5.10 Air Pollution

This chapter describes vehicle air pollutants including greenhouse gasses, describes emission rates of different vehicles, factors that affect emission rates, and vehicle air pollution costs.

5.10.1 Chapter Index

5.10.2 Definitions

Air Pollution Costs refers to motor vehicle air pollutant damages, including human health, ecological and esthetic degradation. *Tailpipe emissions* are pollutants released directly from vehicle exhaust pipes. *Lifecycle emissions* include both tailpipe emissions and indirect emissions from fuel extraction and refining, vehicle manufacturing, and construction of facilities for transportation.

5.10.3 Discussion

Motor vehicles produce various harmful air emissions, as summarized in Table 5.10.3-1. Some impacts are localized, so where emissions occur affects their costs, while others are regional or global, and so location is less important.

Table 5.10.3-1 **Vehicle Pollution Emissions**[1]

Emission	Description	Sources	Harmful Effects	Scale
Carbon dioxide (CO_2)	A product of combustion.	Fuel production and tailpipes.	Climate change	Global
Carbon monoxide (CO)	A toxic gas caused by incomplete combustion.	Tailpipes	Human health, climate change	Very local
CFCs and HCFC	A class of durable chemicals.	Air conditioners and industrial activities.	Ozone depletion, climate change	Global
Fine particulates (PM_{10}; $PM_{2.5}$)	Inhaleable particles.	Tailpipes, brake lining, road dust, etc.	Human health, aesthetics.	Local and Regional
Road dust (non-tailpipe particulates)	Dust particles created by vehicle movement.	Vehicle use, brake linings, tire wear.	Human health, aesthetics.	Local
Lead	Element used in older fuel additives.	Fuel additives and batteries.	Human health, ecological damages	Local
Methane (CH_4)	A flammable gas.	Fuel production and tailpipes.	Climate change	Global
Nitrogen oxides (NOx) and nitrous oxide (N_2O).	Various compounds, some are toxic, all contribute to ozone.	Tailpipes.	Human health, ozone precursor, ecological damage.	Local and Regional
Ozone (O_2)	Major urban air pollutant caused by NOx and VOCs combined in sunlight.	NOx and VOC	Human health, plants, aesthetics.	Regional
Sulfur oxides (SOx)	Lung irritant and acid rain.	Diesel vehicle tailpipes.	Human health and ecological damage	Local and Regional
VOC (volatile organic hydrocarbons)	Various *hydrocarbon* (HC) gasses.	Fuel production, storage & tailpipes.	Human health, ozone precursor.	Local and Regional
Toxics (e.g. benzene)	Toxic and carcinogenic VOCs.	Fuel production and tailpipes.	Human health risks	Very local

This table summarizes various types of motor vehicle pollution emissions and their impacts.

[1] USEPA (2000), *Indicators of the Environmental Impacts of Transportation*, Center for Transportation and the Environment (www.itre.ncsu.edu/cte); ORNL, *Transportation Energy Data Book* ORNL (www.ornl.gov).

Health Effects

Air pollution is a commonly recognized external cost of motor vehicle use. Mobile (motor vehicle) emissions are considered more difficult to control than other emissions sources, such as electricity generation plants and factories, because they are numerous and dispersed, and have relatively high damage costs because motor vehicles operate close to people.

Table 5-10.3-2 **Human Health Effects of Common Air Pollutants**[2]

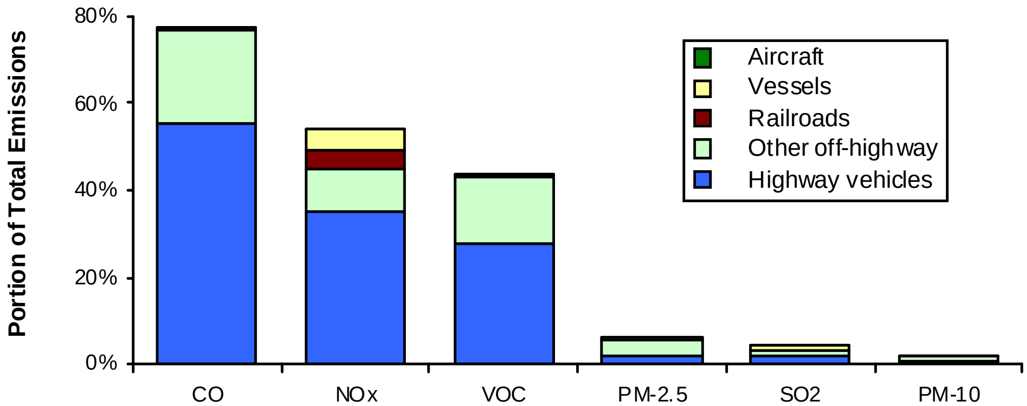
Pollutant	Quantified Health Effects	Unquantified Health Effects	Other Possible Effects
Ozone	Mortality Minor RADs* Respiratory RADs Hospital admissions Asthma attacks Changes in pulmonary function Chronic sinusitis and hay fever	Increased airway responsiveness to stimuli Centroacinar fibrosis Inflammation in the lung	Immunologic changes Chronic respiratory diseases Extrapulmonary effects (changes in the structure or function of the organs)
Particulate matter / TSP/ Sulfates	Mortality Chronic and acute bronchitis Hospital admissions Lower respiratory illness Upper respiratory illness Chest illness Respiratory symptoms Minor RADs Days of work loss Moderate or worse asthma status	Changes in pulmonary function	Chronic respiratory diseases other than chronic bronchitis Inflammation of the lung
Carbon monoxide	Mortality Hospital admissions– congestive heart failure Decreased time to onset of angina	Behavioral effects Other hospital admissions	Other cardiovascular effects Developmental effects
Nitrogen oxides	Respiratory illness	Increased airway responsiveness	Decreased pulmonary function Inflammation of the lung Immunological changes
Sulfur dioxide	Morbidity in exercising asthmatics: Changes in pulmonary function Respiratory symptoms		Respiratory symptoms in non-asthmatics Hospital admissions
Lead	Mortality Hypertension Nonfatal coronary heart disease Nonfatal strokes Intelligence quotient (IQ) loss	Neurobehavioral function Other cardiovascular diseases Reproductive effects Fetal effects from maternal exposure Delinquent and antisocial behavior in children	

This table summarizes human health impacts of various air pollutants. (RAD = Reactive Airways Disease, a general term for various illnesses that cause breathing difficulties.)*

[2] Ken Gwilliam and Masami Kojima (2004), *Urban Air Pollution: Policy Framework for Mobile Sources*, Prepared for the Air Quality Thematic Group, World Bank (www.worldbank.org); at www.cleanairnet.org/cai/1403/articles-56396_entire_handbook.pdf. Also see, *How Vehicle Pollution Affects Our Health*, Ashden Trust; at www.ashdentrust.org.uk/PDFs/VehiclePollution.pdf.

Despite such challenges, mobile emission reduction efforts can be considered a qualified success. Control technologies (often spurred by regulations or incentives) have substantially reduced many pollutants' emission rates, but this success is qualified because some pollutants are not easily reduced by technology, emission tests often underestimate actual emission rates, emission control systems sometimes fail, and reduced emission rates have been partly offset by increased travel. The harmful impacts of some emissions, such as air toxics, have only recently been recognized and so have minimal control strategies.[3] Because the easiest reduction strategies have been implemented, additional reductions will be more difficult. Figure 5.10.3-1 shows transport's share of major pollutants. This share is even higher in many areas were people congregate, such as cities, along highways and in tunnels.

Figure 5.10.3-1 **Transport Air Pollutant Shares (2002)**[4]



Transportation is a major contributor of many air pollutants. These shares are even higher in certain circumstances, such as in cities, along major roads and in tunnels.

Climate Change

Climate change (also called *global warming* and *the greenhouse effect*) refers to climatic changes caused by gases (called *greenhouse gases* or *GHGs*) that increase atmospheric solar heat gain.[5] Although some organizations argue the evidence is inconclusive or emission reduction economic costs exceed likely benefits (e.g. Center for the Study of Carbon Dioxide and Global Change), such groups generally have little climatic or ecological expertise, and often represent industries that benefit from continued climate change emissions.[6] Major scientific organizations consider anthropogenic (human caused) global warming a significant

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[3] HEI (2007), *Mobile-Source Air Toxics: A Critical Review of the Current Literature on Exposure and Health Effects*, Special Report 16, Health Effects Institute (www.healtheffects.org); at http://pubs.healtheffects.org/view.php?id=282.
[4] ORNL (2005), *Transportation Energy Data Book*, USDOE (www.doe.gov), Table 12.1.
[5] Todd Litman (2009), *Climate Change Emission Valuation for Transportation Economic Analysis*, (www.vtpi.org); at www.vtpi.org/ghg_valuation.pdf.
[6] Sourcewatch (2008), *Global Warming Skeptics*, SourceWatch (www.sourcewatch.org); at www.sourcewatch.org/index.php?title=Climate_change_skeptics.

cost (actual damages) and risk (possibility of future damages).[7] For example, the Intergovernmental Panel on Climate Change, which consists of hundreds of scientists, concluded, "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level".[8] The United Nations Environmental Program's 2007 Global Environment Outlook emphasizes the need for action to reduce the costs and risks.[9]

A study published in the *Proceedings of the National Academy of Sciences* calculated the climate changing impacts of 13 economic sectors taking into account their global warming and global cooling emissions.[10] The analysis concluded that motor vehicles are the greatest contributor to atmospheric warming. Cars, buses, and trucks release pollutants and greenhouse gases that promote warming, while emitting few aerosols that counteract it.

Putting a value on GHG emissions is difficult due to uncertainty and differences in human values concerning ecological damages and impacts on future generations. In addition, climate changes impacts are not necessarily linear, many scientists believe that there may be thresholds or tipping points beyond which warming and damage costs could become catestrphic.[11]

Recent scientific studies indicate the risks are larger than previously considered. For example, the 2006 report by the economist Sir Nicholas Stern called attention to the threat of a permanent "disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century",[12] but two years later stated that his earlier evaluation greatly underestimated the potential costs:

> *"Emissions are growing much faster than we'd thought, the absorptive capacity of the planet is less than we'd thought, the risks of greenhouse gases are potentially bigger than more cautious estimates and the speed of climate change seems to be faster."*[13]

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[7] Pew Center on Global Climate Change (2006), *The Causes of Global Climate Change*, (www.pewclimate.com); at http://pewclimate.com/global-warming-basics/science-brief-092006.

