5.10 Air Pollution

This chapter describes vehicle air pollutants, how emissions of different vehicles can be quantified, factors that affect emission rates, and the costs of vehicle air pollution.

Definition

Air Pollution Costs refers to motor vehicle air pollutant (called *mobile emissions*) damages, including human health, ecological and esthetic degradation.

Discussion

Motor vehicles produce various harmful air emissions, as summarized in Table 5.10-1. Some impacts are localized, so where emissions occur affects their costs, while others are regional or global, and so location is less important.

Table 5.10-1 **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 consisting of bits of fuel and carbon.	Diesel veh. tailpipes and other sources.	Human health, aesthetics.	Local and Regional
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
Road dust (non-tailpipe particulates)	Dust particles created by vehicle movement.	Vehicle use, brake linings, tire wear.	Human health, aesthetics.	Local
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*, USEPA (www.itre.ncsu.edu/cte), 1999; ORNL, *Transportation Energy Data Book* ORNL, (www.ott.doe.gov).

Table 5-10.2 **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.)

Air pollution is a commonly recognized external transportation cost. Compared with some other emissions sources, such as electricity generation plants and factories, mobile (motor vehicle) emissions tend to be relatively difficult to control because they are numerous and dispersed, and have relatively high damage costs because motor vehicles operate close to people.

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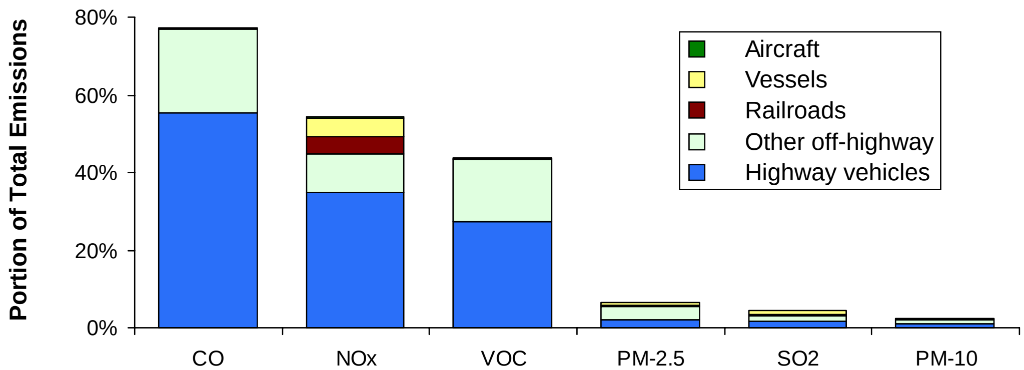
[2] Ken Gwilliam and Masami Kojima (2004), *Urban Air Pollution: Policy Framework for Mobile Sources*, Prepared for the Air Quality Thematic Group, World Bank (www.worldbank.org); available at www.cleanairnet.org/cai/1403/articles-56396_entire_handbook.pdf.

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 5.10-1 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 5.10-1 **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 (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. Although some critics claim that climate change effects are still unproven or that benefits offset costs,[5] major scientific organizations consider climate change a significant risk. For example, the Intergovernmental Panel on Climate Change, which consists of hundreds of scientists, concluded, "The balance of evidence suggests a discernible human influence on global climate" that can impose a variety of costs on society.[6] Similarly, the American Geophysical Union concluded that, "the present level of scientific uncertainty does not justify inaction in the mitigation of human-induced climate change and/or the adaptation to it."[7] The United Nations Environmental Programme's Global Environment Outlook emphasizes the need for action to reduce risks.[8]

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[3] Kathryn A. Sargeant (2003), "Reducing Air Toxics from Transportation Sources," *TR News 227*, Transportation Research Board (www.trb.org), July-August 2003, pp. 18-21.
[4] ORNL (2005), *Transportation Energy Data Book*, USDOE (www-cta.ornl.gov/data), Table 12.1.
[5] *Center for the Study of Carbon Dioxide and Global Change* (www.co2science.org).
[6] www.ipcc.ch.
[7] AGU (1998), *Climate Change and Greenhouse Gases*, American Geophysical Union (www.agu.org).
[8] *Global Environmental Outlook*, UNEP (www.unep.org/geo2000/ov-e/0012.htm), 1999.

