle insurance is charged from a categorical rate to a rate that varies continuously with the mileage driven. Categorical fees tend to result in more driving than variable fees because under variable fees drivers are able to save money on their car insurance by driving less. In this way, PAYD insurance has an effect on vehicle travel that is similar to that of mileage taxes.

- **Parking Pricing**. Parking pricing is typically implemented in congested and developed urban areas where land is very valuable. Parking pricing reinforces land use and transportation strategies for reducing vehicle miles traveled, and has a substantial effect on how people travel in urban areas. Higher prices are associated with less driving and more travel by public transportation, walking and bicycling.

Analytical Methods and Tools

A new model, GreenSTEP[15], was developed by ODOT for the specific purpose of estimating and forecasting the effects of various policies and other influences on the amount of vehicle travel, the types of vehicles and fuels used, and the resulting GHG emissions. Work on GreenSTEP started in 2008 as a result of an inquiry by the Oregon Global Warming Commission into the availability of models that could be used to provide information support for transportation planning decisions aimed at reducing GHG emissions. ODOT modelers made a decision to develop GreenSTEP because other transportation models could not address the scope of relevant factors and could not be readily adapted to do so. The development of GreenSTEP was reviewed extensively by state, national and international travel and emissions modeling experts in multiple venues. Evaluation at the national level lead to the Federal Highway Administration adopting GreenSTEP as the basis for their EERPAT[16] model. In 2010, the American Association of State Highway and Transportation Officials (AASHTO) awarded ODOT staff its President's Award for Planning for the development of the GreenSTEP model.

The GreenSTEP model estimates vehicle ownership, vehicle travel, fuel consumption, and GHG emissions at the individual household level. This structure was chosen to account for the synergistic or antagonistic affects of multiple policies and factors (e.g. gas prices) on vehicle travel and emissions. For example, because a household residing in a more compact mixed-use neighborhood will tend to drive fewer miles each day, a higher percentage of their driving would be powered by electricity if they use a PHEV. Modeling at this level makes it possible to evaluate the relationships between GHG emissions and the characteristics of households, land use, transportation systems, vehicles, and other factors of interest. In addition, household level analysis makes it possible to evaluate the equitability of the costs and benefits of different GHG reduction strategies. Figure 17 shows a schematic of model calculation steps.[17]

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[15] GreenSTEP is an acronym that originally stood for Greenhouse gas State Transportation Emissions Planning. The meaning of the acronym was changed later to reflect revisions to the model to enable it to be applied at a metropolitan area level and to address a more general set of transportation energy considerations as well as greenhouse gas emissions. The current full name for GreenSTEP is Greenhouse gas Strategic Transportation Energy Planning.

[16] EERPAT is an acronym for Energy and Emissions Reduction Policy Analysis Tool. It is based on the version of GreenSTEP used for the first few rounds of modeling for the STS. https://www.planning.dot.gov/FHWA_tool/default.aspx

Several changes have been made to GreenSTEP since then to allow evaluation of technical and policy issues identified by STS advisory committees.

[17] The diagram shows the current structure of the GreenSTEP model. Changes to the model have been made over the course of the STS study.

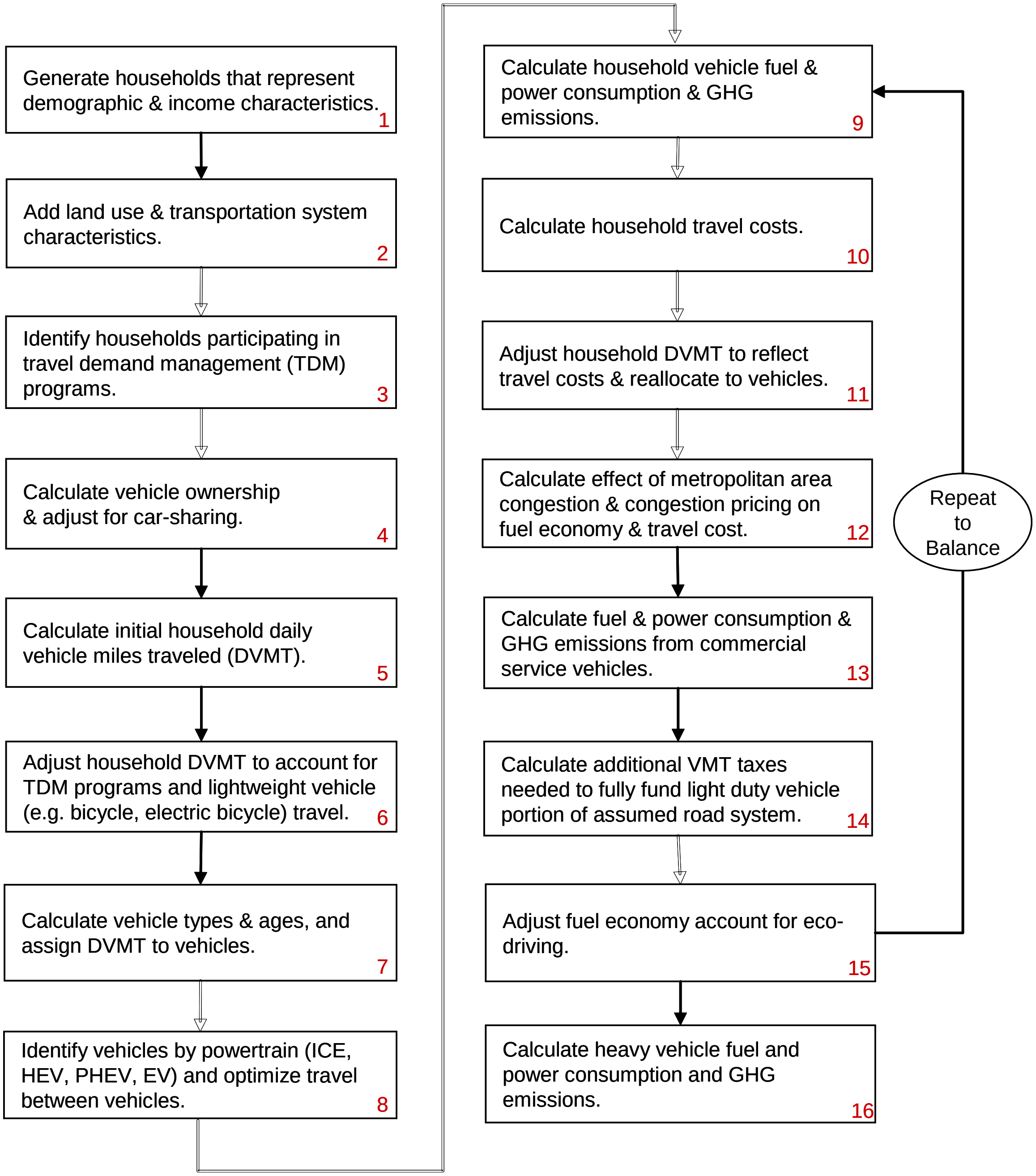

Figure 17. GreenSTEP Model Schematic

Each calculation step is composed of a number of calculations that operate on the results of the previous calculation step and on input data that reflect scenario assumptions. The nature of each calculation was determined through the statistical analysis of several data sources such as the National Household Travel Survey. Each component calculation was estimated and checked using source data. The following summary descriptions of each step identify the scenario inputs that affect the results of the calculations.

1. ***Generate households:*** A set of households is created for each forecast year that represents the likely household composition for each county given the county-level forecast of persons by age. Each household is described in terms of the number of persons in each of six age categories residing in the household. A total household income is assigned to each household given the ages of persons in the household and the average per capita income of the region where the household resides.

2. ***Add land use and transportation system characteristics:*** Households are assigned to an area type (metropolitan, other urban, or rural) based on scenario assumptions about the proportions of population growth occurring in each area. Neighborhood population density and mixed-use characteristics are assigned based on scenario assumptions about the growth of urban boundaries and mixed-use development targets. In metropolitan areas, transit and road service levels are assigned based on scenario assumptions regarding expansion of these services and facilities.

3. ***Identify households participating in TDM programs:*** Each household is assigned as either a participant or non-participant in a number of travel demand management programs. Examples of these include employee commute options or individualized marketing programs. Additionally, households are either assigned or not assigned to vehicle operations and maintenance programs that include eco-driving or low rolling resistance tire programs based on policy assumptions about the degree of deployment of those programs and the household characteristics.

4. ***Calculate vehicle ownership and adjust for car-sharing:*** Each household is assigned the number of vehicles it is likely to own based on the characteristics of the household and the land use and transportation characteristics of its location. Households are identified as participating in a car-sharing program based on the characteristics of the household and scenario assumptions regarding the future extent of car-sharing. The vehicle ownership of car-sharing households is adjusted.

5. ***Calculate initial household DVMT:*** An initial estimate of average daily vehicle miles traveled (DVMT) is calculated for each household based on the household characteristics determined in previous steps. Household demographics, income, transportation services, and land use are all important to the calculation.

6. ***Adjust household DVMT to reflect TDM and bicycle travel:*** Household DVMT is reduced for households identified as participating in TDM programs. Calculations are also performed to estimate the amount of single-occupant vehicle travel that might shift to bicycles or other light-weight vehicles such as electric bicycles. These are based on scenario input targets for shifting a portion of short distance single-occupant vehicle (SOV) trips. For example, the STS Vision includes a goal for shifting 40% of all SOV trips that

have a round trip length of 20 miles or less (10 miles or less each way) to bicycles and similar modes. Given this goal, GreenSTEP calculates the sum of all SOV travel that has round trip lengths less than or equal to 20 miles and removes 40% of that amount of travel from household DVMT (since it is presumed to be diverted to bicycling etc.).

7. ***Calculate vehicle characteristics and assign household DVMT to vehicles:*** Household vehicles are assigned as either autos or light trucks (e.g. SUV, pickup truck, van) based on the household and land use characteristics and light truck percentage targets established for the scenario. The age of each vehicle is determined based on current age profiles by vehicle type and household income and any objectives for adjusting the vehicle age distribution that might be established for the scenario. Average household DVMT is assigned to vehicles without optimizing use in order to minimize fuel consumption. Optimization occurs in the following step.

8. ***Identify vehicles by powertrain and optimize travel between vehicles:*** The powertrain of each household vehicle is identified as either being an internal combustion engine (ICE), hybrid-electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), or electric vehicle (EV). The identification of vehicle powertrain type is based on scenario input assumptions regarding future market shares by model year. Vehicle fuel economy and power efficiency (for PHEV and EV) is assigned to each vehicle based on the vehicle type, age and powertrain and corresponding input assumptions for the scenario for each model year. Households are identified as fuel economy optimizers based on scenario input assumptions regarding the proportion of households that will optimize their use of vehicles to minimize fuel use. Vehicle travel of fuel-economy optimizing households is allocated among household vehicles so that the most miles are assigned to the vehicle with the highest fuel economy. The proportion of household DVMT powered by fuel vs. electricity is also calculated.

9. ***Calculate household fuel and power consumption and GHG emissions:*** Total household fuel consumption is calculated based on the DVMT assigned to each vehicle, the proportion of the DVMT that is powered by fuel, and the average fuel economy of the vehicle. Likewise, electrical power consumption is calculated for the miles of household vehicle travel powered by electricity. GHG emissions are calculated based on the future lifecycle carbon intensity of fuels and electricity production assumed for a scenario.

10. ***Calculate household travel costs:*** Household travel costs are calculated from the number of miles driven, fuel consumed, electricity consumed, and GHG emitted. In addition, a parking model is applied to calculate how much each household would pay for parking based on scenario input assumptions. These assumptions include: the proportion of employees who pay for parking, the proportion of non-work trips that also involve paid parking, and the long-term daily parking rates. Scenario input assumptions establish the rates for

fuel costs, power costs, fuel taxes, VMT taxes, PAYD insurance, and several external costs (e.g., costs imposed on society by driving that drivers do not pay for such as pollution). Scenario input assumptions also establish what portion of external costs will be paid by drivers.

11. ***Adjust household DVMT to reflect travel costs:*** A household budget model is used to adjust household DVMT to reflect the effect of household travel costs on the amount of household travel. The adjusted household DVMT is allocated to vehicles in proportion to the previous allocation.

12. ***Calculate the effects of metropolitan area congestion and pricing:*** Total light duty vehicle (household and commercial service vehicle), truck and bus DVMT is calculated for each metropolitan area and assigned to portions of the road system (freeway, arterial, other). Congestion levels are calculated and the effects of congestion on speeds are estimated considering the traffic loads, scenario input assumptions regarding the deployment of traffic operations programs (e.g. ramp metering, traffic signal coordination), and scenario input assumptions regarding congestion pricing. Fuel economy adjustments are calculated for each vehicle powertrain type based on the calculated speeds and scenario input assumptions regarding the congestion efficiency of powertrains in the future. The average added travel cost per mile due to congestion pricing is also calculated.

13. ***Calculate fuel and power consumption and GHG emissions from commercial service vehicles:*** Commercial service vehicle DVMT is split between different vehicle types, powertrains, and fuels based on input assumptions for the scenario being analyzed. The vehicle age distributions and fuel economy and power efficiency by vehicle type, powertrain and model year are the same at those used for household light duty vehicles.

14. ***Calculate additional VMT taxes needed to fully fund road system:*** In the future, as vehicle fuel economy improves and PHEVs and EVs become more prevalent, fuel taxes will be insufficient to pay the cost to maintain, operate and improve the road system. In order to maintain a fair comparison of scenarios having very different assumptions about fuel economy and EV use, it is assumed that in all cases sufficient revenues would be collected from VMT taxes to pay for the road system that is assumed to exist. This is accomplished by calculating total costs imposed by light duty vehicles and total revenues collected from light duty vehicles. The revenue gap is divided by the total light duty vehicle VMT to calculate a VMT surcharge fee large enough to generate sufficient revenue to pay for the road system that is assumed to exist.

15. ***Adjust fuel economy to account for eco-driving:*** The average fuel economy of households identified as eco-driving is adjusted to reflect the effect that eco-driving has on improving fuel economy. Although this step is

included in the loop of steps that is repeated several times, it is only executed the first time through the loop.

At this point, the calculation process cycles back to step #9. This is necessary because the congestion calculations change fuel economy and thus affect the amount and cost of fuel consumed. The congestion calculations also estimate the effect of congestion pricing on the cost of vehicle travel. The calculated VMT surcharge fees affect the cost of vehicle travel as well. Eco-driving improves fuel economy and thus reduces fuel costs. The effect of these adjustments to household travel costs need to be included in the total household travel costs and the adjustment to household DVMT. This is accomplished repeating steps 9-14 several times until DVMT changes very little between iterations.

16. ***Calculate heavy vehicle fuel and power consumption and GHG emissions:*** Public transportation VMT is calculated from scenario input assumptions about future revenue miles per capita, future population, and the average ratio of vehicle miles of travel to revenue miles of travel. VMT is split between vehicles powered by on-board fuels vs. electricity based on scenario input assumptions. The amount of fuel consumed is calculated from the VMT powered by fuel and input assumptions regarding the age distribution of vehicles and the fuel economy of vehicles by age of vehicle. GHG emissions from fuel-powered vehicles are calculated based on input assumptions regarding the mix of fuels used in the future (e.g. diesel, biodiesel, CNG). Electric power consumption is calculated from the VMT powered by electricity and input assumptions regarding the age distribution of vehicles and the power efficiency of vehicles by age of vehicle. GHG emissions from electrically powered vehicles are calculated based on the amount of power consumed and scenario input assumptions regarding the carbon intensity of electrical power generation.

Components of GreenSTEP were tested throughout the development process to check the reasonability of results and whether the model could replicate observed behavior and conditions. Sensitivity tests were also performed to check whether the sensitivity of the model is consistent with results reported by other studies.[18]

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[18] For example, the sensitivity of GreenSTEP to changes in urban area population density and land use mixing was compared to findings published in the Transportation Research Board Special Report 298, *Driving and the Built Environment: Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions.* September 2009.

Evaluation Framework

An evaluation framework and associated assessment process was developed to provide the policy and technical advisory committees and others the ability to understand and evaluate a range of other impacts associated with prospective scenarios.

The evaluation framework addresses the analysis of programs, policies and actions across seven criteria. These criteria include:

1. **Travel and System Performance** – Addresses overall travel and transportation system performance
2. **Energy Consumption and GHG Emissions** **–** Includes GHG emissions and petroleum based fuel consumption
3. **Economic Impact** - Includes household costs, public sector revenue and other social costs
4. **Land Use and Natural Resource Impact** – Addresses the consumption of land for urbanization and the consumption of water
5. **Public Health Impact** - Addresses air quality and level of activity (e.g. walking)
6. **Infrastructure and Implementation Costs** – Addresses capital and operating costs
7. **Potential Implementation Challenges** – The implementation risk a of deploying the statewide strategy

Evaluation measures were developed for each criterion. The evaluation measures were modified as the study progressed. Staff and the advisory committee members gained a better understanding of what measures were most meaningful and could reasonably be calculated. The evaluation criteria and associated measures that came out of that process are shown in Table 6.

Table 6. Evaluation Criteria and Evaluation Measures

Evaluation Criteria	Evaluation Measures
Travel and System Performance	• Statewide light vehicle VMT per capita • Statewide per capita vehicle delay • Per capita transit service level by metropolitan area
Energy Consumption and GHG Emissions	• Statewide light duty vehicle GHG emissions • Statewide light duty vehicle petroleum based fuel consumption
Economic Impact	• Out-of-pocket household costs for vehicle ownership and use including depreciation, financing, insurance, maintenance/repair, fuel/electricity, tires, taxes and fees • Other social costs per capita including: travel delay, climate change damage and adaption, energy (petroleum) security, air and noise pollution, crash costs to non-drivers, other environmental resource damage • Transportation infrastructure capital and operating costs per capita including major roadway and transit system costs • Transportation revenues per capita from taxes and fees including fuel tax, VMT tax, congestion tax, carbon/GHG tax, parking charges • Other public service costs
Land Use and Natural Resource Impacts	• Amount of land consumed for development (metropolitan, other urban, rural) • Proportion of metropolitan area population living in “complete communities” (e.g., urban mixed-use neighborhoods) • Residential water consumption
Public health impact	• Impact on criteria pollutants (PM, NO_X, VOC) • Amount of non-motorized travel (walking and bicycling)
Potential Implementation Challenges	• Legal, legislative or regulatory barriers for implementation • Institutional framework for implementation and long-term “ownership” • Technology

Most of the evaluation measures were calculated from outputs of the GreenSTEP model. The following is a summary of how that was done and what additional information was used where necessary.

- **Statewide light duty vehicle VMT per capita:** GreenSTEP calculates light duty vehicle VMT.

- **Statewide per capita vehicle delay**: GreenSTEP calculates vehicle delay for light duty vehicles, trucks and buses in metropolitan areas.

- **Per capita transit service level by metropolitan area:** Per capita transit service (revenue miles) by metropolitan area is a scenario input.

- **Statewide light duty vehicle GHG emissions:** GreenSTEP calculates light duty vehicle GHG emissions.

- **Statewide light duty vehicle petroleum based fuel consumption:** GreenSTEP calculates hydrocarbon fuels consumed by light duty vehicles. It has not been possible to date to forecast the proportion of hydrocarbon fuels that might be derived from petroleum vs. other sources (e.g. natural gas, biofuels). Therefore, the evaluation measure presented in this report is simply of the quantity of hydrocarbon fuels regardless of source.

- **Out-of-pocket household costs for vehicle ownership and use**: These costs are calculated by the GreenSTEP model, and comprise several components including vehicle cost, depreciation, energy costs, taxes/fees, and other lesser elements. Vehicle depreciation is calculated from the average new vehicle price in 2005 and the vehicle age, using factors derived from the IRS's modified accelerated cost recovery system. As average new car prices have remained fairly stable in recent decades, and given the historical trend automobile manufacturers reducing the cost of ICE vehicles through technological and production improvements, it was assumed that PHEVs and EVs would be priced competitively in the mid-to-long run.[19] The costs of fuel and electricity were calculated from the modeled amounts consumed and the price forecasts described previously. Taxes and fees were calculated based on the input assumptions and the relevant taxed quantities. Other vehicle costs were based on averages reported by the American Automobile Association.

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[19] The average new car price in 1906 was over $50,000 in 1993 dollars but was less than half that price two decades later. The decline was even greater when measured in quality-adjusted terms. Raff, D.M.G. and Trajtenberg, M. (1995), "Quality-Adjusted Prices for the American Automobile Industry: 1906-1940", National Bureau of Economic Research, https://www.nber.org/chapters/c6065.

- **Other social costs per capita:** Hours of vehicle delay for cars and trucks in metropolitan areas is calculated by GreenSTEP. The costs of delay are calculated using average values of time for cars and trucks.[20] Climate change costs are estimated from estimates of average costs per ton of GHG emitted and GreenSTEP's estimates of GHG emissions. Energy security costs are estimated from estimates of average cost per gallon of fuel consumed and GreenSTEP's estimates of the amounts of fuel consumed. Air, noise, crash and other environmental damage costs are calculated from cost rates per VMT for each of these effects and GreenSTEP's estimates of VMT.[21]

- **Transportation infrastructure capital and operating costs:** Highway costs are estimated from lane-mile growth assumptions for each scenario, GreenSTEP's estimates of VMT, and average cost per VMT and lane-mile. Transit costs are estimated from transit revenue mile growth assumptions for the scenario and average cost per revenue mile by transit service type.

- **Transportation revenues from taxes and fees:** Tax and fee rates for congestion, VMT, carbon/GHG, fuels, and parking are scenario inputs. GreenSTEP calculates the amounts paid for each tax or fee given those inputs.

- **Other public service costs:** These costs are calculated based on the density of residential development and average cost of providing public services documented in the literature.[22]

- **Amount of land consumed for development:** Developed land area is calculated using GreenSTEP's estimates of population and population density.

- **Proportion of metropolitan area population living in "complete communities":** This is estimated using GreenSTEP's estimates of the proportion of metropolitan populations living in urban mixed-use neighborhoods.

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[20] Denise Whitney Dahlke, "The Value of Travel-Time: Estimates of the Hourly Value of Time for Vehicles in Oregon 2009", Oregon Department of Transportation, Long Range Planning Unit, June 2011. Values were adjusted to 2005 dollars using the consumer price index for the Portland-Salem OR-WA metropolitan area published by the U.S. Bureau of Labor Statistics.

[21] Cambridge Systematics, *Costs of Motor Vehicle Travel*, September 2011.

[22] Envision Utah (2000). https://www.fhwa.dot.gov/planning/processes/tools/toolbox/utah/index.cfm

- **Residential water consumption:** Residential water consumption is estimated based on average water consumption rates by residential density and GreenSTEP's estimates of population by population density.

- **Impact on criteria pollutants:** Criteria air pollution from light duty vehicle travel is estimated from emission rates per VMT powered by hydrocarbon fuels and GreenSTEP's estimates of the amount of VMT powered by hydrocarbon fuels.

- **Amount of non-motorized travel:** GreenSTEP estimates the number of household walking trips and the miles of short-distance SOV travel diverted to bicycling, etc.

- **Potential Implementation Challenges:** These are qualitatively assessed for each scenario.

Overview of Study Approach and Results

The Statewide Transportation Strategy (STS) breaks new ground for Oregon in a number of respects:

- It addresses a problem, GHG emissions from the transportation sector, that there is much to learn about;

- It addresses very challenging goals to reduce GHG emissions;

- It takes a very long-term perspective (looking out to 2050);

- It deals with more aspects of transportation than have been previously addressed in transportation plans (e.g. fuel economy, fuel prices, vehicle technology);

- It considers how transportation technology may change greatly and what the implications may be for the transportation system and emissions;

- It recognizes there is uncertainty in many respects because of the long time-frame and dynamic changes occurring to many factors affecting transportation.

These aspects of the STS made it necessary to take a different approach to its development. The challenging GHG reduction goals and large number of factors made it necessary to consider many scenarios for potentially meeting the goals. The long-term perspective and potential for dynamic changes in a number of factors required the consideration and analysis of conditions that could be substantial departures from recent trends. The need to consider a number of new prospects required the development of new analysis methods to assess what changes might occur rather than to predicting what changes would occur given known (today's) trends.

The STS Vision for ground passenger and commercial service travel was developed through an extensive process of testing and evaluation of prospective changes. This process was organized in several "rounds" of scenario development and evaluation. Evaluation involved modeling the effects of prospective changes using the GreenSTEP model that was expressly developed for this purpose. Scenario evaluation was structured by the use of an evaluation framework that identified general evaluation criteria and corresponding performance measures (as described above).

What was learned from each successive round of scenario development and evaluation became the basis for making refinements in the following round. The most obvious refinements were made to scenarios as a result of learning about the relative effect of scenario characteristics on GHG emissions and other performance measures. Other refinements were made to the GreenSTEP model and to the calculation of performance measures. In order to model some scenarios, capabilities of the GreenSTEP model needed to be improved so that new scenario aspects could be modeled and additional performance measures could be calculated. The performance measure calculations were revised as needed to make improvements as well.

The sections that follow describe each round of testing and evaluation; the objectives of the round, the scenarios that were evaluated, and significant changes to the modeling and analysis process.

Round 1

The first round of scenario development and evaluation examined a large number of potential strategies for reducing GHG emissions from light duty vehicles. The intent was to move the "levers" by large amounts to evaluate the relative sensitivity of GHG emissions to various changes in factors. Objectives of the first round included:

1. Evaluating a broad range of scenarios for reducing GHG emissions from light vehicle emissions in order to get a better understanding of amount of change required to reduce 2050 GHG emissions to be 75 percent below the 1990 level;

2. Providing direction to the development of the Agencies Technical Report mandated by HB2001 and SB1059; and,

3. Learning about the relative effects of various factors on GHG emissions and learning how changes to different factors can have synergistic or antagonistic effects.

Round 1 Approach

A large number of factors affect greenhouse gas emissions from light vehicles. An even larger number of different combinations of ways to reduce GHG emissions exist. This analytical challenge was addressed by grouping factors into six distinct categories. For each category, several "implementation" levels were defined where each higher level involved a more aggressive application of the factors intended to reduce GHG emissions. Scenarios were then created by combining every possible combination of levels across all six categories. A total of 144 scenarios were developed in this way. The scenarios were modeled for a 2050 forecast year to compare with the 2050 statutory GHG reduction goal. Following is a description of the six categories and the implementation levels:

1. Urban (3 levels): This category included factors that address GHG emissions through land use, transit, parking management, and non-motorized travel. It included the proportion of population growth occurring in urban areas, urban area growth rates, the proportion of households living in urban mixed-use neighborhoods, transit system growth, parking pricing, and the growth in use of bicycles and other light weight vehicles.

2. Roads (2 levels): This category included factors related to the expansion and management of the road system including growth in freeway system capacity, growth in arterial system capacity, and application of incident management.

3. Marketing (2 levels): This category included educational and incentives-based factors that affect GHG emissions by influencing travel choices including employer-based programs, household-based programs, and eco-driving and vehicle use optimization.

4. Vehicle and Fuels Technology (3 levels): This category addressed the technical characteristics of light-duty vehicles and the fuels they run on, including the fuel economy of internal combustion engines, the battery range, fuel economy, market share, and efficiency of plug-in hybrid electric and all-electric vehicles, the mix and carbon intensity of vehicle fuels, and the carbon intensity of electrical power used for transportation.

5. Fleet (2 levels): This category addressed characteristics of light vehicles other than vehicle technology or fuels including auto and light truck proportions, rate of fleet turnover, car-sharing participation rates.

6. Pricing (2 levels): This category included factors relating to the pricing of light vehicle travel including gas taxes, carbon taxes, VMT taxes, PAYD insurance, congestion pricing, and parking pricing.

This process of scenario development and evaluation also included the development of an evaluation framework that identified evaluation criteria and performance measures of importance to the policy committee. (See Table 6) Procedures were developed to calculate most of the evaluation measures from GreenSTEP outputs and supplementary data. The results were presented to the technical and policy advisory committees.

Round 1 Summary Results

1. A large number of scenarios were able to achieve reductions of 60 percent or more and a few were able to achieve reductions greater than 70 percent, but none were able to reach a 75 percent reduction in GHG emissions from 1990 levels.

2. Reductions of 60 percent or more were only achieved with the higher technology levels scenarios.

3. Technology levels made the biggest difference to GHG emissions. The urban and price levels had the next largest effects.

4. The difference between the second and third technology levels was small. This was found to be due to very high assumptions about achievable fuel economy for ICE and HEV vehicles that resulted in GHG emissions for these vehicles that were about as low as the emissions from EVs.

5. There was very little difference in GHG emissions for the two roads levels.

6. The differences in results of the two fleet scenarios were small. This was attributable to rather small differences in the light truck proportions.

Round 2

The purpose of the second round of scenario development and evaluation was to provide the analysis required in order to prepare the “Agencies’ Technical Report” (ATR) required by HB 2001 and SB 1059. The ATR provided the technical basis for the Land Conservation and Development Commission to develop light duty vehicle GHG emission reduction targets for metropolitan areas in 2035. ODOT developed the report in collaboration with the Department of Environmental Quality (DEQ) and the Oregon Department of Energy (ODOE). Objectives of the second round included:

1. Estimating 1990 VMT and GHG emissions from light vehicle travel on metropolitan area roadways;

2. Recommending what the percentage reduction in light motor vehicle emissions should be in 2035 in order to achieve the 2050 statewide GHG reduction goal;

3. Estimating the 2035 average light vehicle GHG emission rates by metropolitan area; and,

4. Estimating the light motor vehicle VMT by metropolitan area needed to meet the 2035 GHG reduction goal.

Round 2 Approach

The GreenSTEP model was used to estimate light duty vehicle VMT and GHG emissions in 1990 and 2035 given various assumptions about future vehicle technologies, fuels, and fleet characteristics. The model was calibrated and validated against independent statewide estimates of light vehicle VMT and gasoline sales for the years 1990, 1995, 2000, and 2005. Independent estimates of 2005 light vehicle VMT in each metropolitan area were used to estimate the ratio of the VMT occurring on roads in each metropolitan area to the VMT of households living in the metropolitan area. This ratio was used to scale the metropolitan household light vehicle VMT and GHG estimates to produce metropolitan area road estimates.

Estimates of 1990 household light vehicle VMT and GHG emissions were produced using 1990 estimates for the required model inputs such as population by age category, average per capita income, vehicle age characteristics and vehicle fuel economy. 1990 estimates of VMT and GHG emissions from light vehicle travel on metropolitan area roads were calculated by multiplying the metropolitan household light vehicle VMT and GHG emissions by the ratios calculated as described in the preceding paragraph.

2035 emission rates were estimated for four levels of possible future technology in combination with three fleet levels. The technology levels varied with respect to the combined average fuel economy of ICE and HEV powertrains, the average fuel economy of PHEV powertrains, the market shares of PHEVs and EVs, and the battery ranges of PHEVs and EVs. The three fleet levels varied with respect to the future proportion of light trucks in the fleet and the average vehicle age. GreenSTEP was run for each combination and total light vehicle GHG emissions and VMT were tabulated for each combination and metropolitan area. GHG emissions rates (per VMT) were the calculated from total GHG and total VMT.

The technology levels were redefined from the levels defined in the first round of scenario development and analysis. Concerns were raised by the technical advisory committee about the feasibility of ICE and HEV fuel economy assumptions. Additional research was done to develop more plausible assumptions about future fuel economy and potential growth of PHEVs and EVs in the fleet[23]. This resulted in the definition of four vehicle technology

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[23] The development of the technology levels relied heavily on the following report by Steve Plotkin and Margaret Singh of the Energy Systems Division of Argonne National Laboratory, “Multi-Path

levels. The first three levels differed primarily with respect to vehicle fuel economy. The fourth level included more ambitious assumptions about the proportions of PHEVs and EVs in the vehicle fleet.

Another change from the first round of scenario analysis was the addition of a third fleet implementation level. This was done to reflect a concern of the technical advisory committee that the previous assumptions about reductions in light truck percentages were not very ambitious. The third fleet level that was added assumed that light truck percentages could be reduced to 1990 levels by 2035.

GHG emission levels required to meet the statutory GHG goals were calculated by applying the statutory reduction rates to the 1990 estimates (e.g., 10 percent reduction by 2020, 75 percent reduction by 2050). These were calculated on a per capita basis using the metropolitan area population forecasts. The 2035 emissions goal was interpolated as the midpoint between 2020 and 2050 emissions levels assuming a constant annual percentage rate of reduction in emissions.

Vehicle VMT consistent with the 2035 reduction goal were then calculated by dividing the 2035 emissions goal by the assumed emissions rates calculated for the 12 scenario combinations.

Round 2 Summary Results

1. As before, vehicle technology was found to have a very large effect on GHG emissions.
2. The third fleet level showed an increased effect of lowering the proportion of light trucks in the fleet on GHG emissions, but the reductions were still modest.
3. A 2035 goal for GHG emissions reduction was developed.
4. The metropolitan area light vehicle GHG emissions reduction targets were based on the assumption that the third (e.g., most aggressive) technology and third fleet levels[24] would be achieved.[25]

Transportation futures Study: Vehicle Characterization and Scenario Analyses" (ANL/ESD/09-5), dated July 22, 2009.

[24] "Technology Level 3" represents a group of assumptions that include major improvements in fuel efficiency of autos and light trucks with internal combustion engines as well as plug-in hybrids. It also assumes improvement in the carbon content of fuels. "Fleet Level 3" assumes that over the next 25 years, the combination of cars and light trucks will favor passenger cars. Source: ODOT, DEQ, ODOE. *Agencies' Technical Report* (2011).

Round 3

The third round of scenario development and evaluation was organized around scenario themes. While the previous rounds were useful for learning about the effects of different factors on GHG emissions, the large number of scenarios made the task of choosing a preferred vision overwhelming to the advisory committees. To address this problem, the third round of scenario development was organized around scenario themes, rather than categories and levels. Each theme reflected a different approach or perspective on what should be done to reduce GHG emissions from ground passenger and commercial service vehicle travel. The consequences of each theme for GHG emissions and other evaluation criteria could then be compared to a reference case and to each other. Objectives of the third round included:

1. Developing a reference case scenario which represents the potential if current trends and policies continue;

2. Developing several scenario themes which represent different approaches and perspectives on what should be done to reduce GHG emissions; and,

3. Evaluating the reference case and theme scenarios using the full evaluation framework to develop an understanding of the tradeoffs associated with different approaches to reducing GHG emissions.

Round 3 Approach

Four theme scenarios were defined in addition to a reference case scenario. The themes were developed to represent different approaches or perspectives about what should be done to reduce GHG emissions. Following are descriptions of each scenario:

1. ***Urban:*** Under the Urban Scenario, changes are focused on the densification of the urban environment, where the majority of development occurs as infill and vertical growth. By 2050, policies result in the vast majority of population growth occurring within urban growth boundaries (UGBs). UGBs grow very little from today, while the population outside of UGBs remains relatively constant. Most Oregon residents live in “complete neighborhoods,” which support a more active healthy environment. Features of complete neighborhoods include more favorable jobs-housing balance, expanded bicycle and pedestrian networks, strategic vehicle traffic calming elements, and increased access to urban and intercity transit systems. Due in part to these changes, a

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[25] Department of Land Conservation and Development, “Target Rulemaking Advisory Committee Recommendations on Greenhouse Gas Reduction Targets”, April 2011, https://www.oregon.gov/LCD/docs/rulemaking/2009-11/TRAC/TRAC_Report_to_LCDC.pdf

substantial number of SOV trips in urban areas will shift to walking, biking, personal electric vehicle (PEV), and transit. A number of additional efforts support this modal shift, including a statewide pay-as-you-drive insurance program, widespread travel demand management (TDM) programs, increases in urban parking pricing, freeway management that discourages short-distance travel, and modest VMT fees to pay for road infrastructure and services. Vehicle technology is assumed to increase slightly over Reference Case levels. The majority of GHG reductions in this scenario come from a decrease in overall vehicle miles traveled (VMT).

2. ***Vehicle Technology:*** Under the Vehicle Technology Scenario, rapid and significant advances in vehicle technology improve energy efficiency and decrease the demand on highway capacity. Alternative fuel vehicles of various types and sizes dominate the light vehicle fleet, and are supported by various technological innovations including reduced carbon intensity of fuels and electricity generation. The average vehicle on Oregon roads is younger, smaller and more fuel efficient. These changes to the vehicle fleet would likely result in an accelerated decline in fuel tax receipts, so VMT taxes are added to offset fuel tax revenue loss and support future infrastructure improvements. The spread of innovative technologies extends to the personal electric vehicle (e.g. electric bicycle) market, making these vehicles an inexpensive and attractive alternative for short-distance travel. The majority of GHG reductions in this scenario result from per mile GHG reductions due to the prevalence of substantially more energy-vehicle technology and lower-carbon fuels.