[8] IPCC (2007) *Climate Change 2007: Synthesis Report - Summary for Policymakers* (www.ipcc.ch); at www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

[9] UNEP (2007) *Global Environmental Outlook 4*, (www.unep.org); at www.unep.org/geo/

[10] Nadine Unger, et al. (2011), "Attribution Of Climate Forcing To Economic Sectors," *Proceedings of the National Academy of Sciences of the U.S.* (www.pnas.org): at www.pnas.org/content/early/2010/02/02/0906548107.abstract.

[11] James Hansen (2008) *Global Warming Twenty Years Later: Tipping Points Near - Briefing before the Select Committee on Energy Independence and Global Warming, U.S. House of Representatives*, Columbia University (www.columbia.edu); at www.columbia.edu/~jeh1/2008/TwentyYearsLater_20080623.pdf

[12] Sir Nicholas Stern (2006), *Stern Review on the Economics of Climate Change*, UK Office of Climate Change (www.occ.gov.uk); at www.sternreview.org.uk

[13] David Adam (2008) "I underestimated the threat, says Stern", *The Guardian* (www.guardian.co.uk), April 18 2008; at www.guardian.co.uk/environment/2008/apr/18/climatechange.carbonemissions

Factors Affecting Emission Costs

Various factors that affect air pollution cost estimates are discussed below.

Scope

Emission analysis scope may be narrow, only considering tailpipe emissions, or broader, including emissions produced during vehicle operation, and during fuel and vehicle production, as indicated below. Lifecycle analysis is especially appropriate for climate change emissions since impacts are unaffected by where they occur.[14] For example, transport tailpipe emissions account for about 30% of total Canadian GHG emissions but more than 50% of total lifecycle emissions.[15] Similarly Chester and Horvath (2008) estimate that total emissions for a passenger car are 0.36 kg CO_2e per passenger mile, 57% higher than tailpipe emissions of 0.23 kg per passenger mile.[16]

Table 5.10.3-3 **Scope of Emissions considered**

Scope	Description	Pollutants
Tailpipe	Emissions from vehicle tailpipe	CO, CO_2, NOx, particulates, SOx, VOCs
Vehicle Operation	Includes non-tailpipe particulates and evaporative emissions while parked.	Those above, plus additional particulates (road dust, brake and tire wear), VOCs, air toxics, CFCs and HCFCs.
Lifecycle	Total emissions from vehicle production, fuel production and vehicle use.	Those above, plus emissions during vehicle and fuel production, and roadway constructions and maintenance.

The scope of analysis may only consider tailpipe emissions, or it can include additional emissions.

Fuel Type

Various fuels can power vehicles. Alternative fuels may reduce some emissions, but in many cases their net benefits (including "upstream" emissions during production and distribution) are modest.[17] In some cases alternative fuels can have higher overall emissions than conventional fuels.[18]

Units of Measure

Emissions are measured in various units, including grams, pounds, kilograms, tons or tonnes.[19] For more information climate change emission measurement see the VTPI paper *Climate Change Emission Valuation for Transportation Economic Analysis*.[20]

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[14] Mark A. Delucchi (2003), *A Lifecycle Emissions Model (LEM)*, UCD-ITS-RR-03-17 (www.its.ucdavis.edu); at www.its.ucdavis.edu/publications/2003/UCD-ITS-RR-03-17-MAIN.pdf

[15] Luc Gagnon (2006); *Greenhouse Gas Emissions from Transportation Options*, Hydro Quebec (www.hydroquebec.com); at www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/transport_en_2006.pdf.

[16] Mikhail Chester and Arpad Horvath (2008), *Environmental Life-cycle Assessment of Passenger Transportation: Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air*, UC Berkeley Center for Future Urban Transport, (www.its.berkeley.edu/volvocenter); at http://repositories.cdlib.org/its/future_urban_transport/vwp-2008-2.

[17] E.g. Alternative Fuels and Advanced Vehicles Data Center (www.eere.energy.gov/afdc).

[18] Almuth Ernsting, Deepak Rughani and Andrew Boswell (2007), *Agrofuels Threaten to Accelerate Global Warming*, Biofuels Watch (www.biofuelwatch.org.uk); at www.biofuelwatch.org.uk/docs/biofuels-accelerate-climate-change.pdf.

[19] *USEPA Transportation Tools* (www.epa.gov/climatechange/wycd/tools_transportation.html).

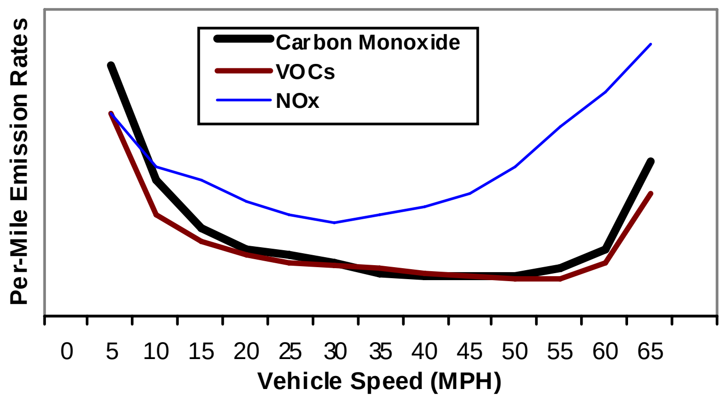
[20] Todd Litman (2009), *Climate Change Emission Valuation for Transportation Economic Analysis*, VTPI (www.vtpi.org); at www.vtpi.org/ghg_valuation.pdf.

Vehicle-mile Emission Rates

Vehicle emission models, such as MOBILE6 and its variants, can be used to predict vehicle emissions under various circumstances.[21] The following factors affect emission rates:[22]

- Vehicle type. Larger vehicles tend to produce more emissions.
- Vehicle age and condition. Older vehicles have less effective emission control systems. Vehicles with faulty emission control systems have high emissions.
- Driving cycle. Emission rates tend to be relatively high when engines are cold.
- Driving style. Faster accelerations tend to increase emission rates.
- Driving conditions. Emissions per mile increase under hilly and stop-and-go conditions, and at low and high speeds, as illustrated in Figure 5.10.3-2. As a result, energy consumption and emissions are likely to decline if roadway conditions shift from Level of Service (LOS) F to D, but are likely to increase with shifts from LOS D to A.[23]

Figure 5.10.3-2 **Vehicle Emissions by Speed**[24]



This figure shows how typical vehicle emissions are affected by speed.

Per Capita Emission Rates

Various factors affect per capita annual vehicle mileage, and therefore per capita vehicle emissions, including land use patterns, vehicle ownership rates, pricing, and the quality of alternative modes, such as walking, cycling and public transit.[25] Models such as URBEMIS (*www.urbemis.com*) can be used to predict the emission reduction effects of various mobility and land use management strategies.[26]

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[21] US EPA (2008) *MOBILE Model (on-road vehicles)*, (www.epa.gov); at www.epa.gov/OTAQ/mobile.htm.
[22] USDOT (2005), *Sensitivity Analysis of MOBILE6 Motor Vehicle Emission Factor Model*, (www.dot.gov); at www.tdot.state.tn.us/mediaroom/docs/2005/emission_reductions.pdf.
[23] VTPI (2008), "Multi-Modal Level of Service" *TDM Encyclopedia*, at www.vtpi.org/tdm/tdm129.htm.
[24] TRB (1995), *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, TRB Special Report #345, National Academy Press (www.nap.edu); www.nap.edu/openbook.php?record_id=9676.
[25] VTPI (2005), "Land Use Impacts on Transportation," "Transportation Elasticities," and other chapters in the *Online TDM Encyclopedia*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/tdm.
[26] Nelson/Nygaard (2005), *Crediting Low-Traffic Developments: Adjusting Site-Level Vehicle Trip Generation Using URBEMIS*, Urban Emissions Model, California Air Districts (www.urbemis.com).

Location and Exposure

Local pollutants such as carbon monoxide, air toxins and particulates, tends to be concentrated in vehicles and along adjacent to roadways.[27] Air pollution costs (per ton of emission) are higher along busy roads, where population densities are high, and in areas where geographic and climatic conditions trap pollution and produce ozone. Emissions under conditions in which air pollution tends to concentrate due to geographic and weather conditions (such as in valleys during inversions) impose greater damages than the same emissions in less vulnerable locations. Jet aircraft emissions at high altitudes are believed to produce relatively large climate change impacts.[28]

Unit Cost Values

Unit air pollution costs refers to estimated costs per kilogram, ton or tonne of a particular pollutant in a particular location (such as a particular city or country).[29] There are two basic ways to quantify these impacts: *damage costs*, which reflect damages and risks, and *control* (also called *avoidance* or *mitigation*) *costs*, which reflect the costs of reducing emissions. Several studies, summarized in this paper, estimate unit costs of various pollutants using methods discussed in Chapter 4. Some estimates are several years old (for example, Wang, Santini and Warinner's study was completed in 1994). It is possible that health damage unit costs have decline over time as improved medical treatment reduces the deaths and illnesses caused by a given amount of pollution exposure, but this is probably offset by increased urban population (which increases the number of people exposed) and the increased value placed on human life and health that generally occurs as people become wealthier.

Unit costs are affected by:

- The mortality (deaths) and morbidity (illnesses) caused by pollutant exposure (called the *dose-response function)*.
- The number of people exposed.
- The value placed on human life and health (measured based on the *Value of a Statistical Life* [VSL], the *Value Of a Life Year* [VOLY], *Potential Years of Life Lost* [PYLL] and *Disability Adjusted Life Years* [DALYs]).[30]
- The range of additional costs and damages (such as crop losses, ecological degradation, acid damage to buildings, and aesthetic degradation) considered in the analysis.

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[27] CTA (2000), *In-Car Air Pollution: The Hidden Threat to Automobile Drivers*, International Center for Technology Assessment (www.icta.org); Howard Frumkin, Lawrence Frank and Richard Jackson (2004), *Urban Sprawl and Public Health*, Island Press (www.islandpress.org), p. 70-71.

[28] John Whitelegg and Howard Cambridge (2004), *Aviation and Sustainability*, Stockholm Environmental Institute (www.sei.se).

[29] M. Maibach, et al. (2008), *Handbook on Estimation of External Cost in the Transport Sector,* CE Delft (www.ce.nl) Table 130, p 262; at http://ec.europa.eu/transport/costs/handbook/doc/2008_01_15_handbook_external_cost_en.pdf

[30] *Potential Years of Life Lost* and *Disability Adjusted Life Years* take into account the relative age at which people die or become ill and therefore gives greater weight to risks to younger people.

5.10. 4 Estimates & Studies

This section summarizes various cost estimates. All values in U.S. dollars unless otherwise indicated.

Local and Regional Pollutant Summary

The table below summarizes the cost estimates of various studies described in this chapter and converts them to 2007 U.S. dollars.

