APPENDIX AVAILABLE ON REQUEST

Special Report 17

Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects

Chapter 2. Emissions from Motor Vehicles

HEI Panel on the Health Effects of Traffic-Related Air Pollution

Appendix C. Summary of Source Apportionment Studies in the Past Decade

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APPENDIX C. SUMMARY OF SOURCE APPORTIONMENT STUDIES IN THE PAST DECADE

Table C.1. PM source apportionment studies conducted in the United States.

Reference	PM Size	Components Used in Source Apportionment	Method (no. sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Kim et al 2005)	<2.5 µm	Elements, EC, OC, ions, anions	PMF (8)	Northeastern U.S. (13 STN sites), 2000-2003	14%	7%	7%	
(Ogulei et al 2005)	<2.5 µm	Elements, EC, OC, ions, anions, SO_2	factor analysis (9)	Baltimore, MD, (1), 2002	27%	1%	26%	Same site as Ogulei et al 2006, but data were collected from Feb to Nov.
(Ogulei et al 2006)	<2.5 µm	Elements, EC, OC, ions, anions, PM size distribution, CO, NO_x, O_3	PMF (12)	Baltimore, MD, (1), 6 days in 2002	NA	NA	8%	Diesel emissions identified as a source, but their % contribution is not reported.
(Qin et al 2006)	<2.5 µm	Elements, EC, OC, ions, anions	PMF (6-8)	Metropolitan NY City (3 in NY, 1 in NJ), 2000	11-36%	3-14%	8-22%	High diesel contribution only at highway site in New Jersey.
(Zhou et al 2004)	<2.5 µm	Elements, EC, OC, ions, anions	modified PCA (6)	Pittsburgh, PA 6 days in July, 2001	5%	NA	NA	Very high secondary sulfate (75%).
(Zhao et al 2006)	<2.5 µm	Elements, EC, OC, OC1	extended receptor model (4)	Raleigh and Chapel Hill, NC, (2) 2000-2001	19%	NA	NA	

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(Kim et al 2005)	<2.5 µm	Elements, EC, OC, ions, anions	PMF (12)	Atlanta, GA, 1998-2000; Washington, DC, 1988-1997; and Brigantine, NJ, 1992-2001	Atlanta: 17%; Washington: 23%; Brigantine: 16%	Atlanta: 10.5%; Washington: 1.8%; Brigantine: 3.3%	Atlanta: 6.4%; Washington: 21%; Brigantine: 12.5%	Study showed temperature-resolved carbon fractions can enhance source apportionment.
(Liu et al 2006)	<2.5 µm	Elements, EC, OC, ions, anions, CO, SO_2, HNO_3, NO_x	PMF (6)	Atlanta, GA and Birmingham, AL (urban) and 2 rural sites, 2002-2004	Atlanta:15% Birmingham: 12% Rural: 0 to 8%	Atlanta: 10.9%, Birmingham: 6.4%, Rural: 0.3 - 5.5%	Atlanta: 4.4%, Birmingham: 5.4%, Rural: 0 - 2.7%	Study showed temperature-resolved carbon fractions can enhance source apportionment.
(Zheng et al 2002)	<2.5 µm	EC, OC, ions, anions, 107 particle-phase organic species	CMB (10)	Southeast U.S. (4 urban and 4 rural) 1999-2000	14-40%	14-30%	0-10%	Motor vehicle contributions were higher at urban sites than rural sites.
(Fraser et al 2003)	<2.5 µm	OC (24 organic markers), Elements	CMB (8 primary)	Houston, TX (3 urban sites) and Galveston, TX, (1 coastal), 1997-1998	Urban 30% Coastal 8%	Urban 17% Coastal 4%	Urban 13% Coastal 4%	Paved road dust contributions were comparable to vehicle exhaust.
(Connell et al 2006)	<2.5 µm	Elements, EC, OC, ions, anions, NOx, NO_2, CO, winds	PMF with back trajectory modeling	Steubenville, OH,(4) 2000-2002	20%	n/a	n/a	Secondary aerosols were the dominant source.

