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. This information can be used to calculate the benefits of various emission reduction strategies.

Definition

Air Pollution Costs refers to damages caused by motor vehicle emissions. This includes human health, environmental damage and avoidance actions (such as restrictions on sports and other personal physical activities during air pollution events) resulting from various air emissions produced by motor vehicles.

Discussion

Motor vehicle produce various harmful air emissions, as summarized in Table 5.10-1. Some impacts are local, so where emissions occur affects the damages they impose, while other are regional or global, and so where they are released is less important.

Table 5.10-1 **Vehicle Pollution Emissions**[1]

Emission	Description	Sources	Harmful Effects	Scale
Carbon dioxide (CO_2)	A byproduct of combustion.	Fuel production and engines.	Climate change	Global
Carbon monoxide (CO)	A toxic gas that undermines blood's ability to carry oxygen.	Engine	Human health, Climate change	Very local
CFCs	Durable chemical harmful to the ozone layer and climate.	Older air conditioners.	Ozone depletion	Global
Fine particulates (PM_{10}; $PM_{2.5}$)	Inhaleable particles consisting of bits of fuel and carbon.	Diesel engines and other sources.	Human health, aesthetics.	Local and Regional
Hydrocarbons (HC)	Unburned fuel. Forms ozone.	Fuel production and engines.	Human health, ozone precursor.	Regional
Lead	Element used in older fuel additives.	Fuel additives and batteries.	Circulatory, reproductive and nervous system.	Local
Methane (CH_4)	A gas with significant greenhouse gas properties.	Fuel production and engines.	Climate change	Global
Nitrogen oxides (NOx)	Various compounds. Some are toxic, all contribute to ozone.	Engine	Human health, ozone precursor, ecological damages.	Local and Regional
Ozone (O_2)	Major urban air pollution problem resulting from NOx and VOCs combined in sunlight.	NOx and VOC	Human health, plants, aesthetics.	Regional
Road dust	Dust particles created by vehicle movement.	Vehicle use.	Human health, aesthetics.	Local
Sulfur oxides (SOx)	Lung irritant, and causes acid rain.	Diesel engines	Human health risks, acid rain	Local and Regional
Volatile organic hydrocarbons (VOCs).	A variety of organic compounds that form aerosols.	Fuel production and engines.	Human health, ozone precursor.	Local and Regional
Toxics (e.g. benzene)	VOCs that are toxic and carcinogenic.[2]	Fuel production and engines.	Human health risks	Very local

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

[1] USEPA, *Indicators of the Environmental Impacts of Transportation*, USEPA (www.itre.ncsu.edu/cte), 1999; ORNL, *Transportation Energy Data Book* ORNL, (www.ott.doe.gov), 2000.

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

Table 5-10.2 **Human Health Effects of Common Air Pollutants**[3]

Pollutant	Quantified health effects	Unquantified Health effects	Other possible effects
Ozone	Mortality Morbidity: Respiratory symptoms 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 Morbidity: Chronic and acute bronchitis Hospital admissions Lower respiratory illness Upper respiratory illness Chest illness Respiratory symptoms Minor RADs All RADs Days of work loss Moderate or worse asthma status (asthmatics)	Changes in pulmonary function	Chronic respiratory diseases other than chronic bronchitis Inflammation of the lung
Carbon monoxide	Morbidity: Hospital admissions– congestive heart failure Decreased time to onset of angina	Behavioral effects Other hospital admissions	Other cardiovascular effects Developmental effects
Nitrogen oxides	Morbidity: 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 Morbidity: Hypertension Nonfatal coronary heart disease Nonfatal strokes Intelligence quotient (IQ) loss effect on lifetime earnings IQ loss effects on special education needs	Health effects for other age ranges other than those studied 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.

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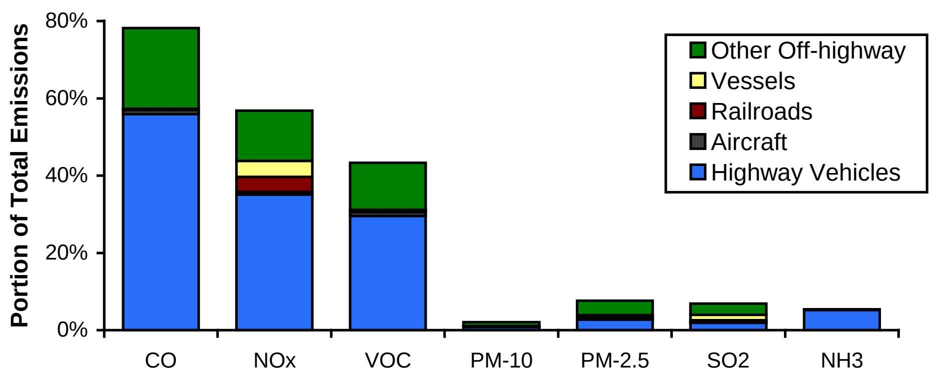
[3] Ken Gwilliam and Masami Kojima, *Urban Air Pollution: Policy Framework for Mobile Sources*, DRAFT Prepared for the Air Quality Thematic Group, World Bank (www.worldbank.org), May 2003.