Table 5.10.4-1 **Regional Pollution Studies Summary Table – Selected Studies**

Publication	Costs	Cost Value	2007 USD
			Per Vehicle Mile
CE Delft (2008)	Urban Car	0.0017 - 0.0024 €/km (2000)	$0.003 - 0.004
	Urban Truck	0.106 - 0.234 €/km	0.189 - 0.417
Delucchi et al (1996)	Light Gasoline Vehicle	$1990/VMT 0.008 - 0.129	0.013 - 0.205
	Heavy Diesel Truck	0.054 – 1.233	0.086 - 1.960
Eyre et al. (1997)	Gasoline Urban	$/VMT 1996 0.030	0.040
	Diesel Urban	0.074	0.098
FHWA (1997)	Automobiles	$/VMT 0.011	0.015
	Pickups/Vans	0.026	0.034
	Diesel trucks	0.039	0.051
			Per Tonne/Ton
AEA Technology (2005)	NH3 / tonne Europe	2005** €19,750	$26,061
	NOx	€7,800	$10,293
	PM2.5	€48,000	$63,339
	SO2	€10,325	$13,624
	VOCs	€1,813	$2,392
RWDI (2006)	PM2.5 / tonne	2005 Canadian $317,000	$277,359
	O3 Total	$1,739	$1,522
Wang, Santini & Warinner (1994), US cities	NOx	1989 $/ ton $4,826	$8,059
	ROG	$2419	$4,040
	PM 10	$6508	$10,868
	SOx	$2906	$4,853

*More detailed descriptions of these studies are found below. 2007 Values have been adjusted for inflation by Consumer Price Index.[31] * Currency year is assumed to be the publication year. ** Average of results, see details below. Later studies focus on very fine particles (PM 2.5).*

- CE Delft (2008) base on Clean Air for Europe (CAFE) Programme values.[32]

Table 5.10.4-2 **Air Pollution Costs** (2000 Euro-Cents/vehicle-km)

	Passenger Car	Heavy Duty Vehicle
Urban, petrol	0.17 (0.17 - 0.24)	
Urban, diesel	1.53 (1.53 - 2.65)	10.6 (10.6 - 23.4)
Interurban, petrol	0.09 (0.09 - 0.15)	
Interurban, diesel	0.89 (0.89 - 1.80)	8.5 (8.5 - 21.4)

[31] Note that CPI is not the only way to adjust for inflation and results can vary significantly with different methods, see: Samuel H. Williamson (2008), "Six Ways to Compute the Relative Value of a U.S. Dollar Amount, 1790 to Present," MeasuringWorth (www.measuringworth.com).
[32] M. Maibach, et al. (2008).

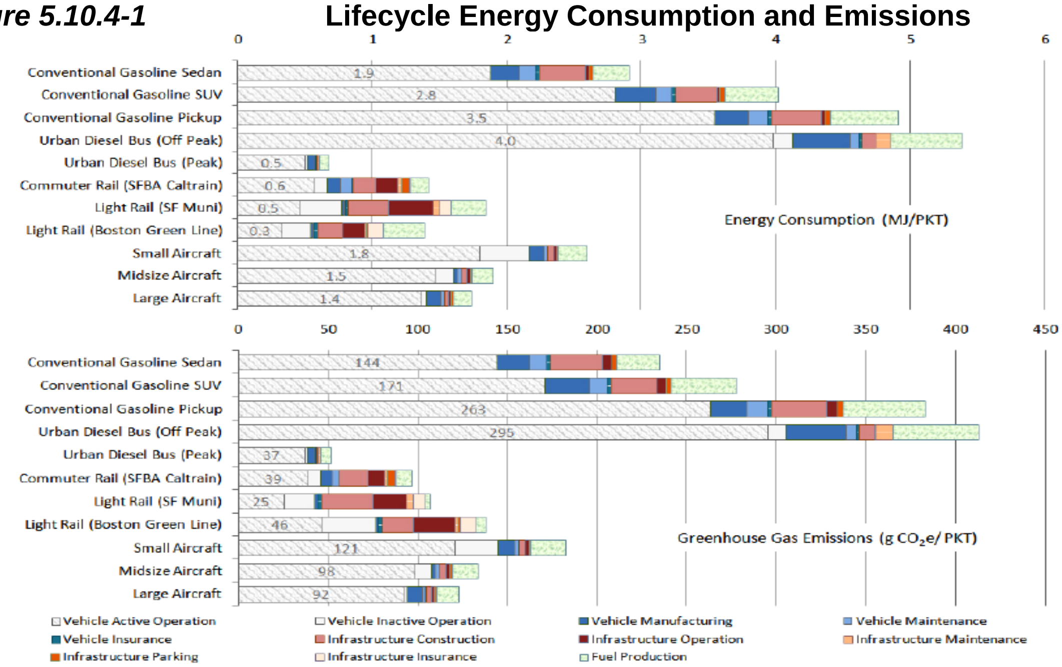
- Table 5.10.4-3 and Figure 5.10.4-1 show lifecycle emissions for various transport modes calculated by Chester and Horvath. Tailpipe emissions represent only about 64% of lifecycle emissions for typical automobiles and 75% for bus transport. Similarly, Gagnon estimated that tailpipe emissions represent about 60% of total emissions.[33]

Table 5.10.4-3 **Lifecycle Climate Change Emissions** (Grams CO_2 Equivalent)[34]

Vehicle Type	**Sedan**		**SUV**		**Pickup**		**Bus-Average**		**Bus-Peak**	
Avg. Occupancy	1.58		1.74		1.46		10.5		40	
	VMT	PMT	VMT	PMT	VMT	PMT	VMT	PMT	VMT	PMT
Operations	370	230	480	280	480	330	2,400	230	2,400	59
Manufacture	45	29	71	41	48	33	320	31	320	8.1
Idling	0	0	0	0	0	0	80	7.6	80	2
Tire production	7.2	4.5	7.2	4.1	7.2	4.9	2.5	0.24	2.5	0.064
Maintenance	17	11	19	11	19	13	45	4.2	45	1.1
Fixed Costs	5.6	3.6	5.7	3.3	5.8	4.0	14	1.4	14	0.35
Roadway const.	52	33	52	30	52	36	52	4.9	52	1.3
Roadway maint.	0	0	0	0	0	0	210	20	11	0.27
Herbicides/Salting	0.37	0.24	0.41	0.23	0.41	0.28	0.37	0.036	0.37	0.0094
Roadway lighting	13	8.5	14	7.8	14	9.4	4.9	0.47	4.9	0.012
Parking	8.5	54	8.5	49	8.5	58	0	0	0	0
Fuel production	59	38	98	56	100	71	260	24	260	6.4
Totals	*578*	*412*	*756*	*482*	*735*	*560*	*3,389*	*324*	*3,190*	*79*
Operations/Total	*0.64*	*0.63*	*0.63*	*0.65*	*0.65*	*0.65*	*0.75*	*0.76*	*0.75*	*0.75*

***VMT** = Vehicle Miles Traveled; **PMT** = Passenger Miles Traveled; **Operations** = tailpipe emissions*

Figure 5.10.4-1 **Lifecycle Energy Consumption and Emissions**



[33] Luc Gagnon (2006); *Greenhouse Gas Emissions from Transportation Options*, Hydro Quebec; at www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/transport_en_2006.pdf.

[34] Mikhail Chester and Arpad Horvath (2008), *Environmental Life-cycle Assessment of Passenger Transportation*, UC Berkeley Center for Future Urban Transport (www.its.berkeley.edu/volvocenter); at www.sustainable-transportation.com.

- Delucchi, *et al.*, estimate the human health costs of motor vehicle air pollution as summarized in Table 5.10-4. Additional costs include $2-4 billion annually in ozone damage to commercial agriculture,[35] and $5-40 billion in reduced visibility.[36]

Table 5.10.4-4 **Air Pollution Health Costs by Motor Vehicle Class** ($1990/VMT)[37]

Vehicle Class	Low Estimate	Middle Value	High Estimate
Light Gasoline Vehicle	0.008	0.069	0.129
Light Gasoline Truck	0.012	0.100	0.188
Heavy Gasoline Vehicle	0.024	0.260	0.495
Light Diesel Vehicle	0.016	0.121	0.225
Light Diesel Truck	0.006	0.061	0.116
Heavy Diesel Truck	0.054	0.644	1.233
Weighted Fleet Average	*0.011*	0.112	*0.213*

- The UK Department For Transport publishes lower, central and upper estimates of the shadow price per tonne of carbon released into the atmosphere from 2000 to 2060, as indicated in the following table.

Table 5.10.4-5 **Shadow Price (£) Per Tonne Of Carbon In 2002 Prices**[38]

Year	2000	2002	2006	2010	2020	2040	2060
Central estimate	71.00	73.87	79.96	86.55	105.50	156.77	232.95
Upper estimate	85.20	88.64	95.95	103.86	126.60	188.12	279.54
Lower estimate	63.90	66.48	71.96	77.89	94.95	141.09	209.66

- The FHWA uses the following air pollution cost estimates in the *1997 Federal Highway Cost Allocation Study*. The *Highway Economic Requirements System* used to evaluate highway improvement needs and benefits includes guidance on air pollution cost analysis, pollution monetization, and factors affecting emission rates.[39]

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35 Mark Delucchi (1996), James Murphy, Jin Kim, and Donald McCubbin, *Cost of Crop Damage Caused by Ozone Air Pollution From Motor Vehicles*, UC Davis, ITS (www.its.ucdavis.edu); at www.its.ucdavis.edu/people/faculty/delucchi/index.php

36 Mark Delucchi, James Murphy, Donald McCubbin and Jin Kim (1996), *Cost of Reduced Visibility Due to Particulate Air Pollution From Motor Vehicles*, UC Davis, ITS (www.its.ucdavis.edu); www.its.ucdavis.edu/people/faculty/delucchi/index.php

37 Donald McCubbin and Mark Delucchi (1996), *Social Cost of the Health Effects of Motor-Vehicle Air Pollution*, UC Davis, ITS (www.its.ucdavis.edu), 1996, Table 11.7-6; at www.its.ucdavis.edu/people/faculty/delucchi/index.php . Also see Mark Delucchi (2000), "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, Vol. 34, No. 2, (www.bath.ac.uk/e-journals/jtep), May 2000, pp. 135-168.

38 DfT (2009), *Transport Analysis Guidance: 3.3.5: The Greenhouse Gases Sub-Objective*, Department for Transport (www.dft.gov.uk); at www.dft.gov.uk/webtag/documents/expert/unit3.3.5.php.

39 FHWA (2002), *Highway Economic Requirements System: Technical Report*, Federal Highway Administration, U.S. Department of Transportation (www.fhwa.dot.gov); at http://isddc.dot.gov/OLPFiles/FHWA/010945.pdf.