3. ***System and Mode Optimization:*** The System and Mode Optimization Scenario focuses on the use of Intelligent Transportation Systems (ITS) and information technology to optimize operation of the roadway network (e.g. signal timing, ramp metering, etc.) and to provide sufficient access to non-SOV modes. Public transportation, bicycle, pedestrian and PEV networks are expanded to enable optimization of travel among modes. Roadway capacity is only affected via: 1) the mitigation of severe freeway bottlenecks[26], and 2) the reallocation of some arterial lanes to enhance walking/biking/PEV and transit networks. Information technology

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[26] A bottleneck is a specific section of a transportation network that experiences particularly heavy delays and reduced speeds. While a random or "non-recurring" bottleneck can occur as a result of a singular event such as a lane closure for maintenance or crash, the term here is reserved for those locations where heavy delays occur on a recurring basis as a result of a capacity or operational deficiency. The term can apply to just about any modal system, e.g., highways, rail networks, or air traffic approach tracks. In the context of the STS we refer most commonly to roadway system bottlenecks. These are often at the junction of two major routes, such as a freeway-to-freeway interchange or the intersection of two major arterial roadways. Freight bottlenecks often are caused by factors specific to freight modes, such as steep upgrades, , insufficient weaving/merging distance at a busy interchange with high truck volumes, or operational delays at freight terminals. (Source: Federal Highway Administration, "Localized Bottleneck Reduction Program." https://ops.fhwa.dot.gov/bn/lbr.htm#g3.)

provides travelers with real-time information, allowing them to make personal choices that further optimize the operation of roadway facilities and encouraging eco-driving practices. Telecommunications technology is often substituted for vehicle trips. Vehicle and fuel technology is assumed to increase slightly over Reference Case levels. The System and Mode Optimization scenario reduces GHG emissions by increasing the efficiency of the transportation system, enabling travelers to meet their needs with lower-carbon modes of transportation, and limiting wasteful energy consumption.

4. ***Pricing and Markets:*** Under the Pricing and Markets Scenario, prices associated with vehicle travel are adjusted to reflect the full cost of travel (including externalities), and travelers respond to these market changes. In particular, fuel, VMT and carbon taxes are set at levels that balance demand and supply but address all relevant externalities associated with SOV travel. Parking pricing is instituted in all urban centers, and all vehicles in Oregon feature pay-as-you-drive insurance. Vehicle and fuel technology is assumed to increase slightly over Reference Case levels. The Pricing and Markets Scenario will reduce GHG emissions by encouraging travelers to utilize more efficient modes and vehicles to reach their destinations.

Additional information was gathered to help define appropriate values for the constituent factors for each theme. In particular, ODOT staff worked with metropolitan planning organization staff to improve the definitions of the Reference and Urban Scenarios.

Changes were made to the GreenSTEP model as well to enable the elements of the scenario themes to be reflected in the model calculations and to improve the evaluation of scenarios.

- The methods for calculating the effects of congestion on emissions were improved to reflect how the effects vary by powertrain type and design.[27] (Congestion has much less effect on emissions for HEVs, PHEVs and EVs.)

- The calculation procedures were changed to expand the capabilities of the model to evaluate the effects of ITS and operations programs such as ramp metering and signal coordination.[28]

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[27] Alex Bigazzi and Kelly Clifton, *Refining GreenSTEP: Impacts of Vehicle Technologies and ITS/Operational Improvements on Travel Speed and Fuel Consumption Curves, Final Report on Task 1: Advanced Vehicle Fuel-Speed Curves*, Portland State University, November 2011.

[28] Alex Bigazzi and Kelly Clifton, *Refining GreenSTEP: Impacts of Vehicle Technologies and ITS/Operational Improvements on Travel Speed and Fuel Consumption Curves, Report on Task*

- The congestion model was changed to enable congestion pricing effects to be evaluated. These enable congestion pricing to vary by congestion level and by roadway type (e.g. freeway or arterial). The model is sensitive to the effects of differential pricing on the balance of traffic by facility and congestion level. Similarly, the balance of traffic is also sensitive to the effects of ITS and operations programs and capacity expansions.

- Procedures were added to allow the model to address the problem of insufficient fuel taxes as fuel economy improves and more vehicles are powered by electricity. Supplemental VMT taxes were calculated and applied so that total revenues were sufficient to pay the cost to maintain, operate and improve the road system assumed for each scenario. This was done in order to provide fair comparisons of scenarios having very different assumptions about fuel economy and electric vehicle use.

- Commercial service vehicles were split out as a separate market component from household vehicle travel. This enables different vehicle characteristics to be applied to commercial service vehicles. For example, many commercial service vehicles are good candidates for powering by compressed natural gas (CNG) or electricity because they are operated as fleets that can have the support for these power sources and because they have relatively short travel ranges.

- A household walk model was added to improve the calculation of a related evaluation measure.

- Procedures were added to estimate household auto ownership costs for use in the calculation of evaluation measures.

The Reference Case scenario and the four theme scenarios were modeled for 2050 with the GreenSTEP model. Evaluation measures were calculated and reviewed by the policy and technical committees. Figure 18 summarizes the results of the theme scenarios relative to the Reference Case scenario. On the left half of the figure, each of the theme scenarios is analyzed with regard to general categories of evaluation measures/indicators such as "Energy Consumption and GHG Emissions" and "Travel and System Performance." On the right half of the figure, the change in each quantifiable indicator (such as emissions reduction, fuel consumption, etc.) is shown, expressed as percent change relative to the Reference Case. Note that estimated emissions reductions are shown relative to 1990, not relative to the Reference Case as with the other metrics.

2: *Incorporation of Operations and ITS Improvements*, Portland State University, November 2011.

Round 3 Summary Results

1. The Reference Case scenario was estimated to reduce GHG emissions by about 34 percent below 1990 levels. This is largely the result of the planned fuel economy and low carbon fuel standards. In addition, the reference case assumes that although metropolitan area UGBs will grow, they will grow more slowly than metropolitan area populations. This will dampen the growth of VMT.

2. The theme scenarios were estimated to reduce GHG emissions by similar amounts. All had reductions that fall well short of the 2050 goal of 75% reduction, however:

    - Urban = 46 percent below 1990 levels
    - Vehicle and Fuel Technology = 45 percent
    - System and Mode Optimization = 45 percent
    - Pricing and Markets = 43 percent.

3. The Vehicle and Fuel Technology scenario reduced GHG emissions primarily by reducing the GHG emissions rate per mile.

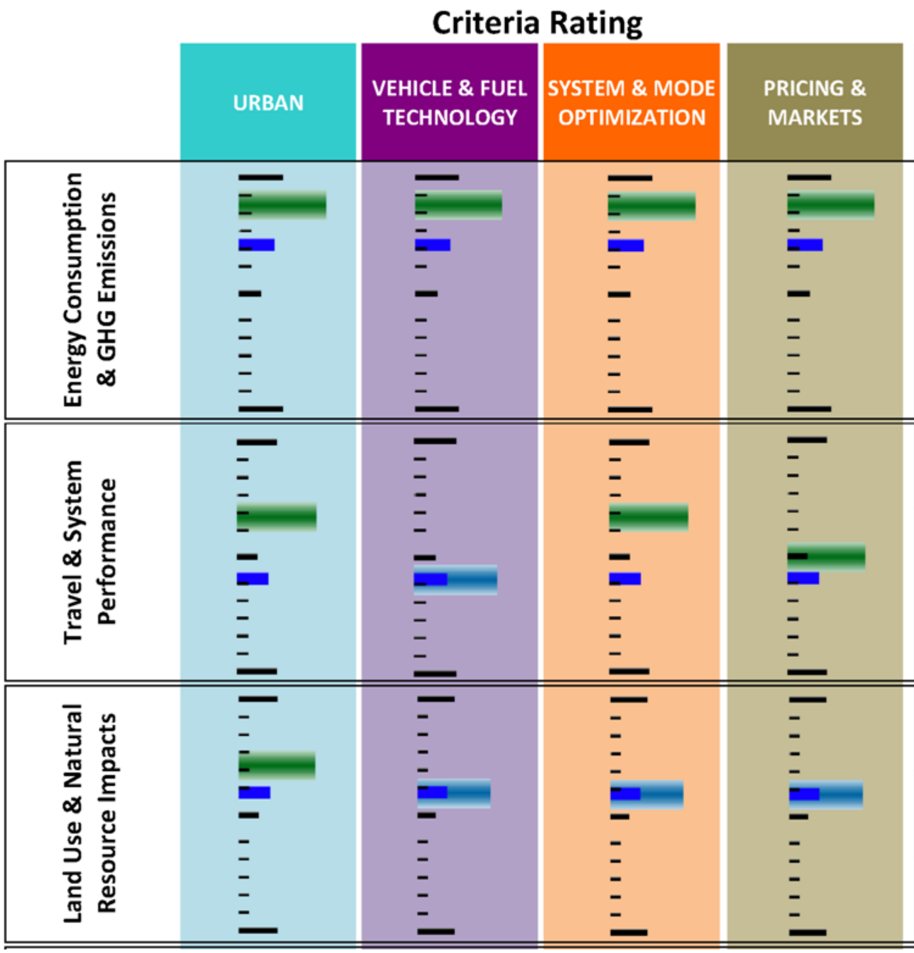
4. The Urban, System and Mode Optimization, and Pricing and Markets scenarios reduced GHG emissions primarily by reducing per capita VMT. Lowering of VMT was associated with other benefits including lower delay and lower highway maintenance and operation costs.

5. The Urban and System and Mode Optimization scenarios had substantially higher public transit service levels and costs. They also had higher amounts of non-motorized travel.

6. The Pricing and Markets scenario had higher household auto ownership and use costs because of higher taxes. The other scenarios had lower costs because of lower taxes and fuel consumption.

7. Several of the assumptions that go into one or more scenarios were identified as having the potential for greater impact on GHG emissions if applied more assertively. For example, more ambitious assumptions would be credible for increasing the percentage of short distance SOV travel that shifts to bicycling or similar modes, increasing parking pricing in all urban centers, and increasing the percentage of electric vehicles in both the passenger and commercial service vehicle fleets.

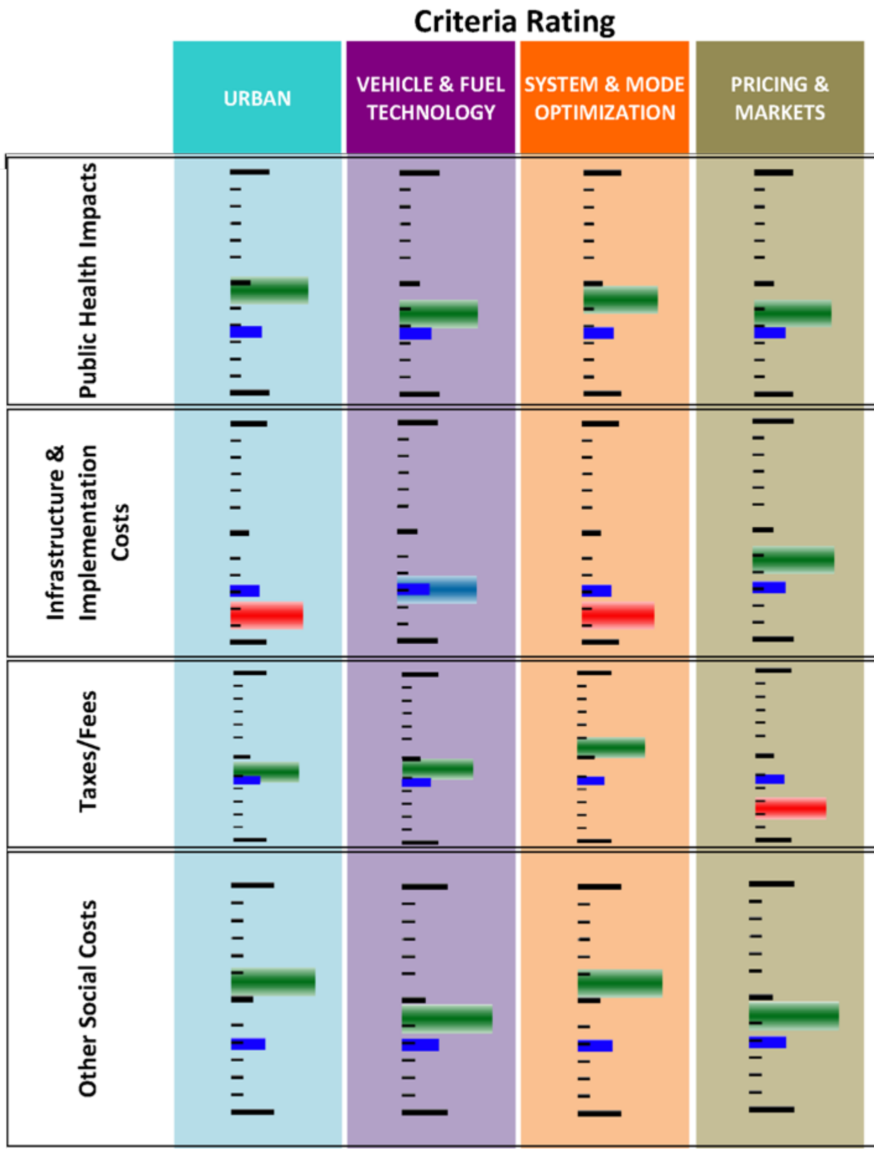
(Graphic continues on the following page)



Indicator Change (vs. Reference Case)

Indicator	URBAN	VEHICLE & FUEL TECHNOLOGY	SYSTEM & MODE OPTIMIZATION	PRICING & MARKETS
Emissions reduction (vs. 1990)	46%	45%	45%	43%
Δ fuel consumption	-24%	-24%	-28%	-16%
Δ lt. vehicle VMT per capita	-19%	0%	-14%	-14%
Δ statewide vehicle delay per capita	-37%	0%	-34%	-25%
Δ transit service levels per capita	118%	0%	118%	0%
Δ Land consumed for development	-3%	0%	0%	0%
Δ in urban mixed-use neighborhoods (MPOs)	16%	0%	0%	0%
Δ per capita water consumption	-3%	0%	0%	0%

Figure 18. Comparison of Round 3 Theme Scenarios



Indicator Change (vs. Reference Case)

Indicator	URBAN	VEHICLE & FUEL TECHNOLOGY	SYSTEM & MODE OPTIMIZATION	PRICING & MARKETS
Δ criteria polutants	-19%	-18%	-15%	-15%
Δ non-motorized travel per capita (MPOs)	17%	0%	9%	0%
Δ Highway capital/O&M costs	-20%	0%	-14%	-14%
Δ Transit O&M costs	143%	0%	143%	0%
Δ tax/fee cost per capita	-4%	-12%	-21%	50%
Δ fuel & electricity costs per capita	-19%	-17%	-23%	-14%
Δ MPO truck travel costs per capita	-17%	-15%	-22%	-13%
Δ MPO residential floorspace costs	0%	0%	0%	0%
Δ MPO area public service costs	-11%	0%	0%	0%
Δ External social costs	-19%	-9%	-19%	-14%
Δ household auto ownership costs	-9%	-4.9%	-14%	9%

Figure 18. Comparison of Round 3 Theme Scenarios (Continued)

Round 4

The purpose of the fourth round of scenario development and evaluation was to find a combination of scenario elements that would enable GHG emissions from the Ground Passenger and Commercial Services travel market to reach the goal of 75 percent below the 1990 level. It was clear from the results of the 3rd round, that the goal could only be achieved by combining elements from all of the themes. This result confirmed what was found in the 1st round of scenario development and evaluation. The objectives of this round were to develop two to three scenarios that achieve a 75 percent reduction in GHG emissions and up to 2 more that address other goals such as maximizing investments, maximizing co-benefits, etc.

Round 4 Approach

Work on this round was started by combining all of the elements of the theme scenarios developed in the previous round to determine how much GHG reduction could be achieved in that way. The result, a 63 percent reduction in GHG emissions, was substantially below the goal. This combination scenario was then enhanced to include the additional changes identified by the policy advisory committee. This "Enhanced Combo" scenario was found to reduce GHG emissions by 69 percent. The technical advisory committee reviewed these results and recommended that staff develop and evaluate two additional scenarios: 1) an Enhanced Combo scenario with additional pricing assumptions; and 2) and Enhanced Combo scenario with additional technology assumptions including a higher percentage of PHEVs and EVs. It was also recommended that the "Enhanced Combo Tech" scenario assume that the electric power sector also achieve the 75 percent GHG reduction goal. There were several reasons for the recommended focus on technology and pricing:

- Diminishing returns on GHG reduction strategies were evident once reductions of 60-70 percent were reached;
- There were few opportunities to increase system optimization beyond what was already assumed;
- Further urban enhancements showed only minor reductions in GHG; and,
- It was possible to identify technology scenarios that could meet the 75 percent reduction goal.

The Enhanced Combo Price scenario was developed by modeling the Enhanced Combo scenario with successively higher VMT taxes until GHG emission reductions achieved the goal.

The Enhanced Combo Tech scenario was developed by increasing the proportions of vehicles that are PHEVs or EVs (53 percent of the fleet in 2050).

Several sensitivity tests were also performed to estimate the relative effect of bottleneck removal, congestion pricing, road expansion, transit expansion, and UGB growth.

Round 4 Summary Results

1. Figure 19 shows the evolution of the scenarios from the individual theme scenarios to the Combo, Enhanced Combo, and finally the Enhanced + Price and the Enhanced + Technology. The figure shows major assumptions and changes in assumptions for each scenario. The figure also shows the estimated GHG emissions reductions for each scenario.

2. The Enhanced+Price scenario achieves almost a 75 percent reduction with a 15 cent per mile tax on top of other taxes that average 6 cents per mile.

3. The Enhanced+Technology scenario achieves a 75 percent reduction with a light duty vehicle fleet that is more than half PHEVs and EVs.

4. The Enhanced+Price scenario is significantly more costly for households than the Enhanced+Technology scenario. The higher costs would use a substantial share of household income in the rural parts of Oregon. The Enhanced+Technology scenario helps to mitigate the effects of higher gas prices in the rural portions of the state. For these reasons, the policy advisory committee decided to advance the Enhanced+Technology scenario.

5. Bottleneck removal was removed from further consideration because it was estimated to have little effect on GHG emissions and total delay, and could be very expensive.

6. Congestion pricing was found to have little effect of GHG emissions as well, but was not removed because it was found to reduce vehicle delay.

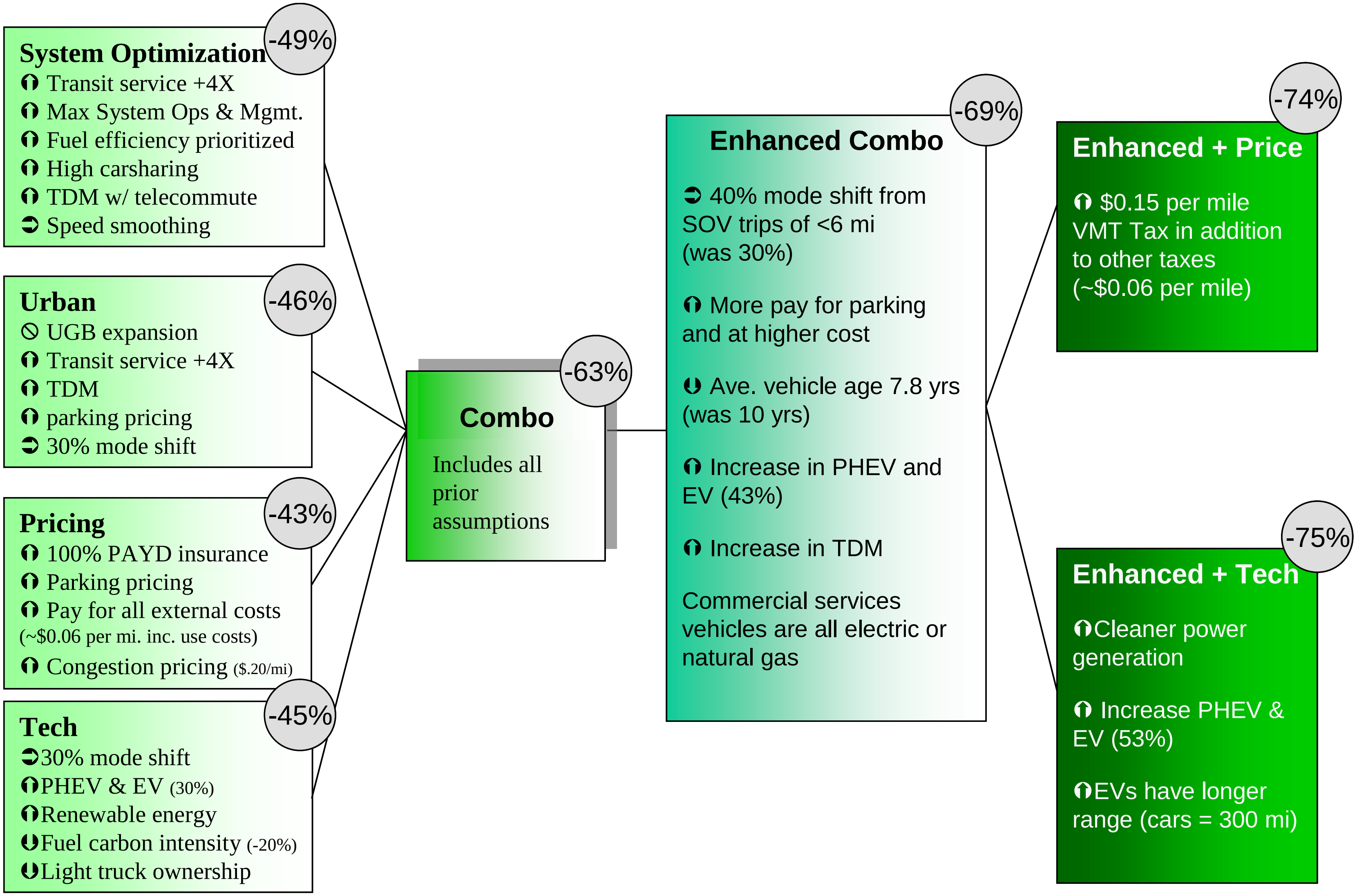
7. Allowing a moderate amount of road expansion was found to not increase GHG emissions so tight constraints on road expansion were not included in the final vision.

8. Allowing moderate expansion to urban growth boundaries was found to have very little effect on GHG emissions so prohibiting UGB expansion was not included in the final vision.

9. There are diminishing returns as reductions increase beyond 60%. This can be appreciated by considering the reductions in terms of average fuel use per capita. In 1990, the average per capita gasoline consumption was about 450 gallons per year. Since population 2050 is expected to be about

double the 1990 population, a reduction of GHG by 60 percent would be equivalent to reducing per capita fuel consumption to 90 gallons. Increasing the GHG emission reduction an additional 10 percentage points (70 percent) would require cutting the 90 gallons down to 68 gallons, an additional 25 percent. Cutting GHG by an additional 5 percentage points (75 percent) would require cutting the 68 gallons down to 56 gallons, an additional 18 percent. At that level, per capita gasoline consumption would be about 12 percent of the 1990 level.

10. The policy advisory committee suggested that the Enhanced+Technology scenario be modified to reduce GHG emissions further by assuming that the electric power sector will also reduce GHG emissions by 75 percent. This would provide a buffer in case the Freight and Air Passenger travel markets are not able to achieve the reduction goals.



System Optimization -49%
- ⬆ Transit service +4X
- ⬆ Max System Ops & Mgmt.
- ⬆ Fuel efficiency prioritized
- ⬆ High carsharing
- ⬆ TDM w/ telecommute
- ➲ Speed smoothing

Urban -46%
- ⊘ UGB expansion
- ⬆ Transit service +4X
- ⬆ TDM
- ⬆ parking pricing
- ➲ 30% mode shift

Pricing -43%
- ⬆ 100% PAYD insurance
- ⬆ Parking pricing
- ⬆ Pay for all external costs (~$0.06 per mi. inc. use costs)
- ⬆ Congestion pricing ($.20/mi)

Tech -45%
- ➲ 30% mode shift
- ⬆ PHEV & EV (30%)
- ⬆ Renewable energy
- ⬇ Fuel carbon intensity (-20%)
- ⬇ Light truck ownership

Combo -63%

Includes all prior assumptions

Enhanced Combo -69%

➲ 40% mode shift from SOV trips of <6 mi (was 30%)

⬆ More pay for parking and at higher cost

⬇ Ave. vehicle age 7.8 yrs (was 10 yrs)

⬆ Increase in PHEV and EV (43%)

⬆ Increase in TDM

Commercial services vehicles are all electric or natural gas

Enhanced + Price -74%

⬆ $0.15 per mile VMT Tax in addition to other taxes (~$0.06 per mile)

Enhanced + Tech -75%

⬆ Cleaner power generation

⬆ Increase PHEV & EV (53%)

⬆ EVs have longer range (cars = 300 mi)

Figure 19. Evolution of Ground Passenger and Commercial Services Travel Market Scenarios

Round 5

The fifth round of scenario development resulted in the decision to use the Enhanced+Technology scenario as the basis for the STS Vision for the Ground Passenger and Commercial Services travel market segment. The primary purpose of the fifth round of scenario development and evaluation was to detail how the scenario elements would change over time and compare the results to the GHG reduction goals for 2020 and 2035. The 5th round also involved making additional changes to the chosen scenario to reflect suggestions of the policy advisory committee.

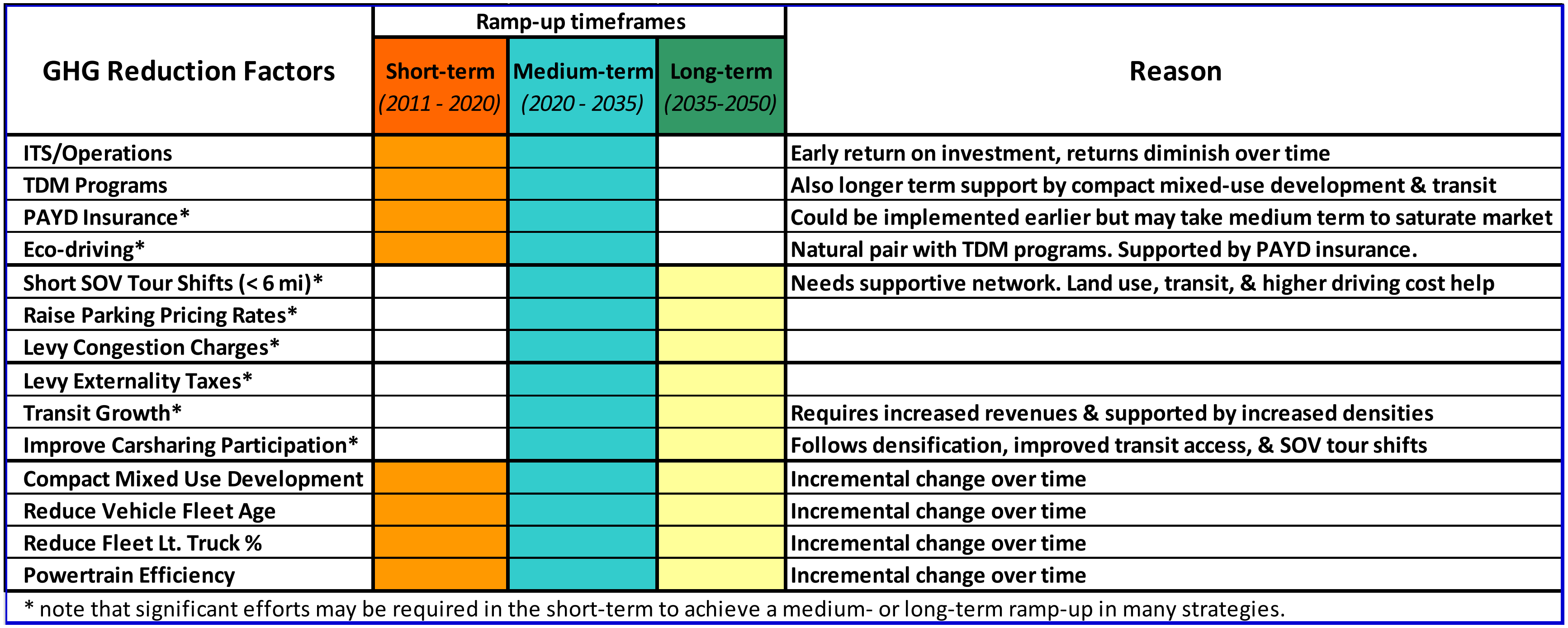
Round 5 Approach

2050 input values for the scenario were adjusted as necessary to reflect suggestions for changes to the Enhanced+Technology scenario including reducing the assumed GHG emissions from the electric power sector and changing the UGB inputs to provide for a modest growth of UGBs as population grows.

Once the 2050 values for all inputs were established, the changes from the present to 2050 were defined. This was done in two steps. First, qualitative judgments were made to identify most of the changes for an input could occur in the short-term (2011-2020), mid-term (2020-2035), or long-term (2035-2050). Figure 20 shows the results.

Once the general ramp-up timelines were determined, the specific changes in values over time were established mathematically to produce smooth transitions from year to year. The trajectories were reviewed with the policy advisory committee to get feedback on their reasonability.

GreenSTEP was then run for the years 2020, 2035 and 2050 and compared to the GHG reduction goals.



GHG Reduction Factors	Ramp-up timeframes			Reason
	Short-term *(2011 - 2020)*	Medium-term *(2020 - 2035)*	Long-term *(2035-2050)*	
ITS/Operations	🟧	🟦		Early return on investment, returns diminish over time
TDM Programs	🟧	🟦		Also longer term support by compact mixed-use development & transit
PAYD Insurance*	🟧	🟦		Could be implemented earlier but may take medium term to saturate market
Eco-driving*	🟧	🟦		Natural pair with TDM programs. Supported by PAYD insurance.
Short SOV Tour Shifts (< 6 mi)*		🟦	🟨	Needs supportive network. Land use, transit, & higher driving cost help
Raise Parking Pricing Rates*		🟦	🟨	
Levy Congestion Charges*		🟦	🟨	
Levy Externality Taxes*		🟦	🟨	
Transit Growth*		🟦	🟨	Requires increased revenues & supported by increased densities
Improve Carsharing Participation*		🟦	🟨	Follows densification, improved transit access, & SOV tour shifts
Compact Mixed Use Development	🟧	🟦	🟨	Incremental change over time
Reduce Vehicle Fleet Age	🟧	🟦	🟨	Incremental change over time
Reduce Fleet Lt. Truck %	🟧	🟦	🟨	Incremental change over time
Powertrain Efficiency	🟧	🟦	🟨	Incremental change over time

* note that significant efforts may be required in the short-term to achieve a medium- or long-term ramp-up in many strategies.

Figure 20. General Timing of Changes to Input Assumptions

Round 5 Summary Results

- The proposed trajectories produced GHG reductions that meet the reduction goals for 2020, 2035 and 2050. This is shown in Figure 21.
- The GHG emissions reductions for 2050 approach 80%.
- Additional work needed to be done on the public transportation growth assumptions. The assumptions about the amount of growth of public transportation service for the Portland metropolitan area were not high enough in the short to mid-term ranges, and conversely were too high in the long-term range. Moreover the long-term growth rate for the smaller metropolitan areas needed to be higher because those areas are starting from a lower base level.

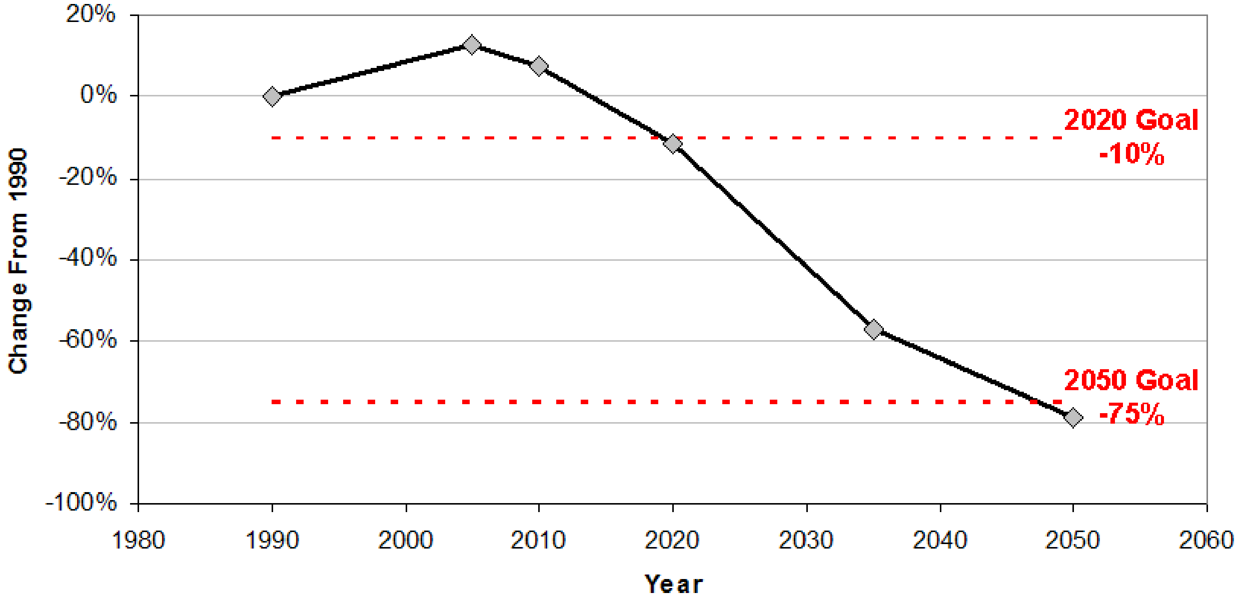


Figure 21. GHG Emissions Reductions for Ground Passenger and Commercial Services Travel Market Over Time (1990 – 2050)

Round 6

The purpose of the sixth round of scenario development was to make final changes to the Enhanced+Technology scenario input trajectories and report on the outcomes.

Round 6 Approach

Staff researched the public transit inputs further and consulted with Metro and TriMet on the assumptions about plausible short to mid-term growth rates for public transit service in the Portland metropolitan area. The 2050 targets for public transportation service levels in metropolitan areas were developed through comparison with the ranges of service levels offered in similarly sized metropolitan areas around the U.S.

Figure 22 shows the public transit service level values in bus equivalents for all U.S. metropolitan areas in 2009 by metropolitan area population. It should be noted that the populations and public transit service levels shown are for the entire urbanized portion of each metropolitan area. The urbanized portion of Clark County is included in the Portland area numbers. The chart groups metropolitan areas into population size categories and shows the range of public transit service levels for each size category with highlighted boxes. The median values are shown by horizontal black lines. Oregon's metropolitan areas are highlighted, as are the metropolitan areas with the highest service levels in each population size group.

The 2050 service level assumption for each of Oregon's metropolitan areas was established based on the reasoning that it is plausible for the service level to be at or near the top of the range for metropolitan areas in the same size category. Figure 22 also shows the assumed 2050 population and public transit service levels for each of Oregon's metropolitan areas. Rates of growth in per capita public transit service were calculated from these values.

Staff also refined the trajectories for ITS/operations programs because it was found that assumed present values for the deployment of ramp metering and incident management were below values reported by the Texas Transportation Institute in the Urban Mobility Study.