Air pollution is one of the most often cited external costs of vehicle use. It is common to hear claims that vehicle emissions have declined by 90% or more over the last few decades, but this is an exaggeration.[4] Although tailpipe emission rates measured by standard tests have declined significantly, actual reductions are smaller. Tests do not reflect real driving conditions, and vehicles produce harmful emissions are not measured in these tests.[5] Some harmful emissions, such as air toxics, have only recently been recognized as harmful, and so have minimal regulations and control strategies.[6] Researchers estimate that actual CO and HC emissions are four to five times higher, and NOx emissions about twice as high as test standards.[7] Increased vehicle mileage has offset much of the reduction in per-mile emissions, so vehicle emissions continue to be a major problem.

Vehicle tire and brake lining wear produce about the same quantity of small particulates as tail pipe emissions, and road dust produces even more.[8] This is significant because recent research indicates that particulates pose the greatest mortality risk.[9] Even lower-bound estimates of their impacts indicate that particulates from tires, brakes and road dust probably impose human health costs equal to or greater than tail pipe emissions.[10]

Motor vehicle's share of some pollutants is shown in figure 5.10-1.

Figure 5.10-1 **Transport Contribution to Air Pollution**[11]



Transportation is a major contributor to air emissions.

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[4] John DeCicco and Mark Delucchi, *Transportation, Energy and Environment; How Far Can the Technology Take Us*, American Council for an Energy-Efficient Economy (www.aceee.org), 1997, p. 5.
[5] *Mobility and Access, Transportation Statistics Annual Report 1997*, BTS (www.bts.gov), p. 109-110.
[6] Kathryn A. Sargeant, "Reducing Air Toxics from Transportation Sources," *TR News 227*, Transportation Research Board (www.trb.org), July-August 2003, pp. 18-21.
[7] Ibid.
[8] Based on EPA PART5 vehicle emission model.
[9] Seaton, et al., "Particulate Air Pollution and Acute Health Effects," *The Lancet*, Vol. 345, Jan. 21, 1995, pp. 176-178.
[10] 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.
[11] ORNL, *Transportation Energy Data Book, Edition 21*, Oak Ridge National Labs, USDOE (www-cta.ornl.gov/data), 2001, Table 4.1.

Table 5.10-3 **Gasoline Fuel Parameters that Affect Air Quality**[12]

Parameter	Characteristic features
Lead	Lead is an inexpensive octane enhancer and has historically been added to gasoline as alkyl lead. It deactivates catalytic converters permanently. Because lead is extremely toxic, its use in gasoline has been banned in a growing number of countries.
Benzene	Benzene, the smallest aromatic compound with no alkyl groups, is a carcinogen. It is emitted from gasoline as a result of evaporation and as unconverted benzene from the exhaust pipe. Benzene is extremely high in octane, and hence a good gasoline blending component from the point of view of combustion.
Sulfur	Sulfur in gasoline acts as a poison for conventional catalytic converters. (The effect of the poison is temporary and reversible to a large extent.) Vehicle manufacturers recommend for conventional catalytic converters that the level of sulfur in gasoline be kept below 500 wt ppm, and preferably below 100 wt ppm. The impact of reducing sulfur on the performance of catalytic converters follows a nonlinear relationship, with emissions decreasing more rapidly below 100 to 150 wt ppm.13 Sulfur not trapped in catalytic converters is emitted as SOx, some of which undergoes chemical transformation to become secondary particle matter or acid rain.
Aromatics	Aromatics with two or more alkyl groups are photochemically reactive and contribute to ozone formation. Alkyl-aromatics (that is, nonbenzene aromatics) also dealkylate (lose alkyl groups) during combustion, and a fraction is emitted as benzene. However, it takes 10 to 20 times as much alkyl-aromatics to form benzene in the exhaust gas as benzene found in gasoline itself. The photochemical reactivity of aromatics and its decomposition to benzene are the two primary environmental concerns with aromatics. Aromatics are extremely high in octane, and hence they make good gasoline blending components from the point of view of combustion.
Olefins	Olefins in gasoline are formed primarily during cracking processes. Olefins are photochemically reactive and are ozone precursors. This is the primary concern. In addition, at elevated levels olefins increase the emissions of NOx. NOx is a precursor for ozone, particulate matter and acid rain. Olefins are fairly high in octane, and saturating them to reduce their quantity adversely affects the combustion characteristics of gasoline.
Alkylates	Alkylates are high-octane paraffinic hydrocarbons with essentially no adverse effects on air quality. They are excellent substitutes for less desirable blending components such as aromatics. However, alkylation is an expensive process, and requires the presence of a catalytic cracking unit at the refinery.
VOCs	Volatile organic compounds contain photochemically reactive hydrocarbons. Reductions in VOC emissions will therefore reduce the amount of ozone precursors in the atmosphere. VOCs are also transformed to particles in secondary particulate formation. Evaporative emissions comprise entirely of VOCs, and VOCs are found in the exhaust gas.
Oxygen	Oxygenates such as ethers and alcohols have high-blending octane and hence help compensate for octane shortfall after lead removal. The presence of oxygen in oxygenates also facilitates combustion in vehicles not equipped with oxygen sensors. Oxygenates also dilute gasoline, thereby decreasing the amount of such undesirable gasoline components as benzene, total aromatics, and olefins. Oxygenates are more miscible with water than gasoline, and contamination with ground and drinking water with methyl tertiary-butyl ether (MTBE), an ether, is a growing concern in the United States.
RVP	The Reid vapor pressure is a measure of gasoline volatility. Lowering RVP is a cost-effective way of controlling VOC emissions, including those of light olefins and benzene. This requires lowering the level of butanes, and, possibly, C5 hydrocarbons (hydrocarbons with five carbon atoms). Butanes are the cheapest source of octane, and their removal typically adversely affects refinery economics.
Additives	Gasoline in industrial countries contains additives to prevent the accumulation of deposits in engines and fuel supply systems. Deposits can increase tail pipe emissions.