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(Hu et al 2006)	<2.5 µm	Elements, EC, OC, ions, anions	UNMIX (4)	Cincinnati, OH, (2), 2002-2004	23 to 24%	n/a	n/a	One highway site and one urban site.
(Lee et al 2006)	<2.5 µm	Elements, ions, anions	PMF (10)	St. Louis, MO, (1) 2001-2003	18%	2%	16%	Diesel vehicle contribution includes railroads.
(Ward and Smith 2005)	<2.5 µm	Elements, EC, OC, ions, anions	CMB (7)	Missoula, MN, (1 urban and 1 rural site), 2000-2001	urban 19-20%; rural 18-19%	urban 19-20%; rural 18-19%	urban 0% rural 0%	
(Brown et al 2007)	<2.5 µm	Elements, EC/OC, inorganic ions, anions	PMF(8)	Phoenix, AZ, (1), 2001-2003)	26%	9%	17%	Study showed temperature-resolved carbon fractions can enhance source apportionment.
(Lewis et al 2003)	<2.5 µm	Elements, ions, anions	UNMIX (5)	Phoenix, AZ, (1), 1995-1998	49%	16%	33%	
(Sawant et al 2004)	<2.5 µm	Elements, EC, OC, ions, anions, gaseous nitric acid and carbonyls	CMB (8)	Mira Loma, CA, (urban), 2001-2002	10%	5%	5%	High secondary aerosol (56%) downwind of Los Angeles.

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Reference	PM Size	Components Used in Source Apportionment	Method (no. sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Schauer et al 1996)	<2.5 µm	Elements, EC, OC, ions, anions, individual organic PM compounds (hopanes, steranes, alkanes)	CMB (13)	Los Angeles, CA, (4), 1982	15-38%	17% W LA; 32% D LA; 19% Pasadena; 14% Rubidoux	6% W LA; 6% D LA; 6% Pasadena; 1% Rubidoux	Calculated from table.
(Schauer et al 2002)	<2.5 µm	Elements, EC, OC, ions, anions, speciated semivolatile, volatile, and PM-associated organic compounds	CMB (11)	Los Angeles , CA, (4), 1993 (2 days)	24-40%	15-27%	9-13%	Calculated from table.
(Kim and Henry 2000)	<10 µm	Elements, OC, ions, anions	SAFER (4)	Los Angeles, CA, (5), 1986	39-55%	n/a	n/a	
(Schauer and Cass 2000)	<2.5 µm	Elements, EC, OC, ions, anions, individual organic compounds, gas-phase HCs	CMB (11)	San Joaquin Valley, CA (2 urban, 1 rurual), 1995,1996	11-14% urban 4-6% rurual	8-11% urban 4-6% rural	2-3% urban 0% rural	During two severe winter pollution episodes.

Table C.2. PM source apportionment studies conducted outside the United States

Reference	PM Size	Components Used in Source Apportionment	Method (No. Sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Almeida et al 2005)	<2.5 µm and 2.5-10 µm	Elements, BC, OC, ions, anions	PCA with Verimax rotation (6-7)	Bobadela, Portugal, (1), 2001	22% $PM_{2.5}$ 0% $PM_{2.5-10}$	NA	NA	Found an additional traffic/industry source (14% for $PM_{2.5}$; 13% for $PM_{10-2.5}$).
(Harrison et al 1997)	<2.5 µm and <10 µm	BC, OC, ions, anions, NO_x	Regression analysis, PCA (3)	Birmingham, UK, (3), 1994-1995	Winter: 41% $PM_{2.5}$; 32% PM_{10}; 3% coarse Summer: 40% $PM_{2.5}$; 23% PM_{10}	NA	NA	During summer months coarse particles accounted for 50% of PM_{10}.
(Manoli et al 2002)	<2.5 µm and 2.5-10 µm	Elements, ions, anions, PAHs	PCA (4-5)	Thessaloniki, Greece (1), 1994-1995	38% $PM_{2.5}$	NA	NA	$PM_{2.5}$ was 28% road dust. Coarse PM was 57% road dust.
(Samara et al 2003)	<10 µm	Elements, ions, anions, 16 PAHs	CMB (6)	Thessaloniki, Greece (3), 1997-1998	47-63%	19-38%	24-33%	PM_{10} was 18-22% road dust.
(Vallius et al 2003)	2.5 µm	Elements, BC, particle number, SO_2, NO_x	PCA (5)	Helsinki, Finland (1), 1996-1997, 1998-1999	30% (96-97) 23% (98-99)	NA	NA	
(Salvador et al 2004)	<10 µm	Elements, TC, ions, anions	rotated factor analysis (4)	Madrid, Spain (1), 1999-2002	48%	NA	NA	
(Viana et al 2006)	<10 µm	Elements, EC, OC, ions, anions, acids, wind direction	PCA (6)	Llodio, Spain, (1), 2001	22% (annual) 19-23% for wind sectors	NA	NA	The vehicle contribution from local streets and motorways was related to wind direction.