Factors Affecting Emission Costs

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

Scope

The scope of analysis may be narrow, only considering tailpipe emissions, or it can be 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 when and where they occur.[9] Motor vehicles produced the following portion of U.S. air toxic emissions: benzene, 48%; butadiene, 42%; formaldehyde, 24%; xylene, 43%.[10]

Table 5.10-3 **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.

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

Fuel Type

A variety of fuels can power vehicles, as summarized below. Alternative fuels tend to reduce some emissions, but in many cases their total net benefits (including "upstream" emissions during production and distribution) are modest.

Table 5.10-4 **Alternative Fuels Compared** (www.afdc.doe.gov)

Fuel	CO_2*	Advantages	Disadvantages
Diesel	20%	Widely available and used. Reduces carbon emissions.	Increases emissions of particulates, sulfur and noise.
LPG	10%	Increased efficiency and reduced emissions.	Requires rebuilding engines. Limited availability.
CNG	20%	Increased efficiency and reduced emissions.	Requires rebuilding engines. Limited availability. May reduce methane.
Methanol	60%	Reduces some emissions.	Poisonous. Increases some emissions.
Ethanol	0-60%	Reduces some emissions.	Increases some emissions. Total impacts depend on feed stock.
Electricity	20-70%	No tailpipe emissions. Can be generated from renewable sources.	Reduced vehicle performance and increased costs. Total impacts depend on source of electricity.
Hydrogen	20-70%	No tailpipe pollutants.	Not currently available. Total impacts depend on source of hydrogen.

* Estimated reduction in lifecycle CO_2 emissions per vehicle-mile compared with gasoline.

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[9] Mark A. Delucchi, *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/publications/2003/UCD-ITS-RR-03-17-MAIN.pdf), 2003.

[10] BTS, *Transportation Statistics Annual Report 2000*, Bureau of Transportation Statistics (www.bts.gov), 2002, p. 192.

Emissions are measured in various units, including grams, pounds, kilograms, tons or tonnes. Below are some useful conversion factors.

Useful Conversion Factors
Convert CO_2 to carbon: multiply by 0.2727
Convert pounds (16 ounces) to kilograms (1,000 grams): multiply by 2.20
Convert grams to tons: multiply by 909,091
Convert tons (2,000 pounds) to tonnes (1,000 kilograms): multiply by 1.1
Convert liters to U.S. gallon: multiply by 3.785

The table below indicates CO_2 equivalences of common fuels.

Table 5.10-5 **Carbon Dioxide Equivalences** (Grams Per Liter)[11]

Fuel Type	CO_2	CH_4	NO_2	Total CO_2 Equivalent	
CO_2 Equivalent Factor	*1*	*21*	*310*	*Grams Per Liter*	*Grams Per Gallon*
Gasoline	2,360	0.2273	0.3358	2,469	9,345
Diesel	2,730	0.0605	0.2	2,793	10,572
Ethanol 10	2,124	0.2273	0.3358	2,233	8,452
Ethanol 85	531	0.2273	0.358	640	2,422
Conventional Aircraft Fuel	2,330	2.19	0.23	2,447	9,262
Jet Fuel	2,550	0.08	0.25	2,629	9,951

This table indicates the CO_2 equivalents of various fuels.

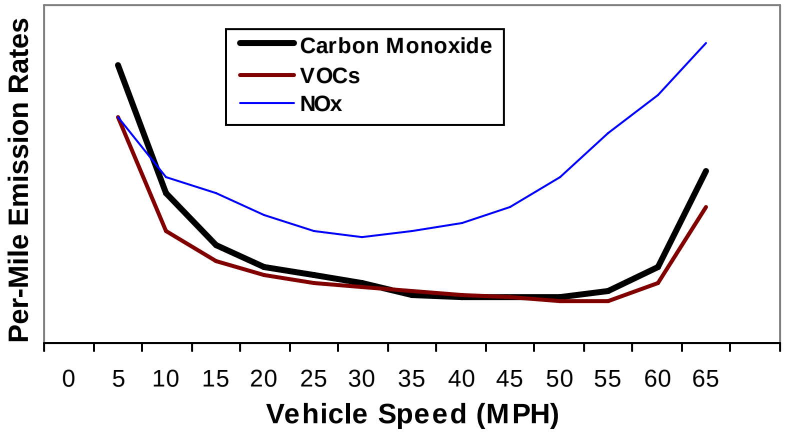
Emission Rates

Vehicle emission models, such as MOBILE6 and its variants developed for specific geographic areas, can be used to predict total emissions under various circumstances.[12] Various factors that affect vehicle emission rates are described below.[13]

- 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. Emission rates increase under hilly conditions, for stop-and-go driving, and at low and high speeds, as illustrated in Figure 5.10-2. NOx emissions increase above 15-20 miles per hour, VOC emissions increase above 30-35 mph, and CO above 30. As a result, reducing highway congestion from roadway Level of Service (LOS) F to LOS D probably reduces energy consumption and emissions, but shifting from LOS D to A probably increases energy consumption and most emissions.