This table describes how various gasoline factors affect air pollution.

[12] Ibid.

[13] Manufacturers of Emission Controls Association, *The Impact of Gasoline Fuel Sulfur on Catalytic Emission Control Systems*, September 1998.

Table 5.10-4 **Diesel Fuel Parameters that Affect Air Quality**[14]

Parameter	Characteristic features
Density	Diesel fuel is metered volumetrically, so that the higher the density, the more mass is injected. The use of a fuel with greater density than that used in the pump calibration could even result in overfueling at maximum load, resulting in substantially higher smoke emissions.
Sulfur	Sulfur in diesel contributes to secondary particulate formation, elevated ambient concentrations of SO2, and acid rain. If also decreases the efficiency of oxidation catalysts and degrades advanced exhaust treatment devices (such as particulate traps) rapidly.
Aromatics	Polyaromatic hydrocarbons (aromatics with more than one benzene ring) have been linked to higher particulate emissions. The impact of reducing aromatics on vehicular emissions is less clear.
T90/T95	The temperatures at which 90 and 95 percent, respectively, of diesel evaporates. Decreasing T90/T95 could have a favorable impact on emissions, especially if heavy PAHs are removed as a result.
Cetane	A measure of the ignition quality of a diesel fuel. A high cetane number indicates a shorter lag between fuel injection and ignition. The cetane number is measured in an engine test. A cetane index is an approximation of the cetane number calculated from the density and distillation temperatures. Cetane improvement additives will increase the cetane number but not the cetane index, and hence many countries specify minimal cetane index or cetane number.
Cleanliness	With respect to satisfactory operation of diesel vehicles, cleanliness refers to the absence of water and particulate contamination. Dirt and water can plug fuel filters and cause serious damage to the fuel injection system because of the close tolerance of fuel pumps and injectors. Diesel engines are equipped with fuel filters to protect the fuel delivery system.
Stability	The ability of a fuel to resist the formation of gums and insoluble oxidation products. Fuels with poor oxidation stability contain insoluble particles that can plug fuel filters, potentially leading to decreased engine performance or engine stalling from fuel starvation.

This table describes how various diesel fuel factors affect air pollution.

Climate change impacts are particularly difficult to quantify. Some critics argue that there is still insufficient evidence that global climate change is occurring, or that benefits offset costs.[15] However, most major scientific organizations now consider climate change a significant risk. 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.[16] 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."[17] The United Nations Environmental Programme's Global Environment Outlook emphasizes the need for action to reduce risks.[18] Nitrogen pollution released by vehicles threatens ecosystem function on both land and water. Increased nitrogen from atmospheric deposition shifts ecosystems to weedy species and reduces biodiversity.[19]

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[14] Ibid.

[15] *The Greening of Planet Earth* and other publications by the Western Fuels Association (www.westernfuels.org), and Green Earth Society (www.greeningearthsociety.org).

[16] See websites http://gcmd.nasa.gov, www.unfccc.de and www.igcc.ch for information.

[17] *Climate Change and Greenhouse Gases*, American Geophysical Union (www.agu.org), 1998.

[18] *Global Environmental Outlook*, UNEP (www.unep.org/geo2000/ov-e/0012.htm), 1999.

[19] D.A. Bainbridge, "The Nitrogen Pollution Problem," *Ecesis*, Newsletter of the Society for Ecological Restoration, California Section (www.sercal.org), Vo. 7, No. 3, 1997, pp. 3-4.

Factors Affecting Emission Costs

Quantifying air pollution costs requires information about vehicle emission rates, the impacts these pollutants have on human mortality, morbidity, crop damages, wildlife, and aesthetics and climates, and placing values on these impacts. Factors affecting emission costs are discussed below.

Perspective

Emission ratings depend on whether only tailpipe emissions are considered, total vehicle emissions (including non-tailpipe emissions), or lifecycle emissions, which also includes emissions that occur during vehicle and fuel production.[20] Lifecycle analysis is particularly important for climate change emissions, since their impacts are hardly affected by when and where they occur.