Table 5.10.4-6 **Air Pollution Costs**[40]

Vehicle Class	Total ($1990 Million)	Cents per Mile
Automobiles	$20,343	1.1¢
Pickups/Vans	$11,324	2.6¢
Gasoline Vehicles >8,500 pounds	$1,699	3.0¢
Diesel Vehicles >8,500 pounds	$6,743	3.9¢

- The FHWA published a detail study of future freight transport emissions, indicating that emission rates of most pollutants will decline significantly between 2002 and 2020, as indicated in the table below. The report includes emission rates for several other driving conditions.

Table 5.10.4-7 **Arterial Truck Emission Factors (grams/mile)**[41]

Truck Class	Year	VOC	CO	NOX	PM-10 Total	PM-10 Exhaust Only
Single-Unit Truck – Gasoline	2002	2.29	59.87	7.18	0.13	0.11
	2010	0.61	14.24	4.95	0.09	0.07
	2020	0.21	9.00	1.92	0.05	0.03
Single-Unit Truck – Diesel	2002	0.59	2.86	15.34	0.42	0.38
	2010	0.37	1.41	6.18	0.17	0.13
	2020	0.26	0.30	1.01	0.07	0.03
Combination Truck – Diesel	2002	0.61	3.18	17.02	0.41	0.37
	2010	0.39	1.47	6.38	0.17	0.13
	2020	0.28	0.33	1.03	0.07	0.03

- Forkenbrock estimates air pollution costs for large intercity trucks to average 0.08¢ for "criteria" pollutant emissions per ton-mile of freight shipped, and 0.15¢ per ton-mile for CO_2 emissions.[42]

- A study exploring geographic differences in medical care use and air pollution using millions of Medicare records from 183 metropolitan areas showed that air pollution significantly increases the use of medical care among older adults - even after controlling for other demographic and geographic factors including income, cigarette consumption, and obesity.[43] The study found that hospital admissions for respiratory problems average 19% higher, outpatient care 18% higher, and total hospital admissions 10% higher for elderly people in the 37 areas with the highest pollution compared with the 37 areas with

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[40] FHWA (2000), *1997 Federal Highway Cost Allocation Study Final Report Addendum*, Federal Highway Administration, USDOT (www.fhwa.dot.gov), 2000, Table 12.
[41] ICF Consulting (2005), *Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level*, US Federal Highway Admin. (www.fhwa.dot.gov); www.fhwa.dot.gov/ENVIRonment/freightaq/index.htm
[42] David Forkenbrock (1999), "External Costs of Intercity Truck Freight Transportation," *Transportation Research A*, Vol. 33, No. 7/8, Sept./Nov. 1999, pp. 505-526.
[43] Victor R. Fuchs and Sarah Rosen Frank (2002), "Air Pollution and Medical Care Use by Older Americans: A Cross Area Analysis," *Health Affairs*, Vol. 21, No. 6 (www.healthaffairs.org), November/December, 2002, pp. 207-214.

the least pollution. The researchers estimate that Medicare would save an average of $76.70 US per person in inpatient care and $100.30 in outpatient care for every 10-microgram-per-cubic-meter reduction in air pollution.

- RWDI Inc. (2006) estimates the costs of air pollutants in the Vancouver BC region as reported in the table below. Note that the value for very fine particulates (PM 2.5) is much higher than reported in some earlier studies, based on more recent health studies.[44]

Table 5.10.4-8 **Air Pollutant Costs by Economic Category** (2005 Canadian $/tonne)

Economic Category	Pollutant	Marginal Damage Costs
Human health	CO	$205
	$PM_{2.5}$	$317,000
	O_3	$1,086
Visibility	PM_{10}	$3,175
	NO_x	$934
	VOC	$44
Agricultural crops	O_3	$280
Exterior materials	O_3	$373
Total	O_3	$1739

Source: Table 4-2 in original.

- Henderson, Cicas and Matthews compare the energy consumption and pollution emission rates of various freight modes.[45] They find that truck transport consumes about 15 times as much energy and produces about 15 times the pollutant emissions per ton-mile as rail, water and pipeline transport.

- A major study evaluated the effects of proximity to major roads on human coronary artery calcification (CAC).[46] The results indicate that reducing the distance between the residence and a major road by half was associated with a 7.0% increase in CAC.

- An extensive European research program calculates the air emission cost values in Table 5.10-9. The $PM_{2.5}$ and SO_2 values for a particular size city should be added to the national values to account for both local and long-range emission impacts.

[44] RWDI (2006), *South Fraser Perimeter Road Regional Air Quality Assessment: Technical Volume 16 of the Environmental Assessment Application.* BC Ministry of Transportation (www.gov.bc.ca/tran/).
[45] Chris Hendrickson, Gyorgyi Cicas and H. Scott Matthews (2006), "Transportation Sector and Supply Chain Performance and Sustainability," *Transportation Research Record 1983* (www.trb.org), pp. 151-157.
[46] B. Hoffmann, et al. (2007), "Residential Exposure to Traffic Is Associated With Coronary Atherosclerosis," *Circulation*, July 31, 2007 (www.circulationaha.org); at www.precaution.org/lib/traffic_and_atherosclerosis.070717.pdf.

Table 5.10.4-9 **European Emission Costs** (2002 Euros Per Tonne)[47]

	SO2	NOx	PM2.5	VOCs
Rural				
Austria	7,200	6,800	14,000	1,400
Belgium	7,900	4,700	22,000	3,000
Denmark	3,300	3,300	5,400	7,200
Finland	970	1,500	1,400	490
France	7,400	8,200	15,000	2,000
Germany	6,100	4,100	16,000	2,800
Greece	4,100	6,000	7,800	930
Ireland	2,600	2,800	4,100	1,300
Italy	5,000	7,100	12,000	2,800
Netherlands	7,000	4,000	18,000	2,400
Portugal	3,000	4,100	5,800	1,500
Spain	3,700	4,700	7,900	880
Sweden	1,700	2,600	1,700	680
UK	4,500	2,600	9,700	1,900
EU-15 average	*5,200*	*4,200*	*14,000*	*2,100*
Urban				
100,000 population	6,000		33,000	
500,000 population	30,000		165,000	
1,000,000 population	45,000		247,500	
Several million pop.	90,000		495,000	

- Wang and Santini estimate that electric vehicles reduce CO and VOC emissions 98%, with smaller reductions in NOx and SOx, and 50% reductions in CO_2 emissions.[48] A Union of Concerned Scientists study compares lifetime emissions for new standard and ultra low emission vehicles (ULEV), and electric vehicles, based on Southern California electrical generation mix, shown in Table 5.10-10.[49]

Table 5.10.4-10 **Lifetime Emissions for Gasoline and Electric Vehicles** (kilograms)

Pollutant	Average Gasoline	ULEV Gasoline	Electric
ROG	89-119	46-54	0.49
CO	531-1,072	198-478	2.76
NOx	110-121	60-66	24.28
PM_{10}	2.5	2.5	1.11
Sox	11.8	11.8	13.8
Carbon	19,200	19,200	5,509

47 Mike Holland and Paul Watkiss (2002), *Estimates of Marginal External Costs of Air Pollution in Europe*, European Commission (www.ec.europa.eu); at http://europa.eu.int/comm/environment/enveco/studies2.htm
48 Quanlu Wang and Danilo Santini (1993), "Magnitude and Value of Electric Vehicle Emissions Reductions for Six Driving Cycles in Four U.S. Cities," *Transportation Research Record* 1416 (www.trb.org), p. 33-42.
49 Roland Hwang, et al. (1994), *Driving Out Pollution: The Benefits of Electric Vehicles*, UCS (www.ucsusa.org).

- A major National Research Council study provided an extensive review of energy consumption external costs.[50] It estimated emissions of criteria (conventional air pollution) and climate change gases (CO_2-equivelent per vehicle-mile), and their unit costs (per vehicle-mile and gallon of fuel) for various vehicle fuels and time periods. It provided the following estimates of motor vehicle fuel exernal costs:
    - The aggregate national damages to health and other non-GWP effects would have been approximately $36.4 billion per year for the lightduty vehicle fleet in 2005; the addition of medium-duty and heavy-duty trucks and buses raises the aggregate estimate to approximately $56 billion. These estimates are likely conservative since they do not fully account for the contribution of light-duty trucks to the aggregate damages, and of course should be viewed with caution due to the various uncertainties incorporated in such analysis.
    - They estimate that non-climate change damages from transportation energy use average 1.2¢ to >1.7¢ per vehicle-mile for the current U.S. vehicle fleet, plus 0.15¢ to >0.65¢ climate change emissions at $10 per tonne of CO_2-equivelent; 0.45¢ to >2.0¢ climate change emissions at $30 per tonne of CO_2-eq; and 1.5¢ to >6.0¢ climate change emissions at $100 per tonne of CO_2-eq. The table below summarizes these estimates. This suggests that external energy costs range from about 1.4¢ to 7.7¢ per vehicle mile in 2007 dollars.

	$10/Tonne CO_2-Eq	**$30/Tonne CO_2-Eq**	**$100/Tonne CO_2-Eq**
Non-climate change	$0.012- >0.017	$0.012- >0.017	$0.012- >0.017
Climate change	$0.0015- >0.0065	$0.045- >0.020	$0.015- >0.060
Total	*$0.0135->0.0235*	*$0.057- >0.037*	*$0.027->0.077*

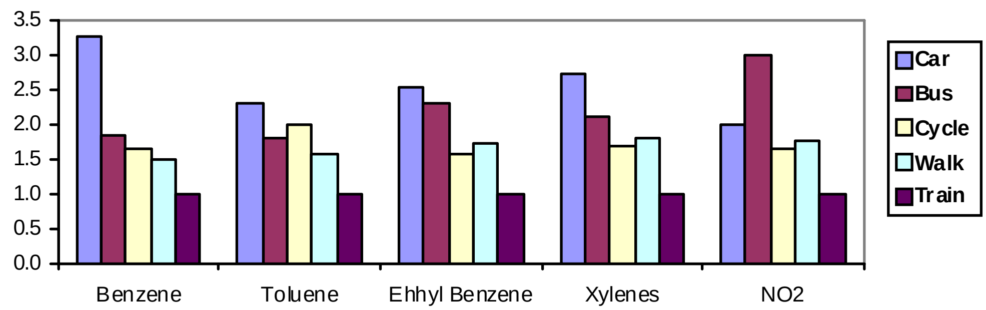
    - Electric vehicles and grid-dependent hybrid vehicles showed somewhat higher damages than many other technologies for both 2005 and 2030. Although operation of the vehicles produces few or no emissions, electricity production at present relies mainly on fossil fuels and, based on current emission control requirements. In addition, battery and electric motor production added up to 20% to the damages from manufacturing.
    - Depending on the extent of projected future damages and the discount rate used for weighting them, the range of estimates of marginal damages spanned two orders of magnitude, from about $1 to $100 per ton of CO2-eq, based on current emissions. Approximately one order of magnitude in difference was attributed to discount-rate assumptions, and another order of magnitude to assumptions about future damages from emissions. At $30/ton of CO2-eq, motor vehicle climate change damage costs begin to approach the value of non-climate damages.