[11] FHIO (2003), *Greenhouse Gas Table of Conversion Factors*, Government of Canada (www.fhio-ifppe.gc.ca/default.asp?lang=En&n=F837EFD4-1).
[12] www.epa.gov/OTAQ/mobile.htm.
[13] USDOT, *Sensitivity Analysis of MOBILE6 Motor Vehicle Emission Factor Model*, FHWA, USDOT (www.epa.gov/OTAQ/m6.htm); available at www.tdot.state.tn.us/mediaroom/docs/2005/emission_reductions.pdf.

Figure 5.10-2 **Vehicle Emissions By Speed**[14]



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

Location and Exposure

"Local" pollutants such as carbon monoxide, air toxics and particulates, tends to be concentrated in vehicles and along adjacent to roadways.[15] 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.[16]

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.[17] Models such as URBEMIS (*www.urbemis.com*) can be used to predict the emission reduction effects of various mobility and land use management strategies.[18]

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[14] TRB, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, TRB Special Report #345, National Academy Press (Washington DC; www.trb.org), 1995.

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

[16] John Whitelegg and Howard Cambridge, *Aviation and Sustainability*, Stockholm Environmental Institute (www.sei.se/aviation/index.html), 2004.

[17] VTPI, "Land Use Impacts on Transportation," "Transportation Elasticities," and other chapters in the *Online TDM Encyclopedia*, Victoria Transport Policy Institute (www.vtpi.org), 2005.

[18] Nelson/Nygaard, *Crediting Low-Traffic Developments: Adjusting Site-Level Vehicle Trip Generation Using URBEMIS*, Urban Emissions Model, California Air Districts (www.urbemis.com), 2005.

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). Unit costs are affected by the mortality (deaths) and morbidity (illnesses) caused by exposure to that pollutant (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]),[19] and the range of additional costs and damages (such as crop losses, ecological degradation, and aesthetic degradation) considered in the analysis.

Several studies, summarized later in this paper, estimate unit costs of various pollutants using methods discussed in Chapter 4. Some of these estimates are several years old (for example, Wang, Santini and Warinner's study was completed in 1994), and updated based on inflation rates. It is possible that 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 pollution costs can also be calculated based on emission reductin (often called *control* or *avoidance*) costs, that is, the marginal cost of reducing a unit of emissions. It is often possible to create an emission market in which buyers purchase emission reduction credits, so businesses and countries can meet emission reduction obligations. These credits represent a reduction in emissions compared with what would otherwise occur. Examples include the *European Union Emissions Trading Scheme* (http://ec.europa.eu/environment/index_en.htm), created in conjunction with the Kyoto Protocol, and the *International Emissions Trading Association* (www.ieta.org).

In general, if damage and control costs differ, cost analysis can be based on the lower value. For ecample, if carbon dioxide emissions are estimated to cause $100 per ton, but emission reductions cost $10 per ton, cost analysis should be based on the $10 control cost value, but if damage costs are determined to be $20 per ton and emission reductions would cost $30 per ton, cost analysis should be based on the $20 damage cost value.

[19] *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.

Calculated Air Pollution Costs

The VTPI *Air Pollution Costs Spreadsheet* calculates air pollution costs for various vehicle classes (cars, light trucks and heavy vehicles) and locations (urban and rural), and can be adjusted to reflect specific conditions.[20] The table below summarizes the default unit costs used in the spreadsheet, based on studies described in this chapter. This analysis excludes several types of harmful air pollutants, such as non-tailpipe particulates and "upstream" emissions that occur during fuel production and distribution (these would be included in the "other" row), so true total costs are actually somewhat higher than indicated.

Table 5.10-6 **Air Pollution Unit Costs** (2002 Dollars Per Ton)[21]

	Urban	Rural
Carbon monoxide (CO)	$435	$0
Nitrogen oxides (NOx)	$15,419	$8,789
Volatile organic compounds (VOC)	$14,419	$11,823
Particulate Mater (PM)	$5,346	$2,620
Carbon dioxide (CO_2)	$18.13	$18.13

This table summarizes the default unit air pollution costs used in the Air Pollution Cost Spreadsheet, based on studies described in this chapter.