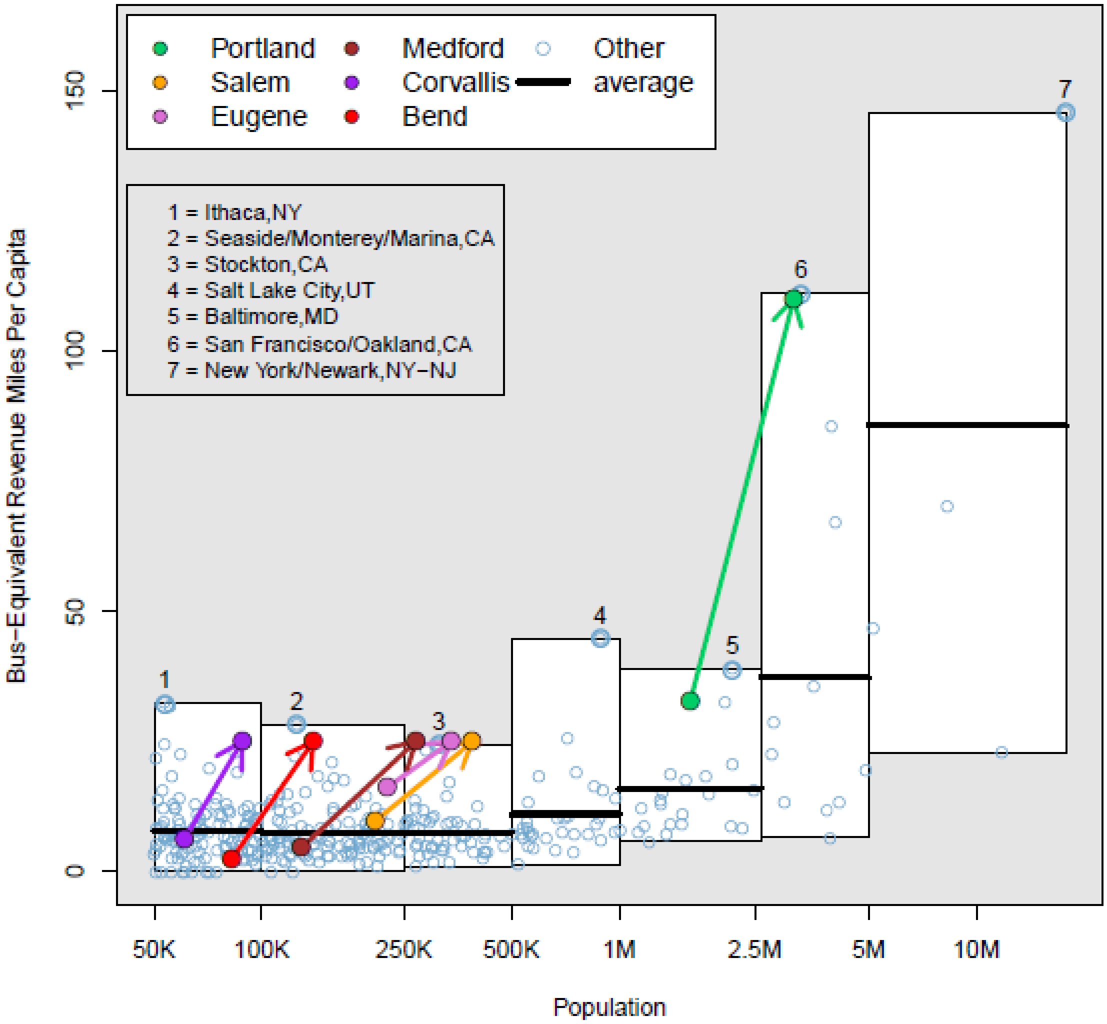


Figure 22. U.S. Metropolitan Area Transit Service Levels in 2009 by Population Size (Present and Assumed Future Service Levels for Oregon's Metropolitan Areas)

Round 6 Summary Results

Results of the sixth round of scenario development and evaluation are discussed in the following section.

Evaluation of the STS Vision

Travel and System Performance

Under the Reference Case, per capita light vehicle travel is projected to increase over the period 2010 to 2050. This is most likely the result of the assumption that real incomes will increase over time. Although the STS Vision uses the same income growth assumptions as the Reference Case, daily per capita light vehicle travel is projected to decrease significantly, relative to both the Reference Case and to 2010 levels (Figure 23). When considering annual total VMT per capita, the VMT projection for the 2050 Reference Case is approximately 10,000 annual VMT per capita whereas the projection for the 2050 STS Vision is less than 8,000 annual VMT per capita. Figure 24 shows the annual VMT per capita for both the Reference Case and the 2050 Vision in comparison to other industrialized countries. The comparison indicates that the STS Vision is reasonable when compared to these countries.

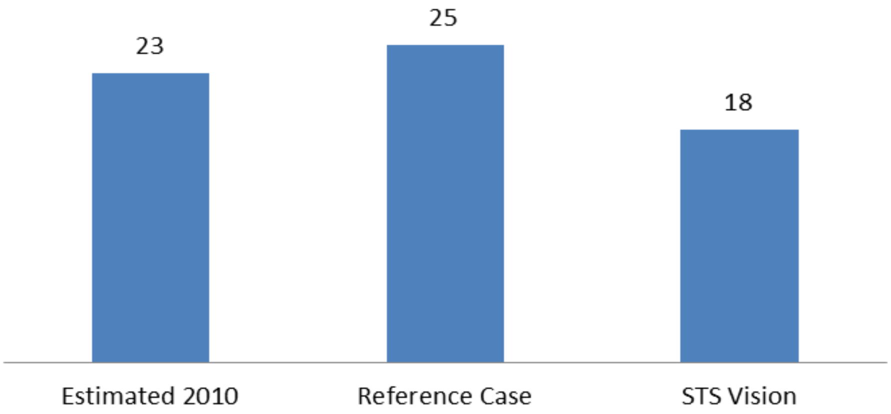


Figure 23. Per Capita Light Vehicle Travel Daily Vehicle Miles Traveled (DVMT)

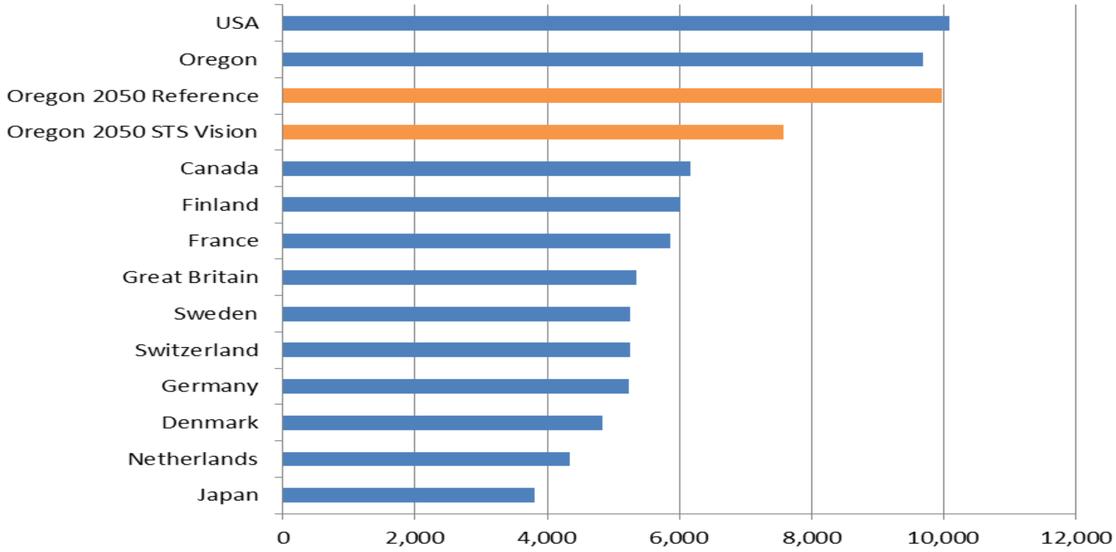


Figure 24. Comparison of 2050 Scenarios with 2005 for Oregon, U.S. And Selected Countries (Annual Total VMT Per Capita)

As shown in Figure 25, the STS Vision is projected to decrease total metropolitan area annual vehicle delay (light and heavy vehicles) from the current level. The projected delay for the Reference Case is projected to be much higher. The lower levels of delay for the STS Vision are the result of lower light vehicle VMT and ITS and other operational improvements. The large expansion of public transit service (Figure 26) contributes to the reduction in metropolitan area delay for the STS Vision.

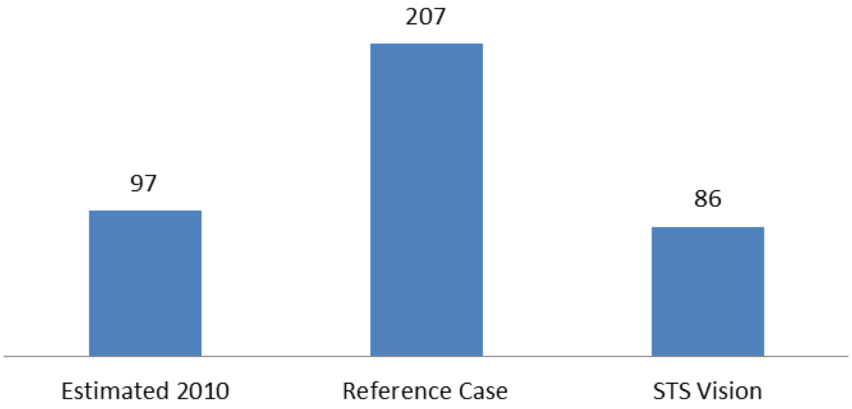


Figure 25. Total Metropolitan Area Annual Vehicle Delay (million hours)

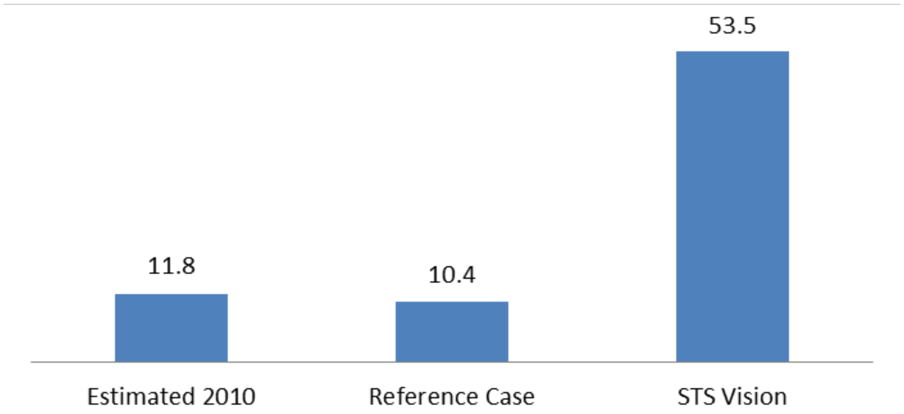


Figure 26. Average Metropolitan Per Capita Transit Service (annual revenue miles per capita)

Energy Consumption and GHG Emissions

The STS Vision reduces light vehicle GHG emissions more than the 2050 goal (Figure 27). Total fuel[29] consumption declines by a very large amount as well (Figure 28).

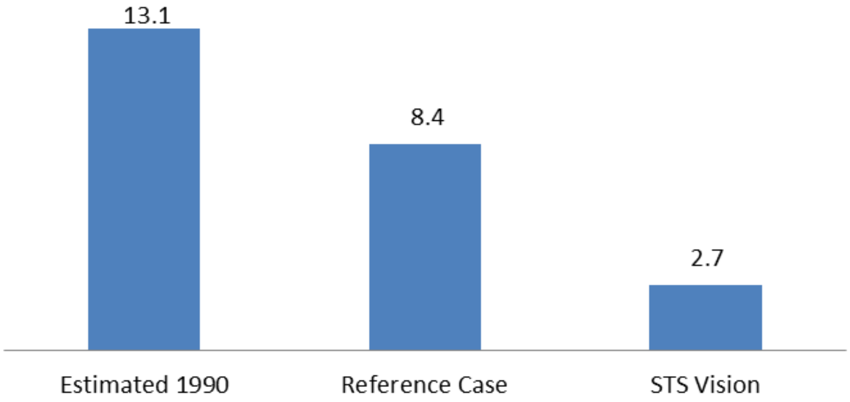


Figure 27. Annual Statewide Light Vehicle GHG Emissions (million metric tons)

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[29] Fuels include liquid and gaseous compounds that are combusted in light vehicle engines. They do not include electricity or hydrogen that is produced by electricity. The distinction is made because most light vehicle fuels are imported whereas most electricity is domestically produced. The STS analysis did not specifically address the imported vs. domestic proportions of fuels.

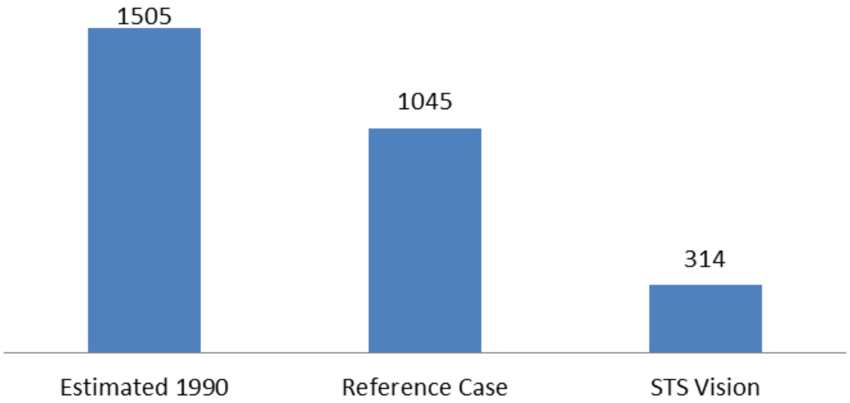

Figure 28. Annual Light Vehicle Fuel Consumption (million gasoline equivalent gallons) [30]

Economic Impacts

The STS Vision reduces out-of-pocket household costs for owning and operating vehicles for all but the highest income level households (Figure 29). Reductions from today's levels are possible despite higher taxes and fees because higher fuel economy and a shift to electric vehicles would lower fuel costs and because compact urban growth and the increased availability of public transit and other modes would reduce the amount of driving necessary. Vehicle ownership and operating costs are higher in the STS Vision than the Reference Case at higher household income levels. This is because of the higher income households will generate more auto VMT than other households generate, and thus pay more related fees and taxes. STS Vision costs are slightly lower than Reference Case costs for lower income levels.

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[30] Because fuels (gasoline, diesel, compressed natural gas, etc.) contain different amounts of energy per gallon, all fuel consumption is calculated in terms of the amounts of gasoline that would be required to produce the same amount of energy (gasoline equivalent gallons). This only applies to petroleum-based and other liquid and gaseous fuels (e.g. ethanol, compressed natural gas) that are combusted by vehicles to produce power. Electrical power that comes from the grid (not produced by an on-board generator) is calculated separately.

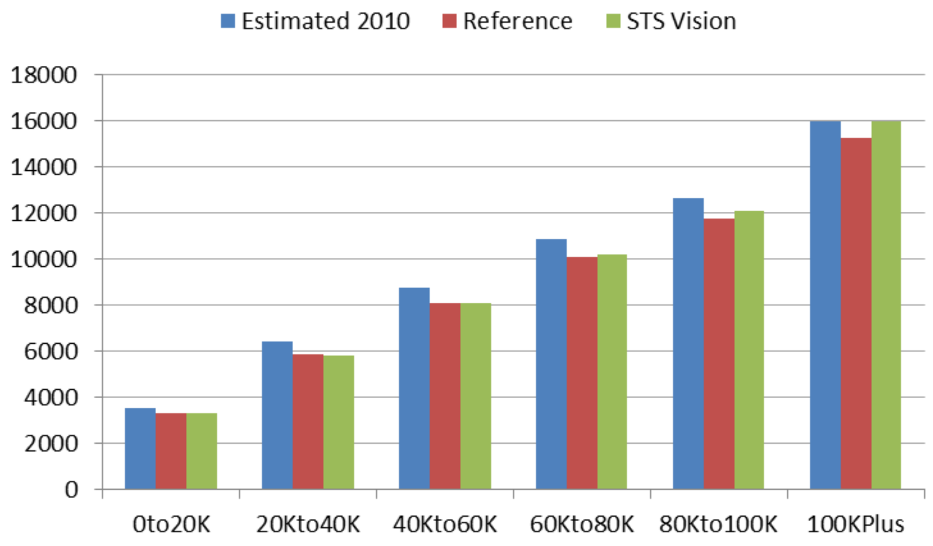

Figure 29. Average Annual Household Out-Of-Pocket Costs for Owning and Operating Vehicles by Household Income (2005 dollars)

The effect of household out-of-pocket costs on the ability to pay is shown in Figure 30, which displays costs as a percentage of income. It can be seen that the relatively small absolute reductions in costs for the lowest income households translates into relatively large savings as a percentage of household income. Cost reductions resulting from the STS Vision provide the greatest benefits to lower income households because the cost savings represent a larger percentage of their annual household budget. In addition, since lower income households are more likely to depend on public transportation to meet their mobility needs, the large increase in public transportation service proposed with the STS Vision will benefit those households even more.

The benefits of reduced household costs are not limited to metropolitan areas, where a number of different factors combine to reduce VMT. The benefits also accrue to households in rural areas and smaller urban areas. Changes to vehicle fleets and technology will reduce the impact of rising fuel costs on household budgets. Figure 31 shows the average proportions of household incomes spent by households earning $100 thousand or less in metropolitan, other urban and rural places. Higher income households are not included because they skew the results and mask the trend for large majority of households.

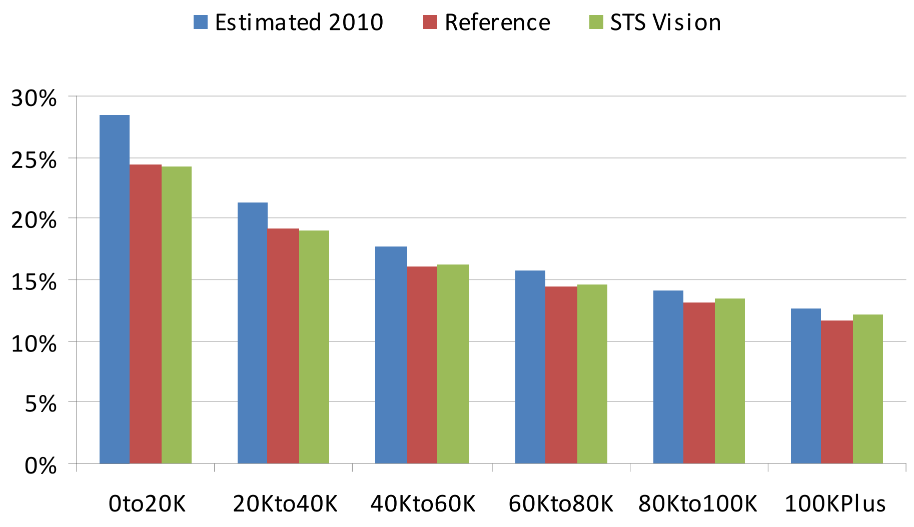

Figure 30. Average Annual Household Out-Of-Pocket Costs for Owning and Operating Vehicles as a Percentage of Household Income

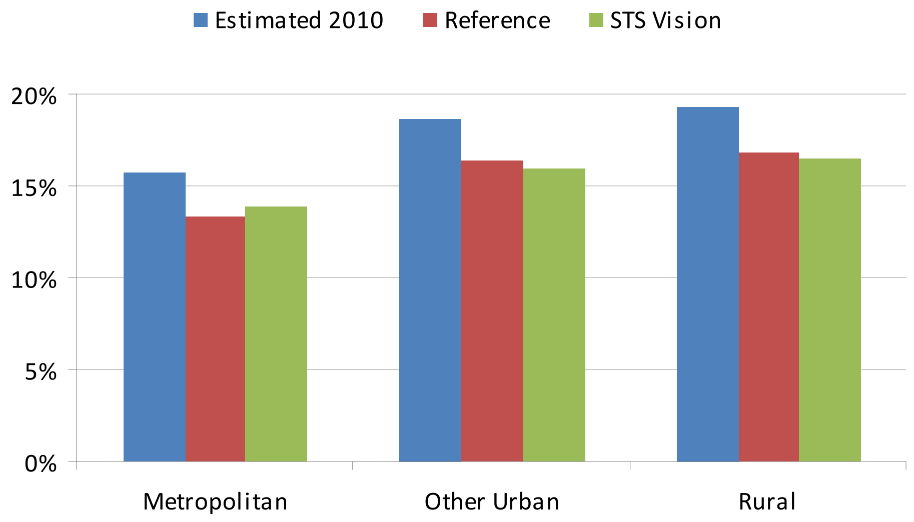

Figure 31. Average Annual Household Out-Of-Pocket Costs for Owning and Operating Vehicles by Type of Area as a Percentage of Household Income

In addition to reducing out-of-pocket household expenses for motor vehicle travel, the STS Vision reduces the cost of delay (light vehicle and truck) in metropolitan areas and other social costs (e.g. climate change, pollution, energy security, etc.). Figure 32 shows these costs on a per household basis. The estimated social costs for the STS Vision are less than half of current costs. Both delay and other social costs are reduced. Total costs go up for the Reference Case scenario even though other social costs decrease. That decrease is more than offset by increasing delay.

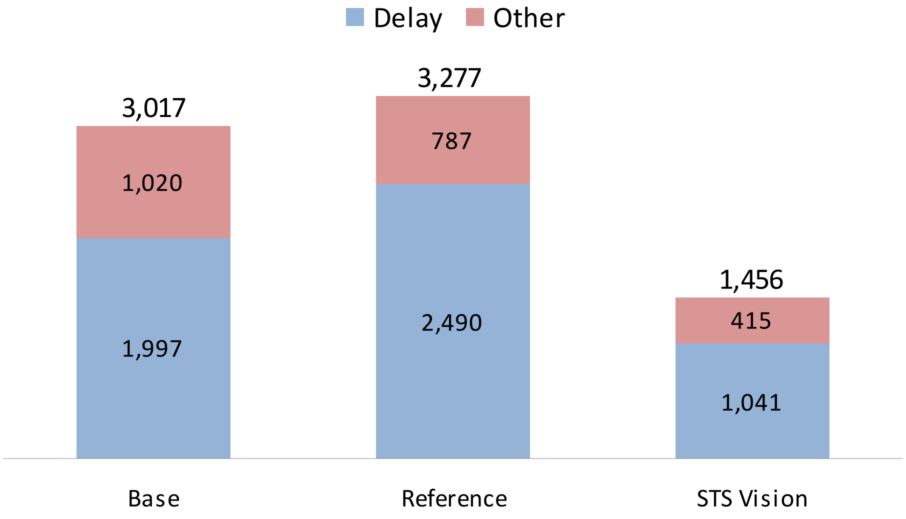

Figure 32. Delay and Other Social Costs per Household (2005 dollars)

Figure 33 provides a partial comparison of the estimated transportation revenues and transportation infrastructure costs for the STS Vision. Revenues and costs are shown in terms of annual averages per household. (The presentation as household averages is a convenience to allow the magnitude of the values to be compared with other quantities presented in this section. It is not meant to imply that all households will pay the amounts shown or that only households will pay.) The estimates only show the revenues from light duty vehicles and include the proportion of infrastructure costs attributable to passenger vehicle travel, and not the revenues or costs attributable to heavy duty trucks.

The revenue side of the picture is partial because it only includes the taxes and fees that were accounted for in the analysis, e.g., fuel, VMT, congestion, and parking. STS Vision taxes and fees are sufficient to address social costs exclusive of delay, but it should be noted that congestion pricing is included to address delay costs. The revenues also do not include taxes and fees levied to pay for public transportation (e.g., a payroll tax). The “Taxes and Fees” column also includes charges for parking, since they make up a substantial portion of the total transportation cost to metropolitan households. However, the amount of the parking revenue that would accrue to the public to pay for transportation services and facilities depends on how those parking charges are levied.

The transportation infrastructure side of the picture is also partial because it only includes the costs to construct and operate freeways, arterials and public transportation. Minor road costs, walkways and bikeways, and various other transportation program costs are not shown. A more complete enumeration of potential costs and revenues is outside the scope of this study, but will be done prior to selection or implementation of specific strategies and actions.

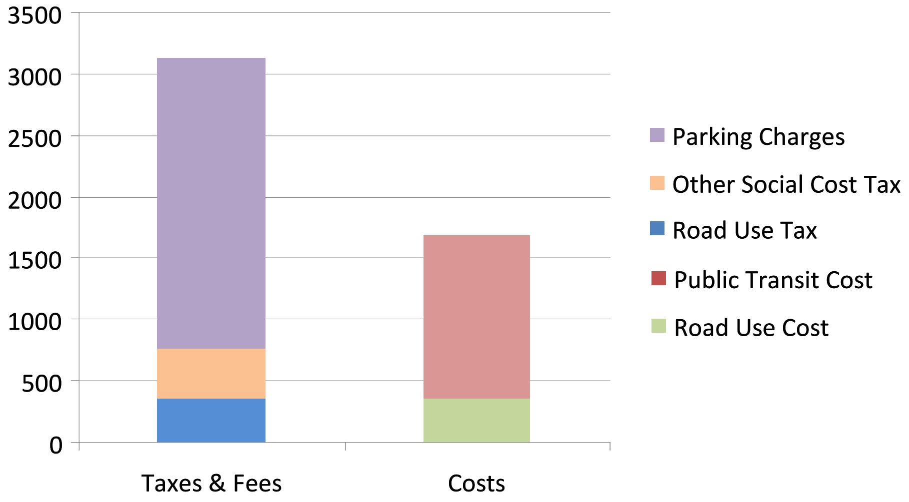

Figure 33. Partial Estimate of Transportation Revenues and Costs of STS Vision Calculated as an Annual Average Per Household (2005 dollars)

Land Use and Natural Resources

The amount of land consumed to accommodate development in urban and rural areas would increase about the same amount for both the STS Vision and the Reference Case (Figure 34). The effect of substantial population growth is moderated by limited expansion of urban growth boundaries. Compact metropolitan urban growth boundaries contribute to a significant increase in the percentage of people living in urban mixed-use neighborhoods (Figure 35) and reduction in residential water consumption (Figure 36).

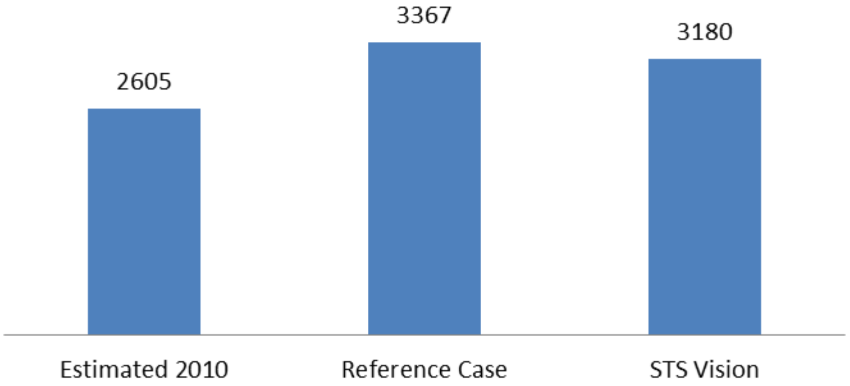

Figure 34. Urban and Rural Land Area Consumed By Development (square miles)

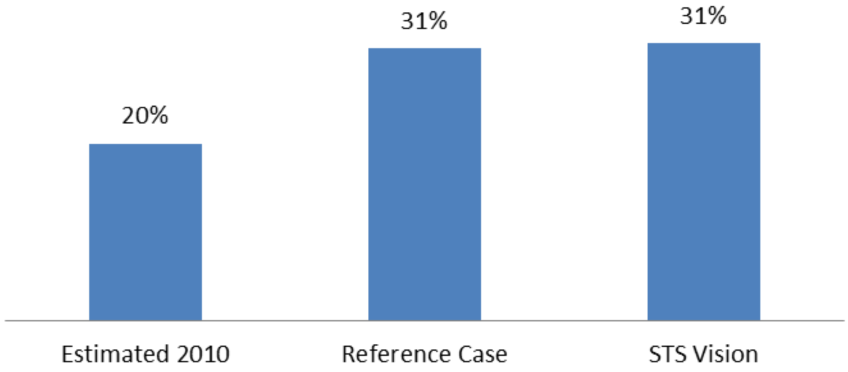

Figure 35. Percentage of Metropolitan Households Living in Urban Mixed-Use Neighborhoods

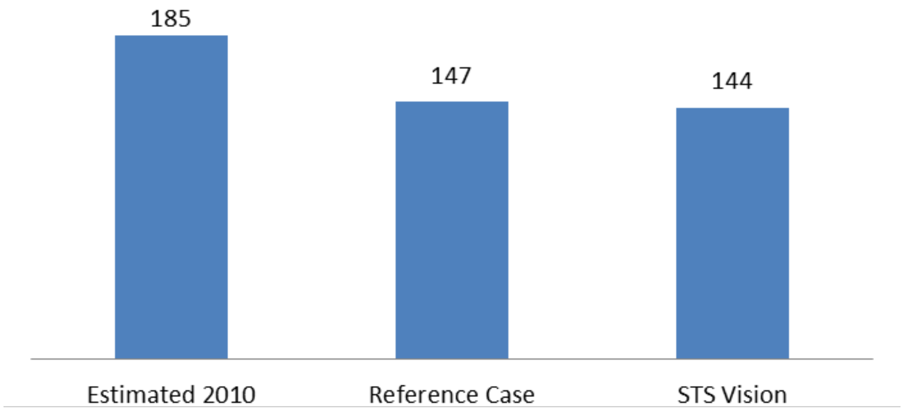

Figure 36. Metropolitan Per Capita Residential Water Consumption (gallons)

Public Health

The STS Vision is projected to decrease emissions of criteria air pollutants substantially (Figure 37). This is a consequence of reductions in VMT and substantial improvements in vehicle technology that reduce the use of hydrocarbon fuels. The STS Vision also contributes to improved public health by increasing the number of annual walking trips and annual biking miles (Figure 38). It should be noted that the walking trip estimates shown in the figure do not include walking to and from transit stops. Accounting for walk access to transit would substantially increase the future walk trips for the STS Vision. The mileage estimates in Figure 38 include travel by bicycles, electric bicycles, and other similar conveyances.

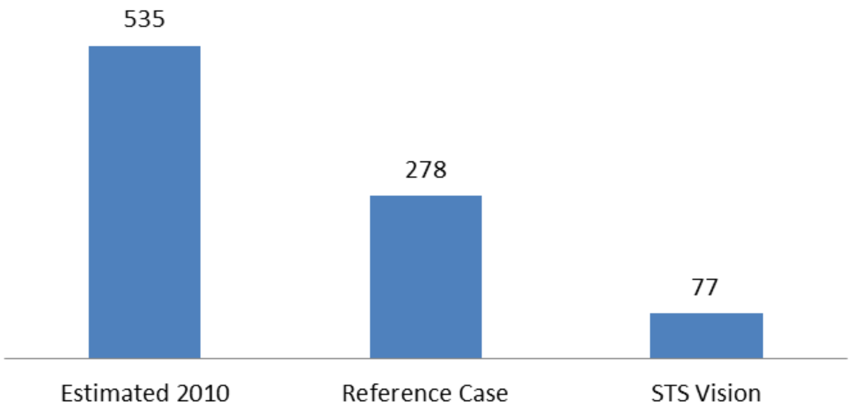

Figure 37. Metropolitan Criteria Air Pollutants (kilograms per day)

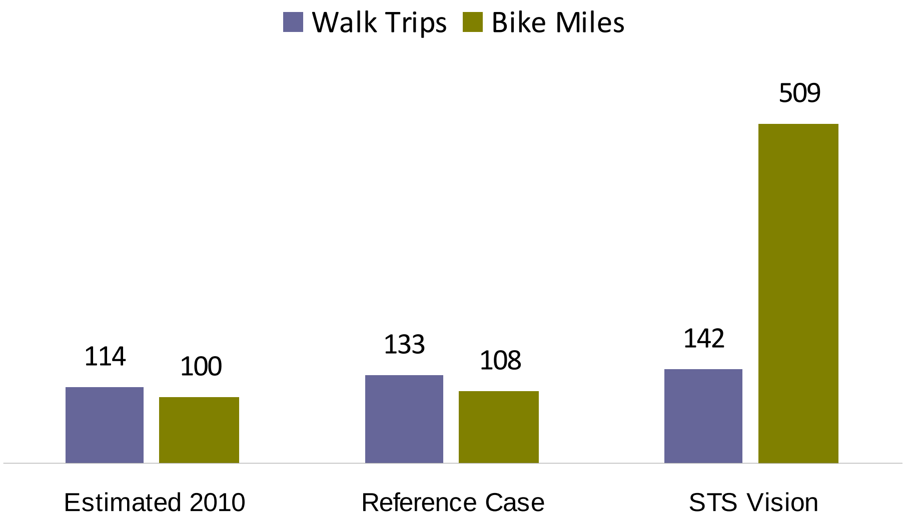

Figure 38. Average Annual Walk Trips and Bike Miles Per Capita

This summarizes the estimated performance of the envisioned strategy to meet the light vehicle 2050 GHG emission targets. Technical Appendix 5 discusses the challenges for achieving the vision. Technical Appendix 3 and Technical Appendix 4 continue with the presentation of the freight and air travel portions of the transportation sector's GHG emissions, respectively.

TECHNICAL APPENDIX 3

FREIGHT TRAVEL MARKET ANALYSIS METHODOLOGY

TECHNICAL APPENDIX 3

Freight Travel Market Analysis Methodology

Introduction

Technical Appendix 3 summarizes the assumptions, methods and process used to estimate potential GHG emissions reductions from the Freight travel market.

The GHG estimates reported in the Freight travel market were based on the scenario definitions developed by the Technical Advisory Committee and Policy Committee, and estimated using a combination of 1) extensive research on existing studies pertaining to Freight travel market emissions; 2) data provided by the FHWA FAF3 Model; 3) data provided by the ODOT SWIM2 Model; and 4) data provided by the ODOT GreenSTEP Model.

Technical Appendix 3 includes estimates of GHG reductions that represent the expected result of three sequential analysis frameworks: First, an initial set of potential strategy definitions developed by the STS advisory committees; second, a series of “combined” scenarios that include multiple GHG emissions reduction strategies; and third, the combined suite of Freight travel market elements that are included in the STS “Vision” scenario.

Initial Freight Market Evaluation Scenarios

The freight market GHG emissions analysis looked at potential GHG emissions reductions using a variety of scenarios based on groupings of complementary GHG emissions reduction strategies organized by “theme.” Four initial scenarios were developed to test projected emissions reduction potential. Each featured a 2050 horizon year. Several “combined” GHG emissions reduction scenarios were also analyzed, in which strategies from initial scenarios were combined with other potential actions and policies to achieve a greater level of GHG emissions reduction. See the “Combined Strategy Scenarios” section of Technical Appendix 3 for more information.

Reference Case

The Reference Case assumes that existing freight policies and technological trends continue into the future in a “business as usual” scenario. This scenario illustrates the potential freight GHG emissions if nothing more than anticipated is done. It is similar to the “Pessimistic Scenario” outlined in the *Oregon Freight Plan* regarding the level of economic activity anticipated in the future.

In terms of vehicle fuel economy, the following assumptions were made:

- Truck fuel economy per ton-mile improves by 12 percent, consistent with the US EPA's new rules for GHG and fuel economy standards for heavy duty trucks[31]
- Train fuel economy per ton-mile improves by about 5 percent[32]
- Marine vessel fuel economy per ton-mile improves by about 6 percent[33]
- Aircraft fuel economy per ton-mile improves by 10 percent, which is about half of the anticipated fuel economy benefit anticipated from widespread adoption of the most advanced aircraft documented in the *Oregon Freight Plan*[34]
- Table 10 in the methodology section summarizes the freight market GHG emissions rates for all scenario

The Reference Case also assumes that existing trends in mode shift continue into the future. Namely, the US Federal Highway Administration (FHWA) has documented a trend toward increasing ton-mileage shipped by truck and air modes over the past several decades.[35] Based on FHWA projections, this trend is expected to continue and has been accounted for in the Reference Case.[36]

System and Mode Optimization

As discussed above, the FHWA expects that the trend toward more truck and air freight shipping will continue into the future. Since truck and air freight are the two most carbon-intensive shipping modes, this trend erodes other gains made to reduce the GHG emissions of the freight market. The System and Mode Optimization scenario evaluates the potential GHG benefits if this trend toward more truck and air freight were not to occur. In addition, this scenario assumes that a variety of other actions take place to improve the overall efficiency of the freight market. Two levels of aggressiveness are considered with respect to potential mode shift patterns. The specific assumptions incorporated in the less aggressive and more aggressive versions of this scenario are as follows:

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[31] https://www.epa.gov/vehicles-and-engines#1-2

[32] https://www.eia.gov/analysis/projection-data.php#annualpro

[33] https://www.eia.gov/analysis/projection-data.php#annualpro

[34] https://www.oregon.gov/ODOT/Planning/Pages/Plans.aspx#OFP

[35] https://www.fhwa.dot.gov/environment/air_quality/publications/effects_of_freight_movement%20/chapter02.cfm

[36] https://ops.fhwa.dot.gov/freight/freight_analysis/faf/

- **Less aggressive assumption -** Current freight mode shares are maintained into the future
- **More aggressive assumption -** The share of rail shipment ton-miles doubles, resulting in a decrease in truck ton-mileage; air ton-mileage decreases by 30 percent

Both the less and more aggressive cases assume the following trends and changes, just to different degrees and rate of geographic or market coverage:

- Urban consolidation centers[37] are built in the Portland area
- Electric delivery vehicles are used for final distribution from urban consolidation centers
- More efficient land use patterns allowing closer proximity between buyers and sellers
- Urban bottleneck removal on Portland area freeways
- More efficient truck driving patterns (eco-driving) and lower truck highway speeds (50 miles per hour[38]) for greater fuel efficiency; better enforcement of truck speed limits

This scenario features the same assumptions about freight fuel economy as the Reference Case.