- Each year in California, fright transport air pollution is estimated to cause 2,400 premature deaths, 2,830 hospital admissions, 360,000 missed workdays and 1,100,000 missed days of school, with an esiamted cost of about $13 billion.[51]

[50] NRC (2009), *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*, Committee on Health, Environmental, and Other External Costs and Benefits of Energy Production and Consumption; National Research Council, National Academy of Sciences (www.nap.edu/catalog/12794.html).
[51] Meena Palaniappan, Swati Prakash and Diane Bailey (2006), *Paying With Our Health: The Real Cost of Freight Transport in California*, Pacific Institute (www.pacinst.org); at www.pacinst.org/reports/freight_transport/index.htm.

- Vehicle occupants tend to receive relatively high exposure to air pollution, indicating that air pollution costs may be higher than previously estimated and a greater share of this cost is borne by motorists.[52] Automobile occupants tend to be exposed to more air pollution than people traveling by other modes, as indicated in the figure below.

Figure 5.10.4-2 **Relative Air Pollutant Exposure By Mode**[53]



Motorists tend to experience greater exposure than travelers by other modes.

- One study found a six-fold increase in childhood cancers in households living adjacent to high traffic roads (20,000+ vehicles per day).[54] The authors suggest that this results from residents' exposure to air toxins, such as benzene, and perhaps NOx.

- One major study for the World Health Organization found that road pollution emissions in Austria, France and Switzerland cause significant increases in bronchitis, asthma, hospital admissions and premature deaths. Air pollution economic costs are estimated to total about 50 billion Euros in these three countries, of which about half is due to motor vehicle particulates.[55]

- A widely cited study by Small and Kazimi estimated human morbidity and mortality costs from vehicle tailpipe particulate and ozone emissions in Southern California.[56] Their middle estimate for gasoline cars was 3.3¢ per vehicle-mile in 1995, declining 50% by the year 2000 due to improved emission controls. Heavy diesel trucks costs were estimated to average 53¢ per vehicle-mile. Emissions costs in other urban regions were estimated to average about 1/3 of these values. The authors emphasized that this is only a partial analysis since the study omitted other pollutants such as CO and non-tailpipe

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[52] Charles Rodes, et al. (1998), *Measuring Concentrations of Selected Air Pollutants Inside California Vehicles*, California Air Resources Board (www.arb.ca.gov).
[53] Michael Chertok, Alexander Voukelatos, Vicky Sheppeard and Chris Rissel (2004), "Comparison of Air Pollution Exposure for Five Commuting Modes in Sydney – Car, Train, Bus, Bicycle and Walking," *Health Promotion Journal of Australia*, Vol. 15, No. 1 (www.healthpromotion.org.au/journal.php), pp. 63-67.
[54] Robert Pearson, Howard Wachtel and Kristie Ebi (2000), "High Traffic Streets Linked to Childhood Cancers," *Journal of the Air and Waste Management Association* (www.awma.org), Feb. 2000.
[55] Rita Seethaler (1999), *Health Costs Due to Road Traffic-Related Air Pollution; An Assessment Project of Austria, France and Switzerland*, Ministry Conference on Environment and Health, World Health Organization (www.euro.who.int), June 1999.
[56] Ken Small and Camilla Kazimi (1995), "On the Costs of Air Pollution from Motor Vehicles," *Journal of Transport Economics and Policy* (www.bath.ac.uk/e-journals/jtep/), January, pp. 7-32.

particulates, plus less acute human health impacts and ecological damages. The authors stated that road dust may add 4.3¢ per VMT.

- Transport Concepts estimates freight air pollution costs as shown below. Another study found that per unit shipped (ton-kilometer) rail transport tends to produce less HC, CO and CO_2 than trucks, but more PM and NOx.[57]

Table 5.10.4-11 **Environmental Costs of Freight** (1990 Vehicles)[58]

	Net Payload	Load Factor	NOx	VOC	CO_2	Total
	Tonnes	Percent	Canadian Cents Per Tonne Km			
Semi-Truck	24.5	65%	0.28	0.061	0.38	0.72
B-Train Truck	44.2	65%	0.23	0.050	0.31	0.58
Truck Average						*0.71*
Piggyback	24.5	60%	0.20	0.010	0.15	0.36
Container	26.3	60%	0.16	0.008	0.12	0.29
Box Car	71.7	36%	0.14	0.007	0.11	0.25
Hopper Car	70	60%	0.08	0.004	0.06	0.15
Rail Average			*0.13*	*0.007*	*0.10*	*0.23*

- New motorcycles produce over double HC and CO, and higher NOx than automobile fleet averages, since they lack emission control equipment.[59]

- van Essen, et al describe various method that can be used to calculate air pollution costs, and summarize monetized estimates of various pollutants.[60] They recommend the Impact Pathway Approach (IPA) developed by the ExternE-project.

- Wang, Santini and Warinner calculate unit emission costs for 17 U.S. cities using two analysis methods: control and damage costs, as shown the table below. They also suggest using the following values per ton for global warming gases based on control costs: $15 for CO_2; $150 for methane; $2,700 for nitrogen oxide; $33 for carbon monoxide; $150 for nonmethane organic gases; and $210 for NOx; $19,500 for CFC-11; and $55,500 for CFC-12 (for greenhouse gas impacts only).

[57] Gordon Taylor (2001), *Trucks and Air Emissions*, Environment Canada (www.ec.gc.ca) March 2001.
[58] TC (1994), *External Costs of Truck and Train*, Transport Concepts (Ottawa), October 1994, p.22.
[59] EPA (1989) *Compilation of Air Pollution Emission Factors*, USEPA (www.epa.gov), tables 1.8.1, 1.8.4.
[60] van Essen, et al (2004), *Marginal Costs of Infrastructure Use – Towards a Simplified Approach*, CE Delft (www.ce.nl); in Vermeulen, et al (2004), *Price of Transport: Overview of the Social Costs of Transport*, CE Delft; at www.rapportsysteem.nl/artikel/index.php?id=181&action=read.

Table 5.10.4-12 **Estimated Emission Values** (1989 $/ton)[61]

	NOx		ROG		PM10		SOx		CO	
	Dam.	Con.	Dam.	Con.	Dam.	Con.	Dam.	Con.	Dam.	Con.
Atlanta	4,330	9,190	2,150	8,780	5,170	3,460	2,760	6,420	N/A	2,280
Baltimore	4,430	10,310	2,210	9,620	4,520	3,170	2,620	5,600	N/A	2,490
Boston	4,120	7,980	2,030	7,850	5,090	3,120	2,820	5,060	N/A	1,610
Chicago	5,380	7,990	2,700	8,150	10,840	4,660	3,600	9,120	N/A	2,440
Denver	2,840	6,660	1,350	6,590	3,390	2,790	2,330	4,900	N/A	2,960
Houston	6,890	17,150	3,540	15,160	5,190	2,780	2,910	3,590	N/A	2,680
Los Vegas	910	5,220	320	5,100	2,450	4,190	N/A	11,650	N/A	2,770
Los Angeles	9,800	21,850	5,110	19,250	17,200	6,060	3,970	13,480	N/A	4,840
Milwaukee	3,890	11,350	1,930	10,250	2,960	2,560	2,210	4,380	N/A	1,590
New Orleans	3,880	9,190	1,910	8,670	3,600	2,400	2,471	3,130	N/A	1,410
New York	7,130	12,340	3,650	11,720	15,130	5,390	4,030	11,090	N/A	3,910
Philadelphia	5,940	11,360	3,010	10,730	8,360	4,040	3,340	7,330	N/A	3,160
Sacramento	3,870	11,350	1,920	10,240	3,150	2,950	2,190	5,800	N/A	3,040
San Diego	5,510	14,110	2,800	12,630	4,800	3,460	2,600	6,640	N/A	2,740
San Francisco	3,730	5,230	1,810	5,760	5,970	3,200	2,970	4,900	N/A	2,460
San Joaquin	4,490	10,310	2,240	9,630	6,550	5,110	2,610	12,480	N/A	2,750
Wash. DC	4,900	9,190	2,450	8,910	6,260	3,340	3,070	5,320	N/A	3,010
Average	*$4,826*	*$10,634*	*$2,419*	*$9,944*	*$6,508*	*$3,687*	*$2,906*	*$7,111*	*N/A*	*$2,714*

Dam. = damage cost analysis method. Con. = Control cost analysis method.

- Wang summarizes various air pollution reduction unit cost studies in dollars per ton of reduction.[62] He describes factors that affect such cost estimates, including perspective (individual or social), emissions considered, emission rates calculations, baseline assumptions, geographic and temporal scope, and how program costs are calculated. Ignores cobenefits (congestion reduction, road and parking savings, crash reductions, etc.) from mobility management.

- The chemical composition of the fine latex particles produced by modern automobile tires appears to be highly allergenic, both alone and in combination with other pollutants.[63] Researchers conclude that this probably contributes to significant human morbidity and mortality in urban areas, particularly increased asthma.

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[61] M.Q. Wang, D.J. Santini and S.A. Warinner (1994), *Methods of Valuing Air Pollution and Estimated Monetary Values of Air Pollutants in Various U.S. Regions*, Argonne National Lab (www.anl.gov). Also see M.Q. Wang, D.J. Santini and S.A. Warinner (1995), "Monetary Values of Air Pollutants in Various U.S. Regions," *Transportation Research Record 1475* (www.trb.org), pp. 33-41.
[62] Michael Q. Wang (2004), "Examining Cost Effectiveness of Mobile Source Emission Control Measures," *Transport Policy*, Vol. 11, No. 2, (www.elsevier.com/locate/tranpol), April 2004, pp. 155-169.
[63] Brock Williams, et al. (1995), "Latex Allergen in Respirable Particulate Air Pollution," *Journal of Allergy Clinical Immunology* (www.jacionline.org), Vol. 95, pp. 88-95.

- The Clean Air for Europe (CAFE) Programme developed monetized damage costs per tonne of pollutant for each European Union country (excluding Cyprus) and for surrounding seas. The analysis provides a range of estimates based on various input values. The table below summarizes overall average values. Emissions occurring at sea impose 50-80% of the damage of the same emissions occurring on land.