Table 5.10-7 shows calculated U.S. average air pollution costs per year and vehicle-mile, based on standard vehicle emission rates and mileage published by government agencies. This analysis indicates that average cars impose air pollution costs of approximately 5¢ per mile in urban areas and 1¢ per mile in rural areas, and light trucks impose about 20% higher emissions. New vehicles that produce lower emissions per mile impose lower costs. For example, based on these unit costs a 2007 Honda Accord 3 liter automatic transmission car, categorized as a Bin 6 vehicle (according to the USEPA rating system), imposes air pollution costs of about 1¢ per vehicle-mile.[22]

[20] VTPI (2006), *Air Pollution Costs Spreadsheet*, VTPI (www.vtpi.org/airpollution.xls).

[21] Based on values from Wang, Santini and Warinner (1994), updated to reflect inflation and discounted for rural conditions based on AEA Technology (2005). 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, Transportation Research Board (www.trb.org), pp. 33-41.

[22] USEPA (2006), *Green Vehicle Guide*, US Environmental Protection Agy. (www.epa.gov/greenvehicles).

Table 5.10-7 **Estimated Vehicle Air Pollution Costs** (2002)[23]

	Urban					Rural				
	Unit Costs	**Emissions**	**Mileage**	**Total Costs**	**Unit Costs**	**Unit Costs**	**Emissions**	**Mileage**	**Total Costs**	**Unit Costs**
	Dollars Per Ton	Million Tons	Billion Miles	Billion Dollars	Dollars Per Mile	Dollars Per Ton	Million Tons	Billion Miles	Billion Dollars	Dollars Per Mile
Light Vehicles										
CO	$435	22.47	1,092	$9.8	$0.009	$0	11.94	580	$0.0	$0.000
NOx	$11,209	1.42	1,092	$16.0	$0.015	$6,389	0.76	580	$1.7	$0.003
VOC	$8,963	1.63	1,092	$14.6	$0.013	$7,350	0.87	580	$2.2	$0.004
PM	$7,391	0.03	1,092	$0.3	$0.000	$3,622	0.02	580	$0.0	$0.000
CO2	$12.50	113.99	1,092	$1.4	$0.008	$12.50	60.55	580	$0.3	$0.003
Totals			*1,092*	*$42.0*	*$0.045*			*580*	*$4.2*	*$0.009*
Light Trucks										
CO	$435	15.72	611	$6.8	$0.011	$0	9.59	373	$0.0	$0.000
NOx	$11,209	0.88	611	$9.8	$0.016	$6,389	0.53	373	$1.3	$0.003
VOC	$8,963	1.02	611	$9.1	$0.015	$7,350	0.62	373	$1.7	$0.005
PM	$7,391	0.02	611	$0.1	$0.000	$3,622	0.01	373	$0.0	$0.000
CO2	$12.50	86.70	611	$1.1	$0.010	$12.50	52.93	373	$0.3	$0.004
Totals			*611*	*$27.0*	*$0.053*			*373*	*$3.3*	*$0.012*
Heavy Vehicles										
CO	$435	1.58	94	$0.7	$0.007	$0	2.09	124	$0.0	$0.000
NOx	$11,209	1.63	94	$18.3	$0.194	$6,389	2.15	124	$7.8	$0.063
VOC	$8,963	0.17	94	$1.5	$0.016	$7,350	0.23	124	$0.9	$0.008
PM	$7,391	0.05	94	$0.4	$0.004	$3,622	0.07	124	$0.1	$0.001
CO2	$12.50	42.46	94	$0.5	$0.033	$12.50	56.01	124	$0.4	$0.019
Totals			*94*	*$21.4*	*$0.255*			*124*	*$9.3*	*$0.091*
Total Vehicles										
CO	$435	39.77	1,797	$17.3	$0.009	$0	7.87	1,077	$0.000	$0.000
NOx	$11,209	3.93	1,797	$44.0	$0.075	$6,389	1.15	1,077	$3.595	$0.023
VOC	$8,963	2.82	1,797	$25.3	$0.015	$7,350	0.57	1,077	$1.632	$0.005
PM	$7,391	0.11	1,797	$0.8	$0.002	$3,622	0.03	1,077	$0.060	$0.000
CO2	$12.50	243.16	1,797	$3.0	$0.017	$12.50	56.50	1,077	$0.304	$0.008
Totals			*1,797*	*$90.5*	*$0.118*			*1,077*	*$5.6*	*$0.037*

This table summarizes U.S. vehicle fleet air pollution costs, based on standard unit cost values.