Fuel Type

A variety of fuels can power automobiles, as summarized in Table 5.10-5. Alternative fuels tend to reduce some types of emissions, but in most cases their total benefits (including "upstream" emissions during production and distribution) are modest, and many increase other harmful emissions. For detailed information see the *Alternative Fuels Data Center* (www.afdc.doe.gov) and the Greenhouse Gas Table of Conversion Factors (www.fhio.gc.ca/GHG/ghg_guidelines.htm#conversion_table).

Table 5.10-5 **Alternative Fuels Compared**

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. Energy savings depend on fuel source.
Electricity	20-70%	No tailpipe emissions. May be generated from renewable sources.	Reduced vehicle performance. Vehicles are currently expensive. Energy savings depend on how electricity is generated.
Hydrogen	20-70%	No tailpipe pollutants.	Not currently available. Energy savings depend on how hydrogen is produced.

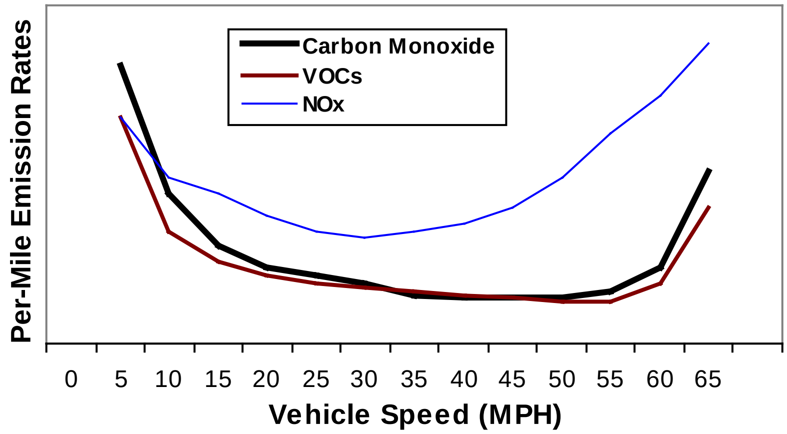
* Estimated reduction in lifecycle CO_2 emissions per vehicle-mile compared with gasoline.

[20] 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.

Per-Mile Emission Rates

Emission rates for most pollutants are higher when engines are cold. Older vehicles that lack current emission control systems, and vehicles that are poorly tuned, tend to have high emissions rates. Emission rates tend to increase under stop-and-go conditions, and at very low and very high speeds, as illustrated in Figure 5.10-2. EPA's latest research indicates that for newer, cleaner vehicles emissions increase at much lower speeds than previously thought. NOx emissions increase with highway speeds above 15-20 miles per hour, VOC emissions increase with speeds above 30-35 mph, and CO above 30. On arterials and local streets emissions increase above 30-35. A congestion reduction program that improves roadway Level of Service from F probably reduces energy consumption and emissions, but shifting Level of Service from D to A probably increases energy consumption and most emissions.

Figure 5.10-2 **Vehicle Emissions By Speed**[21]



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

Location and Exposure

Concentrations of "local" pollutants, such as carbon monoxide, air toxics and particulates, tends to be several times greater in vehicles and adjacent to roadways than overall ambient levels.[22] 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 in areas such as Southern California, where air pollution problems are severe, impose damages estimated to be about three times greater than the same emissions in less vulnerable locations. Pollution emissions by jets at high altitudes produce special environmental harms, including climate change impacts.[23]

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[21] TRB, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, TRB Special Report #345, National Academy Press (Washington DC; www.trb.org), 1995.
[22] CTA, *In-Car Air Pollution: The Hidden Threat to Automobile Drivers*, International Center for Technology Assessment (www.icta.org), 2000.
[23] John Whitelegg and Howard Cambridge, *Aviation and Sustainability*, Stockholm Environmental Institute (www.sei.se/aviation/index.html), 2004.

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.[24] Models such as URBEMIS (*www.urbemis.com*) can be used to predict the emission reduction effects of various mobility management and smart growth strategies.[25]

Estimates

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

- Apogee Research estimated air pollution costs in Boston, MA and Portland, ME for peak and off-peak travel at high, medium and low land use densities as shown below.

Table 5.10-6 **Air Pollution Costs in Two Cities** (¢ per passenger mile)[26]

	Expwy		**Non-Expwy**		**Comm. Rail**		**Rail Transit**		**Bus**	
Boston	Peak	Off-P	Peak	Off-P	Peak	Off-P	Peak	Off-P	Peak	Off-P
High	7.9	6.6	10.6	8.9	0.9	2.2	<0.2	<0.2	0.8	4.4
Medium	6.6	9.5	7.9	7.3	1.0	2.5	<0.2	<0.2	2.4	5.8
Low	7	9.5	7.3	6.9	2.0	4.9	n/a	n/a	2.4	5.5
Portland										
High	6.5	6.9	7.9	7.3	n/a	n/a	n/a	n/a	5.2	4.7
Medium	6.6	7.0	7.3	6.9	n/a	n/a	n/a	n/a	5.2	4.6
Low	12.1	12.1	6.6	6.6	n/a	n/a	n/a	n/a	11.0	11.0

- The values in Table 5.10-7 are recommended for assessing vehicle air pollution costs in British Columbia urban areas.