Vehicle and Fuel Technology

The Vehicle and Fuel Technology scenario assumes that substantial improvements are made to overall freight vehicle fuel economy. Specific assumptions are outlined below:

- **Less aggressive assumption -** The “best available” technologies outlined in Table 5.1 of the Oregon Freight Plan are adopted for all freight modes, producing between 20 and 25 percent improvements in fuel economy for each mode.
- **More aggressive assumption -** Vehicle and engine technologies allow for a 50 percent reduction in GHG emissions[39] for truck, train, and marine

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[37] An urban consolidation center is a type of warehouse, typically located at urban peripheries, at which common types of goods are stored for final delivery to an urban area. An example would be a consolidation center for groceries from which all grocery stores in an area would receive common deliveries, rather than each chain maintaining a separate distribution facility.

[38] A 50 mph speed limit represents the most GHG-efficient speed for the majority of current trucks. This speed will likely change over time as truck technology evolves.

modes. Examples from a literature review indicate that some of the following ideas would need to be employed to obtain a halving of GHG emissions per ton-mile:

- Hybrid powertrain technologies for trucks
- Liquefied natural gas (LNG) engines for trucks and marine vessels
- Diesel or LNG-electric traction[40] technology for trucks and marine vessels
- Trailer weight, braking, and handling improvements to allow for longer and heavier trailer combinations for trucks[41]
- Train car weight reduction (e.g., greater use of aluminum or other lightweight materials)
- Partial electrification of the freight rail network
- Aerodynamic improvements and lighter materials for aircraft[42]

Both the less and more aggressive cases assume the following changes:

- 30 percent reduction in fuel carbon content (consistent with Ground Passenger and Commercial Services travel market analysis)[43]
- Extensive deployment of idle reduction technologies for trucks, ships, and aircraft

Tolling and Pricing

Unlike the System and Mode Optimization scenario and the Vehicle and Fuel Technology scenarios, the Tolling and Pricing scenario does not directly reduce

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[39] As measured in grams of CO2 per ton-mile of freight shipped. Note that GHG efficiency gains can be made through engine efficiency improvements; more efficient trailer, vessel, airframe, or rail car design; or more efficient loading and logistic practices. This analysis did not explicitly model each of the above components since only the overall GHG efficiency per ton mile was modeled.

[40] Diesel/LNG-electric traction uses an internal combustion engine (ICE) or gas turbine engine to power a generation to supply electricity to electric drive motors.

[41] This measure is generally relevant for truck travel outside of Oregon since most other states do not allow for triple trailers.

[42] Aircraft efficiencies were assumed to improve by 35 percent, which is similar to the mid-range efficiency gains estimated in the air passenger market analysis.

[43] This fuel carbon content improvement can include gains from both renewable biofuels and lower-carbon conventional fuels like LNG.

freight market GHG emissions. Rather Tolling and Pricing is a tool to encourage widespread adoption of the actions and strategies that directly reduce emissions as outlined in the previous two scenarios.

The assumptions included in the Tolling and Pricing scenario are based on a similar scenario incorporated into the ground passenger market analysis. Specifically, Tolling and Pricing includes various fees and charges to ensure that the cost of freight shipments include the full monetized cost of the impacts of those shipments related to climate change and other environmental degradation. These are the impacts that would be caused by GHG emissions, motor vehicle collisions, climate change, air pollution, consumption of other environmental resources, and transportation system congestion. Some of the specific fees/charges are described below:[44]

- **Less aggressive assumption** - carbon fee of $50 per metric ton
- **More aggressive assumption** - carbon fee of $100 per metric ton
- Both the less and more aggressive cases assume the following charges as well:
- Energy security fee equivalent to $44 per metric ton of carbon
- Air pollution, other environmental resources, crashes, and noise impact fees equivalent to $33 per metric ton of carbon for truck and train modes[45]
- Metropolitan area congestion pricing consistent with ground passenger scenario

While not explicitly modeled, it was assumed that Oregon would continue to assess its weight-mileage fee for trucks to account for transportation system maintenance and preservation costs. Since this fee is assessed under the Reference Case, no changes were made for the Tolling and Pricing scenario. The fees listed in the bullets above were assumed to be applied above and beyond the existing weight-mileage fee for trucks.

As described in the methodology section, the Tolling and Pricing scenario assumes that some level of mode shift occurs between truck and train modes. This shift in mode is based largely on existing commodity proportions by type,

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[44] All of the cost/fee levels are based on the Costs of Motor Vehicle Travel white paper prepared for the ground passenger market analysis by Cambridge Systematics. This paper includes explicit cost/eternality estimates for trucks. The externality costs for other modes are based on the costs for all other externalities relative to carbon.

[45] Given the long distances of travel at high altitude or across the open ocean for air and marine freight modes, respectively, there is insufficient information to calculate an equitable externality fee for these modes.

and mode and price elasticities, documented in several academic articles. In addition, about half the GHG emissions reduction benefits identified in the Vehicle and Fuel Technology scenario are assumed to be a response to higher vehicle operating costs.

1990 and 2007 Scenarios

Freight travel market analysis results for 1990 and 2007 conditions were also estimated to help compare the results of the 2050 scenarios described above, The 1990 scenario was selected since the GHG emissions reductions for the 2050 scenarios are based on 1990 emissions levels. The 2007 scenario is based on the most recent freight movement inventory conducted by the FHWA.[46] Given the recessionary environment since 2008, the 2007 scenario was assumed a reasonable representation of existing conditions in early 2012.

The GHG emissions factors for both of the 1990 and 2007 scenarios are based on data contained in the *Oregon Freight Plan*. Additional information about how the performance measures were calculated for these two scenarios is contained in the General Methodology section of this appendix in the following pages.

Combined Strategy Scenarios

As described earlier, elements of the four basic 2050 analysis scenarios (Reference Case, System and Mode Optimization, Vehicle and Fuel Technology, and Tolling and Pricing) were combined to develop four additional GHG emissions reduction strategies. The assumptions incorporated into each of these combined scenarios are described in this section.

Changing Import Patterns

This scenario features elements of the System and Mode Optimization and Tolling and Pricing scenarios. Key assumptions driving this scenario are:

- The tonnage of foreign imported goods and commodities into Oregon decreases by 50 percent when compared to the Reference Case; the equivalent tonnage of goods is assumed to be domestically sourced from suppliers within and outside of Oregon based on the existing proportion of in-state versus out-of-state ton mileage

- The average distance of domestic interstate imports decreases by 50 percent (e.g., ton-mileage decreases by half)

In order to induce this shift in import patterns, it is assumed that price signals must be given to consumers of goods and commodities. Therefore, full cost

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[46] https://ops.fhwa.dot.gov/freight/freight_analysis/faf/

pricing (as described in the Tolling and Pricing scenario) is also incorporated into this scenario.[47]

Different Economy

A key feature of this scenario is the assumption that Oregon's economy will be focused on higher value goods and services than today. Table 7 shows the annual dollar value of goods shipped to, from and within Oregon, subtotaled by commodity groups under the 2007, Reference Case, and Different Economy scenarios.

As shown in Table 7, the Reference Case assumes that all sectors of the economy grow at the same rate relative to 2007 conditions, reflecting the continuation of typical trends under this scenario. In contrast, the Different Economy scenario assumes total economic value growth remains identical to the Reference Case, but that there is uneven growth among economic sectors. In the Different Economy scenario, all sectors except fuel experience growth over 2007 conditions, although growth in the agricultural and resource extraction sectors is lower than was assumed under the Reference Case. The lower (or negative in the case of fuel) growth reflects the following assumptions:

- Reduced demand for fuels (particularly coal) is based on the assumption that light-duty vehicle engine technology and electricity generation will be less focused on non-renewable fossil fuels. This assumption is consistent with the ground passenger market analysis.[48]

- Transition of economic activity from lower value-density goods such as logging and mining, to higher value-density goods such as electronics and consumer products.[49]

Acknowledgement that agricultural and resource extraction activities may not be sustainable at the levels suggested under the Reference Case (e.g., there is a finite amount of farm and forest land).

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[47] Note that there is very little data related to how externality costs impact import or export patterns across different commodity groups and long periods of time. This scenario does not presuppose that the full externality fees incorporated in the Tolling and Pricing scenario would cause the changed import/export pattern it suggests, but is illustrative of the GHG emissions benefits of a major shift in import and export patterns.

[48] This scenario still assumes substantial fuel imports, reflecting the fact that fossil fuels will continue to be an important part of the energy mix into the future.

[49] Value density is a common measure in the freight industry. Value density represents the dollar value per weight of goods shipped. Heavy, high value goods like electronics have high value densities while lighter commodities like wood chips have low value densities.

Table 7. Annual Value of Goods Moves in Oregon, by Commodity Group

Commodity Group	2007 Scenario	Reference Case		Different Economy Scenario	
		Value	Change from 2007	Value	Change from 2007
Agricultural	$14.3	$22.9	60%	$15.8	11%
Resource Extraction	$21.2	$33.9	60%	$22.7	8%
Foods	$19.6	$31.4	60%	$31.4	60%
Fuels	$17.0	$27.2	60%	$14.7	-13%
Basic Manufactured Goods	$35.7	$57.3	60%	$52.9	48%
Advanced Manufactured Goods	$79.9	$128.0	60%	$158.7	99%
Consumer Goods	$24.9	$39.9	60%	$42.6	71%
Waste/Other	$23.4	$37.6	60%	$37.6	60%

Note: [a] Constant 2007 dollars, rounded
Source: FHWA FAF3; Fehr and Peers, 2012

As was the case with the Changing Import Patterns scenario, this scenario includes that full cost pricing is adopted, along with the associated changes in freight mode and vehicle technology described in the Tolling and Pricing scenario.

Aggressive Technology and Pricing

This scenario pushes the gains in vehicle and fuel technology significantly farther than assumed under the Vehicle and Fuel Technology scenario. In this case the following changes are assumed in addition to what was previously listed under the Vehicle and Fuel Technology Scenario:

- 30 percent reduction in fuel carbon content
- Full rail system electrification
- Use of zero-carbon electricity for rail and pipeline transportation

In association with the more aggressive assumptions about improved vehicle and fuel technology, higher fees and shifts in economic output (as described in the Different Economy scenario) are also assumed. A carbon fee is set at $100 per ton, which spurs additional mode shift and land use pattern changes that contribute to lower GHG emissions rates.

High Effectiveness

The High Effectiveness scenario combines the most effective GHG reduction strategies from the scenarios listed previously. Specifically, this scenario assumes the changed import patterns, economic growth that favors the highest value-density sectors, the most aggressive vehicle and fuel technology improvements, and higher fees, as described previously. This scenario represents the maximum GHG reduction potential from the freight market barring the adoption of some revolutionary manufacturing technology such as localized 3D printing or other micro-scale personal manufacturing techniques.

Analysis Approach

This section describes the performance measures and analysis methodology used for the freight market analysis.

Performance Measures

The key performance measures developed to support the freight market analysis process are:

- **GHG emissions** – based on the freight market emissions rates shown in Table 10. The GHG emissions rates are based on the data published in the *Oregon Freight Plan*, with modifications to account for more aggressive adoption of vehicle and fuel technologies for some of the scenarios.

- **External social costs** – based on the findings of the *Costs of Motor Vehicle Travel* white paper prepared by Cambridge Systematics. as in the Ground Passenger and Commercial Services travel market. For non-truck modes, externality costs documented in the white paper were converted to costs per ton-mile for each mode based on the relative energy/fuel efficiency of each mode.

  Beyond GHG emission costs, no other externality costs were applied to air and marine modes. Insufficient information exists regarding how those costs should be allocated given the long stretches of travel through unpopulated areas for air and marine freight.

- **Total shipping costs as a proportion of the value of goods shipped** – based on detailed information regarding the costs of truck shipments per ton-mile.[50] Truck cost data includes information on fuel, purchase/lease payments, maintenance, tires, tolls, permits/fees, wages, and benefits. Research into the costs of other freight modes revealed little

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[50] *An Analysis of the Operational Costs of Trucking: A 2011 Update*, American Transportation Research Institute, June 2011.

available data. However, several sources described relative costs per ton-mile for the major modes (marine, rail, truck, and air). These relative cost differences[51] were applied to the calculated truck costs per ton-mile to estimate total shipping costs for all modes. These shipping costs were then divided by the total value of goods shipped to develop this performance measure.

- **Full cost user fees as a proportion of the value of goods shipped** – based on the *Costs of Motor Vehicle Travel* white paper described above. The new user fees (based on full cost pricing) described above are set to equal the external social costs described above.

- **Air pollution costs** - calculated based on the data in the *Costs of Motor Vehicle Travel* white paper. These are annual costs and are calculated for both truck and train modes for all domestic freight movements associated with shipping goods to Oregon. Cost data consider national health impact costs and are not isolated to Oregon residents.

General Methodology

The general analysis methodology is summarized in the following flowchart (Figure 39). A more detailed description of some of the data sources and analysis methods is presented following Figure 39.

Data Sources

The freight market analysis primarily relies on data from FHWA's FAF3 and data obtained from ODOT's SWIM2 results produced for the Oregon Freight Plan. These two data sources provided relationships between population, income, and ton-miles for 42 different classes of commodity flows. The bulk of this information is from the FAF3 dataset, which provides estimates of shipment by value, weight, and mode.

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[51] Rodrigue and Comtois, *The Geography of Transport Systems – Chapter 7 Transport Costs and Rates*, https://transportgeography.org/?page_id=5268

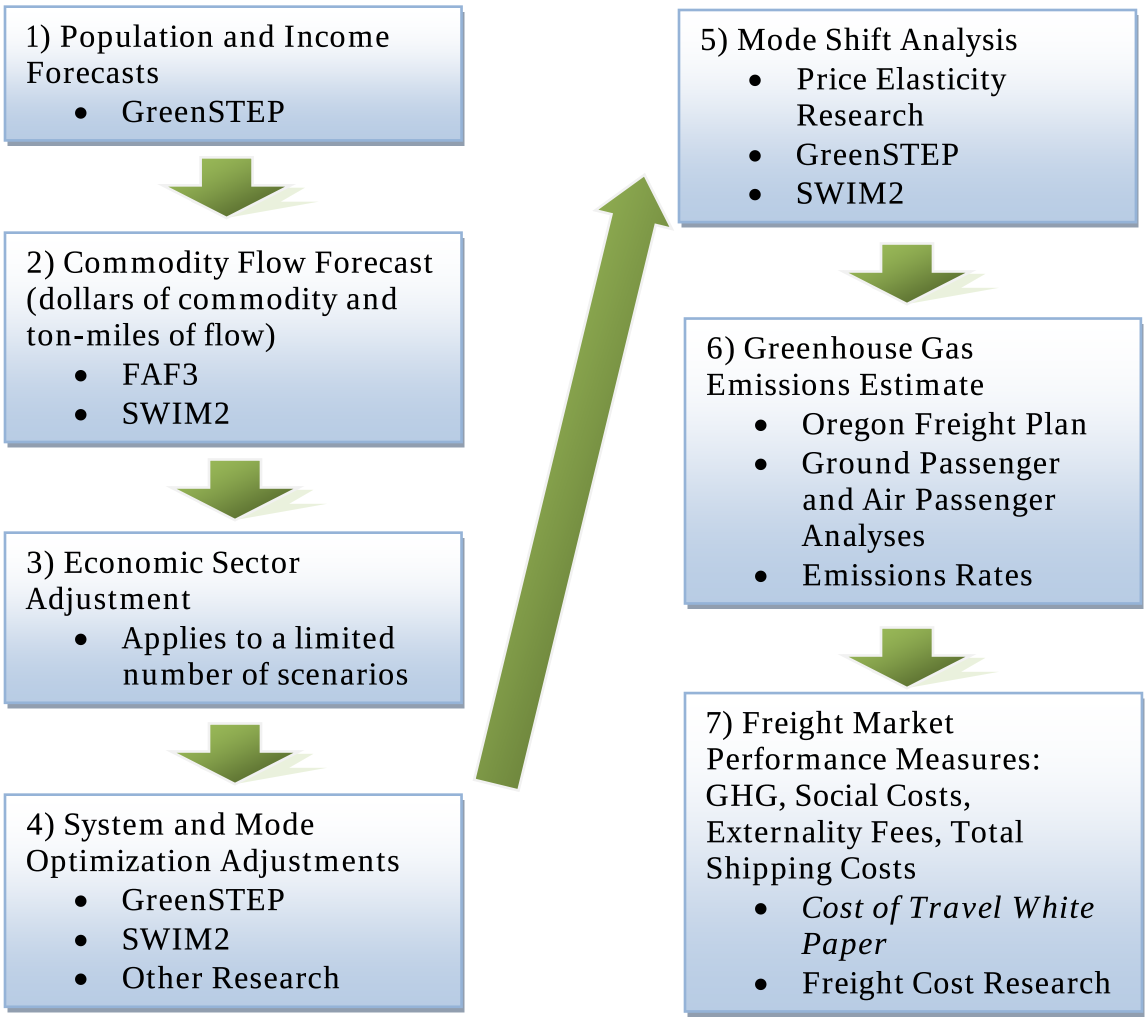


Figure 39. Freight Travel Market General Analysis Methodology

FAF3 Projections

The FAF3 dataset estimates commodity movements by all freight modes at a fairly aggregate level. The FAF3 database contains 163 zones across the country, as shown in Figure 40.

Source: http://cta.ornl.gov/cta/One_Pagers/FAF3.pdf

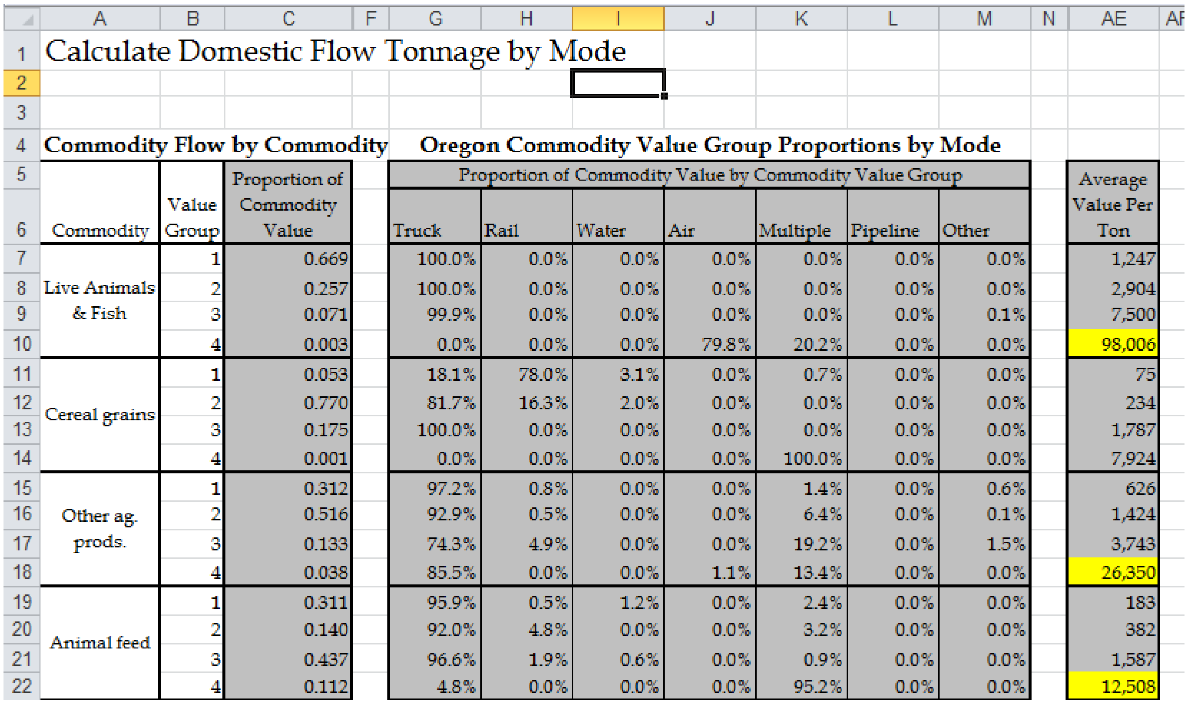
Figure 40. FAF3 Zones

FAF3 is a database of regional freight flows by value and weight for all domestic, export, and import shipments, and includes a 30 years forecast in five year increments out to 2040. The database also includes an assignment of the average number of trucks to individual highway segments on the national network. The FAF3 framework derives from multiple data sources, which include:

- Commodity Flow Survey (CFS)
- TransBorder Freight Data
- Foreign Trade Statistics
- Waterborne Commerce Statistics
- Port Import/Export Reporting Service (PIERS)
- Vehicle Inventory and Use Survey
- Highway Performance Monitoring System
- National Transportation Atlas Database
- Transportation Satellite Accounts

Three macro-level distributions were reviewed for the purposes of this analysis. The first distribution plotted each commodity for the entire FAF3 dataset, or within, inbound, and outbound shipments (foreign and domestic). A second distribution plotted origins / destinations in West Coast states. The third distribution plotted the FAF3 flows that have origins / destinations in Oregon. Results of this process concluded that value densities vary much more between modes than between distances. Therefore, distance is not as critical in mode choice. Instead, the *value density* of goods determines what modes can be afforded, and in turn affects the distances that products can be shipped and the geographic size of markets.

A method was developed to estimate domestic commodity flows by tonnage and mode using the FAF3 data sources. A simple spreadsheet model was created which presents the data by commodity value, domestic mode tons, import mode tons, and export mode tons. A portion this model is shown in Figure 41.



Calculate Domestic Flow Tonnage by Mode

Commodity Flow by Commodity **Oregon Commodity Value Group Proportions by Mode**

Commodity	Value Group	Proportion of Commodity Value	Truck	Rail	Water	Air	Multiple	Pipeline	Other	Average Value Per Ton
			Proportion of Commodity Value by Commodity Value Group							
Live Animals & Fish	1	0.669	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1,247
	2	0.257	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2,904
	3	0.071	99.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	7,500
	4	0.003	0.0%	0.0%	0.0%	79.8%	20.2%	0.0%	0.0%	98,006
Cereal grains	1	0.053	18.1%	78.0%	3.1%	0.0%	0.7%	0.0%	0.0%	75
	2	0.770	81.7%	16.3%	2.0%	0.0%	0.0%	0.0%	0.0%	234
	3	0.175	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1,787
	4	0.001	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	7,924
Other ag. prods.	1	0.312	97.2%	0.8%	0.0%	0.0%	1.4%	0.0%	0.6%	626
	2	0.516	92.9%	0.5%	0.0%	0.0%	6.4%	0.0%	0.1%	1,424
	3	0.133	74.3%	4.9%	0.0%	0.0%	19.2%	0.0%	1.5%	3,743
	4	0.038	85.5%	0.0%	0.0%	1.1%	13.4%	0.0%	0.0%	26,350
Animal feed	1	0.311	95.9%	0.5%	1.2%	0.0%	2.4%	0.0%	0.0%	183
	2	0.140	92.0%	4.8%	0.0%	0.0%	3.2%	0.0%	0.0%	382
	3	0.437	96.6%	1.9%	0.6%	0.0%	0.9%	0.0%	0.0%	1,587
	4	0.112	4.8%	0.0%	0.0%	0.0%	95.2%	0.0%	0.0%	12,508

Figure 41. Commodity Flow Mode Allocation Model

The model calculated the split of commodities in each value group by mode, then computed the tons of flow by applying the average value per ton by commodity to the individual value split. The “multiple” mode was reallocated across truck, rail, water, and air using value breaks and existing proportions. If the average value per ton was greater than or equal to 10,000, that commodity value group was shifted solely to air. If under 10,000, the value group was dispersed across truck, rail, and water, based on existing proportions. The “other” mode was reallocated using a similar methodology and distributed across truck, rail, and water. Once the data was converted to tons of flow and the “multiple” mode was reallocated, the total tonnage by mode was distributed by “direction.” Direction of flows equates to the total tonnage shipped within Oregon, to Oregon, and from Oregon, as seen below. Once disaggregated by direction, the commodity flows can be grouped within mileage bin data for GHG emissions evaluation. Table 8 shows the total ton flows by mode and direction for 2007 conditions. For comparison, Table 9 shows the same data for the 2050 Reference Case.

Table 8. Total Ton Flows by Mode and Direction: 2007

	Total Ton Flows by Mode and Direction (000s)				
Direction	**Truck**	**Rail**	**Water**	**Air**	**Total**
Within Oregon	162,159	541	3,187	139	166,027
Proportion	97.7%	0.3%	1.9%	0.1%	100.0%
External to Oregon	27,008	15,562	265	252	43,086
Proportion	62.7%	36.1%	0.6%	0.6%	100.0%
Oregon to External	35,000	5,257	171	190	40,618
Proportion	86.2%	12.9%	0.4%	0.5%	100.0%
Total	224,167	21,360	3,623	581	249,731
Proportion	89.8%	8.6%	1.5%	0.2%	100.0%

Table 9. Total Ton Flows by Mode and Direction: 2050 Reference Case

	Total Ton Flows by Mode and Direction (000s)				
Direction	**Truck**	**Rail**	**Water**	**Air**	**Total**
Within Oregon	397,040	1,038	5,258	282	403,618
Proportion	98.4%	0.3%	1.3%	0.1%	100.0%
External to Oregon	66,119	29,875	436	1,115	97,545
Proportion	67.8%	30.6%	0.4%	1.1%	100.0%
Oregon to External	85,682	10,092	283	840	96,897
Proportion	88.4%	10.4%	0.3%	0.9%	100.0%
Total	548,840	41,005	5,977	2,237	598,060
Proportion	91.8%	6.9%	1.0%	0.4%	100.0%

To estimate ton-miles, the FAF3 trip length distributions were applied to the total ton flows by mode and direction. Note that FAF3 does not provide an accurate measure of trip lengths within the state of Oregon. To estimate the in-state flows (which make up a substantial portion of overall ton-flows), SWIM2 model results from the Oregon Freight Plan were used. Since the SWIM2 model does not explicitly estimate trip lengths for modes not using the highway system, the SWIM2 distribution was modified by ODOT staff to reflect trip lengths for the other (non-truck) modes within the state.

Projecting the Rate of Growth in Freight Ton-Miles

This section describes the method used to predict the total growth in freight ton-miles in 2050.

Income and Population Data

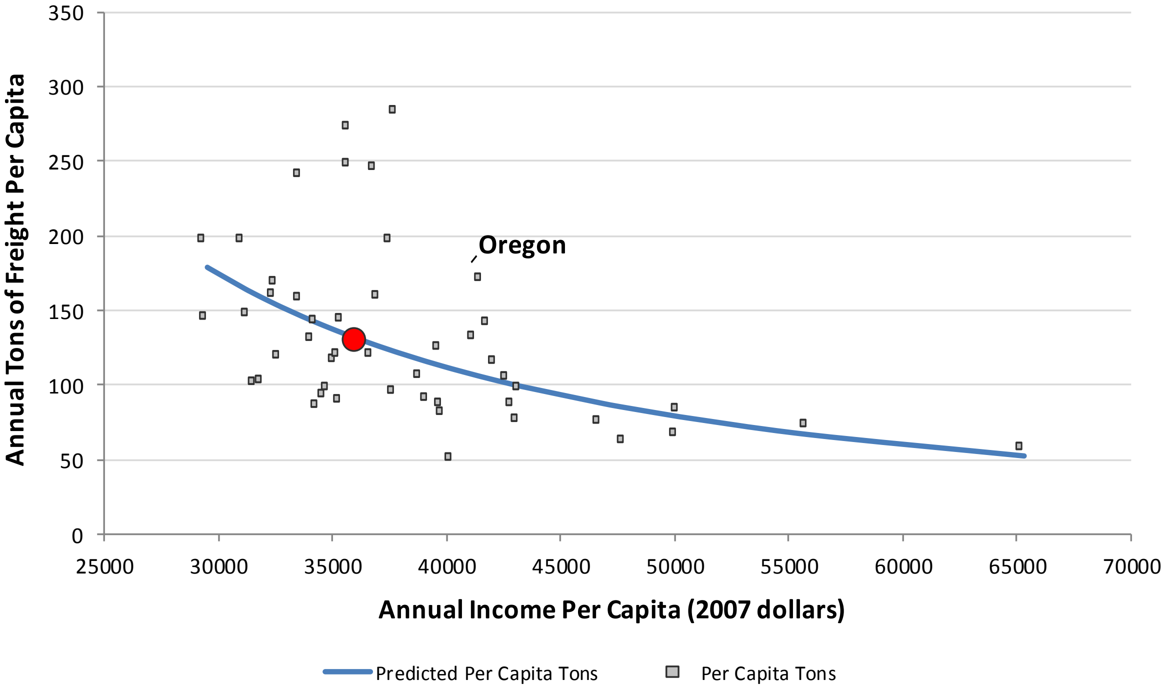
For information on underlying income and population forecasts, see Technical Appendix 1.

Freight Ton-Mile Forecasts

Two methods were used to estimate 2050 freight ton-miles. The first assumed that future freight demand will remain constant on a “per dollar” level. This means that as a household’s income rises, the level of freight generated (or consumed) per household also rises.

An alternative approach assumed that freight demand remains constant on a “per capita” basis. In other words, the level of freight generation remains constant relative to population, regardless of household income. This constant per capita freight generation is consistent with the FHWA’s future FAF3 total ton flow projections.

Arguments can be made for both methods; however, the “per capita” method used by the FHWA may be more reasonable. The graph shown in Figure 42 highlights the relationship between per capita income and per capita freight tonnage shipped by state. The graph shows that as incomes rise, the level of freight tonnage per capita tends to decrease somewhat. While FHWA does not explain this relationship, it is likely due to the shift toward higher paying service and high-tech manufacturing jobs that generate higher value goods requiring lower tonnage moved than lower paying resource extraction jobs. Based on the research above, only the “per capita” FHWA scenario is presented.



Notes: Total tons of freight with origin or destination in state (and District of Columbia). Wyoming and North Dakota not shown because they have atypically high freight tonnage. Sources: FHWA FAF3 database & BEA regional accounts data.

Figure 42. Relationship Between Freight Movement (tons) and Per Capita Income (2007)

Predicting the Mode Shift Impacts of Tolling and Pricing

As described earlier, the Tolling and Pricing scenario represents a set of policy options that could encourage faster or more widespread adoption of the actions and strategies outlined in the System and Mode Optimization and the Vehicle and Fuel Technology scenarios. The Tolling and Pricing scenario assumes that some level of mode shift occurs between truck and train modes. This shift is based largely on the existing commodity proportions by type and mode and price elasticities documented in several academic articles. A literature review provided significant data on truck and rail operating costs, yet the data was too disaggregated to allow application to statewide, national and international mode shifts. Still, applicable data on elasticities of truck and rail demand was available from the following sources:

- *Transportation Elasticities, How Prices and Other Factors Affect Travel Behavior*, Litman, Todd; Victoria Transport Policy Institute, 21 July 2011.

- *Port and Modal Elasticity Study, Phase II*, Leachman, Robert, Leachman and Associates LLC, September 14, 2010.

- *The Response of Railroad and Truck Freight Shipments to Optimal Excess Capacity Subsidies and Externality Taxes, An Empirical Study of Florida's Surface Freight Transportation Market,* University of Florida; BEBR, September 30, 2002.

- *Analysis of Freight Movement Mode Choice Factors,* CUTR; Florida Department of Transportation in association with the University of Florida, 2003.

- *Characteristics and Changes in Freight Transportation Demand,* Rail/Truck Modal Diversion; Cambridge Systematics, 1997.

Results of the literature review tended to be inconclusive, dated, too case-specific or otherwise inapplicable to the needs of this project. Although the literature provided a range of elasticities for specific commodity groups, a transferrable price elasticity model was not available for this project. However, the Florida Department of Transportation study presented an approach to identifying the commodities most likely to shift modes, based on the observation that commodities that are currently split among two or more modes are more susceptible to modal shift in response to changing modal shipping prices. This mode shift susceptibility approach provided the foundation for the analysis of mode shift impacts used in the freight market GHG emissions analysis.

To predict the mode shift impacts of tolling and pricing, a simple logic model was developed that estimates commodities eligible for modal shift due to a change in shipping cost.[52] Existing modal splits were reviewed by commodity to determine the sensitivity of each to a potential train-rail modal shift. All commodities with a 90 percent or less mode share in one mode were considered "elastic," and therefore eligible for modal split. This categorization resulted in 34 percent of total freight tonnage being considered eligible for modal shift. The most elastic commodities include cereal grains, gravel, non-metallic minerals, basic chemicals, fertilizers, and wood products.

Once eligible commodities were identified, mode cross-price elasticities were applied to each to reallocate tonnage between truck and train modes. As noted above, literature contains a wide variety of rail-train cross-price elasticities. The elasticity range varies from near zero (inelastic to price) to well over 5.0[53] (highly elastic). Literature indicated that the least elastic goods are those that tend to be shipped primarily by a single mode, while more elastic goods can shift between modes easily. Commodities such as coal are inelastic because they are shipped in large quantities over long distances and will tend to continue being transported

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[52] In this case, the commodities referred to are the 42 FAF3 commodity groups split by four value-density categories for a total of 168 commodity flows.

[53] A cross-price elasticity of 5.0 indicates for that every one percent increase in truck travel prices, 5 ton-miles of goods shift to rail transportation.

by train. Additionally, highly perishable goods are inelastic because trucks typically represent the most efficient way to move such goods (except over very long distances when air freight becomes more efficient).

When applying the cross-price elasticities as part of the Tolling and Pricing scenario analysis, relatively high elasticities were selected (3.0 for the "less aggressive" analysis assumptions, and 5.0 for the "more aggressive" analysis assumptions), since the commodity groups had already been split such that inelastic commodities would not be subject to modal shift. Note that the mode shift elasticities were only applied to freight shipments between Oregon and other states. All the literature indicated that the relatively short freight trips within Oregon are generally not subject to mode shift.

Estimating the Costs of Travel for the Freight Market

The costs of shipping are an important factor when considering cross-price elasticities, and cost as a proportion of total freight value is a key performance measure.

Direct costs to the trucking sector are well publicized. The American Transportation Research Institute recently published a study on the costs of trucking indicating that truck operating costs are approximately $1.41 per mile, composed of: $0.465 per mile for fuel, $0.48 per mile in maintenance and lease costs, and $0.546 in wages and benefits.[54] Using this information and FAF3 ton-mileage results, a truck shipping cost of $0.31 per ton-mile was estimated and checked against other sources to verify reasonability. Anticipated increases in fuel costs would raise shipping costs to $0.45 per ton-mile by 2050.

Limited data exists on the costs of other freight modes. However, a study by Rodrigue and Comtois documented estimated relative costs of other modes to trucks.[55] Based on this research, the average per ton-mile costs of shipping by mode is assumed as follows:

- $0.009 – marine
- $0.03 – rail
- $0.31 – truck
- $0.73 – air

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[54] *An Analysis of the Operational Costs of Trucking: A 2011 Update*, American Transportation Research Institute, June 2011.

[55] Rodrigue and Comtois, *The Geography of Transport Systems – Chapter 7 Transport Costs and Rates*, https://transportgeography.org/?page_id=5268

Predicting the Impacts of Land Use Changes on the Freight Market

This section describes the methodology to account for land use changes related to freight market GHG emissions.

Urban Consolidation Centers

To model the impacts of urban consolidation centers, research was used to determine the commodity types most likely to use an urban consolidation center. These included finished consumer goods and foods.[56] The FAF3 data was reviewed, and eligible commodity groups (including alcohol, electronics, furniture, miscellaneous manufacturing products, and printed goods) were selected. For each commodity group, FAF3 and SWIM2 data was applied to estimate total ton-miles shipped within the Portland Metro area.