[23] VTPI (2006), *Air Pollution Costs Spreadsheet*, VTPI (www.vtpi.org/airpollution.xls).

Estimates

All values are in U.S. dollars unless otherwise indicated.

- A comprehensive (535-page) Australian study estimates full social costs of various greenhouse gas emission control strategies.[24] Some pricing and transit promotion strategies have negative social costs (they provide overall benefits) when congestion reduction, safety and other secondary benefits are considered.

- 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 5.10-8 **Average Damages Per Tonne Of Emissions** (2005)[25]

Assumptions				
PM mortality	VOLY median	VSL median	VOLY mean	VSL mean
O3 Mortality	Mortality	VOLY median	VOLY mean	VOLY mean
Health Core?	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")*

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24 Bureau of Transport and Communications Economics, *Transport and Greenhouse; Costs and Options for Reducing Emissions*, Australian Government Printing Service (Canberra), 1996.

25 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 (http://ec.europa.eu/environment/air/cafe/activities/cba.htm); available at http://ec.europa.eu/environment/air/cafe/activities/pdf/cafe_cba_externalities.pdf.

- Delucchi, *et al.*, estimate the human health costs of motor vehicle air pollution as summarized in Table 5.10-9. Additional costs include $2-4 billion annually in ozone damage to commercial agriculture,[26] and $5-40 billion in reduced visibility.[27]

Table 5.10-9 **Air Pollution Health Costs by Motor Vehicle Class** ($1990/VMT)[28]

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 European Commission *ExternE* program monetized energy production external costs for 14 countries. Table 5.10-10 summarizes estimates of global warming unit costs. This indicates a greenhouse gas cost of 18¢ to 56¢ U.S. per gallon of gasoline.

Table 5.10-10 **Greenhouse Gas Damage Costs**[29]

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

- The table below shows estimated tailpipe emission costs for vehicles meeting current control standards.

Table 5.10-11 **Damage Costs of Emissions from New Vehicles** (1996)[30]

	Rural		Urban	
	(Pence/km)	¢/mile	(Pence/km)	¢/mile
Gasoline Vehicle	0.5	1.4	1.1	3.0
Natural Gas Vehicle	0.2	0.5	0.4	1.0
Diesel Vehicle	0.7	1.9	2.7	7.4

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26 Mark Delucchi, 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), 1996.

27 Mark Delucchi, James Murphy, Donald McCubbin and Jin Kim, *Cost of Reduced Visibility Due to Particulate Air Pollution From Motor Vehicles*, UC Davis, ITS (www.its.ucdavis.edu), 1996.

28 Donald McCubbin and Mark Delucchi, *Social Cost of the Health Effects of Motor-Vehicle Air Pollution*, UC Davis, ITS (www.its.ucdavis.edu), 1996, Table 11.7-6. Also see Mark Delucchi, "Environmental Externalities of Motor-Vehicle Use in the US," *Journal of Transportation Economics and Policy*, Vol. 34, No. 2, May 2000, pp. 135-168.

29 *ExternE; Newsletter 6*, European Commission (http://externe.jrc.es), March 1998.

30 N. J. Eyre, et al, "Fuel and Location Effects on the Damage Costs of Transport Emissions," *Journal of Transport Economics and Policy*, Vol. 31, No. 1, Jan. 1997, pp. 5-24.

- 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.[31]

Table 5.10-12 Air Pollution Costs[32]

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 5.10-13 Arterial Truck Emission Factors (grams/mile)[33]

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.[34]

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[31] FHWA, *Highway Economic Requirements System: Technical Report*, Federal Highway Administration, U.S. Department of Transportation (www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.htm), 2002; available at http://isddc.dot.gov/OLPFiles/FHWA/010945.pdf.

[32] FHWA, *1997 Federal Highway Cost Allocation Study Final Report Addendum*, Federal Highway Administration, USDOT (www.ota.fhwa.dot.gov/hcas/final), 2000, Table 12.

[33] ICF Consulting, *Assessing the Effects of Freight Movement on Air Quality at the National and Regional Level*, US Federal Highway Admin. (www.fhwa.dot.gov/ENVIRonment/freightaq/index.htm), 2005.