Table 5.10-7 **Recommended Shadow Prices** (1996 Canadian Cents per Kilometer)[27]

	$PM_{2.5}$	**Ozone**	**CFCs** (Vehicles with AC)	**Total** (With AC)	**Total** (Without AC)
Light Gasoline Vehicle	0.6-1.0¢	0.1¢	2.7¢	3.4-3.8¢	0.7-1.1¢
Light Diesel Vehicle	2.5-6.3¢	0.1¢	2.7¢	5.3-9.1¢	2.6-6.4¢
Heavy Gasoline Vehicle	2-4¢	0.1¢	2.7¢	4.8-6.8¢	2.1-4.1¢
Heavy Diesel Vehicle	9-27¢	0.1¢	2.7¢	11.8-29.8¢	9.1-27.1¢

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

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

26 Apogee, *The Costs of Transportation*, Conservation Law Foundation (www.clf.org), 1994, p. 148.

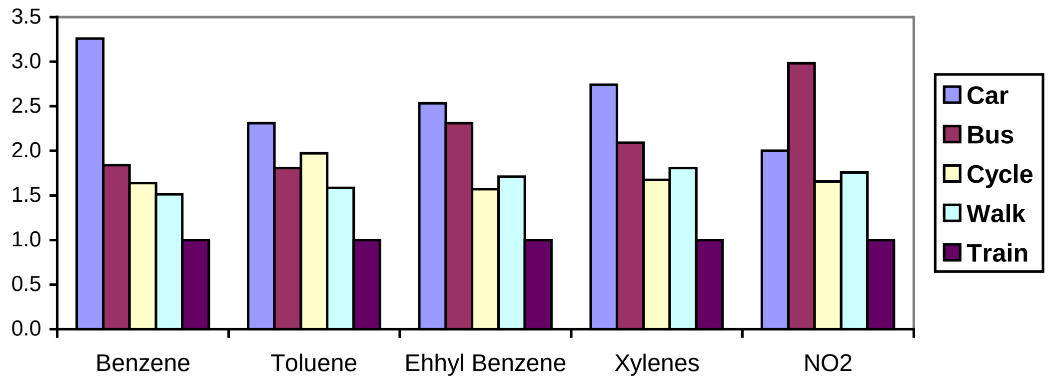
27 Dr. Peter Bein, *Monetization of Environmental Impacts of Roads*, Planning Services Branch, B.C. Ministry of Transportation and Highways (Victoria, BC; www.th.gov.bc.ca/bchighways), 1997.

- A comprehensive (535-page) Australian study estimates the full social costs of various greenhouse gas emission control strategies.[28] Some road and parking pricing strategies, and transit promotion strategies, have negative social costs (they provide overall benefits) when congestion reduction, safety and other secondary benefits of reduced automobile travel are considered.

- One study concludes 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.[29]

- Studies indicate that automobile passengers tend to be exposed to more air pollution than people traveling in other modes. The figure below summarizes the results of one study.

Figure 5.10-6 **Releative Air Pollutant Exposure By Mode**[30]



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

[29] Center for Transportation Research, *Texas Transportation Energy Savings: Assessment of Control Measures, Technologies and Policies*, Texas Sustainable Energy Dev. Council (Austin), 1995, p. 99.

[30] 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.

- The European Community's CORINAIR program is developing data on air pollution costs. The table below shows particular air pollution costs in Italian cities.

Table 5.10-8 **Particulate Air Pollution Costs in Italian Cities** (1992 lire / km)[31]

	City 20,000-100,000	City 100,000 to 500,000	City > 500,000
Petrol Vehicles	10.7	16.4	20.2
> 1400 cc	7.1	10.9	13.4
1400-2000 cc	10.3	5.8	19.4
> 2000 cc	14.7	22.4	27.7
Diesel Vehicles	326.7	498.4	614.5
Light duty	191.4	292.0	360.1
Heavy duty & buses	1210.8	1847.2	2277.5
LPG	8.3	12.6	15.6
Total	*124.2*	*204.8*	*252.5*

- Mark 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,[32] and $5-40 billion in reduced visibility.[33]

Table 5.10-9 **Air Pollution Health Costs by Motor Vehicle Class** ($1990/VMT)[34]

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*

- U.S. EPA data indicates that motor vehicles produced 48% of U.S. benzene, 42% of Butadiene, 24% of formaldehyde, and 43% of Xylene emissions in 1996.[35]

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[31] Romeo Daniels and Aline Chiabai, "Estimating the Cost of Air Pollution from Road Transport in Italy," *Transportation Research D*, Vol. 3, No 4, July 1998, pp. 249-258.

[32] 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.

[33] 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.

[34] 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.

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

- 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**[36]

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

- Researchers estimate emission costs for vehicles meeting current control standards, taking into account various tailpipe pollutants and impacts, as shown in Table 5.10-11.