Other regional centers in the state appear to be too small for urban consolidation centers to be cost effective. For the Portland Metro region, it was assumed that 50 miles of the total shipment of the eligible commodities would occur between the consolidation center(s) and final local destinations or sources, and that such local mileage would occur by electric delivery vehicles by 2050. This 50-mile local pickup/delivery leg was assigned a GHG emissions factor associated with the lower carbon-intensity of electricity and the higher efficiency of electric motors.

Other Land Use Effects

In addition to urban consolidation centers, it was assumed that as freight shipping costs increase, some buyers and sellers shift their purchasing patterns to reduce shipping costs. Based on analysis from the SWIM2 model, this is expected to result in a reduction of 1.5 percent of overall statewide truck ton-miles.

Base GHG Emissions Rates

Base GHG emissions rates were obtained from the Oregon Freight Plan and modified by the level of vehicle and fuel technology gains assumed for each scenario. Table 10 summarizes the rates.

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[56] *Urban Freight Consolidation Centers*, Browne, et.al. Transport Studies Group, University of Westminster, 2005.

Table 10. GHG Emissions Rate by Analysis Scenario (grams per ton-mile)

Scenario	Truck	Rail	Marine	Air	Pipeline
1990 and 2007 Scenarios	313	28	24	1,472	35
Reference Case and System and Mode Optimization	275	27	23	1,325	35
Vehicle and Fuel Technology	155 - 125	18 - 11	15 - 11	942 - 765	28 - 14
Tolling and Pricing, Different Economy, Changing Import Patterns	200	19	16	1,045	25
Vision Scenario (similar to the "High Effectiveness" scenario)	125	11	11	765	14
Aggressive Pricing and Vehicle Technology and Maximum Reduction	113	0	11	689	0

Results

The analysis resulted in an estimated GHG reduction potential for each of the individual and combined scenario cases. Results are also presented for a "Vision Scenario" that assumes a level of aggressiveness in the freight analysis that is somewhat less than the "High Effectiveness" scenario, but that is most consistent with the maximum level of aggressiveness used in the Ground Passenger and Commercial Services and Air Passenger travel market analyses (see Technical Appendix 2 and Technical Appendix 4). The elements and recommendations of the Vision Scenario were selected based on the input of the Technical Advisory and Policy Committees for inclusion in the final STS. The Vision Scenario results also include information related to non-GHG performance measures.

Performance of Initial Strategy Scenarios

Figure 43 summarizes the results of the GHG emissions analysis relative to 1990 conditions. In addition, the results of the 2007 scenario are presented as another point of reference. In this figure, the zero percent change line represents 1990 conditions; thus, a 100% change indicates a doubling of 1990 emission levels.

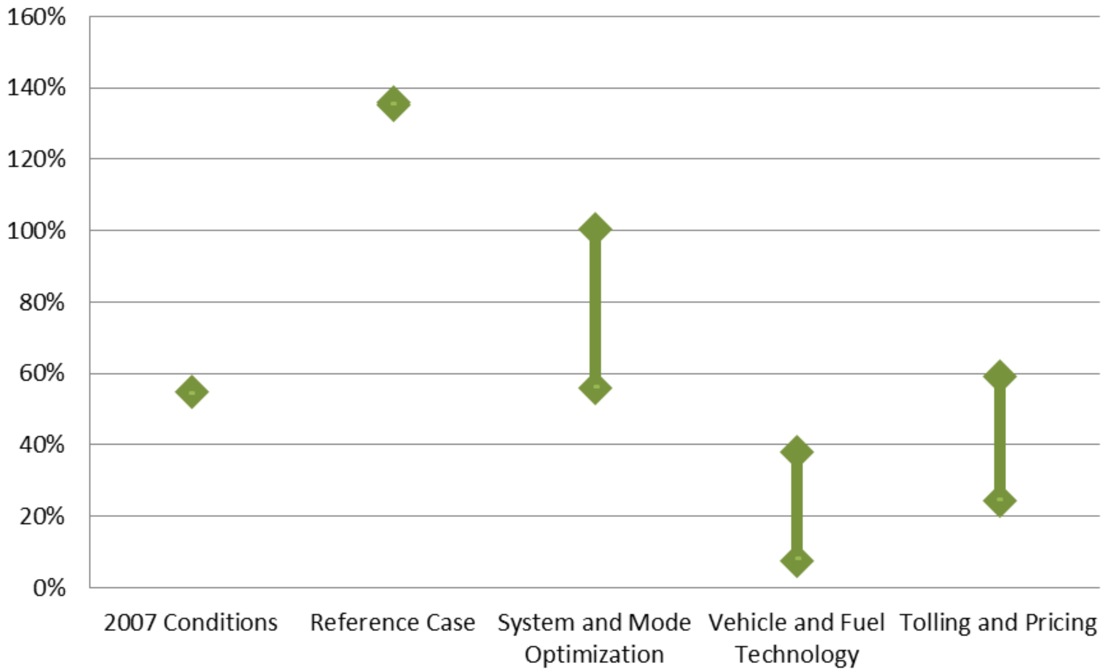

Figure 43. Percent Change in Total Freight GHG Emissions Relative to 1990 Conditions

As indicated in Figure 43, freight GHG emissions in the Reference Case are forecast to increase by 136 percent over 1990 levels, e.g., well more than double 1990 levels. This increase is put into better context by considering the anticipated future growth in other descriptors of overall freight activity. For example, relative to 1990 conditions, the Reference Case anticipates these changes:

- Total Freight ton-miles increase 134 percent
- Truck ton-miles increase 152 percent
- Air ton-miles increase up to 294 percent
- Population increases by 109 percent
- Aggregate statewide income increases by 74 percent

As also shown in Figure 43, the various GHG emissions reduction scenarios substantially reduce freight GHG emissions below the Reference Case, particularly when considering the general trends toward more shipment via air and truck modes. Table 11 summarizes the initial GHG reduction scenarios emissions levels relative to the 2050 Reference Case and 1990 conditions:

Table 11. Initial GHG Reduction Scenario Results, 2050

Scenario	Change Relative to 2050 Reference Case	Change Relative to 1990 Conditions
System and Mode Optimization	-33%	+56%
Vehicle and Fuel Technology	-69%	+8%
Tolling and Pricing	-64%	+24%

As shown in Table 11, despite large reductions in freight market GHG emissions relative to the Reference Case, none of the reduction scenarios are near the state's goal of reducing transportation GHG emissions by 75 percent *below* 1990 levels. All three reduction scenarios resulted in some amount of *increase* in GHG emissions over 1990 levels.

Performance of Combined Strategy-Set Scenarios

Figure 44 shows the GHG emissions results of the combined scenarios, including the most aggressive "High Effectiveness" scenario and a "Vision Scenario" that combines slightly less aggressive technology and pricing assumptions than the "High Effectiveness" scenario. The Vision Scenario differs from the Aggressive Technology and Pricing Scenario in the following respects:

- The fuel carbon content reduction assumption is 20 percent rather than 30 percent

- There is no assumption of full rail system electrification or zero-carbon electricity for any modes

By scaling back the two assumptions above, the Vision Scenario is consistent with the very aggressive, but plausible, scenarios adopted in the Ground Passenger and Commercial Services and Air Passenger travel market analyses.

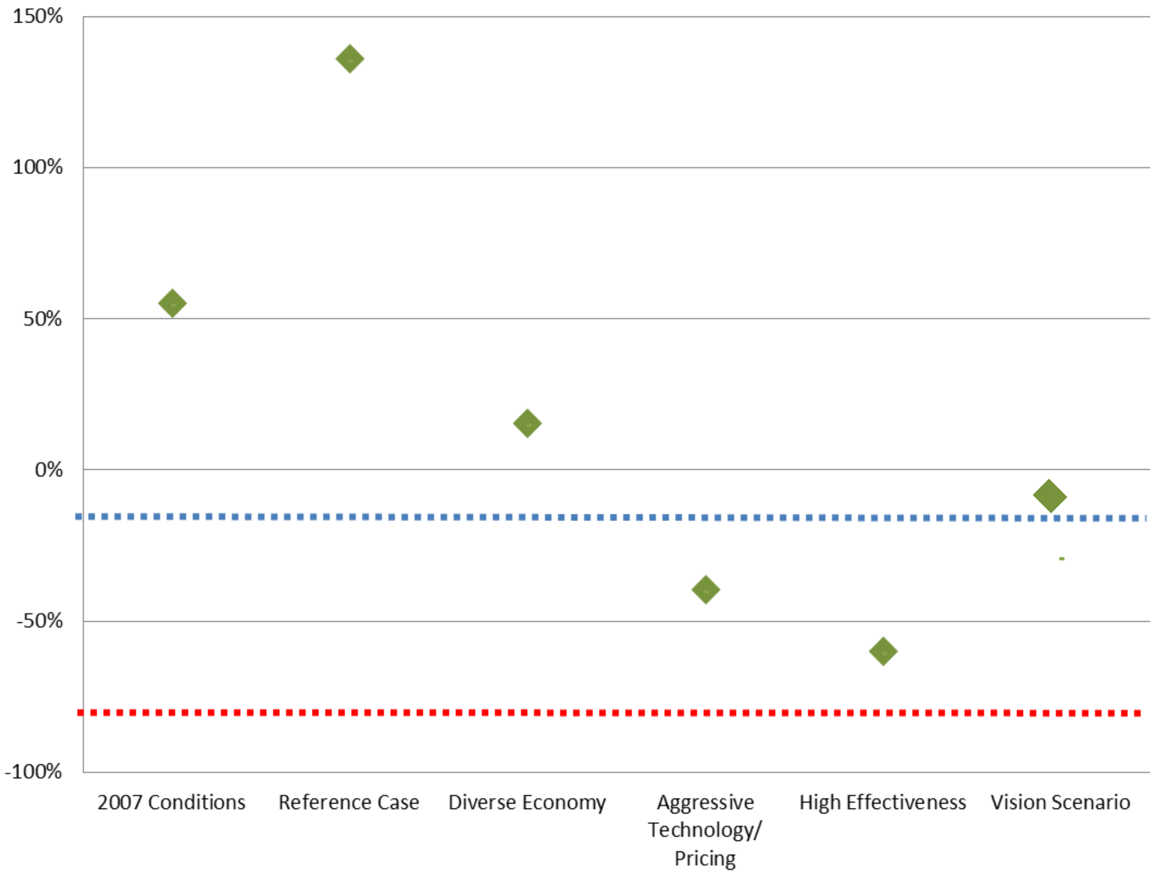

Figure 44. Percent Change in Total Freight GHG Emissions for Combined 2050 Scenarios Relative to 1990 Conditions

In Figure 44, the zero percent change line (dashed blue) indicates 1990 levels of total Freight GHG emissions. The dashed red line indicates the state's goal of 75% reduction below 1990 levels. As the plotted data points indicate, the most aggressive packages of strategies in the combined scenarios do achieve actual reductions in GHG emissions below 1990 conditions. However, even the most effective, most highly aggressive, scenario falls short of the statewide target of 75 percent reduction below 1990 levels. The Vision Scenario, which adopts assumptions for the freight sector similarly aggressive as those taken in the ground passenger and air passenger sector analysis, achieves a 2050 GHG reduction that is 30 percent below 1990 levels.

For reference, Table 12 shows the total ton flow by mode assumed under the Vision Scenario.

Table 12. Total Ton Flows by Mode and Direction: 2050 Vision Scenario

	Total Ton Flows by Mode and Direction (000s)				
Direction	**Truck**	**Rail**	**Water**	**Air**	**Total**
Within Oregon	214,930	4,271	2,897	282	222,380
Proportion	96.6%	1.9%	1.3%	0.1%	100.0%
External to Oregon	29,033	23,857	240	614	53,744
Proportion	54.0%	44.4%	0.4%	1.1%	100.0%
Oregon to External	37,623	15,146	156	463	53,387
Proportion	70.5%	28.4%	0.3%	0.9%	100.0%
Total	281,587	43,274	3,293	1,359	329,513
Proportion	85.5%	13.1%	1.0%	0.4%	100.0%

Economic Analysis of Vision Scenario

Figure 44 showed that the Vision Scenario reduced freight market GHG emissions by 30 percent compared to 1990 conditions. It is also important to consider the other performance measures when evaluating this strategy. Table 13 shows how the Vision Scenario compares to the Reference Case relative to the ratio of shipping costs to the value of the goods shipped, the percentage of fees[57] relative to the value of goods shipped, and societal costs of air pollution from trucks and trains.

Table 13. Year 2050 Reference Case and Vision Scenario Performance Measures

Performance Measure	2050 Reference Case	2050 Vision Scenario
Total Shipping Cost as Proportion of Total Dollar Value of All Goods Shipped	12%	7%
New User Fees as Proportion of Value	0%	0.78%
Air Pollution Costs	$631M	$310M

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[57] Full cost user fees related to the environmental impact of carbon and other externalities, as described above.

Table 13 highlights some important findings. In both cases, the relative value of goods shipped is similar.[58] However, in the Vision Scenario, gains in freight fuel/carbon economy and the higher value-density of goods shipped (same dollar value of goods shipped with fewer ton-miles of travel) lead to a net reduction in the total shipping costs per dollar of goods moved (expressed here as a proportion of the total dollar value of all goods moved.) This reduction in costs is in spite of higher user fees and higher volumes of high value density commodities which tend to rely more on air and truck freight. The benefits of a more efficient freight market and a more diverse economy overcome the higher fees and the costs of carbon emissions and fuel consumption that result from the propensity to move more goods by truck and air.

In addition to the reduction in GHG emissions and the lower overall costs of shipping, the Vision Scenario offers substantial public benefits as demonstrated by the lower external costs related to air pollution and other social/environmental issues when compared to the Reference Case.

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[58] The Vision Scenario assumes that fewer tons of fossil fuels are imported into Oregon since the power sector and ground passenger market are expected to be less reliant on these fuels.

TECHNICAL APPENDIX 4

AIR PASSENGER TRAVEL MARKET ANALYSIS METHODOLOGY

Technical Appendix 4
Air Passenger Travel Market Analysis Methodology

Introduction

This appendix summarizes the methods used to estimate potential GHG emissions reductions from the Air Passenger travel market.

Generally speaking, the reductions reported in the Air Passenger travel market were based on the scenario definitions developed by the Technical Advisory Committee and Policy Committee, and estimated using a combination of 1) extensive research on existing studies pertaining to air passenger travel emissions, and 2) data provided by the ODOT GreenSTEP model.

Technical Appendix 4 includes estimates of GHG reductions based on an initial set of potential strategy definitions developed by the advisory committees. It also includes estimates of the net impact on emissions of a “combined” scenario that incorporates the full complement of Air Passenger travel market GHG emissions mitigation strategies included in the STS Vision scenario.

The passenger air transportation GHG reduction strategies can be characterized into the following two categories:

1. **Those that result in changes in travel activity** – GHG emissions from passenger air transportation activity are lowered as a result of strategies that shift passenger demand to less carbon intensive modes or eliminate the demand for a trip; and
2. **Those that result in changes in emission rates** –GHG emissions are lowered as a result of improved aircraft technology and fuels, improved in-flight and on-ground operations, improved operating efficiency, and decreased emissions from passenger and cargo access and ground support equipment (GSE).

For each category, two initial scenarios were specified and estimated:

Changes in Travel Activity

1. **Demand Management** – Implement improved rail service in Vancouver–Seattle–Portland–Eugene corridor and broaden telecommunication technologies to reduce demand for business travel.
2. **Pricing** – Set new aviation fuel tax rates and adjust passenger facility charges to price short-haul travel higher and implement carbon emissions based pricing.

Changes in Emission Rates

3. **Aviation System** – Improve efficiency of passenger and cargo access by all modes, reduce emissions from airside support equipment (e.g., baggage tugs, pushback tractors, service and maintenance equipment), improve efficiency of the ground portion of FAA-regulated phases of aircraft movement, improve efficiency of the in-flight portion of FAA-regulated phases of aircraft movement, and optimize efficiency of airlines' operations, such as flight schedules, fleet mix, load factors.

4. **Aircraft and Fuel Technology** – Improve fuel efficiency and emissions profile through engine and airframe technology, and reduce the carbon intensity of aviation fuel.

Overview of Changes in Travel Activity and Emission Rates Due to Aviation Strategies

Greenhouse gas emissions are estimated using the following equation:

$$\Delta \text{GHG Emissions} = \Delta \text{Activity X } \Delta \text{Emission Rate}$$

Reductions in GHG emissions are achieved by using strategies that either impact the level of activity (vehicle-miles traveled, passenger-miles traveled, passenger trips, etc.) or the emission rate (grams of GHG emissions emitted per unit of activity). Changes in passenger-mile activity were broken out into business/leisure trips and short haul/long haul trips. The full scope of scenarios, strategies, and data requirements are presented in Table 14.

Table 14. Data Items Provided For Each Strategy

		Δ activity					Δ emission rate	
		% Δ passenger-miles				% Δ pax-trips	On-ground (grams/ pax-trip)	In-flight (grams/ pax-mile)
		Business		Recreation				
Scenario	**Strategy**	Short Haul*	Long Haul	Short Haul*	Long Haul			
1. Demand Management	High Speed Rail	X		X		X		
	Telecommunications	X	X			X		
2. Pricing	Aviation Fuel Tax	X	X	X	X	X		
	Passenger Fees	X		X		X		
	Carbon Tax	X	X	X	X	X		
3. Aviation System	Ground Access Vehicles						X	
	Ground Support Equipment						X	
	Air Traffic Control – In-Flight							X
	Air Traffic Control – Ground						X	
	Airline Operating Efficiency							X
4. Aircraft and Fuel Technology	Airframe and Engine Technology							X
	Aviation Fuel Carbon Intensity							X

* Note: Short haul includes all airports within 700 miles of flight including transfers.

Each "X" shown in Table 14 represents four data elements representing two levels of implementation and three evaluation years:

- **Scenario Levels** – Due to unknown technical, policy, economic, and other future factors, the first round of analysis assumed two levels of deployment, aggressive to maximum. This created a range of emission reduction levels from low to high for each scenario. The final round of analysis utilized that range of aggressive and maximum scenario definitions combined with advisory committee comments, to define a single recommended deployment trajectory for each individual scenario, as well as a "combined" Air Passenger travel market scenario.

- Evaluation Years –
    - **2020** – Short-term year to establish initial GHG emission reduction trajectory.
    - **2035** – An interim year (mid-term), based on Oregon's interim GHG goal.
    - **2050** – The horizon year (long-term) for Oregon's GHG goal.

Base Activity and Base Emission Rates Used in GreenSTEP Model

Base Activity

Base and forecast travel activity by total air passenger trips is estimated through the GreenSTEP model. Air passenger trips are translated to passenger miles based on average trip lengths by trip type (business or leisure) and length (short or long-haul). The activity represents trips by Oregonians only, excluding visitors and through trips. Oregonians account for roughly 55 percent of the total Oregon air passenger demand.[59]

Base Emission Rates (kg/passenger-mile)

The Energy Information Administration (EIA) publishes the Annual Energy Outlook (AEO)[60] every year with forecasts for aircraft fuel efficiency (in seat-miles/gallon) and aircraft occupancy (% of seats occupied), as shown in Figure 45 and Figure 46 respectively. In addition, EIA provides the CO_2 content for jet fuel.[61] These three items are combined to calculate emission rates (kg CO_2/passenger-mile) as shown in the calculation presented in Table 15.

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[59] A survey of departing passengers in the Portland International Airport (PDX) terminal conducted by Aviation Research at the Port of Portland shows that 43.5 percent of passengers lived in Oregon in 2009. The total passengers consisted of 6,472,267 enplanements including transfers. The U.S. DOT DB1B database shows that 5,082,320 passengers traveled from PDX in 2009, not including transfers. So the percentage of Oregonians is (6,472,267 × 43.5%) / 5,082,320, equal to 55 percent.

[60] https://www.eia.gov/outlooks/aeo/

[61] Voluntary Reporting of Greenhouse Gases Program: Fuel Emission Coefficients.

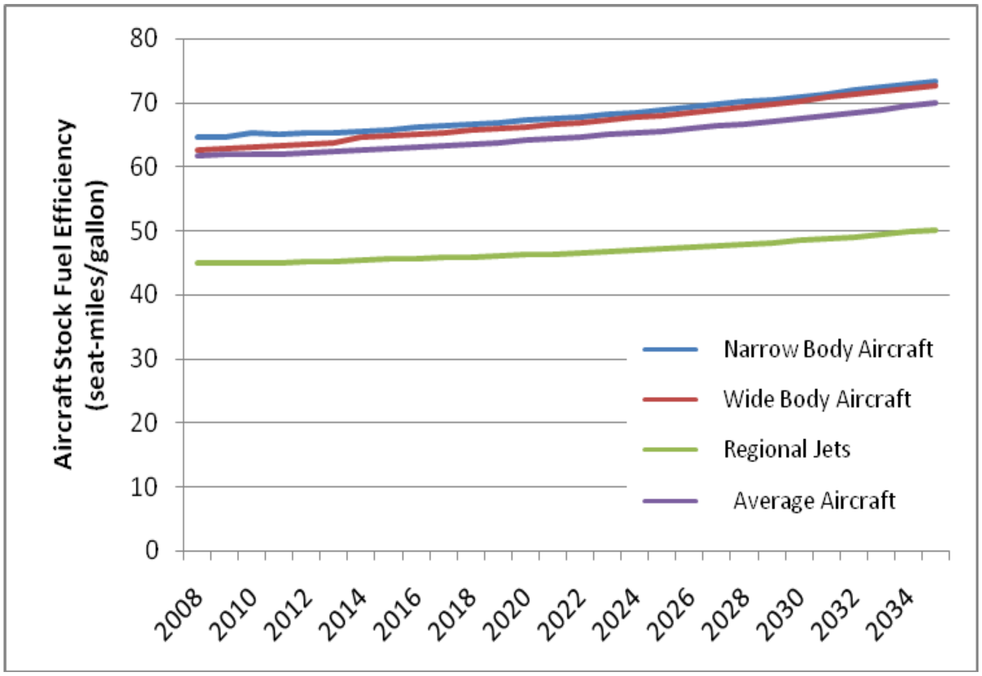

Figure 45. AEO 2011 Aircraft Stock Fuel Efficiency Forecast

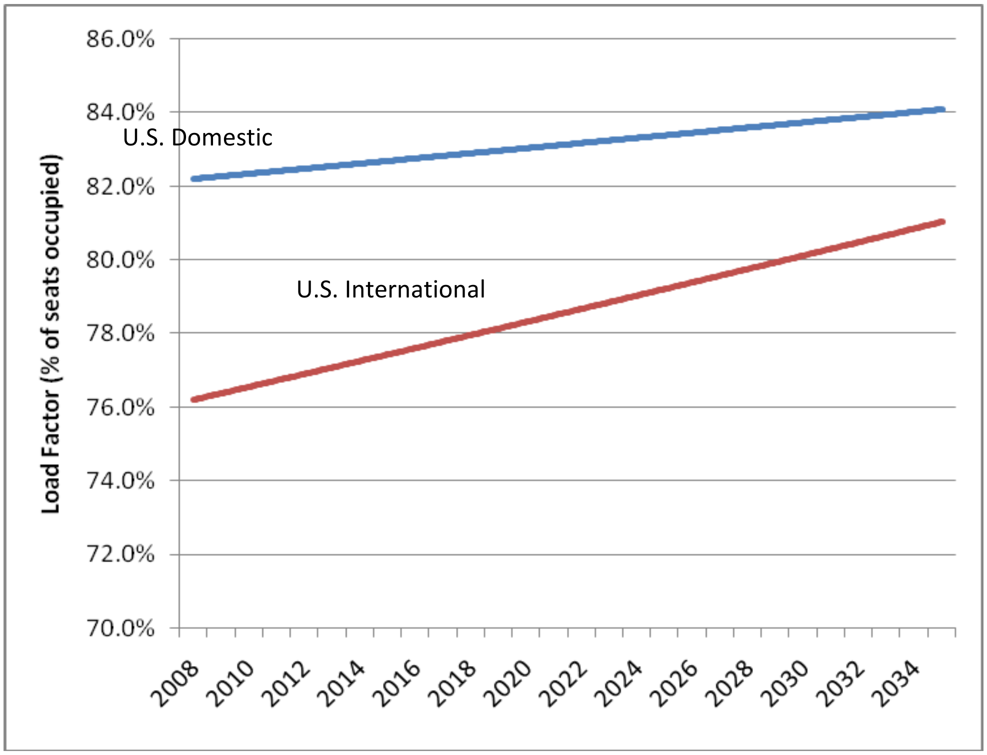

Figure 46. AEO 2011 Load Factor Forecast

Table 15. Calculation of Emission Rates (All Trip Lengths)

Value	2020	2035 - 2050	Source	Notes
CO_2 Content of Jet Fuel (kg/gallon)	9.57	9.57	EIA Fuel Emission Coefficients	Assume no change over time
Aircraft Stock Fuel Efficiency (seat-miles/gallon)	64.1	69.9	AEO 2011	Average aircraft with 2035 efficiency for 2050
Load Factor (% of seats occupied = passenger-miles/seat-miles)	0.83	0.84	AEO 2011	Assume U.S. domestic load factor. Assume 2035 load factor for 2050.
Emission Rate (kg CO_2/passenger-mile)	0.1799	0.1630	Calculation: Emission Rate = CO_2 Content / (Fuel Efficiency x Load Factor)	Average for all trip lengths.

The emission rates in Table 15 are for all air travel, regardless of trip length. Because the GreenSTEP Model segments trips into short versus long-haul, unique emission rates are required for each trip length category. Note that emission rates are constant beyond 2035, as baseline data is not available from AEO 2011 on new technologies and efficiency impacts beyond 2035.

We know that short-haul trips show higher average emission rates than long-haul trips because: (1) taxi, take-off, and climb is a larger proportion of the total trip emissions, and (2) the aircraft type, often regional jets, are less efficient per passenger mile. Table 16 presents calculated results based on AEO data segmented by short and long-haul.

Table 16. Calculation of Emission Rates (Short and Long-Haul)

Value	Length	2010	2020	2035-2050	Source	Notes
CO_2 Content of Jet Fuel (kg/gallon)	All	9.57	9.57	9.57	EIA Fuel Emission Coefficients	Assume no change over time
Aircraft Stock Fuel Efficiency (seat-miles/gallon)	Short	55.2	56.8	61.7	AEO 2011	Assume 50/50 split of seat/miles between narrow body and regional jet
	Long	64.2	66.8	73.05	AEO 2011	Assume 50/50 split of seat/miles between narrow body and wide body
Load Factor (% of seats occupied = passenger-miles/seat-miles)	Short	70%	71%	72%	CCAP*	Assume lower load factor consistent with CCAP report.
	Long	82%	83%	84%	AEO 2011	Assume U.S. domestic load factor.
Emission Rate (kg CO_2/passenger-mile)	Short	0.2477	0.2373	0.2154		Short-haul average.
	Long	0.1818	0.1727	0.1560		Long-haul average.

* Note: Data from High Speed Rail and Greenhouse Gas Emissions in the U.S., Center for Clean Air Policy and Center for Neighborhood Technology, 2006

To validate this calculation, it was cross-checked with information from The World Resource Institute (WRI) Greenhouse Gas Protocol (Mobile Combustion), which includes air travel emission rates by trip distance. Table 17 presents the WRI emission rates. The estimates provided in Table 16 are overall consistent with the WRI data.

Table 17. Current emission factors for air travel

Flight distance (mile)	CO_2 Emission (kg per passenger mile)
<300 mile	0.27595
300 to 700 mile	0.15611
>700 mile	0.18216

Source: "Emission Factors from Cross-Sector Tools" published by World Resource Institute (https://ghgprotocol.org/calculation-tools)

Base Emission Rates (kg/passenger-trip)

The GHG emissions for the ground portion of air-travel were develop by applying a kilogram-per passenger-trip (kg/passenger-trip) emission rate. This rate was based on the 2009 GHG emissions inventory from the Port of Portland Aviation Division and passenger trip information from Portland International Airport for the year that aligns with the GHG emissions inventory.

Sources of air travel related ground GHG emissions include:

- **Surface Traffic** (Ground Access Vehicles, including vehicles related to passenger, employee, service and cargo delivery activities);
- **Ground Service Equipment [GSE]** (including all operations, service and maintenance vehicles on the air-side of the gate); and
- Aircraft Taxi/Idle/Delay.

Total Aviation Scenario Results – GHG Emission Reductions (2020, 2035 and 2050)

Table 18, Table 19 and Table 20 display the results of an analysis of base year emissions and the expected trajectory of Air Passenger travel market emissions under a "reference case" (e.g., business as usual) scenario. Table 18 shows base year emissions for 1990, 2000 and 2010; Table 19 displays estimated business as usual emissions projections for future years 2020, 2035 and 2050; and Table 20 shows the emissions breakdown by travel market component. Figure 47 displays the projected trend in GHG emissions over time.

Baseline and Reference Scenario

Table 18. 1990, 2000, and 2010 Base Emissions

Air Passenger Base Years	1990	2000	2010
Aircraft Emissions			
Total (tons CO2)	1,475,544	2,711,070	3,004,565
GSE Emissions			
Total (tons CO2)	16,711	23,470	32,962
Airport Surface Traffic Emissions			
Total (tons CO2)	153,573	179,319	209,382

Table 19. 2020, 2035 and 2050 Reference Scenario Emissions

Air Passenger Baseline	**2020**	**2035**	**2050**
Aircraft Emissions			
Total Demand (round-trips)			
Business-Short	354,242	416,157	503,746
Business-Long	1,274,725	1,497,522	1,817,966
Leisure-Short	1,164,672	1,328,013	1,641,277
Leisure-Long	4,113,268	4,690,139	5,789,262
*Total Passenger Miles (millions)**			
Business-Short	283.39	332.93	403.00
Business-Long	3,824.17	4,492.6	5,543.9
Leisure-Short	931.74	1,062.4	1,313.0
Leisure-Long	12,339.80	14,070.4	17,367.8
CO2 per passenger mile (kg CO2/pax-mi)			
Short-haul	0.237	0.215	0.215
Long-haul	0.173	0.156	0.156
Total tons CO2 (Oregon OD commercial air travel)			
Business-Short	67,249	71,712	86,806
Business-Long	660,435	700,840	850,808
Leisure-Short	221,101	228,843	282,825
Leisure-Long	2,131,084	2,194,985	2,709,375
Total (tons CO2)	**3,079,870**	**3,196,381**	**3,929,813**
GSE Emissions			
Total (tons CO2)	35,691	40,213	49,443
Airport Surface Traffic Emissions			
Total (tons CO2)	213,443	219,683	207,227

* Note: Total demand is translated to passenger miles based on average round-trip distances from BTS, T-100 Market All Carrier database (*2010*). For short-haul trips, average length is 800 miles. For long-haul trips, average length is 3,000 miles.

Table 20. Oregon Air Passenger Reference Scenario Emissions – Summary

	1990	**2000**	**2010**	**2020**	**2035**	**2050**
Aircraft Emissions						
Total (tons CO2)	1,475,544	2,711,070	3,004,565	3,079,870	3,196,381	3,929,813
GSE Emissions						
Total (tons CO2)	16,711	23,470	32,962	35,691	40,213	49,443
Airport Surface Traffic Emissions						
Total (tons CO2)	153,573	179,319	209,382	213,443	219,683	207,227
Air Passenger Reference Scenario						
TOTAL (tons CO2)	**1,645,828**	**2,913,859**	**3,246,908**	**3,329,004**	**3,456,277**	**4,186,483**

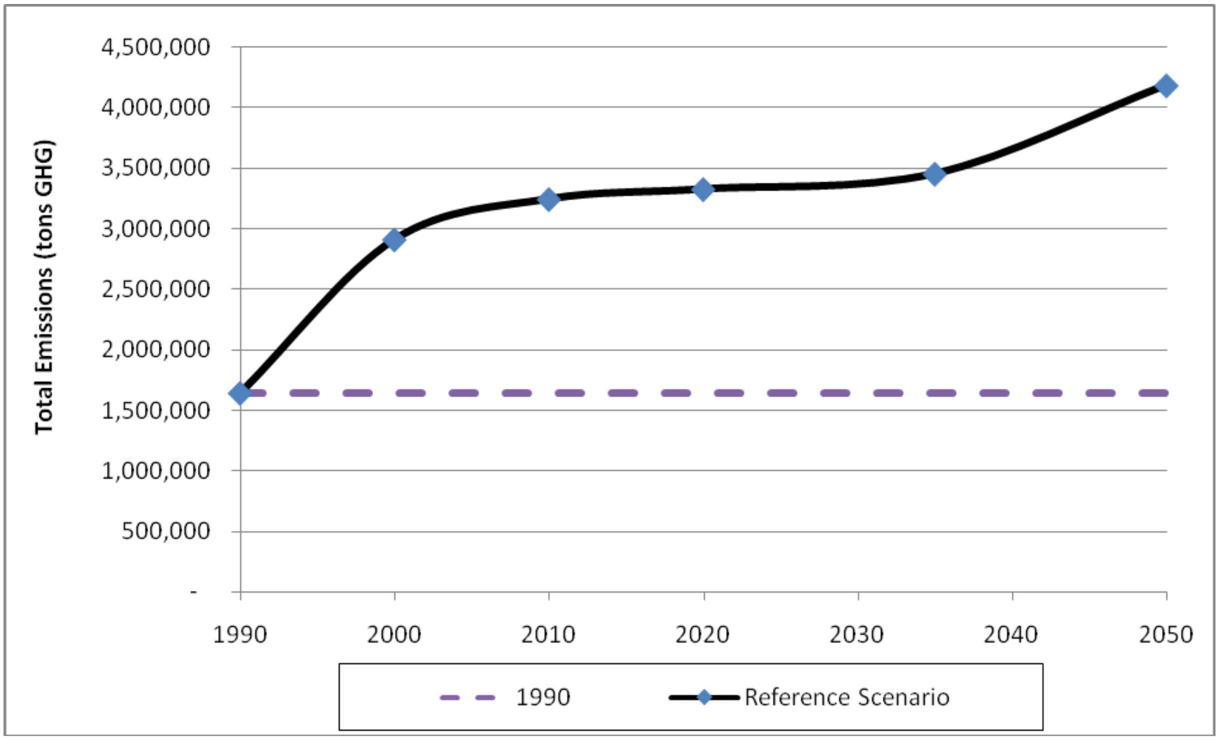

Figure 47. 1990 - 2050 Reference Scenario Emissions

Alternative Air Passenger Market Scenarios

Table 21 displays the projected reductions in GHG emissions in 2020, 2035 and 2050, by initial scenario. Table 22 compares those results to the base year, 1990, to estimate a percentage growth/reduction in GHG emissions for each initial scenario.

Table 21. 2020, 2035 and 2050 Air Passenger Market Scenarios GHG Reductions

Air Passenger Market Scenario Reductions (tons CO2)	2020	2035	2050
Scenario 1 - Travel Demand Management			
High-Speed Rail	(2,422)	(7,814)	(14,416)
Telecommunications	(109,153)	(509,885)	(618,825)
Scenario 2 - Pricing			
Aviation fuel tax	(26,601)	(49,175)	(60,412)
Passenger fees	-	(26,551)	(37,511)
Carbon tax	(109,356)	(171,628)	(295,182)
Scenario 3 - Aviation System			
Ground Access Vehicles	(17,075)	(65,905)	(155,420)
Ground Support Equipment	(7,138)	(20,107)	(49,443)
Air Traffic Control - Flight Operations	(117,651)	(244,203)	(300,238)
Air Traffic Control - Ground Operations	(5,544)	(14,384)	(17,684)
Airline Operating Efficiency	(61,597)	(90,978)	(111,863)
Scenario 4 - Aircraft and Fuel Technology			
Airframe/Engine and Fuel Technology	(156,325)	(1,438,371)	(2,750,869)

Table 22. 2020, 2035 and 2050 Air Passenger Market Scenarios GHG Emissions Compared to 1990

	1990	2020	2035	2050
Reference Case				
Total Emissions (tons CO2e)	1,645,828	3,329,004	3,456,277	4,186,483
Percent Change from 1990	-	102%	110%	154%
Scenario 1 - Travel Demand Management				
Total Emissions (tons CO2e)		3,217,429	2,938,578	3,553,243
Percent Change from 1990		95%	79%	116%
Scenario 2 - Pricing				
Total Emissions (tons CO2e)		3,193,046	3,208,923	3,793,379
Percent Change from 1990		94%	95%	130%
Scenario 3 - Aviation System				
Total Emissions (tons CO2e)		3,119,998	3,020,701	3,551,835
Percent Change from 1990		90%	84%	116%
Scenario 4 - Aircraft and Fuel Technology				
Total Emissions (tons CO2e)		3,175,010	2,017,906	1,435,614
Percent Change from 1990		93%	23%	-13%

Combined Air Passenger Market Scenario

A “combined” scenario was created based on the cumulative components of the initial four scenarios, and accounting for interactions between their component parts. The combined scenario reflects an aggressive approach across all strategy components to reduce GHG emissions in 2020, 2035 and 2050. Table 23 presents total emissions in the reference and combined scenario, and comparisons to 1990 emissions.

