COSTS OF MOTOR VEHICLE TRAVEL

White Paper for the purpose of modeling Statewide Transportation Strategy scenarios

The purpose of this paper is to explain how the costs of motor vehicle travel in Oregon will be estimated for the purpose of modeling scenarios for the Statewide Transportation Strategy (STS) for reducing greenhouse gas emissions from the transportation sector. It is being assumed for all scenarios that sufficient revenues will be raised from charges on motor vehicles to pay for the road and highway system assumed. In addition, for some of the scenarios it will also be assumed that motor vehicle use will be charged to account for social costs that accrue due to use. This paper describes how those costs will be estimated and on what basis they will be allocated 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.

Cost Categories Included

Table 1 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 1 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

Cost Category	Description	Preferred Assignment Method
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.[1]

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

[1] 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.

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 2 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.

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.

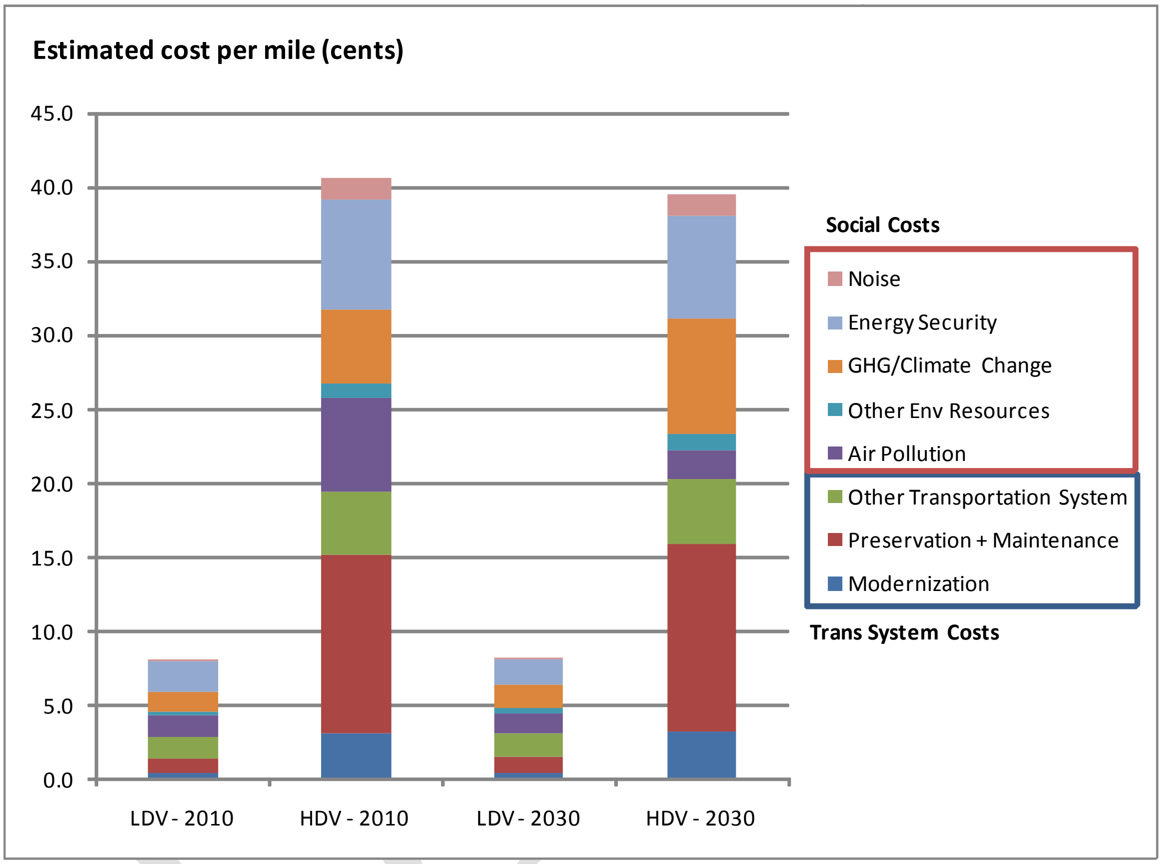
Table 2 Summary of Unit Costs (2010$)

	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 1 provides a graphical comparison of the data presented in Table 1. 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 1 Estimated Unit Costs of Vehicle-Travel in Oregon



Each of the cost categories shown in Table 1 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 biennial 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 2 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.[i]

Table 2 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

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 3.