Table 5.10-11 **Damage Costs of Emissions from New Vehicles** (1996)[37]

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

- Air pollution exposure appears to be much higher than ambient in vehicles traveling on highways, indicating that air pollution costs may be higher than previously estimated and that a greater share of this cost is borne by motorists as a group.[38]

- The FHWA uses the following air pollution cost estimates in the *1997 Federal Highway Cost Allocation Study*

Table 5.10-12 **Air Pollution Costs**[39]

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¢

36 *ExternE; Newsletter 6*, European Commission (http://externe.jrc.es), March 1998.
37 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.
38 Charles Rodes, et al., *Measuring Concentrations Of Selected Air Pollutants Inside California Vehicles*, California Environmental Protection Agency, Air Resources Board (www.arb.ca.gov) and Southern California Air Quality Management District, 1998.
39 FHWA, *1997 Federal Highway Cost Allocation Study Final Report Addendum*, Federal Highway Administration, USDOT (www.ota.fhwa.dot.gov/hcas/final), 2000, Table 12.

- 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.[40]

- 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.[41] 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.[42]

- Gilbert estimates the CO_2 equivalent emissions shown in Table 5.10-13.

Table 5.10-13 **Greenhouse Gas Emissions by Mode** (CO_2 Equivalents)[43]

Passenger Modes	Grams/Passenger-Km	Freight Mode	Grams/Tonne-Km
1990 Average Auto	278	7.5-tonne truck	174
New Auto	197	40-tonne truck	56
Diesel Auto	161	Fast rail	39
Bus	69	Slow rail	14
Train (diesel/electric/local)	79 / 76 / 54	Aircraft	3,414
Aircraft	853		

[40] David Forkenbrock, "External Costs of Intercity Truck Freight Transportation," *Transportation Research A*, Vol. 33, No. 7/8, Sept./Nov. 1999, pp. 505-526.
[41] 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.
[42] 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.
[43] David Martin and Laurie Michaelis, *Research and Technology Strategy to Help Overcome Environmental Problems in Relation to Transport*, U.K. Atomic Energy Authority, March 1992.

- 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**[44]

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

- An extensive European research program calculates the air emission cost values in Table 5.10-15. The PM2.5 and SO2 values for a particular size city should be added to the nationally specific rural externality values to account for both local and long-range emission impacts.

Table 5.10-15 **European Emission Costs** (2002 Euro Per Tonne)[45]

	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	

44 Quentin Heaney, Margaret O'Mahony, and Eithne Gibbons, "External Costs Associated With Interregional Transport," *Transportation Research Record 1959*, TRB, 1999, pp. 79-86.

45 Mike Holland and Paul Watkiss, *Estimates of Marginal External Costs of Air Pollution in Europe*, European Commission DG Environment (http://europa.eu.int/comm/environment/enveco/studies2.htm) 2002.

- 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%. [46]

- Table 5.10-17 shows emission rates per passenger for various modes under average and peak urban conditions in the Vancouver, BC region.

Table 5.10-17 **Emission Rates for Selected Modes** (grams per passenger-km)[47]

Mode	Passengers	HC	CO	NOx	SOx	PM
Average						
Automobile	1.0	3.15	23.57	1.91	0.07	0.10
Car Pool	2.4	1.31	9.82	0.80	0.03	0.04
Van Pool	5.0	0.72	5.42	0.44	0.02	0.02
Diesel Bus	20	0.11	1.50	0.67	0.09	0.17
Articulated Diesel	23	0.12	1.67	0.74	0.10	0.19
Methanol Bus	20	0.01	0.02	0.49	0.00	0.00
Trolley Coach*	20	0.00	0.001	0.006	0.00	0.00
Articulated Trolley*	32	0.00	0.001	0.007	0.10	0.00
Rail Transit*	25	0.00	0.001	0.006	0.00	0.00
Rush Hour						
Automobile	1.3	2.42	18.13	1.47	0.05	0.08
Car Pool	3.6	0.88	6.55	0.53	0.02	0.03
Van Pool	7.2	0.50	3.77	0.31	0.01	0.02
Diesel Bus	37	0.06	0.81	0.36	0.05	0.09
Articulated Diesel	44	0.06	0.87	0.39	0.05	0.10
Methanol Bus	37	0.01	0.10	0.27	0.00	0.00
Trolley Coach*	37	0.00	0.001	0.003	0.00	0.00
Articulated Trolley*	44	0.00	0.001	0.004	0.00	0.00
Rail Transit*	53	0.00	0.001	0.003	0.00	0.00

* *Electric Vehicles*

- Kreith, et al., estimates that electric vehicles reduce VOC and CO emissions, but increase most other emissions overall.[48]

- James MacKenzie et al. estimate local air pollution costs to average about 0.5¢ per motor vehicle mile, and global warming about 1.2¢ per mile based on control costs.[49]

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46 IPCC, *Climate Change 2001: Synthesis Report*, Intergovernmental Panel on Climate Change (www.ipcc.ch/pub/SYR-text.pdf), 2001.
47 KPMG, *GVRD Air Quality Management Plan: Stage 2 Draft Report: Priority Emission Reduction Measures*, Greater Vancouver Regional District (Vancouver), May 1992, Table 5-8, p.5-43.
48 Frank Kreith, Paul Norton and DenaSue Potestio, “Electric Vehicles: Promise and Reality,” *Transportation Quarterly*, Vol 49, No. 2, Spring 1995, pp. 5-21.
49 James MacKenzie, Roger Dower and Donald Chen, *The Going Rate: What it Really Costs to Drive*, World Resources Institute (Washington DC; www.wri.org), 1992, p. 13.