Table 24 presents the component specific GHG emission reductions within the combined scenario. The table presents the order of operations to estimate the total combined effect of each of the four primary components. The components are similar in definition to the four individual scenarios presented in Table 21 and Table 22, however they are ordered differently to better account for interactions. The GHG emission reductions from component #2 and component #3 are significantly less than those reported in Table 21 and Table 22, because improvements in system efficiency and reduction in passenger miles are now applied to much lower emission rates as a result of new technologies and fuels included in component #1.

Figure 48 presents the reference and combined scenario emission results, along with combined scenario GHG emission trends, including the GHG reduction contribution from each component as presented in Table 24.

Table 23. 2020, 2035 and 2050 Combined Air Passenger Market Scenario Compared to 1990

	1990	2000	2010	2020	2035	2050
Air Passenger Reference Scenario						
TOTAL (tons CO2)	1,645,828	2,913,859	3,246,908	3,329,004	3,456,277	4,186,483
Air Passenger Combined Scenario						
TOTAL (tons CO2)	1,645,828	2,913,859	3,246,908	**2,745,701**	**1,277,264**	**768,973**

Percent Change from 1990 Emissions	**2020**	**2035**	**2050**
Air Passenger Reference Scenario	102%	110%	154%
Air Passenger Combined Scenario	**67%**	**-22%**	**-53%**

Table 24. 2020, 2035 and 2050 Combined Air Passenger Market Scenario Emission Reduction Components

	2010	2020	2035	2050
Reference Scenario (tons CO2e)	**3,246,908**	**3,329,004**	**3,456,277**	**4,186,483**
Combined Scenario GHG Reduction Components				
1. Engine/Airframe Technology and Fuels	-	(153,993) +	(1,438,371) +	(2,750,869) +
2. *NextGen* and Airline Operational Strategies	-	(184,792) +	(314,608) +	(214,892) +
3. Travel Demand Management and Pricing	-	(220,304) +	(340,199) +	(246,886) +
4. Ground Access Improvements and GSE	-	(24,214)	(86,012)	(204,863)
Total Combined Scenario (tons CO2e)	**3,246,908**	**2,745,701**	**1,277,087**	**768,973**

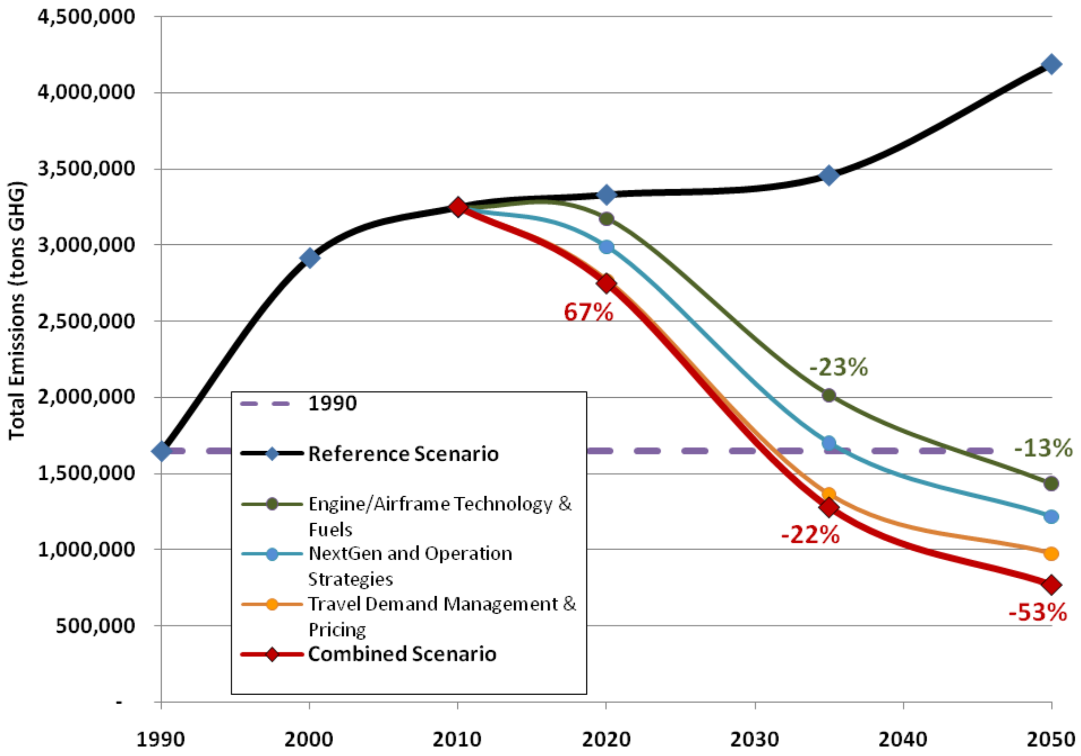

Figure 48. 2020, 2035 and 2050 Combined Air Passenger Market Scenario GHG Reductions

Strategy-Specific Changes in Travel Activity and Emission Rates – Definitions, Data, and Results

This section defines each key advisory committee recommendation, details specific elements included in each scenario; outlines a proposed trajectory of GHG emissions reduction strategy in the short- (2020), mid- (2035) and long-term (2050) as proposed by the Policy Committee; indicates the source of data underlying the analysis; and indicates analysis results.

Scenario 1: Demand Management – Passenger rail improvements (including High Speed Rail)

Recommendation:

Prioritize passenger rail investments in the Eugene to Vancouver, BC corridor, ensuring service that is performance- and cost-competitive with air travel.

Elements:

- Short-term incremental operational and geometric improvements to improve operational efficiency and reduce delays from sharing right-of-way with freight traffic
- Upgrade to overall level of service including station and rail car improvements
- Mid-term full upgrade to high-speed operations including new alignments and parallel tracks in congested corridors
- Long-term additional upgrades to locomotives, rail cars and signal/propulsion systems to increase maximum speeds

Trajectory:

- By 2020: Incremental geometry and operational corridor improvements to increase average speeds
- By 2035: Corridor improvements allow average maximum operating speeds of 100 mph
- By 2050: Further corridor improvements and technology enhancements allow maximum corridor operating speeds up to 140 mph

Data:

The air travel passenger mile data for this analysis is for the year 2010, from the T-100 Market (All Carriers) database from U.S. Department of Transportation (DOT)[62]. The following data was summarized:

- In 2010, 8.4 percent of short-haul trips (<700 mi one-way) are between Eugene (EUG) and Portland International (PDX) to/from Seattle (SEA), Bellingham (BLI), and Vancouver, BC (YVR).

Results:

Air to rail diversion rates are consistent with factors in the 1997 Federal Railroad Administration report[63]. Incremental upgrades through 2020 are assumed to result in a diversion rate up to 10 percent. For 110 mph maximum speed rail, the air to rail diversion rate is 31 percent (2035). For 140 mph maximum speed rail, assuming advanced conventional rail technology, the air to rail diversion rate is 46 percent (2050). As noted above, these diversion

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[62] The data are reported by participating air carriers from the continuous 10 percent sample of airline tickets where a ticket contains only domestic points/airports. https://www.transtats.bts.gov/

[63] https://www.fra.dot.gov/page/P0247

rates are only applied to origin-destination trips in the corridor, not transfer trips.

The resulting changes in total short-haul Oregon based air passenger miles are noted below:

- **2020** – 0.9 percent reduction in short-haul air passenger miles
- **2035** – 2.6 percent reduction in short-haul air passenger miles
- **2050** – 3.9 percent reduction in short-haul air passenger miles

Scenario 1: Demand Management – Telecommunications

Recommendation:

Broadly support and deploy technologies for virtual meetings and other communication technologies to decrease business air travel demand.

Elements:

- Support aggressive deployment of video conferencing and virtual meeting technologies

Trajectory:

- By 2020: Incremental improvements in the short-term could reduce business travel demand up to 15 percent

- By 2035: Based on Oregon air travel demand forecasts, business travel represents 24 percent of total Oregon origin or destination air travel in 2030 – by 2035, up to 66 percent of this travel activity would be reduced by remote business technologies

- By 2050: Same as 2035

Data:

Based on air travel demand forecasts estimated using GreenSTEP, business travel represents 24 percent of total Oregon origin or destination based air travel in 2030. Research conducted by the World Wildlife Fund in 2009 indicates that in 2030, 50 to 66 percent of business travel could be avoided as a result of expansion of virtual meeting technology.[64] This range of impact is based on a conceptual definition whereby policy makers and the IT industry converge and aggressively deploy technologies to meet goals of reducing GHG emissions.

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[64] World Wildlife Fund. From Workplace to Anyplace – Assessing the Global Opportunities to Reduce Greenhouse Gas Emissions with Virtual Meetings and Telecommuting. 2009. assets.panda.org/downloads/wwfteleworking.pdf

Results:

- **2020 –** 15 percent reduction in business air passenger trips (applied evenly to both short- and long-haul trips)

- **2035 and 2050 –** 66 percent reduction in business air passenger trips (applied evenly to both short- and long-haul trips)

Scenario 2: Pricing – Aviation Fuel Charges

Recommendation:

Set aviation fuel charges at a level sufficient to pay for non-climate change related externalities associated with fuel consumption. Non-climate change related externalities include energy security, air pollution, and surface environmental impacts.

Elements:

- Increase aviation fuel tax to a level that accounts for externalities

Trajectory:

- By 2020: Airlines pass-thru 100 percent of tax to passengers through implementing a $2.75 per roundtrip fuel tax surcharge (equivalent to a 6 cents per gallon fuel tax plus noise impact fee)

- By 2035: Airlines pass-thru 100 percent of tax to passengers through implementing a $5.00 per roundtrip fuel tax surcharge (equivalent to a 12 cents per gallon fuel tax plus noise impact fee)

- By 2050: Same as 2035

Data:

For commercial aviation, existing aviation fuel taxes are 1 cent per gallon in Oregon and 4.4 cents per gallon Federal. Data developed for the Ground Passenger and Commercial Services travel market scenarios reflect the following externality costs per gallon: energy security ($0.45/gallon), air pollution ($0.014/mile), noise ($0.001/mile), and other environmental impacts ($0.003/mile). Using this data and relationships between air and surface travel impacts, general impacts for air travel are derived.

- Air travel consumes one-seventh the total equivalent barrels of oil per day of on-road vehicle travel.

- Based on national emissions data from EPA, average air travel criteria air pollution impacts per passenger mile are one-fifth to one-twentieth of on-road impacts per passenger mile. For example, aviation operations below 3000 feet contribute 0.4 percent to the total national NOx inventory.[65]

Based on the above relationships, the scenario alternative aviation fuel tax rates (for energy security and air pollution impacts only) are **$0.06 cents per gallon (aggressive by 2020)**, $**0.12 cents per gallon (maximum by 2035)**. The only comparable existing state aviation fuel tax is Florida at $0.069/gallon, however there is no state sale and use tax on aviation. California and Washington exempts commercial aviation from state aviation fuel taxes.

Noise impacts are more localized for the air passenger market and therefore difficult to compare to ground and commercial market impacts. The environmental impact of aircraft noise is projected to remain constant in the United States through 2025 and then increase as air travel growth outpaces expected technological and operational advancements, and public acceptance of noise impacts changes.[66] Based on research from the University of British Columbia, for airports in Canada the marginal cost impact of noise is $64 per landing and takeoff (LTO).[67] Assuming 84 percent occupancy, on a 124 seat jet[68], this equals *$0.61 per passenger per LTO.*

Results:

All additional aviation fuel taxes are passed on directly to passengers with a trip origin or destination in Oregon. Based on the current and future emission factors in Table 16 for Oregon air passenger travel, for all trip lengths in 2035 – 2050, 0.0170 gallons are consumed per passenger mile. The average round-trip length for all Oregonian air passenger trips (domestic and international) is 2,100 miles (per BTS data). Based on the fuel consumption rate, fuel tax rates, and proposed noise impact fee, per average passenger round-trip the tax would total **$2.75 (aggressive by 2020)** to **$5.00 (maximum by 2035)**.

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[65] Federal Aviation Administration, "Report to the United States Congress – Aviation and the Environment," Massachusetts Institute of Technology, 2004.
https://www-auth.oregon.egov.com/ODOT/Planning/Documents/STS-Technical-Appendices.pdf

[66] National Research Council, "For Greener Skies – Reducing Environmental Impacts of Aviation," Committee on Aeronautics Research and Technology for Environmental Compatibility, Washington DC, 2002. https://www.nap.edu/catalog/10353/for-greener-skies-reducing-environmental-impacts-of-aviation

[67] Dr. David Gillen, "Noise and the Full Cost Investigation in Canada – Final Report", University of British Columbia, March 2007.

[68] According to the FAA Aerospace Forecast Fiscal Years 2011–2031, average aircraft size in 2031 will be 124 seats.

Using price elasticity[69] and an average domestic itinerary airfare for PDX of $378[70], the percent reduction in passenger miles resulting from the fuel tax was estimated for these four different air passenger travel markets. These estimates are presented in Table 25. The first row of Table 25 indicates the average percentage increase in airfare from the fuel tax applied in 2020 and 2035. The following four rows present the resulting percentage decline in air passenger miles for each of the four air passenger markets, also for the years 2020 and 2035. No change in the fuel tax beyond 2035 was assumed or modeled.

Table 25. 2020 – 2050 Reduction in Passenger Miles (based on current average ticket price)

	2020	**2035 - 2050**
Average fare increase due to fuel tax	0.7%	1.3%
Passenger Mile Change		
Short-haul business	-0.5%	-0.9%
Short-haul leisure	-1.1%	-1.9%
Long-haul business	-0.9%	-1.6%
Long-haul leisure	-0.8%	-1.4%

Scenario 2: Pricing – Passenger Fees

Recommendation:

Increase passenger fees for air travel with both an origin and destination in the Eugene to Vancouver, BC corridor to encourage mode shift to passenger rail or other lower-carbon modes such as express intercity bus.

Elements:

- Increase passenger fees for all origin/destination pairs between EUG and PDX from/to SEA, BLI, YVR

Trajectory:

- By 2020: N/A – high speed rail corridor should be fully operational prior to initiating fees
- By 2035: 3x increase in current passenger facility charges for round trips in the EUG/PDX to SEA, BLI, YVR travel market
- By 2050: Same as 2035

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[69] The Carbon Tax Strategy applies the following price elasticities: Short-haul leisure travel: -1.50, Short-haul business travel: -0.70, Long-haul leisure: -1.1, Long-haul business: -1.2

[70] https://www.bts.gov/

Data:

See Scenario 1: Demand Management – Passenger rail improvements (including High Speed Rail). Assuming that external costs are taken into account fully through the fuel and carbon tax strategies, this strategy focuses on increased passenger fees for origin-destination trips in the HSR corridors included in Scenario 1 (therefore this strategy assumes that the HSR corridor is complete).

The application of passenger fees for flights in the HSR corridor markets will act to move additional demand (compared to the results for Scenario 1) from air travel to HSR travel. Scenario 1, high-speed rail estimates a 2.6 percent reduction (2035) and 3.9 percent reduction (2050) of total short-haul passenger miles. The increases in fees are associated with the comparative per passenger mile carbon emissions impact of regional air travel versus rail travel (3 to 1).

Results:

To reflect the 3:1 ratio, passenger facility charges for a round-trip in the HSR markets triple, from a current average of $9 to $27. Based on elasticity applied in the fuel and carbon tax measures, total short-haul air passenger miles would decrease an additional 6.2 percent in both 2035 and 2050.

Scenario 2: Pricing – Carbon fee

Recommendation:

Institute a carbon fee for all commercial air passenger services, with scheduled fee increases over the long-term.

Elements:

- Institute a carbon tax in 2020 which increases in 2035 and 2050

Trajectory:

- By 2020: $30 per metric ton CO2e translated to a per passenger mile fee
- By 2035: $50 per metric ton CO2e translated to a per passenger mile fee
- By 2050: $70 per metric ton CO2e translated to a per passenger mile fee

Data:

Research associated with implementation of the European Trading Scheme (ETS) reflect average ticket price increases on short-haul flights of 1.5 - 2.5 percent and long-haul flights of 2 - 3 percent, based on a carbon price of 20-50 eu/metric ton of carbon. The following elasticities are used to translate changes in ticket price to changes in passenger demand:

- Short-haul leisure travel: -1.50
- Short-haul business travel: -0.70
- Long-haul leisure: -1.1
- Long-haul business: -1.2[71]

Results:

A $50 per metric ton carbon tax in 2035 would equal less than a one cent per passenger mile fee for both short- and long-haul flights. The average round-trip length for short-haul trips is 800 miles, and the average for long-haul is 3,000 miles (per BTS data). The percent reduction in passenger miles is presented in Table 26 for each of the three horizon years. These reductions assume that airlines rationalize schedules to optimize load factors, consistent with current practice.

Table 26. 2020 – 2050 Percentage Reduction in Passenger Miles (based on current average ticket price)

	2020	2035	2050
Average roundtrip fare increase due to carbon tax	3.0%	4.5%	6.3%
Passenger Mile Change			
Short-haul business	-2.1%	-3.2%	-4.4%
Short-haul leisure	-4.5%	-6.8%	-9.5%
Long-haul business	-3.6%	-5.4%	-7.6%
Long-haul leisure	-3.3%	-5.0%	-7.0%

Scenario 3: Aviation System Optimization – Ground Access Vehicles

Recommendation:

Increase efficiency in all airport terminal access activities, including shift to low- and zero-emission vehicles and modes for passenger, employees and vendors.

Elements:

- Support implementation of related ground transportation recommendations including public transportation, pricing, TDM, system operations, and vehicle fuels and technology

- Work with airports to improve efficiency of ground access activities

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[71] International Air Traffic Association, “Estimating Air Travel Demand Elasticities, ” InterVISTAS Consulting Inc., December 2007.

Trajectory:

- By 2020: 8 percent reduction in all ground access vehicle emissions at Oregon airports compared to 1990
- By 2035: 30 percent reduction in all ground access vehicle emissions at Oregon airports compared to 1990
- By 2050: 75 percent reduction in all ground access vehicle emissions at Oregon airports compared to 1990

Data:

Total Oregon airport ground access emissions are based on the proportion of PDX passenger travel to all Oregon travel from BTS (*2010*) compared to PDX ground access emissions as reported in the Port of Portland – Aviation Division GHG Emissions Report (*2009*). Total Oregon Surface Traffic (or GAV, Ground Access Vehicle) emissions are reported in Table 18, previously.

Results:

The ground access vehicle GHG emission reductions are consistent with the Ground Passenger and Commercial Services travel market scenarios.

Scenario 3: Aviation System Optimization – Ground Support Equipment (GSE)

Recommendation:

Deploy efficient operation and maintenance practices and use low- or zero-emission equipment for all airport ground service operations.

Elements:

- Work with airports to promote and support replacement of fueled airside equipment including employee shuttles, baggage tugs, belt loaders, pushback tractors, service and maintenance equipment, jet bridges, and gate installation of power and preconditioned air units with electric or ultra-low emission to reduce use of aircraft APUs

Trajectory:

- By 2020: 20 percent electric/ULEV fleet
- By 2035: 50 percent electric/ULEV fleet
- By 2050: 100 percent electric fleet with all recharging power from renewable sources

Data:

Includes airside equipment including baggage tugs, belt loaders, pushback tractors, and service and maintenance equipment. Broad deployment of efficient operation/maintenance practices and lower or zero-emission equipment is included. Examples include:

- Gate installation of 400 Hz power and preconditioned air units reduces the use of aircraft auxiliary power units (APUs)
- Electric ground support equipment (bag tugs, belt loaders, pushback tractors) recharged using electricity from renewable sources

According to the PDX GHG Emissions Inventory, GSE represent 1 percent of all airport CO_2 emissions. This ratio is assumed constant across all Oregon airports.

Results:

The aggressive deployment case assumes that *50 percent of* CO_2 *emissions* from GSE are reduced by 2035. The maximum deployment case assumes that *100 percent of* CO_2 *emissions* are reduced by 2050 through a complete conversion to an electric fleet, and all electricity used for repowering and preconditioned air units comes from renewable sources.

Scenario 3: Aviation System Optimization – Air Traffic Control (Flight Operations)

Recommendation:

Accelerate and complete implementation of FAA "Next Generation" (*NextGen*) Air Transportation System (ATS).

Elements:

- Equip aircraft and airports with *NextGen* avionics and air traffic control technologies

Trajectory:

- By 2020: 4 percent CO2e emission reduction for combined in-flight strategies (in-flight emissions represent 95 percent of all aircraft CO2e emissions)
- By 2035: 8 percent CO2e emission reduction for combined in-flight strategies
- By 2050: Up to 8 percent CO2e emission reduction for combined in-flight strategies (longer term CO2 benefits on *NextGen* will decrease due to expected advances in aircraft engines and low carbon fuels)

Data:

Accelerated and complete implementation of FAAs "Next Generation" Air Transportation System (ATS) results in more fuel-efficient climbs, routing and descents. FAA *NextGen* ATS documentation estimates reduced fuel burn and emissions from pilot programs such as optimized routing and altitude, surface traffic management, and Pacific and Atlantic interoperability initiatives. Per the 2012 FAA reauthorization bill (*FAA Modernization and Reform Act of 2012*), *NextGen* arrival procedures will be fully operational at the nation's 35 busiest airports (including PDX) by June 2015. Target date for implementation at all airports is 2020. The FAA bill also enables the FAA to implement an avionics equipage incentive program for the purpose of equipping commercial aircraft with communications, surveillance, and navigation equipment to help achieve *NextGen* routing capabilities.

Transportation's Role in Reducing U.S. Greenhouse Gas Emissions analyzes the same measures associated with *NextGen*, and estimates a 6 – 8 percent reduction in emissions for combined in-flight NAS strategies through 2035.[72]

According to the PDX GHG Emissions Inventory, in-flight operations represent 95.5 percent of all aircraft CO_2 emissions. This ratio is assumed constant across all Oregon airports.

Results:

Table 27 presents the revised 2020 – 2050 per passenger mile emission factors resulting from full deployment of *NextGen* ATS (in-flight operation strategies).

Table 27. 2020 – 2050 Revised CO2 Emission Rate per Passenger Mile (due to deployment of NextGen ATS)

	Distance Category	2020	2035	2050
Emission Rate (kg CO_2/passenger-mile)	Short	0.228	0.199	0.199
	Long	0.166	0.144	0.144

Scenario 3: Aviation System Optimization – Air Traffic Contro*l* (Ground Operations)

Recommendation:

Accelerate and complete implementation of FAA "Next Generation" (*NextGen*) for ground operations.

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[72] United States Department of Transportation. "Report to Congress – Transportation's Role in Reducing U.S. Greenhouse Gas Emissions", 2009. Volume 2, pg. 4-77.

Elements:

- Improve airfield management practices (collaborative departure queue management) that lead to reductions in the time and number of aircraft idling on taxiways waiting for takeoff, or for open gate slots upon arrival
- Implement Ground Based Augmentation System technology (precision approach, departure, and terminal operations)

Trajectory:

- By 2020: 4 percent carbon dioxide equivalent emission (CO2e) reduction for combined ground strategies (in-flight emissions represent 5 percent of all aircraft CO2e emissions)
- By 2035: 10 percent CO2e emission reduction for combined ground strategies
- By 2050: Up to 10 percent CO2e emission reduction for combined ground strategies (longer term CO2 benefits on *NextGen* will decrease due to expected advances in aircraft engines and low carbon fuels)

Data:

Per the 2012 FAA reauthorization bill (*FAA Modernization and Reform Act of 2012*), Ground Based Augmentation System technology (precision approach, departure, and terminal operations) will be implemented at nation's 35 busiest airports (including PDX) by 2013.

Transportation's Role in Reducing U.S. Greenhouse Gas Emissions analyzes the same ground operation strategies associated with *NextGen*, and estimates up to a *10 percent reduction* for combined ground operation strategies through 2035.[73]

According to the PDX GHG Emissions Inventory, ground operations represent 4.5 percent of all aircraft emissions. This share of emissions is assumed constant across all Oregon airports.

Results:

Table 28 presents the revised 2020 – 2050 per passenger mile emission factors resulting from full deployment of *NextGen* ATS (ground operation strategies).

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[73] United States Department of Transportation. "Report to Congress – Transportation's Role in Reducing U.S. Greenhouse Gas Emissions", 2009. Volume 2, pg. 4-77.

Table 28. 2020 – 2050 Revised CO2 Emission Rate per Passenger Mile (due to deployment of NextGen ATS)

	Distance Category	2020	2035	2050
Emission Rate (kg CO_2/passenger-mile)	Short	0.237	0.214	0.214
	Long	0.172	0.155	0.155

Scenario 3: Aviation System Optimization – Airline Operating Efficiency[74]

Recommendation:

Improve and expand deployment of individual airlines' environmental and efficiency initiatives, such as engine and aircraft washing, one-engine taxiing, weight reduction programs, load planning, flight routing, and flight scheduling.

Elements:

- Support implementation of routine washing of aircraft and engines
- Support implementation of single-engine taxi
- Support move to larger regional jets for short haul flights (e.g., from 50 seats to 90-100 seats)

Trajectory:

- By 2020: 2 percent reduction in CO2 emissions per passenger mile for short-haul trips, and 2 percent reduction per passenger mile for long-haul trips
- By 2035: 11 percent reduction in CO2 emissions per passenger mile for short-haul trips, and 2 percent reduction per passenger mile for long-haul trips
- By 2050: Same as 2035 (longer term CO2 benefits will be substituted completely due to expected advances in aircraft engines and low carbon fuels)

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[74] This strategy was ultimately excluded from the Vision Scenario, as the Policy Committee consensus was that these activities are largely underway and will continue into the future as airline companies seek further fuel efficiency improvements.

Data:

The following are the benefits of airline operating efficiency programs:

- Based on data from United Continental Holdings (United Airlines), routinely washing aircraft and engines to reduce drag and emissions results in fuel efficiency improvements of 1 percent.[75]

- According to Airbus, single-engine taxi results in approximately a 30 percent fuel savings (the taxi phase of aircraft operations represents < 3 percent of total aircraft emissions).[76]

- The move to larger regional jets (e.g., from 50 seats to 90-100 seats) may lead to increases in short-haul flight average load factors. By optimizing flight schedules and using larger regional jets on short-haul flights, load factors of 80 percent or greater are attainable.[77]

Results:

In aggregate, airline operating efficiency programs listed above will result in decreased emissions per passenger mile as presented in Table 29.

Table 29. 2030 – 2050 Revised CO2 Emission Rate (due to airline operating efficiency programs)

	Distance Category	2020	2035	2050
Emission Rate (kg CO_2/passenger-mile)	Short	0.233	0.192	0.192
	Long	0.169	0.153	0.153

Scenario 4: Airframe and Engine Technology and Aviation Fuel Carbon Intensity

Recommendation:

Airframe and Engine Technology: Support sponsored research and partnerships with aircraft and engine manufacturers to help meet NASA's Environmentally Responsible Aviation (ERA) and Ultra Efficient Engine Technology (UEET) program goals.

Aviation Fuel Carbon Intensity: Reduce the carbon intensity of aviation fuel.

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[75] https://www.continental-corporation.com/en

[76] https://www.aiaa.org/

[77] http://www.oliverwyman.com/index.html

Elements:

- Industry optimizes around lowest fuel consumption per seat consistent with passenger demand in specific markets

- Implement pilot program to promote industry use of bio/renewable fuels

Trajectory:

- By 2020:
    - < 5 percent impact on CO2e per passenger mile emission rates (most gains are through aviation system strategies, through 2020 - widespread fleet replacements to Boeing 737Max, Airbus A-320 Neo aircraft will mostly occur later this decade and early 2020's),
    - No measureable impact of low carbon aviation fuels
- By 2035:
    - Combined 45 percent reduction in grams CO2e per passenger mile emission rates
    - Conservative estimate of a 3 to 5 percent reduction in grams CO2e per passenger mile emission rates by 2035 from the broader use of low-carbon aviation fuels
- By 2050:
    - Combined 70 percent reduction in grams CO2e per passenger mile emission rates
    - Conservative estimate of a 10 to 15 percent reduction in grams CO2e per passenger mile emission rates post- 2035 from the broader use of low-carbon aviation fuels

Data:

Airframe and Engine Technology

According to a National Research Council Report[78]:

- Based on past trends (during which NASA contributed significantly to technological advances), further improvements in engine and airframe efficiency seem likely to reduce fuel consumption per revenue-passenger-kilometer by about 1 percent per year for the next 15 to 20 years.
- New airframe technologies have the potential to reduce current fuel consumption by 25 percent, and new engine technologies could provide an additional improvement of 15 percent over the next 15 years (consistent with a NASA program goal to reduce CO2 emissions with engine technology).
- NASA's ERA Project[79] is conducting research into technologies and integrated aircraft systems that will allow commercial aircraft to simultaneously reduce noise, emissions and fuel burn in the 2025 (or beyond) time frame. Based on a range of potential airframe and engine technology advancements, NASA has established a goal of reducing fuel burn by at least 50 percent over a 1998 new-build reference case aircraft. NASA anticipates that the goal will be met through a combination of airframe, engine, and integrated vehicle efficiency improvements, including the use of unconventional airframe configurations, alternative engine cycles, and alternative fuels. If alternative fuels are used in the design, differences in fuel characteristics (e.g. energy density, and therefore fuel tank volume) are considered. The energy used does not include the energy required to manufacture, refine, transport, or store the fuel prior to being loaded onto the aircraft.

Aviation Fuel Carbon Intensity

An MIT Report[80] on alternative "drop-in" jet fuels evaluated potential reductions in life-cycle GHG intensity of jet fuel. It evaluated 14 different fuel

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[78] Committee on Aeronautics Research and Technology for Environmental Compatibility, National Research Council. For Greener Skies: Reducing Environmental Impacts of Aviation. Pages 30-31. Available at: https://www.nap.edu/catalog/10353/for-greener-skies-reducing-environmental-impacts-of-aviation

[79] NASA Environmentally Responsible Aviation (ERA) Project. January, 2010. Available at: https://www.nasa.gov/aeroresearch

[80] Stratton, Russel, et al. Massachusetts Institute of Technology. "Life Cycle Greenhouse Gas Emissions from Jet Fuels." PARTNER Project 28 Report. Version 1.2. June 2010. Available: http://web.mit.edu/aeroastro/partner/reports/proj28/partner-proj28-2010-001.pdf

pathways with multiple emissions, land use change, and carbon capture and storage scenarios . (See Figure 49, which is from the MIT report).

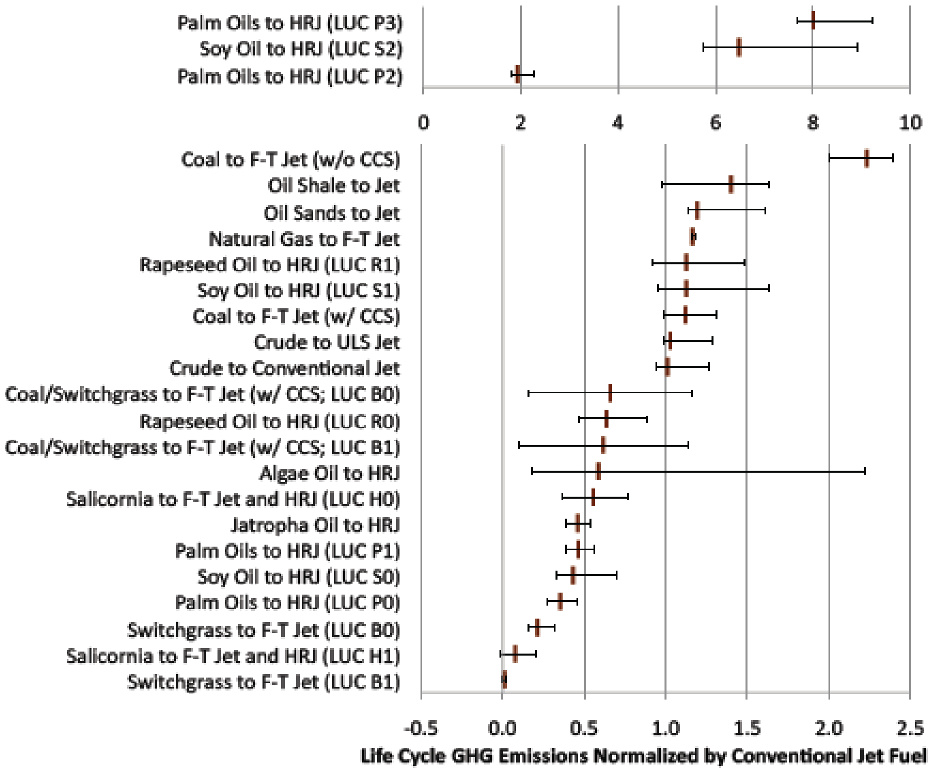

Figure 29: Life cycle GHG emissions for the alternative jet fuel pathways under consideration. Uncertainty bars represent the low emissions, baseline, and high emissions scenarios. Please note the different scales for the top and bottom portions of the figure. Note: CCS denotes Carbon Capture and Storage and Land Use Change (LUC) scenarios are defined in Table 96

Figure 49. Life Cycle GHG Emissions for the Alternative Jet Fuel Pathways

The report concluded that:

“If appropriate renewable feedstocks were used, both Fischer-Tropsch (F-T) fuels and Hydroprocessed Renewable Jet (HRJ) fuel could provide aviation with modest (~10 percent) to large (~50 percent) reductions in emissions that contribute to global climate change.”

However, this is noted within a larger context:

“Aviation is not the only potential user of renewable biomass resources, and it will have to compete for these limited resources. It is critical to continue to examine feedstocks that could be used to create transportation fuels, such as jet fuel, without the need for arable land, with a minimum of fresh water, and with large yields per hectare. The most significant challenge is not in developing viable alternative fuels that could reduce aviation GHG emissions -- the technology exists; rather, the challenge lies in developing and

> commercializing the large scale production of next generation of biomass feedstocks that could be grown in a sustainable manner."

Results:

Using the above data and research conclusions, and accounting for year-by-year changes over time and fleet replacement practices, the following results are estimated. These are based on the following assumptions:

- NASA research begins in 2012;
- A range of targeted efficiency improvements for new aircraft would be achieved by 2025;
- A fleet average reduction in emission rates would be achieved by 2035, based on varying rates of technology adoption.[81]

Post 2035, NASA research is unclear on potential continuing technology advancements and benefits. For the purposes of this analysis, F-T and HRJ fuels are assumed to be included in the emission rate assumptions primarily after 2035. Their incremental effectiveness is based on a 10 – 25 percent improvement, which reflects potential limited access to these fuels.

- 2035 – 45 percent reduction in grams/passenger-mile emission rates (3 – 5 percent of reduction attributed to low carbon fuels)
- 2050 – 70 percent reduction in grams/passenger-mile emission rates (10 – 15 percent of reduction attributed to low carbon fuels)

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[81] EIA's AEO 2011 high-technology case indicates that average emission rate for the passenger aircraft fleet as a whole lags behind new aircraft emission rates by 10 to 15 years. E.g., the fleet average emission rate in 2020 or 2025 would finally be as low as emission rates for new aircraft first appearing in the fleet in the year 2010, due to the slow rate of aircraft turnover in the fleet.

TECHNICAL APPENDIX 5

STRATEGIES, CHALLENGES, AND LEVEL OF EFFORT FOR REDUCING GHG EMISSIONS IN ALL TRAVEL MARKETS

Strategies, Challenges, and Level of Effort for Reducing GHG Emissions in All Travel Markets

Introduction

Technical Appendix 5 includes the strategies for the three travel markets: Ground Passenger and Commercial Services, Freight, and Air Passenger. These strategies are based largely on comments made by the STS Policy Committee throughout the STS development process.

The strategies are grouped under one of the following six categories:

- Vehicle and Engine Technology Advancements
- Fuel Technology Advancements
- Systems and Operations Performance
- Transportation Options
- Efficient Land Use
- Pricing, Funding, and Markets

Each strategy table includes an initial identification (but not an assessment) of potential implementation challenges, as well as the potential trajectory or level of effort that might be required for each factor to substantially reduce greenhouse gas (GHG) emissions to approach year 2050 GHG emission reduction goals related to SB 1059.