Table C.2. PM source apportionment studies conducted outside the United States

Reference	PM Size	Components Used in Source Apportionment	Method (No. Sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Viana et al 2007)	2.5 µm	Elements	PCA (4)	Alacete, Barcelona, Galdakao, Huelva, Oviedo, Spain (5) 2000-2001	39% Alacete 53% Barcelona 44%Galdakao 35% Huelva 41% Oviedo	NA	NA	
(Lee et al 2003)	<2.5 µm	Elements, EC, OC, ions, anions	PMF (8)	Toronto, Canada (1), 2000-2001	10%	NA	NA	$PM_{2.5}$ was 30% road salt and nitrate.
(Song et al 2006)	2.5 µm	Elements, EC, OC, ions, anions	PMF (8)	Beijing, China, (5), 2000	6%	NA	NA	Only 82% of $PM_{2.5}$ resolved.
(Zheng et al 2005)	2.5 µm	Elements, EC, OC, ions, anions, 19 individual organic PM compounds	CMB (9)	Beijing, China, (5), 2000	2-12%	NA	NA	Based on diesel and gasoline exhaust profiles from US vehicles.
(Bi et al 2007)	<10 µm	Elements, OC, TC, ions, anions	CMB (7)	Cities in Northern China, (6), 1999-2002	4-12% winter; 5-12% spring; 7-18% summer/fall	NA	NA	Range across 6 cities.
(Wang et al 2006)	<10 µm	Elements, EC, OC, ions, anions	MLR (5)	Guagzhou, China, (4), 2004	32-43%	NA	NA	
(Senaratne and Shooter 2004)	<10 µm	Elements, EC	PCA (6)	Auckland, New Zealand, (1), 2000-2001	22%	14%	8%	Slightly higher vehicle contributions found on brown haze days (diesel 16%, gasoline 9%).
(Kumar et al 2001)	TSP	Elements, EC, OC, ions, anions, SO_2, NO_2	Factor analysis-multiple regression	Mumbai, India (2), 1991-1992	15-18%	NA	NA	Both sites near traffic junctions. TSP was 33-41% road dust.

Table C.3. Organic aerosol source apportionment studies.

Reference	PM Size	Components Used in Source Apportionment	Method (No. Sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Larsen and Baker 2003)	2.5 µm	Gas and particle phase PAHs	UNMIX, PCA MLRA, PMF (4)	Baltimore, MD (urban location), 1997-1998	16% PAH PMF, 23% PAH UNMIX, 26% PAH PCA/MLRA	n/a	n/a	Study was a comparison of three methods. PMF only method able to segregate diesel and gasoline vehicle contributions (% not listed however).
(Fujita et al 2007)	2.5 µm	Elements, EC, OC, ions, PAHs, alkanes, sterances, hopanes	CMB	Los Angeles, CA (4) 2001	31-72% TC	30-60% TC	1-12% TC	Up to 70% of organic carbon (OC) in the ambient samples collected at the two fixed monitoring sites could not be apportioned to directly emitted PM emissions.
(Lee et al 2004)	2.5 µm	Gas and particle phase PAHs	PMF (8 Factors)	Hudson River Estuary, NY/NJ (three city dataset), 1997-2001	22-31% of PAH	n/a	n/a	
(Harrison et al 1996)	<2.1 µm and 2.1-10 µm	Elements, ions, gas and particle phase PAHs	PCA (6), MLRA	Birmingham, UK (1), 1994-1995	13% PAH, 88% BAP	NA	NA	Results show that a combination of PAH and inorganic pollutant measurements are more powerful tracers than PAH data alone. Result suggests road dust (33%) is a larger contributor ambient PAH than direct vehicle exhaust.

Table C.4. PM source apportionment studies conducted using multiple methods.