- Peter Miller and John Moffet estimate that motor vehicle emission costs range from 3.8-7.1¢ per passenger mile, with higher costs for light trucks and lower costs for van pools, buses, trolleys and trains.[50]

- The Minnesota Public Utility Commission adopted the following air pollution cost values for use in evaluating energy projects, such as electrical generation plants.

Table 5.10-18 **MN PUC Environmental Cost Values** (1995 dollars per ton)[51]

Pollutant	Urban	Metropolitan Fringe	Rural
SO_2	$112-189	$46-110	$10-25
PM_{10}	$4,462-6,423	$1,987-2,886	$562-855
CO	$1.06-2.27	$0.76-1.34	$0.21-0.41
NO_x	$371-978	$140-266	$18-102
Pb	$3,131-3,875	$1,652-1,995	$402-448
CO_2	$0.30-$3.10	$0.30-$3.10	$0.30-$3.10

- Research indicates that ambient carbon monoxide increases heart failure and deaths, accounting for 5.7% of congestive heart failure hospital admissions in major cities.[52]

- An OECD study concludes that electric vehicles reduce CO_2 emissions where electricity is primarily renewable, but may increase with fossil fuel generation.[53]

- 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 toxics, such as benzene, and perhaps NOx.

- After reviewing European studies Émile Quinet concludes that car transport is about 10 times more polluting than railways for passenger transport, and truck transport is about 10 times more polluting than rail per unit of freight transport.[55]

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50 *The Price of Mobility*, Natural Resources Defense Council (Washington DC; www.nrdc.org), 1993, p.48.
51 MNPUC, *Order Establishing Environmental Cost Values*, MN Public Utility Commission, (www.puc.state.mn.us/download/Envestab.pdf), 3 Jan. 1997; *MN PUC Final Environmental Cost Table*, Sustainable Minnesota (www.me3.org), 1997.
52 Robert Morris, Elena Naumova and Rajika Munasinghe, "Ambient Air Pollution and Hospitalization for Congestive Heart Failure Among Elderly People in Several Large US Cities," *American Journal of Public Health*, Vol. 85, No. 10, pp. 1361-1365.
53 *Electric Vehicles: Technology, Performance and Potential*, OECD (Paris; www.oecd.org), 1993.
54 Robert Pearson, Howard Wachtel and Kristie Ebi, "High Traffic Streets Linked to Childhood Cancers," *Journal of the Air and Waste Management Association*, Feb. 2000.
55 Émile Quinet, "The Social Costs of Transport: Evaluation and Links With Internalization Policies," in *Internalising the Social Costs of Transport*, OECD (Paris; www.oecd.org), 1994.

- 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. Estimates air pollution morbidity and mortality economic costs in these three countries total about 50 billion Euros, of which about half is due to motor vehicle particulates.[56]

- Small and Kazimi estimate Southern California motor vehicle air pollution costs of human morbidity and mortality from tailpipe particulate and ozone emissions.[57] Their middle estimate for gasoline cars is 3.3¢ per VMT. This cost is expected to decline 50% by the year 2000 due to improved emission controls. Heavy diesel trucks costs are estimate to averaging 53¢ per VMT. Emissions costs in other urban regions are estimated to average about 1/3 of these values. The authors emphasize that this is only a partial analysis. The study omits CO and non-tailpipe particulate emissions, both of which recent research indicate cause significant medical problems. It omits impacts on people without acute medical symptoms, although residents of polluted cities suffer reduced lung capacity and are regularly instructed to limit their physical activities. It also omits ecological and aesthetic impacts, including global warming, ozone depletion, crops and wildlife damages, and reduced visibility. The authors state that road dust may add 4.3¢ per VMT, and global warming costs may be significant. Total automobile air pollution costs are therefore likely to be much higher than this study's estimates.

- Sweden uses the following values for assessing air pollution in transport planning (1995 U.S. Dollars per kilogram): CO_2 = $0.045; NOx = $5.50; HC = $2.70; Sulfur = $4.10.[58] Sweden has carbon taxes of $38-153 per tonne.[59]

[56] 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.
[57] 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.
[58] Gunnar Lindberg, *Benefit-Cost Analysis in a Multi-Modal Planning Process*, "Exploring the Application of Benefit-Cost Methodologies to Transportation Decision Making," May 1995, Tampa.
[59] Per Kågeson, *Getting the Prices Right*, European Fed. for Transport & Env. (Bruxelles), 1993, p. 69.

- Transport Concepts estimates freight air pollution costs as shown below.