For the potential actions (“elements”) for each strategy, refer to Chapter 4: Strategies of the STS report.

It is important to note that only about 19 percent of total Freight travel market GHG emissions occur within Oregon’s borders. In addition, recent and projected economic trends are leading to a much more rapid increase in overall Freight travel market GHG emissions when compared to the Ground Passenger and Commercial Services travel market.

Additionally, it is recognized that there is less ability to substantially reduce emissions in the Air Passenger travel market, relative to the Ground Passenger and Commercial Services travel market due in part to anticipated sustained significant growth in air passenger demand[82]. It is also recognized that the ability

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[82] The Air Passenger travel market reference case assumes a 50% increase in total travel from 2010 to 2050. To accommodate this passenger growth, the Portland International Airport (PDX) 2010 Master Plan Update identifies $1.2 billion in facility upgrades and expansion at PDX

of the state, the Port of Portland, and other airport operators to directly affect airline fleet replacement practices, fuel purchases, pricing, and operations, is potentially quite minimal. The large majority (greater than 75 percent) of potential GHG reductions for the Air Passenger travel market will ultimately be driven by private sector decisions, which can be stimulated or shaped through public policy actions.

While there are several strategies that can be implemented solely by Oregon at a local and statewide level, the most meaningful and effective strategies will require assistance from regional partners and the federal government. It is important to understand that with respect to freight, Oregon cannot “go-it-alone” since that would put the state at a substantial competitive disadvantage.

The trajectory assumptions for all three travel markets are ambitious. Multiple entities will need to be involved in the implementation of these recommended actions and policies including public agencies at various levels of government and the private sector. An underlying assumption of these strategies is that partnerships and collaboration between government and the private and non-profit sectors will be critical to achieving substantial reduction in GHG emissions.

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through 2035. The implementation of the Master plan and associated costs are included within the reference case and therefore not noted in these strategies.

Vehicle and Engine Technology Advancements

Strategy 1 - More Efficient, Lower-Emission Vehicles and Engines

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
Transition to lower emission and fuel-efficient vehicles, enhanced engine technologies, and efficient vehicle designs. ***Ground Passenger/Commercial Services:*** *Transition to vehicles, such as plug-in hybrids, electric cars and alternative fuel vehicles, and encourage the purchase of newer technology vehicles that are more fuel-efficient and/or are not dependent on higher emission fuels.*	**Ground Passenger and Commercial Services** • An important component of increasing the number of fuel-efficient vehicles on the road is the adoption rate of new technologies with cleaner fuels or zero emissions. The adoption rate may be negatively impacted by other factors that lead to fewer miles driven, and thus less wear and tear on vehicles. This would act to extend the amount of time a household keeps a vehicle, creating a potentially less frequent turn-over of vehicles in Oregon overall. • To encourage the purchase of more efficient vehicles, incentives and/or legislative actions may be required. This would require working with automakers and lawmakers to establish incentive programs and continue the research, development, and implementation of these technologies. • Additionally, the shift to more electric vehicles will create greater demand on the electric power generation and distribution systems. This would require working with the energy sector to assure sufficient energy supply. It will also be important to take actions that result in cleaner electric power generation; the STS assumes that the power generation industry also achieves a 75% reduction in GHG emissions, relative to 1990 levels.	• Deployment of an extensive public electric vehicle recharging system is underway in Oregon. • Newly established fuel economy and greenhouse gas standards and manufacturer efforts will greatly increase the fuel efficient vehicle market in the short-term. • Approximately 50% of the vehicles in Oregon are comprised of light trucks. • Over 60% of vehicles in rural areas are light trucks. • Over 50% and 45% of vehicles are light trucks in urban and MPO areas, respectively.	• Approximately 5% of the vehicles in Oregon are electric (includes plug-in electric and hybrid electric vehicles); the number of internal combustion engine vehicles decreases to less than 95 % of the mix of vehicles in Oregon. • The average fuel economy for vehicles in Oregon is 28 miles per gallon (MPG). • The number of light trucks in each type of area in Oregon is reduced by approximately 4% from present light truck proportions.	• The numbers of internal combustion engine vehicles are reduced to 40% of the mix of vehicles in Oregon; the number of electric vehicles increases to 60%. • The average fuel economy for vehicles in Oregon is 53 MPG. • The number of light trucks in each type of area in Oregon is reduced by approximately 14% from present light truck proportions.	• Approximately 95% of vehicles in Oregon are electric or hybrid electric. • The average fuel economy for vehicles in Oregon is approximately 60 MPG. • The number of light trucks in each type of area in Oregon is reduced by approximately 30% from present light truck proportions. The reduction in light trucks is greater in rural areas because increasing fuel prices will impact the longer travel distances of rural drivers, encouraging a shift to more fuel efficient and smaller vehicles.

Vehicle and Engine Technology Advancements

Strategy 1 - More Efficient, Lower-Emission Vehicles and Engines

Strategy	Challenges	Trajectory / Notes			
		2010	**by 2020**	**by 2035**	**by 2050**
Transition to lower emission and fuel-efficient vehicles, enhanced engine technologies, and efficient vehicle designs. ***Ground Passenger/Commercial Services:*** *Transition to vehicles, such as plug-in hybrids, electric cars and alternative fuel vehicles, and encourage the purchase of newer technology vehicles that are more fuel-efficient and/or are not dependent on higher emission fuels.*	**Ground Passenger and Commercial Services, continued** • The shift to natural gas vehicles for many commercial service vehicles requires the development of natural gas fueling infrastructure. The use of renewable natural gas will require the installation of collection and processing equipment at potential collection locations such as sewage treatment plants.	• Natural gas vehicles are a very small percentage of commercial fleets.	• Natural gas vehicles make up about 5% of commercial vehicles that are not electrically powered.	• Natural gas vehicles make up about 40% of commercial vehicles that are not electrically powered.	• Natural gas vehicles make up almost all of commercial vehicles that are not electrically powered.

Vehicle and Engine Technology Advancements

Strategy 1 - More Efficient, Lower-Emission Vehicles and Engines

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Transition to lower emission and fuel-efficient vehicles, enhanced engine technologies, and efficient vehicle designs. ***Freight:** Support industry transition to more efficient engine technologies, alternative fuel technologies, vehicle designs, and rail car/truck trailer, barge, and car designs.*	**Freight** • Requires partnerships through federal agencies or multi-state collaboratives like the Western Climate Initiative (WCI) to ensure there is adequate market pressure and incentive for more aggressive technologies to be adopted. • Higher vehicle capital costs may lead to additional shipping market consolidation. • High research and development costs. • Higher shipper capital costs may be passed onto consumers. • Long-term GHG emissions reductions since it takes time for fleets to turn over. • Requires the wide deployment of LNG fueling infrastructure.	• LNG and heavy-duty hybrid-electric vehicle engines already available in the market. • New heavy-duty engine efficiency standards introduced by US EPA in 2011.	• Higher adoption rates of SmartWay and other trailer and train car efficiencies in the short-term. • Begin implementing full cost pricing as described in Tolling and Pricing section.	• Develop full LNG or alternative fueling network. • Engine and powertrain technologies ~~that~~ are 25% more efficient for trucks, trains, and ships. • Implement full cost pricing as described in the Tolling and Pricing section.	• Aim for 100% penetration of freight engine/ powertrain designs that are at least 35 % more efficient than existing technologies. • GHG emissions efficiency per ton-mile of goods movement is doubled compared to existing conditions.
Transition to lower emission and fuel-efficient vehicles, enhanced engine technologies, and efficient vehicle designs. ***Air Passenger:** Support aircraft and engine advancements that result in operational efficiency and lower emissions.*	**Air Passenger** • The 2012 FAA reauthorization bill has maintained and in some areas increased funding opportunity for aircraft technology and fuel research programs; however, funding amounts are still below pre-2001 levels. • Research outcomes, new aircraft model characteristics, and airline fleet replacement schedules are outside the purview of ODOT and are driven by economic and cost effectiveness considerations.		• Less than 5% impact on CO2e per passenger mile emission rates (most gains are through aviation system strategies, through 2020 - widespread fleet replacements to next generation aircraft will mostly occur later this decade and early 2020s).	• Combined 40-42% reduction in grams CO2e per passenger mile emission rates.	• Combined 50-55% reduction in grams CO2e per passenger mile emission rates.

Fuel Technology Advancements

Strategy 2 – Cleaner Fuels

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Support development of cleaner fuels, including reduction of the carbon intensity of fuels.	**Ground Passenger and Commercial Services** • Technological, market-based and regulatory challenges exist that could slow the rate at which cleaner, lower-carbon fuels become widely available. For example: - Cost-effective (e.g., without subsidy) mass production of non-petroleum based fuels requires further technological developments. - Extensive distribution systems, even for existing lower-carbon fuels such as natural gas and electricity, will need to be developed to accelerate adoption of alternative fuel vehicles. - Regulatory and technical changes may both be required to achieve the large reduction in GHG emissions from electrical power generation that is a critical component of the Ground Passenger and Commercial Services sector Vision Scenario.		• The average carbon intensity of fuels (e.g., amount of GHG emissions per gasoline-equivalent gallon) is reduced by almost 10% from today's level.	• The average carbon intensity of fuels is reduced by 20% from today's level.	• The GHG emissions from electricity production are reduced by 75% from 1990 levels.

Fuel Technology Advancements

Strategy 2 – Cleaner Fuels

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
Support development of cleaner fuels, including reduction of the carbon intensity of fuels.	**Freight** • High capital cost for new fuel networks (e.g., LNG). • High research and development costs. • Freight will have to compete for limited low-carbon fuel resources. • Further research required of feedstocks that could be used to create fuels with minimal need for arable land and water, and with large yields per acre. • Significant challenge in developing and commercializing the large scale production of next generation of biomass feedstocks. • A certification program may be required to perform a full life-cycle analysis of fuel carbon content. • It is likely that widespread availability of biofuels for freight most likely occurs beyond 2035.	• B5 bio diesel is available in some areas. • LNG Fueling stations (largely private access) already exist in several Oregon communities.	• 10% reduction in fuel carbon intensity. • Develop LNG or alternative fueling network along busiest freight corridors.	• 20% reduction in fuel carbon intensity.	• 30% reduction in fuel carbon intensity.
Support development of cleaner fuels, including reduction of the carbon intensity of fuels.	**Air Passenger** • Aviation will have to compete for these limited resources. • Further research required of feedstocks that could be used to create fuels with minimal need for arable land and water, and with large yields per acre. • Significant challenge in developing and commercializing the large-scale production of next generation of biomass feedstocks. • It is likely that widespread availability of biofuels for aviation is most likely 2035 and beyond.			• Biofuels reduce emissions per mile an additional 3-5% over aircraft and engine technologies.	• Biofuels reduce emissions per mile an additional 15-20% over aircraft and engine technologies.

Systems and Operations Performance

Strategy 3 – Operations and Technology

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Enhance fuel efficiency and system investments, and reduce emissions by fully optimizing the transportation system through operations and technology. ***Ground Passenger/Commercial Services:** Enhance the network through optimization techniques and deploy Intelligent Transportation System (ITS) technology to enhance fuel efficiency and reduce emissions.*	**Ground Passenger and Commercial Services** • Overall there are limited funds for infrastructure improvements, including ITS/technology solutions. Funding would need to be sought. • The strategy for enhanced operations includes an element on reduced speed limits on highways; however, recent proposals in the Oregon Legislature indicate some degree of public preference towards raised speed limits, not lowered. • Another important element of this strategy is eco-driving. It is most likely that eco-driving would be promoted by providing improved information and driver education. Automakers can assist by providing improved driver feedback (such as real time fuel economy information) Rising fuel costs may also provide incentives for drivers to practice eco-driving techniques. Success will depend on the ability to encourage voluntary action. • Also considered as an element of enhanced ITS is the deployment of autonomous vehicles. The cost of implementing a transportation system for autonomous vehicles is largely unknown, but current progress in research is significant; future updates to the STS will be able to include greater information about viability, cost, timing and impact of autonomous vehicle systems on GHG emissions.	• Only a small percentage of drivers in Oregon are estimated to practice eco-driving.	• Approximately 30% of drivers in Oregon practice eco-driving.	• Approximately 60% of drivers in Oregon practice eco-driving.	• Approximately 70% of drivers in Oregon practice eco-driving. • By 2050, 95% of freeway miles have ramp metering and incident management; 95% of the arterial street systems have coordinated traffic signal systems.

Systems and Operations Performance

Strategy 3 – Operations and Technology

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Enhance fuel efficiency and system investments, and reduce emissions by fully optimizing the transportation system through operations and technology. ***Freight:*** *Regulate operations of freight vehicles at speeds that optimize GHG emissions reductions and provide incentives for technology improvements that provide drivers and operators with real-time information on fuel consumption and operating costs. Encourage idle reduction technologies at ports, freight terminals, and truck stops.*	**Freight** • Cost of speed regulators for trucking industry may delay adoption, especially for smaller trucking companies, until/ unless increases in fuel prices or other actions create financial incentive for them to govern their speeds. • Substantial capital cost to implement. • Technical hurdles with shorepower at ports since regulation of international vessels are not always possible. In addition, no standards currently exist for shorepower. • Works better in partnership with other states/federal government to ensure there is adequate market penetration of idle reduction and auxiliary power technology.	• Speed governors are already fairly commonplace in truck fleets. • Auxiliary power units for trucks beginning to come on the market. • Truck stop remote power is available in Oregon. • Shorepower is available at some terminals at the Port of Portland.	• Consider changing the truck speed limit to minimize truck GHG emissions. • Lobby for national speed limit change. • Encourage the adoption of in-vehicle fuel consumption and cost data to provide additional information to vehicle operators and fleet managers. • 25% of truck parking/long-term idling areas equipped with remote power. • Shorepower is available at all ports that service large container and refrigerated cargo ships. • State facilitates the modernization of local codes to reduce barriers to implementation of vehicle idle reduction electrification.	• Periodically adjust truck speed limit to account for changes in engine efficiency characteristics. • 50% of truck parking/long-term idling areas equipped with remote power. • Shorepower availability increased for ports that service commercial marine ships.	• Periodically adjust truck speed limit to account for changes in engine efficiency characteristics. (same as 2035) • 100% of truck parking/idling areas equipped with remote power. • Shorepower available at ports, where appropriate.

Systems and Operations Performance

Strategy 3 – Operations and Technology

Strategy	Challenges	Trajectory / Notes			
		2010	**by 2020**	**by 2035**	**by 2050**
Enhance fuel efficiency and system investments, and reduce emissions by fully optimizing the transportation system through operations and technology. ***Air Passenger:*** *Deploy efficient operations and maintenance practices and use low- or zero-emission equipment for all airport ground service operations. Accelerate and complete implementation of the FAA “Next Generation” (NextGen) Air Transportation System (ATS).*	**Air Passenger** • The fleet size is significant, with approximately 1000 ground support vehicles at Portland International Airport (PDX). • Require implementing partnerships between airport operator and airlines (generally the owner of most equipment). • Space required for installation of recharging equipment on airport property. ***Flight Operations*** • High implementation cost, complex system deployment, and high risk for implementation delays. • Deployment of *NextGen* is a FAA led activity requiring implementation partnerships with local airports and airlines. • Implementation and training required at smaller, non-operational evolution partnership (OEP) airports (e.g., all airports in OR except PDX). • Airline adoption of new avionics to maximize *NextGen* GPS optimized altitude and routing benefits. ***Ground Operations*** • High implementation cost and continued high risk for implementation delays. • Predominantly, deployment of *NextGen* is a FAA led activity requiring implementation partnerships with local airports and airlines. • Implementation and training at smaller, non-operational evolution partnership (OEP) airports.	• Many of the recommended actions and practices are already being deployed at PDX. • Aircraft ground electrification is fairly common.	• Expand practice to achieve 20% electric/ULEV fleets at all Oregon airports. • 4% CO2e emission reduction for combined in-flight strategies (in-flight emissions represent 95% of all aircraft CO_2e emissions). • 4% CO_2e emission reduction for combined ground. • Aircraft ground electrification available at 25% of airports.	• 50% electric/ULEV fleet at all Oregon airports. • 8% CO_2e emission reduction for combined in-flight strategies. • 10% CO_2e emission reduction for combined ground operation strategies. • Aircraft ground electrification available at 50% of airports.	• 100% electric fleet at all Oregon airports with all recharging power from renewable sources. • Up to 8% CO_2e emission reduction for combined in-flight strategies (longer term CO_2 benefits of *NextGen* will decrease due to expected advances in aircraft engines and low carbon fuels). • Up to 10% CO_2e emission reduction for combined ground strategies (longer-term CO_2 benefits of *NextGen* will decrease due to expected advances in aircraft engines and low carbon fuels). • Aircraft ground electrification available at 100% of airports.

Systems and Operations Performance

Strategy 4 – Airport Terminal Access

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Increase efficiency in all airport terminal access activities, including shift to low- and zero-emission vehicles and modes for passengers, employees and vendors.	**Ground Passenger and Commercial Services, Air Passenger** • Ground access activity will grow commensurate with air passenger travel, which is expected to outpace average annual non-air passenger VMT growth. • Extending carbon-efficient access modes and vehicles to airports outside of PDX will be a long-term effort depending on airport location, the suitability and effectiveness of public transit access and changes in parking policies will vary.	• Many of the recommended actions are in place or being implemented at PDX.	• 8% reduction in all ground access vehicle emissions at Oregon airports compared to 1990.	• 30% reduction in all ground access vehicle emissions at Oregon airports compared to 1990.	• 75% reduction in all ground access vehicle emissions at Oregon airports compared to 1990.

Systems and Operations Performance

Strategy 5 – Parking Management

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Promote better management and use of parking in urban areas to support compact, mixed-use development and use of other modes, including – transit, walking and bicycling.	**Ground Passenger and Commercial Services** • Restricting the quantity of parking or raising prices of parking at commercial and retail establishments may be politically challenging, especially in suburban and small urban communities. This would require implementation of programs such as shared parking at mixed-use developments or more stringent parking supply where alternative modes exist. Additionally, this would require development and changes to codes and policies. • It is assumed that larger urban areas, with high employment densities, will have higher parking pricing where spaces are at a premium. The trajectory notes provided here are for MPO areas, but the strategy of parking pricing is for all urban areas.	• Approximately 15% of workers pay the average daily rate of parking of $5 in large MPO areas and 5% of workers pay $3 in medium MPO areas. Very few workers pay for parking in smaller MPO areas.	• Approximately 20% of workers pay the average daily rate of parking of $6 in large MPO areas and 10% of workers pay $3 in medium MPO areas. Very few workers pay for parking in smaller MPO areas.	• Approximately 30% of workers pay the average daily rate of parking of $9 in large MPO areas and 10% of workers pay $5 in medium MPO areas. Less than 5% of workers pay $2 smaller MPO areas.	• The average parking pricing is about 3 times higher than current rates, with parking rates as high as $15/day in large MPOs (50% workers pay parking), $7 in medium MPO areas (25% workers pay parking), and $5 in smaller MPO areas (15% workers pay parking).

Systems and Operations Performance

Strategy 6 – Road System Growth

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Design road expansions to be consistent with the objectives for reducing future GHG emissions by light duty vehicles.	• In the short- to mid-term, programs to reduce demand and increase operational efficiency may not keep pace with growing population and income. That could lead to increases in congestion and delay depending on the availability of alternative modes to help support increased passenger demand.		Expand road capacity strategically to match population growth and alleviate severe congestion.	Expand road capacity strategically to match population growth and alleviate severe congestion.	Expand road capacity strategically to match population growth and alleviate severe congestion.

Transportation Options

Strategy 7 – Transportation Demand Management

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Support and implement technologies and programs that manage demand and make it easier for people to choose transportation options.	**Ground Passenger and Commercial Services, Air Passenger** • There is a lack of incentives or regulations encouraging many employers to take part in TDM programs. This would require working with employers to develop comprehensive commute option programs. • Likely requires public incentives to implement remote conferencing or work-center strategies to improve private sector cost effectiveness and willingness to adopt. • May also reduce travel demand for future deployment of high-speed rail.	• Approximately 5-20% of urban area employees participate in TDM programs. • Approximately 5% of urban area households participate in TDM programs.	• Approximately 5-30% of employees in urban areas participate in TDM programs. • Approximately 5-30% of households in urban areas participate in individualized TDM marketing programs. • Incremental improvements in the short-term could reduce business travel demand from what it would otherwise be[83] up to 15%.	• Approximately 15-40% of urban area employees participate in TDM programs. • Approximately 10-70% of urban area households participate in individualized TDM marketing programs. • Widespread availability and acceptability of telecommunications as an alternative to in-person meetings, such that up to 66% of business travel activity would be replaced by existing and new technologies[84]	• Approximately 25-50% of employees in urban areas participate in TDM programs. • Approximately 20-80% of households in urban areas participate in individualized TDM marketing programs. • Telecommunications: Same as 2035.

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[83] Business travel demand would grow from today's level even with TDM measures.

[84] Based on World Wildlife Fund report, Workplace to Anyplace – Assessing the Global Opportunities to Reduce Greenhouse Gas Emissions with Virtual Meetings and Telecommuting. 2009. assets.panda.org/downloads/wwfteleworking.pdf

Transportation Options

Strategy 8 – Intercity Passenger Growth and Improvements

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
Promote investment in intercity passenger public transportation infrastructure and operations to provide more transportation options that are performance- and cost competitive.	• Cost and implementation barriers include track geometry and right-of-way issues that could make service above 110 mph difficult to achieve. • High upfront capital investment cost, estimated up to $2.2 billion (current dollars) for Eugene to Portland only. • Notable mode-shift from air to rail will only occur with full corridor system improvement, which requires partnerships across state and national boundaries.		• Incremental geometry and operational corridor improvements to increase average speeds and reduce delay. • Increased inter-city public transportation services (e.g., increased bus or rail service along major existing corridor, establish service where needed to connect major population centers and job centers).	• Corridor improvements allow average maximum operating speeds of 110mph. • Increased inter-city public transportation services.	• Further additional improvements in the corridor, including new right of way/new alignment in some sections, would be required to achieve true high-speed service (140mph or greater) in the long-term. • High-speed rail services (between Eugene and Vancouver, BC) divert short-haul passenger trips from air to rail up to 30%. • Increased inter-city public transportation services.

Transportation Options

Strategy 9 – Intracity Transit Growth and Improvements

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Investing in public transportation infrastructure and operations to provide more transportation options and help reduce single-occupancy vehicle travel.	• Current revenue is very limited for transit operations and somewhat limited for infrastructure investments. Federal revenue projections show a drop in the availability of overall transit funds. Alternative sources of funding would need to be explored. • Some existing routes are not at capacity in terms of ridership. Where capacity is not met, ridership rates need to be increased. • In general, there are limited transit service options within/to/from rural areas. • The success of intra-city transit is dependent on land use configurations and needs to be closely coordinated with land use plans.		• Funding sources developed to enable public transit service to be regularly expanded to service greater populations and a greater proportion of trips.	• The number of bus equivalent revenue miles per capita in the Portland metropolitan area is about 2 times the current level. • The number of bus equivalent revenue miles per capita in other metropolitan areas grows substantially at rates depending on present service levels (1.25-6 times current levels) • Intercity transit (bus or rail) service increases.	• The number of bus equivalent revenue miles per capita in the Portland metropolitan area is similar to that of the current San Francisco/ Oakland area (approximately 3.5 times the current level). • The number of bus equivalent revenue miles per capita in other metropolitan areas is at levels that are as high as the highest levels present in comparably sized urban areas in the U.S. (1.5 to 10 times current levels). • Intercity transit (bus or rail) service increases by at least double along major corridors.

Transportation Options

Strategy 10 – Bicycle and Pedestrian Network Growth

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Encourage local trips, totaling twenty miles or less per round-trip, to shift from single-occupant vehicle (SOV) to bicycling, walking, or other zero-emission modes.	**Ground Passenger and Commercial Services** • Building infrastructure to facilitate and support bicycling and walking is sometimes constrained due to limited dedicated funding. Funding options including more flexibility in use of existing funding sources would need to be explored. • While there is an interest to promote zero-emission technological innovations such as personal electric vehicles (PEV) such as electric bicycles, infrastructure costs to support a PEV network may be substantial. • Overall, the ability to shift trips is related to land use and the availability of transportation options, both of which could potentially be limited depending on each jurisdiction's flexibility in changing land use patterns and in providing suitable infrastructure.	• Across the state less than ~~5~~ 10% or less of the mileage in short SOV trips have shifted from SOV to bicycling or similar modes.	• From 7% to 15% of the mileage in short SOV trips shift to bicycling or similar modes.	• From 15% to 30% of the mileage in short SOV trips shift to bicycling or similar modes.	• From 30% to 40% of the mileage in short SOV trips shift to bicycling or similar modes.

Transportation Options

Strategy 11 - Carsharing

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Enhance the availability of carsharing (short-term self-service vehicle rental and/or peer-to-peer) programs to reduce the need for households to own multiple vehicles and to reduce household vehicle miles traveled.	**Ground Passenger and Commercial Services** • It is anticipated that there will be a higher percentage of carsharing participation in urban areas, correlated with density. • One challenge is how to integrate the supply of carsharing vehicles with transit networks, to ensure these programs adequately fill mobility needs.[85] • In order for personal vehicle carsharing (peer-to-peer carsharing) programs to operate, liability insurance issues must be addressed to avoid prohibitively high insurance costs for car owners whose vehicles are used in peer-to-peer carsharing programs.[86]	• Carsharing programs already exist in cities such as Portland, Salem, and Eugene; however, less than 1% of households in Oregon participate in these programs. • Adopted legislation establishes standards for personal vehicle sharing (peer-to-peer sharing).	• Approximately 1% of urban households (depending on community density) participate in carsharing.	• Approximately 2-4% of urban households participate in carsharing.	• Between 2-12% of urban households participate in carsharing.

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[85] This challenge was summarized in a TRB Research Need Statement from 2008 entitled “Next Steps for Car-Sharing: Strategies, Challenges, and Impacts.” Retrieved from https://rns.trb.org/dproject.asp?n=19046

[86] Oregon House Bill 3149, which sets standards for personal vehicle carsharing, was passed by the Oregon House of Representatives on March 21, 2012 with a vote of 47-10.

Transportation Options

Strategy 12 – More Efficient Freight Modes

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
For the commodities and goods where low-carbon modes are a viable option, encourage a greater proportion of goods to be shipped by rail, water, and pipeline modes.	• Many commodity types are not amenable to being shipped by other modes. • There are few modal options for in-state freight shipment. • Considerable capital costs associated with major capacity expansions of rail, marine, and pipeline networks. • Considerable competition among ports and among shippers; can be difficult to induce a shift without price signal.		• Consider investments to remove bottlenecks for energy efficient modes and efficient routing of international trade.	• Same as 2020.	• Same as 2035. • Long-term inbound domestic freight mode split by ton miles is: o 51% truck o 37% rail o 9% pipeline o 2% air o 1% water/ marine

Efficient Land Use

Strategy 13 – Compact, Mixed-Use Development

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
Promote compact, mixed-use development to reduce travel distances, facilitate use of zero- or low-energy modes (e.g., bicycling and walking) and transit, and enhance transportation options.	• Increasing compact, mixed-use development requires supportive public investments in transit, schools, parks, and streets. Some infrastructure investment will be required to accommodate anticipated population growth, regardless of the STS. It is more a question of what percentage of growth will occur in community centers as opposed to on the periphery, and it is likely that total public infrastructure expenditure per capita would be lower with the compact patterns recommended by the STS. Efforts to promote compact mixed-use development need to address concerns about density, including traffic impacts and access to parks and open spaces. Increases in development will also require changes in local codes to efficiently accommodate development proposals. • Compact growth will require redevelopment of some urban properties and development at higher than current average densities. The mix of available housing types will change and housing prices will increase somewhat.	• On average, approximately 20% of Oregon urban households are living in compact, mixed-use neighborhoods.	• Over 20% of urban households live in compact mixed-use neighborhoods.	• Approximately 30% of urban households live in compact mixed-use neighborhoods.	• Over 30% of urban households in Oregon live in compact mixed-use neighborhoods.

Efficient Land Use

Strategy 14 – Urban Growth Boundaries

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
Create full-service healthy urban areas to accommodate most expected population growth within existing Urban Growth Boundaries (UGB) through infill and redevelopment.	• With an increase in density, there is typically an associated increase in demand for infrastructure (e.g., transit) to serve the population. Availability of infrastructure funds may be limited. (Refer to notes in Strategy 13 – Compact, Mixed-Use Development regarding the total infrastructure costs for compact, mixed-use development.)	• On average, the area within metropolitan area urban growth boundaries expands at about 15% of the rate of metropolitan area population growth.			

Efficient Land Use

Strategy 15 – More Efficient Land Uses

Strategy	**Challenges**	**Trajectory / Notes**			
		2010	**by 2020**	**by 2035**	**by 2050**
Encourage and incentivize more efficient use of industrial land through closer proximity of shippers and receivers, consolidated distribution centers, and better access to low-carbon freight modes.	• Vacant industrial land often faces redevelopment and rezone pressures. • There may be resistance to new industrial development from adjacent property owners. • Brownfields can be expensive to redevelop. • Industrial land adjacent to efficient transportation corridors and facilities may be scarce. • Newer forms of industrial uses such as eco-industrial parks and urban consolidation centers have been difficult to establish, in part due to restrictive land use codes.		• Undertake regional assessments of available industrial lands and prepare strategic plans for establishing location-efficient industrial/ transport hubs and urban consolidation centers. • In the short-term, consider local land use regulations are reviewed and revised to remove unnecessary barriers to efficient industrial development.	• Establish urban consolidation centers in the Portland metro region. • Ensure that adequate industrial land is available near transportation corridors, rail lanes, and ports.	• Ensure that the majority of new industrial development occurs near transportation corridors, rail lanes, and ports.

Pricing, Funding and Markets

Strategy 16 – Funding Sources

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Move to a more sustainable funding source that covers the revenue needed to maintain and operate the transportation system and accounts for the true cost of travel.	**Ground Passenger and Commercial Services** • It may be difficult to build sufficient support for the concept that users should pay the true cost of transportation including those of constructing, maintaining and operating the transportation system, as well as social costs or “externalities” such as pollution. • When levying new fees (e.g., social costs) it is important to clearly communicate what the charges are for and why they are necessary. • There could be concerns about privacy if vehicle location is tracked to assess fees. • If the federal government or neighboring states do not implement a similar fee structure, there may be negative economic impacts to Oregon. Establishing such a multiple-state program would require coordination with federal government and neighboring states.	• A congestion pricing program does not currently exist in Oregon.	• Drivers pay a $0.03 per mile charge when driving in very congested conditions in Oregon. • Approximately 5% of external costs are included in vehicle use fees.	• Drivers pay a $0.15 per mile charge when driving in very congested conditions in Oregon. • Approximately 70% of external costs are included in vehicle use fees.	• Drivers pay a $0.20 per mile charge when driving in very congested conditions in Oregon. • All external costs are included in vehicle use fees.

Pricing, Funding and Markets

Strategy 16 – Funding Sources

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
	Freight • Must be implemented at federal level to avoid interstate commerce issues and loss of Oregon economic competitiveness. • Infrastructure/administration for assessing an externality fee would need to be established. • Any externality fee is likely to face stiff opposition from many stakeholders in the freight community. • Argument that higher costs likely to be passed on to consumers; however, ODOT's initial cost analysis indicates that efficiency gains have the potential to make up the difference in increased fees.		• 20% implementation of the full cost pricing strategy.	• 50% implementation of the full cost pricing strategy.	• 100% implementation of the full cost pricing strategy.

Pricing, Funding and Markets

Strategy 16 – Funding Sources

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
	Air Passenger • A collection mechanism for the carbon fee would need to be developed, with options including levying the fee per gallon, collected at the fueling location, or as a cost per passenger mile, added to the base air fare. • Preferred approach is a national/international solution that creates a consistent carbon trading/pricing scheme (see European Trading Scheme) to avoid difficulty in assigning who pays the fee and how it is collected at the state level. • Would require federal as well as state action, including participation of neighboring states and provinces. • Most states, including California and Washington, exempt commercial aviation from state aviation fuel taxes. • Airlines can choose to purchase fuel elsewhere, reducing potential revenue.		• $30 per metric ton CO_2e translated to a per passenger mile charge. • Implement a $2.75 per passenger roundtrip fuel surcharge (equivalent to a 6 cents per gallon fuel charge).	• $50 per metric ton CO_2e translated to a per passenger mile charge. • Implement a $5.00 per passenger roundtrip fuel surcharge. • 3-times increase in current air passenger facility charges for flights in EUG/PDX to YVR market.[87]	• $70 per metric ton CO_2e translated to a per passenger mile charge. • Passenger roundtrip fuel surcharges same as 2035. • Passenger facility charges similar to 2035.

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[87] Increase in fees consistent with the existing comparative passenger mile carbon emissions impact of regional air travel versus rail (3 to 1) and would be applied in high-speed rail markets.

Pricing, Funding and Markets

Strategy 17 – Pay-As-You-Drive Insurance

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Promote Pay-As-You-Drive Insurance (PAYD) programs that allow drivers to pay per-mile premiums, encouraging less driving through insurance savings.	• Accelerating the onset of widespread PAYD by requiring insurers to offer PAYD insurance would require a legislative mandate. Auto insurers have thus far been slow to provide PAYD insurance policies and may resist a regulatory approach.	• Earlier legislation adopted provided tax credits for corporations providing vehicle insurance for mile-based or time-based rating systems.	• Approximately 20% of Oregon households have PAYD insurance.	• Almost all Oregon households have PAYD insurance.	• All Oregon households have PAYD insurance.

Pricing, Funding and Markets

Strategy 18 – Encourage a Continued Diversification of Oregon's Economy

Strategy	Challenges	Trajectory / Notes			
		2010	by 2020	by 2035	by 2050
Maintain economic prosperity through an increase in the value per ton (the "value-density") of goods produced in the state, which is projected to reduce shipping costs and GHG emissions for any given level of economic output.	• Difficult to spread benefits of new economy to rural areas. • Challenges in training workers for high-value density industry; requires investments in post-secondary education, job training programs, etc. • May require new investments in infrastructure in very rural or congested areas. • Highly competitive recruiting environment between states for high-value density industries. • Slow ramp-up period, long payback period.		• Consider supportive legislation to incentivize high-value density industry.	• Same as 2020.	• Same as 2035: Goal: High-value density industrial growth rate is 100% compared to 27% for low-value density industrial growth.

TECHNICAL APPENDIX 6

WHITEPAPER: COSTS OF MOTOR VEHICLE TRAVEL

Whitepaper: Costs of Motor Vehicle Travel

Prepared for the Oregon Department of Transportation by
Cambridge Systematics, Inc.

Christopher Porter, Principal

October, 2011

The purpose of this paper is to provide guidelines for estimating the costs of motor vehicle travel in Oregon, and to identify the most appropriate methods for allocating each of these costs to drivers (e.g., fuel, carbon, or per-mile taxation). Two general types of costs are considered:

- Transportation system costs – These are the costs associated with constructing, maintaining, and operating the state roadway system (including freeways and arterials, but not local streets).
- Social costs – These are costs to society that are not already paid by motor vehicle drivers. Examples include the costs of air pollution and climate change. They do not include costs that are internalized to drivers either individually or as a group, such as the costs of congestion or crashes.

This paper addresses the assignment of costs through 2050, in support of the Statewide Transportation Strategy under development by the Oregon Department of Transportation (ODOT). The assignment of costs considers, for example, how the costs of building, operating, and maintaining the highway system could be paid by drivers through a fee based on vehicle-miles of travel (VMT), as an alternative to the current system of fuel taxes. External costs could be added to this fee as a way of reflecting the full social cost of driving, or assessed in other ways (e.g., fuel or carbon tax) that is proportional to the cost incurred.

Cost Categories Included

Table 30 shows various cost components that are included in this review, a description of each, and a recommendation for how to assign it to drivers.