[34] David Forkenbrock, "External Costs of Intercity Truck Freight Transportation," *Transportation Research A*, Vol. 33, No. 7/8, Sept./Nov. 1999, pp. 505-526.

- 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.[35] The study found that, on average, hospital admissions for respiratory problems were 19% higher, outpatient care was 18% higher, and total hospital admissions were 10% higher for elderly people in the 37 areas with the highest pollution compared with the 37 areas with 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.

- 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.[36]

- Heaney, et al, estimate air pollution unit costs in rural Ireland as summarized in Table 5.10-14.

Table 5.10-14 **Costs of Externalities**[37]

Emission	Euros Per Kilogram
CO2	0.025
NO2	0.009
SO2	0.009
HC	0.0008
CO	Negligible
PM	0.17

- Henderson, Cicas and Matthews compare the energy consumption and pollution emission rates of various freight modes.[38] 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.

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[35] Victor R. Fuchs and Sarah Rosen Frank, "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.
[36] GAO, *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.
[37] Quentin Heaney, Margaret O'Mahony, and Eithne Gibbons, "External Costs Associated With Interregional Transport," *Transportation Research Record 1959*, TRB, 1999, pp. 79-86.
[38] 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.

- An extensive European research program calculates the air emission cost values in Table 5.10-15. 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.

Table 5.10-15 **European Emission Costs** (2002 Euros Per Tonne)[39]

	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	

- According to the International Emission Trading Association (www.ieta.org), the mean price of the 700 million tonnes of carbon credits contracted during 2004-06, has been below €10 per tonne.[40] These costs may increase in the future as demand for emission credits grows and the cheapest emission reduction options are fully implemented, or may decline if cheaper emission reduction strategies are developed.

- 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%.[41]

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[39] Mike Holland and Paul Watkiss, *Estimates of Marginal External Costs of Air Pollution in Europe*, European Commission (http://europa.eu.int/comm/environment/enveco/studies2.htm) 2002.
[40] IETA (2006), *Facts about Emissions Trading*, International Emissions Trading Assoc. (www.ieta.org).
[41] IPCC, *Climate Change 2001: Synthesis Report*, Intergovernmental Panel on Climate Change (www.ipcc.ch/pub/SYR-text.pdf), 2001.

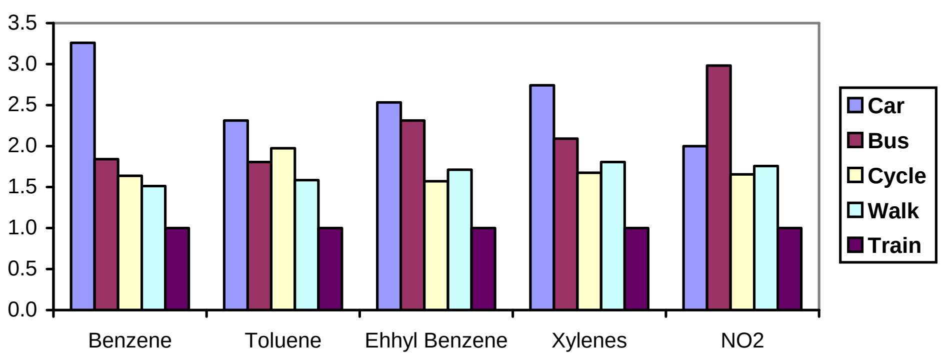
- A U.S. study estimated that electric vehicles produce 33% the air pollution costs of an average gasoline car if electricity is generated by natural gas, and 80% if by coal.[42] Similarly, Wang and Santini estimate that electric vehicles reduce CO and VOC emissions 98%, with smaller reductions in NOx and SOx, and 50% reductions in CO_2 emissions.[43] 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 5.10-16.[44]

Table 5.10-16 **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

- 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.[45] Automobile occupants tend to be exposed to more air pollution than people traveling by other modes, as indicated in Figure 5.10-6.