Table 5.10-19 **Environmental Costs of Freight** (1990 Vehicles)[60]

	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*

- One study funds that per unit shipped (ton-kilometer) rail transport tends to produce less HC, CO and CO_2 than trucks, but more PM and NOx.[61]

- 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 5.10-20.[62]

Table 5.10-20 **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

60 *External Costs of Truck and Train*, Transport Concepts (Ottawa), October 1994, p.22.
61 Gordon Taylor, *Trucks and Air Emissions*, Environment Canada (www.ec.gc.ca) March 2001.
62 Roland Hwang, et al., *Driving Out Pollution: The Benefits of Electric Vehicles*, UCS (Berkeley), 1994.

- USEPA emission models use the values in Table 5.10-21 for predicting average car and light truck emissions.[63]

Table 5.10-21 **Average Per Mile and Annual Emission Rates** (kilograms)

	Average Passenger Car		**Average light Truck**	
Annual Miles	12,500		14,000	
	Per Veh-Mile	Per Veh-Year	Per Veh-Mile	Per Veh-Year
Hydrocarbons	2.9 grams/mile	80 lbs	3.7 grams/mile	114 lbs
Carbon Monoxide	22 grams/mile	606 lbs	29 gram/mile	894 lbs
Nitrogen Oxides	1.5 grams/mile	41 lbs	1.9 gram/mile	59 lbs
Carbon Dioxide	0.8 pound/mile	10,000 lbs	1.2 pound/mile	16,800 lbs

Notes
[1] These values are averages. Individual vehicles may travel more or less miles and may emit more or less pollution per mile than indicated here. Emission factors and pollution/fuel consumption totals may differ slightly from original sources due to rounding.
[2] The emission factors used here come from standard EPA emission models. They assume an "average," properly maintained car or truck on the road in 1997, operating on typical gasoline on a summer day (72 to 96 degrees F). Emissions may be higher in very hot or very cold weather.
[3] Average annual mileage source: EPA emissions model MOBILE5.
[4] Fuel consumption is based on average in-use passenger car fuel economy of 22.5 miles per gallon and average in-use light truck fuel economy of 15.3 miles per gallon.

- New motorcycles produce over double HC and CO, and higher NOx than automobile fleet averages, since they lack emission control equipment.[64]

[63] U.S. Environmental Protection Agency National Vehicle and Fuel Emissions Laboratory, April 1997, citied in Criterion Planners/Engineers, *Smart Growth Index – Sketch Tool for Community Planning: Indicator Dictionary*, US Environmental Protection Agency (www.epa.gov/smartgrowth), 2002.
[64] *Compilation of Air Pollution Emission Factors; Vol.II*, USEPA, 1/91, tables 1.8.1, 1.8.4.

- 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 5.10-22. 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 5.10-22 **Estimated Emission Values** (1989 $/ton)[65]

	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 and Santini estimate electric vehicles reduce CO and VOC emissions 98%, with smaller reductions in NOx and SOx, and 50% reductions in CO_2 emissions.[66]

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

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65 M.Q. Wang, D.J. Santini and S.A. Warinner, *Methods of Valuing Air Pollution and Estimated Monetary Values of Air Pollutants in Various U.S. Regions*, Argonne National Lab, 1994. Also see M.Q. Wang, D.J. Santini and S.A. Warinner, “Monetary Values of Air Pollutants in Various U.S. Regions,” *Transportation Research Record 1475*, 1995, pp. 33-41.
66 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.
67 Brock Williams, et al., “Latex Allergen in Respirable Particulate Air Pollution,” *Journal of Allergy Clinical Immunology*, Vol. 95, 1995, pp. 88-95.

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 greater emission costs per unit of travel. Catalytic converters are ineffective when cold, so emissions are greater 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 per vehicle-mile, but residual tailpipe emissions (especially from cold starts and evaporation) and particulates from tires, brakes and road dust result in 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.

For this analysis, Urban Peak local air pollution is estimated to cost 5¢ per average automobile mile, which is higher than Small and Kazimi's estimate for just tailpipe emissions, but lower than Apogee Research's estimate for urban highway automobile travel and than Delucchi's middle value estimate for all U.S. automobile travel. 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 pollutants (gases that contribute to climate change, ozone depletion and acid rain) are estimated to impose costs of 1.2¢ per mile for all driving. This equals about \$60/t CO_2, representing the European Commission's *ExternE* medium-high estimate for just 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 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 automobile air pollution costs, especially when all impacts (particulate, aesthetic, ozone depletion, emissions during petroleum processing, and global warming) are considered.

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.

Clean Air Initiative (www.worldbank.org/cleanair) is a World Bank urban air quality program.

Climate Change Cost Calculator (www.climcalc.net) calculates personal air emissions.

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

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.

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

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.

FHWA, *The Environmental Guidebook*, Federal Highway Administration, FHWA-99-005 (www.fhwa.dot.gov/environment/guidebook/index.htm), 1999.

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

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

International Energy Agency (www.iea.org), provides fuel supply, demand and price data.

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

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

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

Office of Transportation And Air Quality Modeling Tools, USEPA (www.epa.gov/otaq/transp/traqmodl.htm) has tools for evaluating the emission impacts.

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

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

TransPriceProject (www.cordis.lu/transport/src/transpricerep.htm) is a European study of various pricing strategies for reducing urban traffic congestion and air pollution emissions.

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

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