Table 5.10.4-13 **Average Damages Per Tonne of Emissions** (2005)[64]

Assumptions				
PM mortality	VOLY median	VSL median	VOLY mean	VSL mean
O3 Mortality	Mortality	VOLY median	VOLY mean	VOLY mean
Health Care?	Included	Included	Included	Included
Health sensitivity?	Not included	Not included	Included	Included
Crops	Included	Included	Included	Included
O3/health Metric	SOMO 35	SOMO 35	SOMO 0	SOMO 0
European Land Areas				
NH_3	€11,000	€16,000	€21,000	€31,000
NOx	€4,400	€6,600	€8,200	€12,000
$PM_{2.5}$	€26,000	€40,000	€51,000	€75,000
SO_2	€5,600	€8,700	€11,000	€16,000
VOCs	€950	€1,400	€2,100	€2,800
European Area Seas				
NOx	€2,500	€3,800	€4,700	€6,900
$PM_{2.5}$	€13,000	€19,000	€25,000	€36,000
SO_2	€3,700	€5,700	€7,300	€11,000
VOCs	€780	€1,100	€1,730	€2,300

*This table summarizes air pollution unit cost values from a major study sponsored by the European Union. The full report provides a variety of cost values reflecting various assumptions, with individual values for each country reflecting their specific geographic situation. (*VOLY = *"Value Of a Life Year";* VSL = *"Value of a Statistical Life";* SOMO = *"Sum of Means Over 35 ppbV")*

64 AEA Technology Environment (2005), *Damages Per Tonne Emission of PM2.5, NH3, SO2, NOx and VOCs From Each EU25 Member State*, Clean Air for Europe (CAFE) Programme, European Commission (www.cafe-cba.org); at www.cafe-cba.org/reports.

Climate Change Emissions

This section describes climate change unit costs. For more information see "Climate Change Emission Valuation for Transportation Economic Analysis."[65]

Table 5.10.4-14 summarizes climate change *damage cost* unit values from various studies, with their values converted to 2007 U.S. dollars.

Table 5.10.4-14 **Climate Change Damage Cost Estimates**

Publication	Description	Cost Value/tonne CO_2	2007 USD/t CO_2
Tol (2005)**	Minimum	-4 Euro (2000)	$-4.43
	Central	11	**$12**
	Maximum	53	$59
DLR (2006)**	Minimum	15 Euro (2000)	$17
	Central	70	**$78**
	Maximum	280	$310
Jakob, Craig & Fisher (2005)	Damage	NZ $270 (2003)	**$178**
Hohmeyer & Gartner (1992)	Damage	$220 *	**$326**
Bein (1997)	Recommended	$1,000 Canadian*	**$917**
	Maximum	$4,264	$3,910

*Central or recommended values are shown in bold. 2007 Values were converted to USD in the base year then adjusted for inflation by Consumer Price Index. * Assumes the currency year is the same as the publication year. ** From Maibach et al. 2008. For a graphic comparison of cost values see Figure 4.1 in* Climate Change: The Cost of Inaction and the Cost of Adaptation *(EEA, 2006).*

Table 5.10.4-15 summarizes climate change *control cost* unit values from various studies, with their values converted to 2007 U.S. dollars.

Table 5.10.4-15 **Climate Change Control Cost Estimates – Selected Studies**

Publication	Costs	Cost Value/tonne CO_2	2007 USD/tonne
BTCE (1996)	Social Cost of Transportation Measures	Includes measures with less than zero social cost	Includes less than zero
Bloomberg News (2007)	2007 price of EU CO_2 permits for 2008	€21.45	$29
SEC (2008)**	2010	€14	$16
	2020	€38	$42
	2030	€64	$71
	2050	€120	$133
Stern (2006)**	2015	€32 – 65 (2000)	$35 – 72
	2025	€16 – 45	$18 – 50
	2050	€-41 – 81	$-45 – 90
Markus Maibach et al (2000)		€135	$150

*Mitigation cost estimates vary considerably, but less than damage costs. * Indicates that the currency year is assumed to be the same as the publication year. ** Indicates that the data is cited from Maibach et al., 2008.*

[65] Todd Litman (2009), *Climate Change Emission Valuation for Transportation Economic Analysis.* (www.vtpi.org); at www.vtpi.org/ghg_valuation.pdf.

- A team of economists headed by Sir Nicholas Stern, Head of the U.K. Government Economics Service, performed a comprehensive assessment of evidence on the impacts of climate change, using various techniques to assess costs and risks. Using the results from formal economic models the Review estimates that the overall costs and risks of inaction on climate change will be equivalent to at least 5% of global GDP, and if a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more.[66] This study supports the development of international emission trading, which would establish a monetized unit value of greenhouse gas emissions. In 2008 Stern stated that new scientific findings show that his 2006 evaluation greatly underestimated the potential threat and costs of GHG emissions.[67]

- The Australian Government's Garnault Climate Change Review (2008) provides an updated review of climate science and economics, particularly in light of the IPCC's 2007 reports. It indicates that current emission trends have almost 50% chance of increasing global temperatures 6 degrees Centigrade by 2100, much higher than the 3% risk estimate made in 2007 based on older studies such as the IPCC's 2001 reports.[68]

- A 2006 study of Canadian greenhouse gas emissions from transportation estimates that transportation accounts for 31% of total emissions if only tailpipe emissions are counted, but over 50% if the full lifecycle of transportation is counted.[69]

- The European Commission *ExternE* program monetized energy production external costs for 14 countries. The table below summarizes estimates of global warming unit costs.

Table 5.10.4-16 **Greenhouse Gas Damage Costs**[70]

Emission	Units	Low	Mid Point	High
Carbon Dioxide	tonne carbon	€74	€152	€230
Carbon Dioxide	tonne CO_2	€20	€42	€63
Methane	tonne CH_4	€370	€540	€710
Nitrous Oxide	tonne N_2O	€6,800	€21,400	€36,000

[66] Sir Nicholas Stern (2006), *Stern Review on the Economics of Climate Change*, HM Treasury (www.sternreview.org.uk).
[67] David Adam (2008) "I underestimated the threat, says Stern", *The Guardian* (www.guardian.co.uk), April 18 2008; at www.guardian.co.uk/environment/2008/apr/18/climatechange.carbonemissions
[68] Ross Garnault et al. (2008) *The Garnault Climate Change Review:Final Report*, Australian Government Department of Climate Change (www.climatechange.gov.au); at www.garnautreview.org.au
[69] Luc Gagnon (2006); *Greenhouse Gas Emissions from Transportation Options*, Hydro Quebec (www.hydroquebec.com); at www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/transport_en_2006.pdf . This data includes all domestic transportation, but not international flights or shipping.
[70] EC (1998), *ExternE; Newsletter 6*, European Commission ExternE Project (www.externe.info), March 1998.

- A 1997 BC Ministry of Transportation study recommends a value of $1,000 Canadian per tonne of CO_2 equivalent for damage costs. Table 4.4 of that study reports a wide range of values given different assumptions, with a maximum value of $4,264 Canadian per tonne of CO_2 equivalent representing a catastrophic worst case scenario based on business as usual emissions.[71]

- CE Delft (2008) reviews a number of damage and avoidance cost studies. They base their recommended values on avoidance costs in the short term (2010 and 2020) and on estimated damage costs after 2020. The escalating values recommended are shown in the table below.[72] The recommended per Km value for urban gasoline powered cars is 0.67 Euro cents per km, with a range of 0.19 to 1.20 Euro cents per km (based on tailpipe emissions only and the 2010 values shown below).

Table 5.10.4-17 **External Costs of GHG Emissions** (€/tonne CO_2)

Year	Lower value	Central value	Upper value
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

`Both avoidance and damage cost estimates increase over time in this study

- The Intergovernmental Panel on Climate Change (an organization of leading climate scientists) estimates the costs of mitigating climate change impacts at US $0.10 to $20 per-ton of carbon in tropical regions and US $20 to $100 elsewhere. It also finds that GDP losses in the OECD countries of Europe would range from 0.31% to 1.5% in the absence of international carbon trading, and with full trading the GDP loss would fall to between 0.13% and 0.81%.[73]

- A 2000 report for the International Union of Railways uses a shadow value of 135 Euro per tonne CO2 based on avoidance costs, with a range from 70 to 200 Euro.[74]

- Point Carbon, an emission trading consulting firm, has developed Certified Emissions Reductions (CER) contracts, with prices that vary depending on how risks are distributed between seller and buyer, and the nature of the projects. The table below indicates price ranges prior to 2006, in Euros per tonne of carbon dioxide equivalent (t CO2e).

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[71] Peter Bein (1997), *Reviews of Transport 2021 costs of transporting people in the Lower Mainland*. British Columbia Ministry of Transportation and Highways Planning Services Branch. (www.gov.bc.ca/tran), at www.geocities.com/davefergus/Transportation/0ExecutiveSummary.htm

[72] M. Maibach, et al. (2008), *Handbook on Estimation of External Cost in the Transport Sector*, CE Delft (www.ce.nl); at http://ec.europa.eu/transport/costs/handbook/doc/2008_01_15_handbook_external_cost_en.pdf

[73] IPCC (2001), *Climate Change 2001: Synthesis Report*, Intergovernmental Panel on Climate Change (www.ipcc.ch).

[74] Markus Maibach et al (March 2000) *External Costs of Transport*. INFRAS (www.infras.ch) / IWW Universitaet Karlsruhe (www.iww.uni-karlsruhe.de).

Table 5.10.4-18 **Carbon Emission Credit Prices**[75]

Description	Price Range (EURO/t CO2e)
Non-firm volume. Buyer buys what seller delivers even if emissions reductions turn out not to qualify as CERs.	€3-6
Non-firm volume. Contract contains preconditions, e.g. that the underlying project qualifies for the CDM.	€5-10
Firm volume. Contract contains preconditions (as above). Usually strong force majeure clauses and high credit rating requirements.	€9-14
Firm volume. No preconditions. Forward spot trades will fit this category.	€12-14

- A July 2007 media report notes EU carbon dioxide permits for 2008 were trading at €21.45, or $29.22, a tonne, 47 percent more than the price of 2008 UN credits, called certified emission reductions.[76]

- A U.S. government study concludes that aviation emissions are potentially a significant and growing contributor to climate change, particularly because high-level emissions may have much greater impacts than emissions lower in the atmosphere.[77]

5.10.5 Variability

Vehicle air pollution costs vary depending on vehicle, fuel and travel conditions. Larger, older and diesel vehicles, and those with ineffective emission controls have higher emission costs. Emissions rates tend to be higher for short trips. Urban driving imposes greater air pollution costs than rural driving. Climate change, ozone depletion and acid rain emissions have costs regardless of where they occur. Climate change costs estimates tend to increase with time and depend on the emissions scenario being considered.