Figure 5.10-6 **Relative Air Pollutant Exposure By Mode**[46]



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

[42] Center for Transportation Research, *Texas Transportation Energy Savings: Assessment of Control Measures, Technologies and Policies*, Texas Sustainable Energy Dev. Council (Austin), 1995, p. 99.
[43] Quanlu Wang and Danilo Santini, "Magnitude and Value of Electric Vehicle Emissions Reductions for Six Driving Cycles in Four U.S. Cities," *Transportation Research Record* 1416, 1993, p. 33-42.
[44] Roland Hwang, et al., *Driving Out Pollution: The Benefits of Electric Vehicles*, UCS (Berkeley), 1994.
[45] Charles Rodes, et al. (1998), *Measuring Concentrations Of Selected Air Pollutants Inside California Vehicles*, California Air Resources Board (www.arb.ca.gov).
[46] Michael Chertok, Alexander Voukelatos, Vicky Sheppeard and Chris Rissel, "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.bfa.asn.au/bfanew/pdf/HPJA_air_pollution_exposure.pdf), 2004, pp. 63-67.

- One study found a six-fold increase in childhood cancers in households living adjacent to high traffic roads (20,000+ vehicles per day).[47] The authors suggest that this results from residents' exposure to air toxics, such as benzene, and perhaps NOx.

- 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).

Table 5.10-17 **Carbon Emission Rection Credit Prices**[48]

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 qualifi es 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

- 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.[49]

- A widely cited study by Small and Kazimi estimated human morbidity and mortality costs from vehicle tailpipe particulate and ozone emissions in Southern California.[50] 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 particulates, plus less acute human health impacts and ecological damages. The authors stated that road dust may add 4.3¢ per VMT.

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[47] Robert Pearson, Howard Wachtel and Kristie Ebi, "High Traffic Streets Linked to Childhood Cancers," *Journal of the Air and Waste Management Association*, Feb. 2000.

[48] Point Carbon (2006), *Carbon 2006 Towards a Truly Global Market*, (www.pointcarbon.com).

[49] Rita Seethaler, *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.who.dk), June 1999.

[50] Ken Small and Camilla Kazimi, "On the Costs of Air Pollution from Motor Vehicles," *Journal of Transport Economics and Policy*, January 1995, pp. 7-32.

- 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.[51] This study supports the development of international emission trading, which would establish a monetized unit value of greenhouse gas emissions.

- 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.[52]

Table 5.10-187 **Environmental Costs of Freight** (1990 Vehicles)[53]

	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.[54]

- van Essen, et al describe various method that can be used to calculate air pollution costs, and summarize monetized estimates of various pollutants.[55] They recommend the Impact Pathway Approach (IPA) developed by the the ExternE-project.

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51 Sir Nicholas Stern, *Stern Review on the Economics of Climate Change*, HM Treasury (www.sternreview.org.uk), 2006.
52 Gordon Taylor, *Trucks and Air Emissions*, Environment Canada (www.ec.gc.ca) March 2001.
53 *External Costs of Truck and Train*, Transport Concepts (Ottawa), October 1994, p.22.
54 *Compilation of Air Pollution Emission Factors; Vol.II*, USEPA, 1/91, tables 1.8.1, 1.8.4.
55 van Essen, et al (2004), *Marginal Costs of Infrastructure Use – Towards a Simplified Approach*, CE Delft; results published in Vermeulen, et al (2004), *The Price of Transport: Overview of the Social Costs of Transport*, CE Delft (www.ce.nl/eng/redirect/thema_pricing_index.html).

- Wang, Santini and Warinner calculate unit emission costs for 17 U.S. cities using two analysis methods: control and damage costs, as shown in Table 5.10-19. 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).

Table 5.10-19 **Estimated Emission Values** (1989 $/ton)[56]

	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 studies of air pollution emission reduction unit costs in dollars per ton of reduction.[57] He describes various factors that affect such cost estimates, including perspective (individual or social), which emissions are considered and how emission rates are calculated, how baselines are calculated (emission rates without the policy), geographic and temporal scope (whether emission reduction strategies are only applied in non-attainment areas during peak emission periods), and how program costs are calculated. No analyses appear to consider additional benefits (congestion reduction, road and parking cost savings, crash reductions, etc.) from mobility management strategies.

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[56] 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. 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*, pp. 33-41.
[57]Michael Q. Wang, "Examining Cost Effectiveness of Mobile Source Emission Control Measures," Transport Policy, Vol. 11, No. 2 (www.elsevier.com), April 2004, pp. 155-169.

- 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.[58] Researchers conclude that this probably contributes to significant human morbidity and mortality in urban areas, particularly increased asthma.

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.

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.