Table 30. Cost Categories

Cost Category	Description	Preferred Assignment Method
Transportation System Costs		
Cost of constructing new capacity	Unit costs per freeway or arterial lane-mile for proposed scenarios	Per VMT
Cost of reconstructing highways and bridges	Costs of reconstruction within timeframe	Per VMT
Cost of operating and maintaining the system	Projected costs of transportation system O&M within study timeframe	Per VMT
Other Costs		
Air pollution	Damage to public health, buildings/ materials, agriculture/forestry, and ecosystems	Per VMT
Other resource costs	Other environmental costs, e.g., water and soil pollution	Per VMT
Climate change	Damage value estimates of climate change or control market cost/ton	Per ton CO2, or per unit of fuel (by type)
Energy security	Economic costs of petroleum dependence, including oil shocks, military	Per unit of petroleum fuel
Safety	Crash costs to non-drivers	Per VMT
Noise	Human health and welfare costs from noise	Per VMT

Excluded Cost Categories

Many studies in the literature attempt to estimate costs that are "external" to individual drivers, for the purpose of determining prices that maximize the efficiency of the transportation system. A notable example is congestion pricing, where drivers are charged the cost of lost time that they impose on others. This study is not intended to develop estimates of all costs that are external to individual drivers, but only costs that are external to all drivers as a group.

Therefore, congestion costs, which are incurred by other drivers, are not included.[88]

Most crash costs also are not included, as they are already paid by highway users through insurance premiums or direct payments. Costs external to drivers as a group include pedestrian and cyclist injuries, a portion of property damage and medical costs (external because premiums are lump-sum rather than per-mile), and productivity effects for pedestrians. This paper includes costs to pedestrians and cyclists as discussed in more detail below, but excludes other external crash costs due to lack of data.

Environmental resource costs that are related primarily to the existence of highway infrastructure, rather than proportional to VMT or fuel consumed, are not included. Examples include habitat loss and fragmentation, and water quality degradation due to increased intensity of runoff as a result of impermeable surfaces.

The costs of local roads and on-site parking facilities are also not included. Local roads are funded primarily by property taxes, and therefore drivers do not pay their costs in proportion to use. Some argue that this represents a subsidy to drivers, although others argue that local roads provide necessary access to property regardless of how much the property owner uses them. The cost of on-site parking at commercial properties is also not paid by the driver (except for a few locations such as downtown areas where parking is priced), but is provided by the business and may be indirectly passed on to the customer through the price of goods and services consumed.

Summary of Estimated Unit Costs

Table 31 summarizes estimated unit costs for each cost category, for 2010 and 2030. The 2030 costs are illustrative based on rough VMT, expenditure, and fleet fuel economy forecasts (as described in more detail later in this paper) which should be reviewed and updated. Most costs are presented in cents per mile for light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs). Climate change costs are presented as dollars per metric ton (tonne) of carbon dioxide-equivalent emissions (CO2e) and energy security costs are presented as cents per gallon of petroleum fuel. These costs are also presented in per-mile form, based on 2010 or 2030 projected fuel economy, for direct comparison with other costs. Costs for years between 2010 and 2030, or beyond 2030, will need to be interpolated or extrapolated using appropriate methods.

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[88] Litman (2011 – see p. 5.5-15) argues that there are external costs associated with congestion, but the arguments are not entirely convincing and the available data do not readily support separating external from internal (group) costs. Congestion costs are also highly variant over time and space and would be more appropriately addressed through a congestion pricing framework than through statewide VMT, fuel, or carbon pricing.

It is important to note that there is considerable uncertainty over the valuation of most of the social costs, and a wide range of values is reported in the literature. For example, estimates of the costs of climate change vary by a factor of up to 100, from about 0.04 cents per mile to 4 cents per mile for LDVs in 2010.

Table 31. Summary of Unit Costs (2010$)

	2010 Costs				**2030 Costs**			
	Cents/mi		**$/tonne CO2e**	**Cents/ gal**	**Cents/mi**		**$/tonne CO2e**	**Cents/ gal**
Cost Category	**LDV**	**HDV**			**LDV**	**HDV**		
State Transportation System								
Modernization	0.4	3.1			0.4	3.2		
Preservation + Maintenance	1.0	12.1			1.1	12.7		
Other Transportation System	1.5	4.2			1.6	4.4		
Social Costs								
Air Pollution	1.4	7.5			1.4	2.1		
Other Environmental Resources	0.3	1.0			0.3	1.0		
GHG/Climate Change	1.3	5.0	30		1.6	7.8	50	
Energy Security[1]	2.2	7.4		45	1.7	6.9		45
Crashes	0.5	0.5			0.5	0.5		
Noise	0.1	1.6			0.1	1.6		
Total System	2.9	19.4			3.1	20.3		
Total Social	5.2	22.4			5.1	19.4		
Total, All Costs	**8.1**	**41.8**			**8.2**	**39.7**		

[1]Cents per gallon of petroleum fuel

Figure 50 provides a graphical comparison of the data presented in Table 31. Heavy-duty vehicles incur costs about five times as large as light-duty vehicles on a per-mile basis. Transportation costs and social costs are roughly equal for HDVs, but social costs represent about two-thirds of LDV costs. Preservation and maintenance represents the largest category of transportation system costs. Climate change, energy security, and air pollution (in 2010) represent the largest categories of social costs.

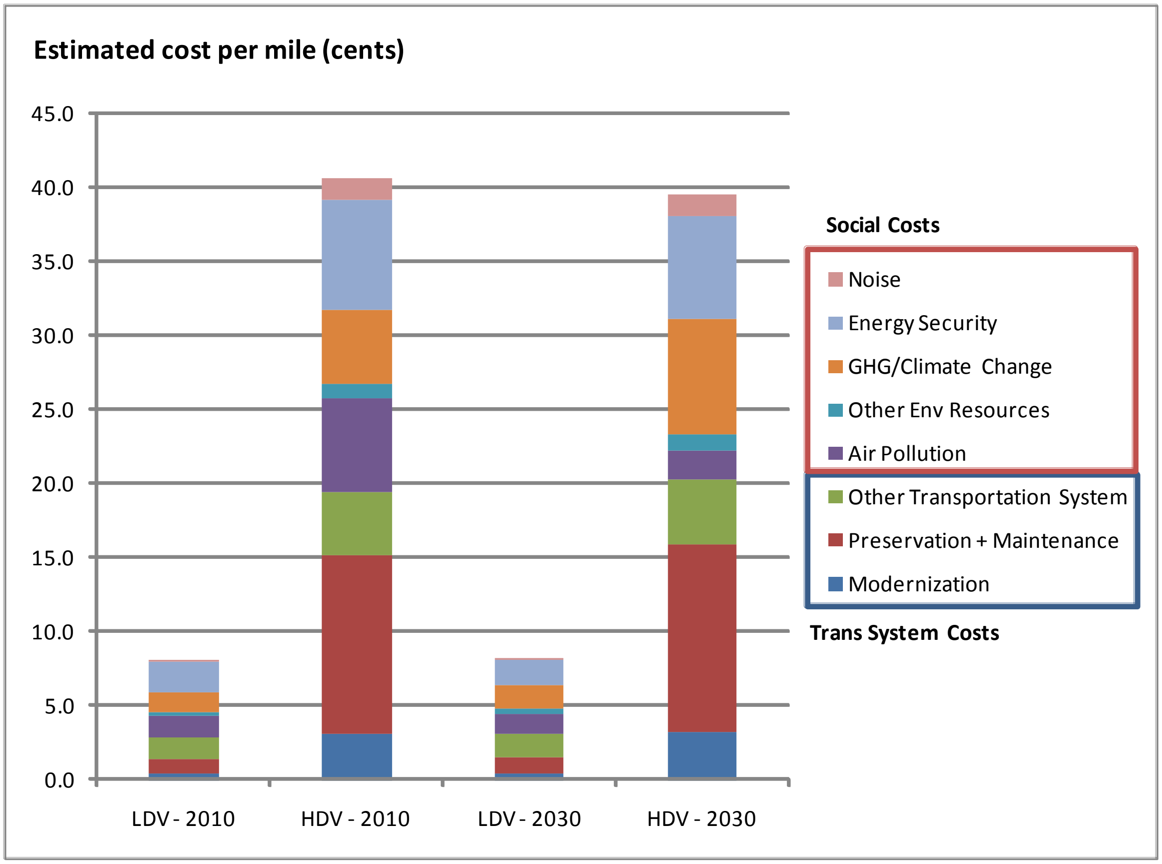


Figure 50. Estimated Unit Costs of Vehicle-Travel in Oregon

Each of the cost categories shown in Table 30 is discussed in more detail below, with data sources presented and key issues discussed. A recommended value (or range of values) is also presented, along with a discussion of how values might be adjusted for future years.

Transportation System Costs

Costs for constructing, operating, and maintaining the state highway system are treated here in three major expenditure categories:

- **Modernization** – New construction or reconstruction, including new facilities, facility expansions (e.g., adding a lane), and reconstruction to improve throughput (e.g., curve straightening).
- **Preservation and maintenance** – Rehabilitation projects such as repaving or bridge reconstruction/replacement; also maintenance (e.g., pothole patching) and operations (e.g., traffic signals).
- **Other** – Administration, planning and project development, safety improvements, bicycle/pedestrian, demand management, and other expenditures.

The Highway Cost Allocation Study (HCAS) prepared by the Department of Administration Services (DAS) is a biannual examination of the responsibility for highway program expenditures across user groups (vehicles by weight class). The study is updated every two years, with the most recent update in 2009. The costs presented in this section are based on data from that study. The HCAS presents a detailed estimate of per-mile charges for heavy vehicles over 26,000 lbs. weight rating, with the objective of establishing fair weight-mileage fees for heavy vehicles. The cost-per-mile estimates presented in this paper are rough average estimates for light and heavy vehicles (less than and greater than 10,000 lb. weight rating, respectively) based on the total expenditure and VMT data presented in this study, and do not reflect cost allocation at the level of detail used to establish these weight-mileage fees.

Table 32 presents average annual highway program expenditures for the FY 2009-2011 Biennium. These are shown by roadway system and expenditure category. Total expenditures are about $1.84 billion, of which $1.57 billion are from state and federal sources.

Table 32. Oregon Highway Program Expenditures by Funding Source, FY 2009-2011 Annual Average ($1,000s)

Expenditure Category	State	Federal	Local	Bond	State + Federal	All
Modernization	$88,374	$140,297	$57,712	$2,834	$228,671	$289,217
Preservation + Maintenance	$372,052	$319,653	$111,525	$26,681	$691,705	$829,911
Other	$450,483	$197,232	$63,187	$5,596	$647,715	$716,498
All Expenditures	**$910,909**	**$657,182**	**$232,424**	**$35,111**	**$1,568,091**	**$1,835,626**

Source: 2009 Oregon Highway Cost Allocation Study, Exhibit 4-5

These estimates can be compared with expenditure estimates from the 2006 Oregon Transportation Plan (OTP), the latest update of the state long-range transportation plan. This plan showed estimated annual expenditures in 2004 of $786 million for the state highway program, which compared with estimated needs of $1.28 billion (Table 31). Expenditures were forecast to grow by 1.35 percent annually.

The 2009 HCAS also shows total statewide VMT by vehicle class and roadway system. Forecast VMT for 2010 (based on actual 2007 VMT), and the respective shares by each vehicle class, are shown in Table 33.

Table 33. Oregon Statewide VMT (2010 projected, millions)

Road System by Ownership	Light Vehicles (<=10,000lb. rating)	Heavy Vehicles (>10,000lb. rating)	Total
State	21,445	2,215	23,660
Local	14,185	539	14,724
Total	**35,630**	**2,754**	**38,384**
Shares			
State	90.6%	9.4%	100%
Local	96.3%	3.7%	100%
All	**92.8%**	**7.2%**	**100%**

Source: 2009 Oregon Highway Cost Allocation Study, Exhibit 4-2

The expenditure estimates combined with the VMT estimates from the HCAS can be used to develop cost per mile estimates for both light and heavy-duty vehicles for 2010. To allocate costs between light and heavy vehicles, the HCAS responsibility estimates specific to expenditure categories are used. These are shown in Table 34. Note that additional expenditure categories are shown compared to the three major categories used in Table 31. Preservation, Maintenance, and Bridge are all included in the “Preservation and Maintenance” category for the purposes of this analysis.

Table 34. Cost Responsibility by Program Category

Expenditure Category	LDV	HDV
Modernization	62.9%	37.1%
Preservation	38.2%	61.8%
Maintenance	61.9%	38.1%
Bridge	45.6%	54.4%
Other	82.1%	17.9%
All Expenditures	**64.5%**	**35.5%**

Source: 2009 Oregon Highway Cost Allocation Study, Exhibit 5-1. “Prior bonds” not shown as a separate category but is included in “all expenditures.”

Table 35 shows the estimated cost per mile for each major category and overall. Table 35 shows the average cost per mile considering all state and Federal funding sources, and for all highway system expenditures including local sources and bonds. The average cost for state and federally-funded expenditures is 2.8 cents per mile for light-duty vehicles and 20.2 cents per mile for heavy-duty vehicles. Considering all funding sources it is 3.3 cents per mile for light-duty vehicles and 23.7 cents per mile for heavy-duty vehicles. These costs are computed by dividing expenditures by *all* VMT in the state for each vehicle class (including both state and local roads).

Table 35. Estimated Average Cost per Mile (¢) by Expenditure Type and Vehicle Class, 2010

	State + Federal Funding		All Funding	
Expenditure Type	**LDV**	**HDV**	**LDV**	**HDV**
Modernization	0.4	3.1	0.5	3.9
Preservation + Maintenance	1.0	12.1	1.2	14.5
Other	1.5	4.2	1.7	4.7
All Expenditures	**2.8**	**20.2**	**3.3**	**23.7**

Source: Calculated based on data from 2009 Oregon Highway Cost Allocation Study as shown above in Tables 32, 33, and 34.

The costs can be compared to weight and distance-based fees for heavy vehicles recommended in the 2009 HCAS. These range from 4.0 cents/mile for the lightest vehicles assessed these fees (26,000 to 28,000 lbs.) to 10 to 14 cents/mile for the heaviest vehicles, which is somewhat lower than the cost estimates shown above. Mileage-based fees are not currently charged to vehicles less than 26,000 lb. so direct comparisons with current fees cannot be made.

These costs can also be compared with (1) an imputed actual cost paid per mile based on forecast annual revenue from state user fees (fuel tax, weight-mile tax, registration fees, title fees, and other fees), and (2) an imputed cost responsibility per mile based on annual responsibility estimates from the HCAS (i.e., what drivers would pay if they covered their entire costs through a mileage-based fee?) As shown in Table 36, the average user fee revenue per mile is 1.6 cents for light vehicles and 10.6 cents for heavy vehicles, while the average annual responsibility is 3.7 cents for light vehicles and 23.5 cents for heavy vehicles. The user fee is considerably lower than the annual responsibility because the user fee does not include federal and local revenue sources. The annual responsibility estimates are close to the average per-mile costs shown in Table 35 considering expenditures from all funding sources.

Table 36. Estimated Average User Fees and Annual Responsibility per Mile

	LDV	**HDV**	**Total**
Forecast Annual User Fees			
Total ($1,000)	$578,351	$291,350	$869,700
Avg. cost/mi (¢)	1.6	10.6	
Annual Responsibility			
Total ($1,000)	$1,304,871	$648,529	$1,953,400
Avg. cost/mi (¢)	3.7	23.5	

Source: Calculated based on data from 2009 Oregon Highway Cost Allocation Study including total fees and responsibility from p. 6-2 and forecast 2010 VMT from Exhibit 4-2.

Recommendations. For base-year per-mile expenditures, we recommend using the values shown in Table 35 for "State + Federal funding." To estimate per-mile costs for future years, expenditures could be increased by 1.35 percent annually, which is the growth rate forecast in the 2006 OTP, or a more recent source of long-term expenditure growth projections. Per-mile costs for future years would then be computed based on VMT growth forecasts for light-duty and heavy-duty vehicles. For this analysis, 2030 costs were estimated based on a VMT growth rate of 1.1 percent for all vehicle types, which is the 2007 – 2010 growth rate used in the 2009 HCAS for LDVs.

It will be important to maintain the breakdown by expenditure type because modernization (expansion) expenditures for future years may vary by scenario for the STS analysis. In this case, the per-mile costs for modernization can be replaced by average costs per new lane-mile added based on ODOT's GreenSTEP model, which will need to be averaged over all VMT.

Social Costs

Air Pollution

Evidence from the literature. Costs associated with air pollution from motor vehicles include public health (mortality and morbidity), building and material damage, and environmental resource damage, including lost agricultural and forest productivity and ecosystem service values. A few studies have conducted in-depth research into these costs, with others summarizing evidence from the literature. Estimating the costs of air pollution involves developing estimates of emissions, translating these into changes in air pollutant concentration, estimating changes in population exposure, identifying damages associated with changes in concentrations and exposure, and then identifying the monetary value of this damage. Parry et al. (*2006*) notes that air pollution damages appear to be dominated by mortality effects, especially those from particulate emissions. In addition, not all of the studies in the literature estimate environmental damage costs.

Probably the best known work on the costs of air pollution is by Mark Delucchi and colleagues at U.C. Davis (*published in 1996 and since updated*). More recent work includes that of Muller and Mendelsohn (*2007*), and a 2009 National Research Council (NRC) study. The NRC study uses damage values per ton from Muller and Mendelsohn, combined with emissions estimates by county, to develop national per-mile estimates of emission damage values for both 2005 and 2030 for both light-duty and heavy-duty vehicles. Both the Delucchi and NRC work take a "life-cycle" approach, accounting for emissions associated with the production, refining, and transport of fuels as well as combustion in vehicles. Table 37 compares per-mile estimates of pollution costs from these and other studies.

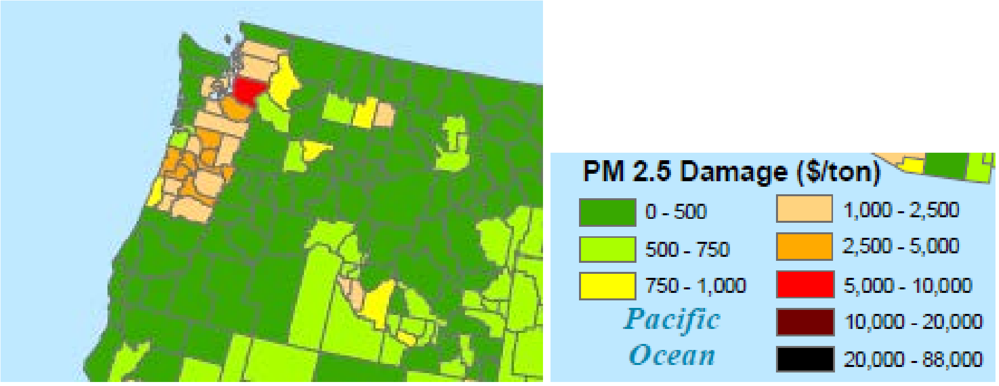
Table 37. Air Pollution Damage Estimates

Source	Units	Costs	Comments
McCubbin and Delucchi (*1996*) per Litman (*2011*)	2007 ¢/VMT	LDGV – 1.3 – 20.5¢ HDDT – 8.6 - 196¢	Health costs only
FHWA (*2000*)	1990 ¢/VMT	Autos – 1.1¢ (1.5¢) LDT – 2.6¢ (3.4¢) HDDT - 3.9¢ (5.1¢)	Health costs only. Values in parentheses are FHWA values in 1990$ inflated by Litman (2011) to 2007$
FHWA (*2000*) per Parry et al. (*2006*)	2005 ¢/VMT	Gasoline-powered vehicles – 2.2¢, range 1.6 – 18.6¢	Based on review of literature
NRC (*2009*)	2007 ¢/VMT	Autos/LDT – 1.3 - 1.4¢ in 2005 and 2030 HDV – 3.2 – 10.1¢ in 2005, 1.2 – 2.6¢ in 2030, depending on vehicle fuel type/class	Somewhat greater for HEV, PHEV and EV (1.5 – 1.6 ¢/mi in 2030) due to higher mfg damages (Table 3.13)

Source: NRC (2009) Tables 3-3 and 3-4.

Note: LDGV = Light-duty gasoline vehicle; LDT = light-duty truck; HDDT = heavy-duty diesel vehicle; HEV = hybrid-electric vehicle; PHEV = plug-in HEV; EV = electric vehicle.

The costs of a given unit of air pollution vary widely over space, due to factors such as population density, local land cover and use, and the relative importance of different emissions (for secondary pollutant formation such as ozone). Muller and Mendelsohn (*2007*) use their Air Pollution Emission Experiments and Policy analysis (APEEP) model to estimate the costs per ton of air pollution at a county level. Their data suggest that the costs of a unit of emissions can vary by an order of magnitude or more across Oregon counties. Figure 51 shows an excerpt of their PM2.5 damage estimates mapped for the Pacific Northwest.



Source: Muller, N., and R. Mendelsohn (2007). "Efficient Pollution Regulation: Getting the Prices Right."

Figure 51. Estimated Benefit of Reducing a Ton of PM2.5 Emissions

Recommendations. All of the estimates shown in Table 31 are broadly consistent with each other, generally showing values in the range of 1 to 4 cents per mile for light-duty vehicles and 3 to 10 cents per mile for heavy-duty vehicles. We recommend using the NRC values as they are the most recent and also have been developed for future as well as base years. An average HDV value of 7.5 cents per mile is estimated based on a distribution of VMT by truck weight class.[89]

The NRC study contains some interesting findings regarding adjustment of future-year costs. While it might be expected that costs per mile should decline in proportion to declining emission rates (as a result of more restrictive emission control standards), this is not necessarily the case. The study finds that damage costs for light-duty vehicles in 2030 are very similar per mile to 2005 values. Lower emission rates per vehicle-mile are offset by increased emissions associated with vehicle and fuel production/manufacture (especially for hybrid and electric vehicles), and also by higher population levels. For diesel vehicles, on the other hand, substantial decreases in PM and NOx emissions mean that damage costs per mile are much lower in 2030 than 2005. Costs for years between 2005 and 2030 can be interpolated. For years beyond 2030, we recommend using the 2030 costs as emissions are likely to have stabilized by then (at least considering current regulations) and further changes in vehicle technology and life-cycle emissions impacts are difficult to anticipate.

Uncertainties. There are substantial uncertainties throughout the process of valuing air pollution damages, including translating emissions into pollutant concentrations, concentrations into exposure, exposure into health and other impacts, and monetary valuation of these effects. The NRC study notes that some damages are not currently quantifiable and therefore were not included (e.g., air toxics, ecosystem damage); and that the methodology assumes that all vehicles meet but do not exceed emission standards. If average vehicle emissions are greater than the standard (e.g., due to deterioration of emission control equipment), damage costs per mile will be greater.

Other Environmental Resources

Other environmental resource costs include water and soil pollution, wildlife mortality, and ecosystem/habitat loss and fragmentation.

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[89] The NRC study provides damage estimates for truck classes based on weight and fuel type as used in EPA's MOBILE6 model, including weight classes 2A and 2B, 3, 4, 5, 6, 7, 8A, and 8B. The only available estimates of VMT by this weight class typology appear to be at least 10 years old, as this classification is not used in FHWA's VMT reporting or in EPA's new MOVES model. The value here should therefore be considered illustrative.

Water and soil pollution have elements that are directly related to vehicle/fuel use, as well as other elements that are not directly related. These elements include:

- Proportional to vehicle/fuel use: hazardous fluid leakage from vehicles, toxic metals in runoff, oil spills;
- Not directly proportional to vehicle/fuel use: road salt, pesticides, storm water/ hydrology/wetlands.

Table 38 shows estimates of VMT and fuel use-related water/soil resource damage costs from the literature, as reported by Litman (*2011*). These costs are not broken out separately for light-duty vs. heavy-duty vehicles.

Table 38. Water and Soil Resource Cost Estimates

Source	Impacts	Cost (2007 ¢/VMT[a])	Comments
Miller and Moffett (*1993*)	Leaking tanks, spills, road deicing	0.2¢	$ year not specified
KPMG (*1993*)	External water pollution	0.25¢	$ year not specified
CEC (*1994*)	Major petroleum spills	0.02¢ (0.4¢/gal)	
Lee (*1995*)	Uncompensated oil spills	0.1¢	$ year not specified
Bein (*1997*)	Pollution and hydrologic	3.0¢	Canadian study
Bray and Tisato (*1998*)	Pollution	0.3¢	Australian study
Delucchi (*2000*)	Oil – leaking tanks, spills, and runoff	0.05¢	Midpoint value, 1991 USD

Source: Litman (2011).
[a] Costs from original study were converted into 2007 U.S. dollars by Litman, except where noted. Full references for the sources presented here were not reviewed and can be found in Litman

Costs associated with ecosystem/habitat loss and fragmentation are primarily “fixed” costs, i.e., associated with the amount of roadway infrastructure built, rather than the total distance driven. Therefore they are not included in this paper.

Recommendations. The cost estimates for water and soil resources show a range of less than 0.1 cent per mile to as high as 3.0 cents per mile**.** However, the studies vary widely as to which damages they include, and most include only a subset of damages. A cost in the range of 0.3 to 1.0 cents per mile is probably reasonable as an order-of-magnitude estimate for all costs in this category. For this estimate, 0.3 is used for light-duty vehicles and 1.0 for heavy-duty vehicles under the assumptions that impacts are roughly proportional to fuel use. Since a large portion of these costs appear to be related to petroleum, an argument could also be made for associating a cost per gallon of fuel rather than per mile, although the literature for the most part does not break out the costs this way.

There is not a clear basis for adjusting these costs for future years. Petroleum-related costs may decline as fuel efficiency improves and non-petroleum vehicles are introduced, but there are likely to be resource impacts associated with alternative fuels production and use as well. Given the wide range of cost estimates and limited study of these types of costs we recommend not making adjustments for future years.

Greenhouse Gas Emissions and Climate Change

The costs of greenhouse gas emissions include damage to both the human and natural environment from increasing (or changing) temperatures, and other changes to weather patterns such as more or less precipitation and increases in severe weather. Given the substantial uncertainty in our understanding of the magnitude and specific impacts of climate change, as well as the long-term nature of effects, the valuation of damage due to climate change is by nature highly uncertain. Even assumptions such as the choice of an appropriate discount rate have a large effect on the magnitude of the estimates.

An alternative method of valuing the damage caused by climate change ("damage cost") is to estimate the cost of controlling emissions at a set level ("control cost"). Control cost is a particularly appealing alternative in the case of climate change, where the science suggests that emissions must be reduced to a given level to avoid substantial irreversible damage. If the proper emissions level can be set, the control cost can be estimated through economic modeling.

Table 39 presents estimates of damage costs ($/tonne CO2e) reported from the literature since 2000. The NRC (*2009*) recently performed a relatively comprehensive review of the estimates of the damage costs of climate change. The study finds that the range of estimates of marginal damages of carbon dioxide-equivalent emissions (CO2e) spans two orders of magnitude, from about $1 to $100 per metric ton (tonne), based on current emissions. The study suggests that approximately one order of magnitude in difference is attributed to discount-rate assumptions, and another order of magnitude to assumptions about future damages from emissions (p.305).

Table 39. Damage Costs of Greenhouse Gas Emissions ($/tonne CO2e)

Study	Lower	Mid	Upper	Secondary Source[a]	Comments
IPCC (*2001*)	$20		$100	Litman	Non-tropical regions
Tol (*2005*)	-$4	$12	$59	Litman	NRC 2009 reports range of $0-6 from this source
Jakob, Craig, and Fisher (*2005*)		$178		Litman	
DLR (*2006*)	$17	$78	$310	Litman	
Stern (*2007*)		$36	$102	NRC 2009	1.4% discount rate
Nordhaus (*2008*)		$8		NRC 2009	Emissions in 2005. 4.5% discount rate
Hope and Newbery (*2008*)	$1-17	$4-60	$21-284	NRC 2009	Low, central, high = different discount rates (4.5, 3, 1.5%). Could be same source as DLR (*2006*)
NRC (*2009*)	$10	$30	$100		Committee ranges based on review of literature
EPA/NHTSA (*2010*)	$5 (2010) - $16 (2050)	$22 (2010) - $46 (2050)	$36 (2010) - $66 (2050)		For 5%, 3%, and 2.5% discount rates, respectively; damage value of emissions in given year, increasing over time

[a]Note: Some of these results are reported from secondary sources and the values have not been verified by checking the primary source. Results from Litman are expressed in 2007 USD as converted by Litman. Sources in this table not listed in the "References" section were not directly reviewed in this study; full citations can be found in Litman.

Estimates of control costs (based on the market price for carbon in trading markets) also are in the range of $10 to $100 per tonne. The $10/tonne figure is typical of near-term prices for voluntary or partial markets, such as early carbon purchases in advance of the California/Western Climate Initiative (WCI) Cap-and-Trade market, as well as low price estimates for the 2020 to 2030 time frame.[90] Mid-range price projections in the range of $30 to $50 per tonne are typical for 2020 to 2030 time frame with mandatory carbon markets, with high projections of up to $80 or $90 per tonne. Control costs increase in future years as emissions limits become progressively more restrictive. Recent estimates from the literature are shown in Table 40.

Table 40. Greenhouse Control Cost Estimates ($/tonne CO2e)

Year	Stern (*2006*)	SEC (*2008*)	WCI (*2010*)	NPPC (*2010*)
2010		$16		
2015	$35 - $72			
2020		$42	$13 /$33/$50	
2025	$18 – $50			
2030		$71		$10/$47/$80
2050	-$45 - $90	$133		

Sources: Stern and SEC as reported in Litman (2011); values in 2007 USD converted by Litman. WCI is based on original economic modeling, values in 2007 USD. Power Council is reported range from literature, with $47 taken as average cost. (Three values shown for sources represent low, midrange, and high estimates.)

Recommendations. The most logical way to price greenhouse gas impacts is by pricing carbon, or by pricing fuel at a rate that is tied to its life-cycle carbon content. A VMT-based fee would need to be adjusted in future years to account for increasing fuel efficiency and decreasing carbon content of fuels. With current light-duty vehicle fuel economy of about 20 mpg, a price of $10 per tonne is about 0.5 ¢/mi, and $50 per tonne is about 2.5 ¢/mi.

The EPA/NHTSA and NRC results shown in Table 39 both represent very recent consensus-based estimates developed by interagency panels or scientific committees. They are therefore recommended as bounds upon the range of values selected. Illustrative values selected here are $30 per tonne in 2010 and $50 per tonne in 2030. It is recommended that costs per tonne increase in future years, reflecting increasing control and damage costs.

Energy Security

Energy-related social costs, aside from climate change and air and water pollution associated with fuel production, are primarily related to oil dependency. These costs include the higher price of oil due to the effects of U.S. demand on

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[90] Based on data in email from Angus Duncan to Brian Gregor, Feb. 2, 2011.

the world market, the risk of oil price shocks (which impact gross domestic product), military expenditures, and costs of maintaining the Strategic Petroleum Reserve. However, Parry et al. (*2006*) report that "analysts usually exclude military spending from computations of the *marginal* external costs of oil consumption, as they are typically viewed as a fixed cost rather than a cost that would vary in proportion to (moderate) changes in US oil imports." The U.S. EPA and NHTSA (*2010*) note that the costs for building and maintaining the Strategic Petroleum Reserve historically have not varied in response to changes in U.S. oil import levels.

Table 41 presents estimates of petroleum dependence costs used by EPA and NHTSA in recent fuel economy rulemakings for both light-duty and heavy-duty vehicles. These are based on a 2008 Oak Ridge National Laboratory (ORNL) study by Leiby, which updated a 1997 ORNL study by Leiby et al. and therefore represents a recent, comprehensive, and peer-reviewed study on the topic.

The mid-range estimate of petroleum dependence costs is about 45 cents/gallon in 2020, with a range of 24 to 74 cents per gallon. Just over 60 percent of this cost reflects the costs of "monopsony benefits," or avoided payments by the U.S. to oil producers in foreign countries that result from a decrease in the world oil price as the U.S. decreases its consumption of imported oil.[91] The remainder represents shocks to the U.S. economy from oil price fluctuations. Costs were projected for 2030 and 2040 as well but show little variation over this time period (less than 5 percent higher). The ranges shown in Table 41 reflect sensitivity analysis for a variety of factors, including the share of world oil flows demanded by U.S. imports, elasticity of U.S. import demand, and gross domestic product (GDP) loss elasticity with respect to oil shock price.

Table 41. Petroleum Dependence Costs (2020)

Cost	Low	Medium	High
Monopsony	$0.10	$0.29	$0.57
Macroeconomic Disruption	$0.08	$0.18	$0.28
Total	$0.24	$0.47	$0.74

Source: U.S. EPA and NHTSA (2010), Table 9-10, based on Leiby (2008). Expressed in $2004 USD.

Recommendations. The most logical way to price petroleum dependence impacts is by price per gallon of petroleum fuel. A VMT-based fee would need to be adjusted in future years to account for increasing fuel efficiency and decreasing petroleum fuel use. We recommend using a value of about 47 cents per gallon as used in the recent EPA/NHTSA fuel economy rulemakings. It is possible that if U.S. petroleum demand is reduced below projections in future

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[91] This is a domestic benefit only, as it is offset by the loss of revenue to oil producers in other countries.

years due to alternative fuels, higher fuel efficiency standards, etc., the marginal cost per gallon of petroleum dependence costs will decrease. However, since military expenditures are not included, and the extent to which such expenditures represent a fixed vs. variable cost is debatable, the midpoint value of 47 cents per gallon is viewed as a conservative estimate of energy security costs.[92]

Crash Costs

Crash costs external to drivers as a group include pedestrian and cyclist injuries, a portion of property damage and medical costs (external because premiums are lump-sum rather than per-mile), and productivity effects for pedestrians and cyclists. Pedestrians and cyclists represent about 13 to 14 percent of total motor vehicle fatalities and about 5 percent of injuries (*NHTSA 2009*).

Most studies have focused on costs external to individual drivers and do not separately break out costs external to drivers as a group. Recent studies put the marginal costs of crashes for the United States (external to individual drivers) at around 2 to 7 cents per mile (*FHWA 1997, Miller et al. 1998, Parry 2004*). This range is about 13 to 44 percent of the average social cost per vehicle mile, which is "broadly consistent with European studies (e.g., *Lindberg 2001, Mayeres et al. 1996*)." (*Parry et al. 2006*) It is not clear what fraction of these costs is external to individual automobile drivers, rather than drivers as a group. However, looking at the fraction of motor vehicle fatalities that are pedestrians or cyclists as an indicator, this fraction would appear to be relatively small (about 10 to 15 percent or less).

Recommendations. Lacking better data, we recommend a crash cost of 0.2 to 0.7 cents per mile, which is the range of 2 to 7 cents per mile multiplied by 10 percent. Ten percent is taken as a rough estimate of the fraction of crash costs incurred by non-motorists, considering both fatality and injury crashes.[93] The midpoint of this range is 0.45 cents per mile. We do not have a basis for assigning a different cost for heavy-duty vs. light-duty vehicles, or for adjusting costs in future years.

Noise

As shown in Table 42, FHWA estimated noise costs as part of their 1997 Highway Cost Allocation Study. Middle estimates for noise costs for passenger cars and light trucks average 0.08¢/mi across both urban and rural roadways. Costs for

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[92] For comparison, Parry (2006) notes that prior to the second Iraq war, oil-related military expenditures were put at anything from $1 to $60 billion per year, or $0.1 to $8.2 per barrel of oil consumption, which represents a range of 0 to 20 cents per gallon.

[93] Fatalities represent only a small percent of total injuries plus fatalities (about 2 percent for pedestrians and 6 percent for all motor vehicle crashes) but impose disproportionately high social costs.

single unit trucks are 0.89¢/mi and for combination trucks are 2.04¢/mi averaged across all roadway types. Noise costs are much lower for travel on rural roads than on urban roads.

Table 42. Estimates of Noise Damage Costs (cents/mile)

Vehicle Class	Rural	Urban	All
Automobiles	0.01	0.14	0.08
Pickups and Vans	0.01	0.13	0.08
Single Unit Trucks	0.13	1.51	0.89
Combination Trucks	0.33	4.74	2.04
All Vehicles	**0.04**	**0.30**	**0.20**

Source: FHWA (1997), inflated from 2000 to 2010 dollars based on the consumer price index.

Recommendations. Noise costs are relatively small compared to most of the other costs discussed in this paper. If noise costs are included, we recommend using the FHWA values averaged over rural and urban roads (inflated to 2010 dollars), with a value of 0.08¢/mile for light vehicles and a value of about 1.6¢/mile for heavy vehicles; this is based on a truck split of 42 percent of VMT by single unit trucks and 58 percent by combination trucks.[94] Future year values should be the same as there is no clear basis for adjusting costs.

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[94] FHWA Highway Statistics 2009, Table VM-1 (entire U.S.) This estimate could be refined with Oregon-specific data on VMT by truck type.

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