5.10.6 Equity and Efficiency Issues

Air pollution emissions are an external cost, and therefore inequitable and inefficient. Lower-income people tend to have relatively high emission vehicles, so emission fees or restrictions tend to be regressive, but many lower-income people experience heavy exposure to air pollutants, and so benefit from emission reduction strategies.

Global warming is inequitable on a global scale since the people with the least responsibility for the problem (lowest incomes and lowest GHG emissions) are the most susceptible to the damage caused.

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[75] Point Carbon (2006), *Carbon 2006 Towards a Truly Global Market*, (www.pointcarbon.com).
[76] Bloomberg News (July 3, 2007), "Price difference between EU and UN carbon credits offers 'huge' profit opportunity" *International Herald Tribune* (www.iht.com); at www.iht.com/articles/2007/07/03/business/carbon.php
[77] GAO (2000), *Aviation and the Environment; Aviation's Effects on the Global Atmosphere Are Potentially Significant and Expected to Grow*, U.S. General Accounting Office (www.gao.gov), Feb. 2000.

5.10.7 Conclusions

Air pollution cost estimates other than GHGs are based on studies described in this chapter, reflecting only tailpipe emissions. It excludes "upstream" emissions that occur during fuel production and distribution, and the pollution associated with vehicle manufacturing and roadway construction, as these costs are captured in chapter 5.12. However, full lifecycle climate change emissions are included in the estimates below.

Greenhouse gas cost estimate

The greenhouse gas emission values are based on the studies summarized in tables 5.10.4-14 and 5.10.4-14. A control cost estimate is used to calculate the default values and damage costs are provided as an upper bound and for sensitivity analysis, as discussed in the VTPI report *Climate Change Emission Valuation for Transportation Economic Analysis*.[78]

Studies by leading experts indicate that climate change may impose significant economic, social and environmental costs. These damages could be catastrophic, far beyond what is considered acceptable and rational, so the upper-bound estimate of damage costs could be virtually infinite. Even more moderate damage predictions imply significant costs that justify significant action to avoid these impacts. Control costs tend to be significantly lower than damage costs. Several recent studies suggest that emission control costs will remain $20-50 per tonne of CO_2e for some time, although this may increase to achieve larger emission reductions. A value of $35 per tonne is used as the default value.

Given that the range of damage cost estimates is from $19 to $917 per tonne, selecting the most appropriate value to use for sensitivity analysis is a difficult task. The value used is 33% of $917 rounded to $300 per tonne CO_{2e}. This value is well above many damage values used in the past, but these lower values must be re-assessed in light of the most recent scientific findings discussed in section 5.10.3 and 5.10.4.

To calculate the per mile value of GHG emissions, the total 2006 US greenhouse gas emissions from the transportation sector was multiplied by the percentage of petroleum use in road transportation (2.010 billion tonnes X 84.1%) for 1.690 billion tonnes of tailpipe emissions.[79] To convert to lifecycle emissions, including automobile manufacturing, roadway construction and maintenance, and upstream emissions from petroleum extraction and refining, values from the Canadian study *Greenhouse Gas Emissions from Transportation Options* are used indication overall transportation emissions at 1.68 times tailpipe emissions.[80] However, as air conditioning emissions are included in the original figures which would bring the factor down to 1.58, and since there is some uncertainty about applying Canadian data to the US and other countries, a more conservative factor of 1.4 is used. This results in a lifecycle emissions estimate of 2.366 billion tonnes. Divided by 3000

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[78] Todd Litman (2009), *Climate Change Emission Valuation for Transportation Economic Analysis.* (www.vtpi.org); at www.vtpi.org/ghg_valuation.pdf

[79] ORNL (2008), Transportation Energy Data Book, Oak Ridge National Laboratory (www.ornl.gov), Tables 1.16 & 11.4; at http://cta.ornl.gov/data/index.shtml

[80] Luc Gagnon (2006); *Greenhouse Gas Emissions from Transportation Options*, Hydro Quebec (www.hydroquebec.com); at www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/transport_en_2006.pdf (52%/31%=1.68)

billion annual miles results in estimated emissions of 0.00079 tonnes per mile (0.79 kg) per mile (including heavy trucks).[81] Emissions for an average car are estimated at 0.49 kg per mile. This estimate is about 15% lower that the lifecycle automobile emissions estimate in the 2008 report, *Environmental Life-cycle Assessment of Passenger Transportation.*[82] Multiplied by $35 per tonne gives an average cost of $0.028 per vehicle mile or $0.017 for an average car.

Summary & Allocation of Costs

Urban Peak local air pollution is estimated to cost about 5¢ per average automobile mile. Urban Off-Peak costs are estimated at a slightly lower 4¢ per VMT to account for smoother road conditions. Rural driving air pollution costs are estimated to be an order of magnitude lower at 0.4¢ per VMT.

Greenhouse gas emissions are estimated at 1.7¢ per mile for an average car and 2.4¢ per mile for light trucks, as shown below in table 5.10.7-2. The upper bound value for greenhouse gas emissions is represented by damage costs of $300 per tonne or about 15¢ per mile for an average car and 20¢ per mile for light trucks, as shown below in table 5.10.7-3.

Compact cars are estimated to have local emissions 10% lower than an average car, and 20% lower global warming costs. Electric vehicles are estimated to produce 25% of local emissions and 25% of global warming costs based on Union of Concerned Scientists data and the fact that electric vehicles produce brake, tire and road dust particulates comparable to gasoline vehicles. Vans and light trucks are estimated to produce 80% more local air pollution than an average car. Motorcycles are estimated to produce twice the local air pollution of an average car, and half the greenhouse gas.

Rideshare passengers impose an air pollution cost 2% of a van based on a 20% emission increase for 10 passengers. Older buses produced relatively high local air pollution costs due to high NOx and particulate output of diesel engines. This is decreasing as strict emission control standards are implemented, so current and near future local emission costs are estimated to be 2.5 times greater than an average automobile, and greenhouse gas costs are 5 times higher based on fuel consumption. Electric trolleys and urban buses are estimated to have air pollution five times greater than an electric car, and GHG emissions 1/3rd that of a diesel bus. Bicycling, walking, and telecommuting are estimated to have negligible air pollution costs.

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[81] This is significantly higher than results obtained using EPA fuel efficiency ratings, but real world fuel consumption and emissions are considerably higher that rated mileage. E.g. Jeremy Korzeniewski (Aug. 2 2008) *Cars.com calculates the real CAFE numbers with True Mileage Index!* (www.cars.com); at www.autobloggreen.com/tag/true+mileage+index/ ; EWG (2006) *Putting the Truth in Your Tank*, Environmental Working Group (www.ewg.org); at www.ewg.org/reports/realmpg.

[82] This report estimates lifecycle emissions for a Camry sedan at 0.36 kg per passenger mile or 0.57 kg per vehicle mile. Mikhail Chester and Arpad Horvath (2008), *Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air v.2*, UC Berkeley Center for Future Urban Transport, (www.its.berkeley.edu/volvocenter/), Paper vwp-2008-2; at http://repositories.cdlib.org/its/future_urban_transport/vwp-2008-2.

Table 5.10.7-1 Estimate **Non-GHG Air Pollution Costs** (2007 US Dollars per VMT)

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.062	0.052	0.004	0.040
Compact Car	0.051	0.042	0.003	0.031
Electric Vehicles	0.016	0.013	0.001	0.010
Van/Light Truck	0.112	0.094	0.007	0.071
Rideshare Passenger	0.002	0.002	0.000	0.001
Diesel Bus	0.185	0.160	0.013	0.129
Electric Bus/Trolley	0.078	0.065	0.005	0.050
Motorcycle	0.106	0.086	0.006	0.061
Bicycle	0.000	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Telecommute	0.000	0.000	0.000	0.000

These only include tailpipe emissions. Other air pollution costs are covered in chapter 5.12.

Table 5.10.7-2 Estimate **Greenhouse Gas Control Costs** (2007 USD per VMT)

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.019	0.017	0.015	0.017
Compact Car	0.014	0.013	0.012	0.013
Electric Vehicles	0.005	0.004	0.004	0.004
Van/Light Truck	0.026	0.024	0.021	0.024
Rideshare Passenger	0.000	0.000	0.000	0.000
Diesel Bus	0.094	0.086	0.077	0.086
Electric Bus/Trolley	0.031	0.028	0.026	0.028
Motorcycle	0.009	0.009	0.008	0.009
Bicycle	0.000	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Telecommute	0.000	0.000	0.000	0.000

These control costs are the default values used for analysis. Damage cost values shown in the table below reflect an upper bound for use in sensitivity analysis. These reflect lifecycle emissions including emissions during petroleum extraction and refining, vehicle manufacturing and maintenance, as well as roadway construction and maintenance.

Table 5.10.7-3 Estimate **Greenhouse Gas Damage Costs** (2007 USD per VMT)

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.161	0.147	0.132	0.147
Compact Car	0.121	0.110	0.099	0.110
Electric Vehicles	0.040	0.037	0.033	0.037
Van/Light Truck	0.222	0.202	0.181	0.202
Rideshare Passenger	0.004	0.004	0.004	0.004
Diesel Bus	0.806	0.733	0.660	0.733
Electric Bus/Trolley	0.269	0.244	0.220	0.244
Motorcycle	0.081	0.073	0.066	0.073
Bicycle	0.000	0.000	0.000	0.000
Walk	0.000	0.000	0.000	0.000
Telecommute	0.000	0.000	0.000	0.000

These damage costs are upper bound values for use in sensitivity analysis. These reflect lifecycle emissions.

Automobile Cost Range
The minimum value estimate is based on the lower range of estimates described. The maximum is based on the higher end range of the estimates described.

Local Air Pollution	Minimum	Maximum
	$0.002	$0.10

GHG Emissions	Minimum	Maximum
	$0.009	$0.15

5.10.8 Resources
Resources on vehicle emissions and emission reduction strategies are listed below.

Emission Calculators
Below are various tools for calculating the emissions of various activities and goods:

- *CarbonCounter* (www.carboncounter.org). Carboncounter.org is an individual carbon dioxide emissions calculator generated by The Climate Trust.
- *Density Effects Calculator* (www.sflcv.org/density). Indicates how neighborhood density impacts the environment (land, materials, energy and driving).
- *EPA's Personal Online Greenhouse Gas Calculator* (www.epa.gov/climatechange/emissions/ind_calculator.html).
- *MetroQuest* (www.envisiontools.com). Evaluates different long-term planning strategies.
- *Personal* CO_2 *Calculation* (www3.iclei.org/co2/co2calc.htm). This worksheet determines yearly direct personal carbon dioxide emissions. Results include yearly personal carbon dioxide emissions and a per capita comparison chart to other industrialized countries.
- *SafeClimate Carbon Dioxide Footprint Calculator* (http://safeclimate.net/calculator). Calculates "carbon footprints" by tracking residential and transportation energy consumption and greenhouse gas emissions in the U.S., Canada and 36 other countries.
- *Tool For Costing Sustainable Community Planning* (www.cmhc-schl.gc.ca/en/inpr/su/sucopl/index.cfm) by the Canadian Mortgage and Housing Corporation allow a user to estimate the major costs of community development, particularly those that change with different forms of development (e.g., linear infrastructure), and to compare alternative development scenarios.
- Travel Matters Emissions Calculators *(www.travelmatters.org). TravelMatters! from the Center for Neighborhood Technology that provides interactive emissions calculators, online emissions maps, and a wealth of educational content that emphasize the relationship between more efficient transit systems and lower greenhouse gas emissions.*

Other Resources

Airimpacts.org (www.airimpacts.org) is a UN Environmental Program website with comprehensive information on the health and economic impacts of air pollution.