Table 3 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 4. Note that additional expenditure categories are shown compared to the three major categories used in Table 2. Preservation, Maintenance, and Bridge are all included in the "Preservation and Maintenance" category for the purposes of this analysis.

Table 4 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 5 shows the estimated cost per mile for each major category and overall. Table 5 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 5 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 in Tables 2, 3, and 4.

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 6, 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 5 considering expenditures from all funding sources.

Table 6 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 5 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. Alternately, given the very long time frame of this analysis (out to 2050), it could be assumed that the cost per vehicle mile traveled will remain approximately constant in real dollars over time. The total cost then could be calculated from the unit costs and respective VMT forecasts for LDVs and HDVs.

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. Also, 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 7 compares per-mile estimates of pollution costs from these and other studies.

Table 7 Air Pollution Damage Estimates

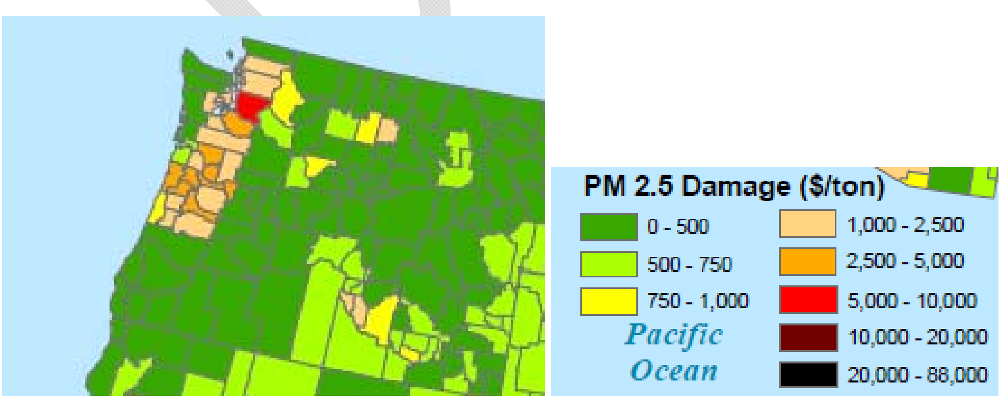
Source	Units	Costs	Comments
Delucchi et al (1996) per Litman (2011)	2007 ¢/VMT	LDGV – 1.3 – 20.5¢ HDDT – 8.6 - 196¢	Check source- just health costs?
Delucchi et al (1996) per FHWA (2007) per Litman (2011)	1990 ¢/VMT	Autos – 1.2¢ LDT – 2.6¢ HDDT - 3.9¢	
FHWA (1997) per Litman (2011)	2007 ¢/VMT	Autos – 1.5¢ LDT – 3.4¢ HDDT – 5.1¢	Might be Delucchi 1990 values inflated to 1997$
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 1 shows an excerpt of their PM2.5 damage estimates mapped for the Pacific Northwest.

Figure 1 Estimated Benefit of Reducing a Ton of PM2.5 Emissions



Source: Muller, N., and R. Mendelsohn (2007). "Efficient Pollution Regulation: Getting the Prices Right." https://seguecommunity.middlebury.edu/view/html/site/nmuller/node/2367900

Recommendations. All of the estimates shown in Table 2 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.[2]

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.

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.

[2] 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.

Table 8 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 8 Water and Soil Resource Cost Estimates

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

Source: Litman (2011). Unless noted, costs from original study were converted into 2007 U.S. dollars by Litman. 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 9 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 9 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.[3] 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 10.

Table 10 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 9 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

[3] Based on data in email from Angus Duncan to Brian Gregor, Feb. 2, 2011.

price of oil due to the effects of U.S. demand on 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 11 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.[4] 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 11 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 11 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 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

[4] This is a domestic benefit only, as it is offset by the loss of revenue to oil producers in other countries.

debatable, the midpoint value of 47 cents per gallon is viewed as a conservative estimate of energy security costs.[5]

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 take as a rough estimate of the fraction of crash costs incurred by non-motorists, considering both fatality and injury crashes.[6] 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

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 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.

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[5] 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.

[6] 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.

Table 12 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¢/mi for light vehicles and a value of about 1.6 cents per mile for heavy vehicles based on truck split of 42 percent of VMT by single unit trucks and 58 percent by combination trucks.[7] Future year values should be the same as there is no clear basis for adjusting costs.

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[i] 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 2). Expenditures were forecast to grow by 1.35 percent annually. The reason for the difference has yet not been determined.