Conclusions

Motor vehicles produce a significant portion of air pollution. Emission controls have reduced emission rates of many pollutants, but motor vehicle emissions still impose significant costs. Average air pollution cost estimates range from 1-8¢ per VMT, depending on assumptions. Many studies underestimate total costs by considering only a portion of total air pollution impacts. The full costs of air pollution, including all types of emissions, and their full impacts on human health (including premature deaths, illnesses, medical care and reduced physical activity), agriculture productivity, ecological resources and aesthetic quality leads to relatively high cost estimates.

Urban Peak local air pollution is estimated to cost 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. In addition, global (climate change, ozone depletion and acid rain) pollutants are estimated to impose 1.2¢ per mile costs for all driving, equaling about \$60/t CO_2, representing the European Commission's *ExternE* medium-high estimate of climate change emissions, and therefore a middle-estimate for total global emissions.

Using these values, average cars are estimated to impose a 6.2¢ per mile cost under Urban Peak (5¢ local + 1.2¢ greenhouse), 5.2¢ under Urban Off-Peak (4¢ local + 1.2¢ greenhouse), and 1.6¢ under Rural driving conditions (0.4¢ local + 1.2¢ greenhouse). Compact cars are estimated to have local emissions 10% lower than an average car, and half the 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

[58] Brock Williams, et al., "Latex Allergen in Respirable Particulate Air Pollution," *Journal of Allergy Clinical Immunology*, Vol. 95, 1995, pp. 88-95.

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 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 1995 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. bicycling, walking, and telecommuting have no air pollution costs.

Estimate **Air Pollution Costs (1996 U.S. Dollars per Vehicle Mile)**

Vehicle Class	Urban Peak	Urban Off-Peak	Rural	Average
Average Car	0.062	0.052	0.016	0.040
Compact Car	0.051	0.042	0.010	0.031
Electric Vehicles	0.016	0.013	0.004	0.010
Van/Light Truck	0.112	0.094	0.029	0.071
Rideshare Passenger	0.002	0.002	0.001	0.001
Diesel Bus	0.185	0.160	0.070	0.129
Electric Bus/Trolley	0.078	0.065	0.020	0.050
Motorcycle	0.106	0.086	0.014	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

To test these estimates, average automobile air pollution costs are multiplied by mileage:

	Annual Mileage (billion)	Estimate	Total (billion)
Urban Peak	460	$0.062	$28.5
Urban Off Peak	920	$0.052	$47.8
Rural	920	$0.016	$14.7
Total			$91.0

This total is within the range of many of the estimate described earlier. It represents a reasonable estimate of vehicle air pollution costs, considering all impacts (particulate, aesthetic, ozone depletion, emissions during petroleum processing, and global warming).

Automobile Cost Range

The minimum value estimate is based on the lower estimates described. The maximum is a combination of the highest local air pollution estimate plus the maximum estimate of carbon global warming costs.

Minimum	Maximum
$0.01	0.20

Resources

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

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 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 (http://ec.europa.eu/environment/air/cafe/activities/cba.htm); available at http://ec.europa.eu/environment/air/cafe/activities/pdf/cafe_cba_externalities.pdf.

Cambridge Systematics (2000), *A Sampling of Emissions Analysis Techniques for Transportation Control Measures*, FHWA, FHWA-EP-01-017 (www.fhwa.dot.gov).

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

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/publications/2003/UCD-ITS-RR-03-17-MAIN.pdf).

Jos Dings (2002), et al, *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).

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.

Richard T.T. Forman, et al (2003), *Road Ecology: Science and Solutions*, Island Press (www.islandpress.com).

INFRAS and IWW (2004), *Exernal Costs of Transport – Update Study*, Community of European Railway and Infrastructure Companies (www.cer.be) and International Union of Railways (www.uic.asso.fr).

Intergovernmental Panel on Climate Change (www.ipcc.ch) provides climate change information.

Gordon McGranahan and Frank Murray (2003), *Air Pollution & Health in Rapidly Developing Countries*, Earthscan (www.earthscan.co.uk).

Lena Nerhagen, Bertil Forsberg, Christer Johansson and Boel Lövenheim (2005), *The External Costs of Traffic Air Pollution*, Report 517, Swedish National Road and Transport Research Institute (www.vti.se).

ORNL (annual reports), *Transportation Energy Data Book*, Oak Ridge National Laboratory, USDOE (www.ott.doe.gov), provides annual energy price, supply, consumption and impact data.

SCAQMD (2002), *Multiple Air Toxics Exposure Study (MATES-II)*, South Coast Air Quality Management District (www.aqmd.gov/matesiidf).

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 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.

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