AEA Technology (2005), *Damages Per Tonne Emission of PM2.5, NH3, SO2, NOx and VOCs From Each EU25 Member State*, Clean Air for Europe Programme, European Commission (http://ec.europa.eu/index_en.htm).

BenMAP (http://benmap-model.org) is a computer program that estimates the health benefits from improvements in air quality.

Cambridge Systematics (2001), *Quantifying Air-Quality and Other Benefits and Costs of Transportation Control Measures*, NCHRP Report 462, TRB (www.trb.org); at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_462-a.pdf

Mikhail Chester and Arpad Horvath (2008), *Environmental Life-cycle Assessment of Passenger Transportation: A Detailed Methodology for Energy, Greenhouse Gas and Criteria Pollutant Inventories of Automobiles, Buses, Light Rail, Heavy Rail and Air v.2*, Paper vwp-2008-2, UC Berkeley Center for Future Urban Transport (www.its.berkeley.edu/volvocenter), at www.sustainable-transportation.com.

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John Davies, Michael Grant, John Venezia and Joseph Aamidor (2007), "Greenhouse Gas Emissions of the U.S. Transportation Sector: Trends, Uncertainties, and Methodological Improvements," *Transportation Research Record 2017*, TRB (www.trb.org), pp. 41-46; at http://trb.metapress.com/content/874k474474g5g767/?p=c4c8c51439f7453d9e494db833250bbb&pi=5.

Mark A. Delucchi (2003), *A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials*, ITS-Davis, Publication No. UCD-ITS-RR-03-17 (www.its.ucdavis.edu); at www.its.ucdavis.edu/publications/2003/UCD-ITS-RR-03-17-MAIN.pdf

Mark A. Delucchi (2005) *A Multi-Country Analysis of Lifecycle Emissions from Transportation Fuels and Motor Vehicles*, Institute of Transportation Studies, University of California Davis (www.its.ucdavis.edu); at www.its.ucdavis.edu/publications/2005/UCD-ITS-RR-05-10.pdf.

Mark Delucchi (2005), *The Social-Cost Calculator (SCC): Documentation of Methods and Data, and Case Study of Sacramento*, Sacramento Area Council of Governments (SACOG) and the Northeast States for Coordinated Air-Use Management (NESCAUM), UCD-ITS-RR-05-37, (www.its.ucdavis.edu); at www.its.ucdavis.edu/publications/2005/UCD-ITS-RR-05-18.pdf.

DfT (2009), *Transport Analysis Guidance: 3.3.5: The Greenhouse Gases Sub-Objective*, Department for Transport (www.dft.gov.uk); at www.dft.gov.uk/webtag/documents/expert/unit3.3.5.php.

Jos Dings, et al. (2002), *External Costs Of Aviation*, CE (www.ce.nl).

EC (2005), *ExternE: Externalities of Energy - Methodology 2005 Update*, Directorate-General for Research Sustainable Energy Systems, European Commission (www.externe.info); at www.externe.info/brussels/methup05a.pdf.

EDRG (2007), *Monetary Valuation of Hard-to-Quantify Transportation Impacts: Valuing Environmental, Health/Safety & Economic Development Impacts*, NCHRP 8-36-61, National Cooperative Highway Research Program (www.trb.org/nchrp); at www.statewideplanning.org/_resources/63_NCHRP8-36-61.pdf.

EEA (2007), *Climate Change: The Cost of Inaction and the Cost of Adaptation*, European Environmental Agency (www.eea.europa.eu); at http://reports.eea.europa.eu/technical_report_2007_13/en.

EEA (2008), *Climate For a Transport Change*, European Environmental Agency (www.eea.europa.eu); at http://reports.eea.europa.eu/eea_report_2008_1/en/EEA_report_1_2008_TERM.PDF.

European Environment Agency (www.eea.eu.int) provides international information on vehicle energy consumption and emissions.

Environmental Valuation Reference Inventory (www.evri.ca) is a searchable storehouse of empirical studies on the economic value of environmental benefits and human health effects.

Christopher Frey (2007), *Best Practices Guidebook for Greenhouse Gas Reductions in Freight Transportation*, Center for Transportation and the Environment (http://itre.ncsu.edu/CTE); at http://itre.ncsu.edu/CTE/Research/project.asp?ID=83

Luc Gagnon (2006); *Greenhouse Gas Emissions from Transportation Options*, Hydro Quebec (www.hydroquebec.com); at www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/transport_en_2006.pdf

Kelly Sims Gallagher, et al. (2007), *Policy Options for Reducing Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector*, ETIP Discussion Paper, Belfer Center for Science and International Affairs (www.belfercenter.org), Harvard University; at www.belfercenter.org/files/policy_options_oil_climate_transport_final.pdf

Ross Garnault et al. (2008) *The Garnault Climate Change Review: Final Report,* Australian Government Department of Climate Change (www.climatechange.gov.au); at www.garnautreview.org.au

Olav Hohmeyer (2006), *External Costs of Climate Change and Normative Judgements*, German Institute for Economic Research (www.diw-berlin.de/english); at www.diw-berlin.de/documents/dokumentenarchiv/17/44230/Hohmeyer%20DIW%202006%20External%20Costs%20Final.pdf.

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ITDP and CAI-Asia Center (2010), *Transport Emissions Evaluation Models for Projects (TEEMP)*, Clean Air Initiative for Asian Cities (www.cleanairinitiative.org) and the Institute for Transportation and Development Policy (www.itdp.org); at www.cleanairinitiative.org/portal/node/6941. These Excel-based TEEMP models were developed for evaluating the emissions impacts of Asian Development Bank's transport projects (www.adb.org/Documents/Evaluation/Knowledge-Briefs/REG/EKB-REG-2010-16/default.asp) and were modified and extended by ITDP, CAI-Asia and Cambridge Systematics for the for Global Environmental Facility (www.thegef.org) Scientific and Technical Advisory Panel (STAP). *The Manual for Calculating Greenhouse Gas Benefits of Global Environmental Facility Transportation Projects* (www.thegef.org/gef/GEF_C39_Inf.16_Manual_Greenhouse_Gas_Benefits) provide step-by-step instructions for developing baseline and impact estimations for various types of transport policies and projects, including transport efficiency improvement, public transport, non-motorized transport, transport demand management, and comprehensive transport strategies.

Todd Litman (2009), *Climate Change Emission Valuation for Transportation Economic Analysis.* (www.vtpi.org); at www.vtpi.org/ghg_valuation.pdf.

McKinsey (2007), *Reducing U.S. Greenhouse Gas Emissions - How Much at What Cost - US Greenhouse Gas Abatement Mapping Project*, McKinsey & Company (www.mckinsey.com); at www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf

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B. Ostro (2004), *Outdoor Air Pollution: Assessing The Environmental Burden Of Disease At National And Local Levels*, No. 5, Environmental Burden of Disease Series, World Health Organization (www.who.int/quantifying_ehimpacts/publications/ebd5/en).

Niklas Sieber and Peter Bicker (2008), *Assessing Transportation Policy Impacts on the Internalization of Externalities of Transport*, Transport & Mobility Leuven for the European Commission; at www.tmleuven.be/project/refit/d3-3.pdf.

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Surface Transportation Environment and Planning Cooperative Research Program (www.fhwa.dot.gov/hep/step/index.htm) provides research information in the area of Planning, Environment and Land Use.

Sir Nicholas Stern (2006), *Stern Review on the Economics of Climate Change*, HM Treasury (www.sternreview.org.uk).

Transportation Air Quality Center, USEPA (www.epa.gov/otaq) provides information on vehicle emissions, emission reduction strategies, and tools for evaluating the emission impacts.

Travel Matters (www.travelmatters.org) is a website with interactive emissions calculators, on-line emissions maps and other information resources to help examine the relationships between transportation decisions and greenhouse gas emissions.

Urban Emissions Information (http://urbanemissions.info) is a website that promotes the sharing of knowledge base on air pollution analysis and management, particularly in developing countries. The *SIM-air Working Paper Series* (http://urbanemissions.info/simair/simseries.html) includes various technical papers concerning air pollution analysis and control.

UNEP (2007) *Global Environmental Outlook 4*, (www.unep.org); at www.unep.org/geo

Nadine Unger, et al. (2011), "Attribution Of Climate Forcing To Economic Sectors," *Proceedings of the National Academy of Sciences of the U.S.* (www.pnas.org): at www.pnas.org/content/early/2010/02/02/0906548107.abstract.

Urban Transportation Emissions Calculator (www.tc.gc.ca/UTEC) provides tools for estimating greenhouse gas (GHG) and criteria air pollution emissions from various types of vehicles.

USEPA (annual reports), *Green Vehicle Guide*, US Environmental Protection Agency (www.epa.gov/greenvehicles) reports emissions and fuel consumption rates per vehicle mile for specific model years.

USEPA (1999), *The Benefits and Costs of the Clean Air Act 1990 to 2010*, EPA-410-R-99-001, US Environmental Protection Agency (www.epa.gov); at www.epa.gov/oar/sect812

USEPA (1999), *Indicators of the Environmental Impacts of Transportation*, Office of Policy and Planning, USEPA (www.itre.ncsu.edu/cte).

USEPA (2000), *Guidelines for Preparing Economic Analyses*, U.S. Environmental Proteciton Agency (http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html).

USEPA Transportation Tools (www.epa.gov/climatechange/wycd/tools_transportation.html) provides links to sources of information on transport activities, emissions and emission reductions.

van Essen, et al (2004), *Marginal Costs of Infrastructure Use – Towards a Simplified Approach*, CE Delft (www.ce.nl).

VTPI (2006), "Energy and Emission Reduction Strategies," *Online TDM Encyclopedia*, VTPI (www.vtpi.org); at www.vtpi.org/tdm/tdm59.htm

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