Reference	PM Size	Components Used in Source Apportionment	Method (No. Sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Hopke et al 2006)	<2.5 μm	Elements, EC, OC, ions	PCA, APCA, FA, Unmix, PMF2, ME, Expanded Model ME, MLR (3-10)	Washington (DC), 1988-1997; Phoenix (AZ), 1995-1998	8-23% Washington 27-59% Phoenix	2-14% Washington 3-13% Phoenix	9-19% Washington	8 Research Groups applied models to common data sets. Source contributions estimated for motor vehicles were better correlated than those for gasoline and diesel vehicle exhaust. A wide range of results for motor vehicle contributions were found from different models.
(Ito et al 2004)	<2.5 μm	Elements, EC, OC, ions, anions	PCA, PMF (4)	New York City, NY,(3) 2001-2002	16-36% PCA; 20-34% PMF	n/a	n/a	
(Marmur et al 2005)	<2.5 μm	Elements, ions, SO_2, NO_x, CO	CMB (7), CMB-LGO (6)	Atlanta (Jefferson street), 1998-2000	57% CMB, 66% CMB-LGO	50% CMB, 40% CMB-LGO	7% CMB 26% CMB-LGO	
(Marmur et al 2006)	<2.5 μm	Elements, EC, OC, ions, anions, SO_2, NO_x, CO	CMB, CMB-LGO, CMAQ (5)	Atlanta, Jefferson St., GA, and Birmingham, AL, 2001-2002	Atlanta: 61% CMB, 58% CMB-LGO, 38% CMAQ Birmingham : 75% CMB, 50% CMB-LGO, 18% CMAQ	Atlanta: 29% CMB, 31% CMB-LGO, 29% CMAQ Birmingham : 7% CMB, 29% CMB-LGO, 14% CMAQ	Atlanta: 31% CMB, 27% CMB-LGO, 8% CMAQ Birmingham : 68% CMB, 20% CMB-LGO, 4% CMAQ	Authors concluded that using results from either receptor or dispersion models in a health study would likely introduce an attenuation of the observed association, due to limited spatial representativeness in receptor modeling results and to limited temporal representativeness in emissions-based models results.
(Maykut et al 2003)	<2.5 μm	Elements, EC, OC, ions, anions	PMF (9), Unmix (7), CMB (7)	Seattle, WA, (1) 1996-1999	22% PMF 28% Unmix 44% CMB	18% PMF 19% Unmix	4% PMF 9% Unmix	CMB did not separate diesel and gasoline.

Table C.4. PM source apportionment studies conducted using multiple methods.

Reference	PM Size	Components Used in Source Apportionment	Method (No. Sources)	Location (Sites) and Period	Vehicle Exhaust Contribution (%)			Comment
					All Vehicles	Diesel Vehicles	Gasoline Vehicles	
(Antony Chen et al 2007)	<2.5 µm	Elements, EC, OC, ions, anions	UNMIX (6-7), PMF (8)	San Joaquin Valley, California (23 sites)	10% PMF and 15% UNMIX in high PM; 13% PMF and 25% UNMIX for low PM	n/a	n/a	Averages for urban and rural sites.
(Brook et al 2007)	<2.5 µm	BC, OC, ions, anions, organic acid, winds	UNMIX (9), PMF (8)	Toronto, Canada, (1), 2000-2001 (1-year)	22% UNMIX 18% for exhaust/road dust PMF	13% UNMIX	8% UNMIX	Secondary fine particle nitrate was the single most important source (35%) with a large fraction of this likely to be related to motor vehicle emissions
(Buset et al 2006)	<2.5 µm	BC, ions, organics from AMS, NO_x, SO_2, O_3	PMF, ME (5)	Toronto, Canada, (1), 2003 (Aug-Sept)	7.5% PMF 11% ME	n/a	n/a	Sources included secondary sulfate and nitrate, fresh organic w/ BC, fresh organic w/o BC, and aged organics. Fresh organic was used for motor vehicle contribution.
(Yuan et al 2006)	<10 µm	Elements, ions, anions	UNMIX, PMF (9)	Hong Kong, (8), 1998-2002	26% (UNMIX) 25% (PMF)	n/a	n/a	Annual average concentrations from 8 monitoring stations were combined for source apportionment.

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