The Centre for Sustainable Transportation

Le Centre pour un transport durable

AIR QUALITY IN INTER-CITY BUSES
FINAL REPORT[†]

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INTRODUCTION

Several studies have indicated that air quality inside road vehicles can be poorer than ambient or nearby air quality. What may still be the most comprehensive study examined air quality inside automobiles and school buses in California in 1997,[1‡] for the California Air Resources Board (CARB). The following is from the abstract of the study report.

> In general, VOC and CO levels inside or just outside the vehicles were higher than those measured at the roadside stations or the ambient air stations. However, in-vehicle levels of $PM_{2.5}$ were consistently lower than $PM_{2.5}$ levels just outside the vehicles and. in many cases, also lower than roadside levels. Nonetheless, $PM_{2.5}$ levels inside or just outside the vehicles were usually higher than levels measured at the nearest ambient site. … Pollutant levels measured inside vehicles traveling in a carpool lane were significantly lower than those in the right-hand, slower lanes. Under the study conditions, factors such as vehicle type and ventilation settings were shown to have little effect on the in-vehicle pollutant levels. Other factors, such as roadway type, freeway congestion level, and time-of-day were shown to have some influence on the in-vehicle pollutant levels. Elevated levels of both fine particles and black carbon were measured inside the test vehicle when it followed diesel-powered vehicles.

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[‡] Superscript numbers refer to reference and other notes on Page7-9.

A more recent study for CARB focused on children's exposure within school buses.[2] It concluded the following:

> Measurements indicated that for some buses, significantly higher exposures of vehicle-related pollutants occurred during the bus commutes than roadway pollutant concentrations alone would indicate. The high commute concentrations were a function of several influences:
>
> - the high concentrations of pollutants already present on roadways, especially if traffic was heavy;
> - the direct influence of other vehicles being followed; and
> - the contribution of the bus's own emissions. The extent of a bus's own contribution to these high concentrations appeared to be highest when windows were closed for the older diesel buses, but bus-to-bus variability was high.

Another study of air quality within school buses concluded the following:[3]

> The results were startling: A child riding inside of a diesel school bus may be exposed to as much as four times the level of toxic diesel exhaust as someone standing or riding beside it. Under federal law, these exposures translate into a significant risk of cancer to children. In fact, these exposures pose from 23 to 46 times the cancer risk level considered significant under federal law.

Yet another study of school buses reached this conclusion:[4]

> Fine particulate concentrations ($PM_{2.5}$) measured on buses in this study were often 5-10 times higher than average levels measured at the 13 fixed-site $PM_{2.5}$ monitoring stations in Connecticut. Levels of fine particles were often higher under certain circumstances: when buses were idling with windows opened, when buses ran through their routes with windows closed, when buses moved through intense traffic, and especially when buses were queued to load or unload students while idling.

Several studies have examined air quality inside regular urban buses. An Australian study examined in-vehicle exposure of commuters by bus, train, and car, and also exposure of commuting walkers and cyclists to nitrogen dioxide (NO_2) and volatile organic compounds (VOCs).[5] Commuting by bus resulted in the highest exposures to NO_2. Commuting by car resulted in the highest exposures to VOCs. Commuting by train resulted in the lowest exposures. Commuting by walking or bicycling generally resulted in intermediate levels of exposure: higher than by train but lower than by car or bus.

A study comparing exposure to carbon monoxide (CO) in public transit modes in Hong Kong found that CO levels in minibuses and taxis were respectively about 60 per cent and 80 per cent above levels in regular buses.[6] Levels were low compared with those reported for other cities. This and a subsequent study[7] showed a high correlation between in-vehicle concentrations of CO and those immediately outside the vehicles.

Work in Mexico City compared concentrations in minibuses, buses, and heavy-rail vehicles (subway trains) of particulate matter of diameter equal to or less than 2.5 microns ($PM_{2.5}$), CO, and benzene.[8] In general, the highest concentrations were found in mini-

buses and the lowest in buses; the results for subway trains were more similar to those for buses than those for minibuses. The highest readings in all vehicles occurred when wind speeds were low.

A study of VOC concentrations inside and just outside transit buses in Detroit, Michigan, showed levels were similar in both kinds of location.[9] Both were much above ambient levels, leading to the authors' conclusion that vehicle-related sources of VOCs dominated VOC exposure, not the many industrial sources in Detroit.

Work for Environment Canada measured levels of VOCs, $PM_{2.5}$, and other pollutants in Ottawa buses and at the roadside.[10] According to the authors, in-vehicle concentrations were generally higher than roadside levels.

Work in Manchester, UK, found high and extremely variable levels of respirable particles ($PM_{4.0}$) inside buses travelling in an urban area, an average of more than ten times background levels. Cyclists on the same route had exposures averaging twice background levels.[11]

Another UK study, conducted in London, found that mean personal exposure levels to respirable particulates ($PM_{2.5}$) in road transport modes—bus, car, and bicycle—were approximately double that of concentration at an urban background fixed site monitor.[12] Exposure in underground trains was several times higher.

Work in Munich, Germany, found that particulate levels (PM_{10}) in buses and streetcars were 1.7-4.0 times higher than those at static outdoor stations, with only minor associations between particulate concentrations and traffic density and time of day.[13]

There has been less work on air quality inside cars. A UK study compared personal exposures to particulates during walking and in-car suburban journeys in winter.[14] Exposures were highly correlated between the two transport modes, with PM_{10} but not $PM_{2.5}$ or PM_1 being higher inside the car than for the walker, and both being higher than at a fixed-side curbside monitor.

One of the few studies of air quality in vehicles while travelling outside urban areas found *lower* $PM_{2.5}$ levels inside highway patrolling police cruisers than were recorded as ambient and roadside concentrations, although in-vehicle levels of CO, NO_2, aldehydes, hydrocarbons, and some metals were higher.[15] Nevertheless, cardiovascular effects were more strongly associated with in-vehicle $PM_{2.5}$ levels than with ambient and roadside levels.

A review conducted for the International Center for Technology Assessment (Washington DC) concluded the following:[16]

> Most people realize that there are risks associated with traveling by automobile—drunk drivers, road rage, and speeding tickets come to mind. The greatest concern of drivers stuck in traffic is most likely that they won't get to their destinations on time. Few people, however, are concerned about the health effects of the air quality inside of

> their cars. If their thoughts turn to the subject at all, they are more likely to consider air pollution an 'outdoor' problem.
>
> This unprecedented survey of international studies shows that air pollution may be even more severe inside of cars than out. The results of 23 separate scientific studies conducted during the 1980s and 1990s reveal that in-car air pollution levels frequently reach concentrations that may threaten human health. The reports show that the air inside of cars typically contains more carbon monoxide, benzene, toluene, fine particulate matter, and nitrogen oxides than ambient air at nearby monitoring stations used to calculate government air-quality statistics. In-car pollution is often even worse than pollution in the air at the side of the road.

Taken together, the foregoing suggests that although concentrations in car and minibuses may be higher, concentrations of vehicle-related pollutants in city buses—although not necessarily inter-city buses—may be sufficiently elevated to pose concerns in respect of vehicle occupants including operators.

The work reported here was undertaken to serve two purposes. The first was to allow development and refinement of methods for assessing air quality within road vehicles. The second was to conduct a preliminary investigation of levels of some pollutants in inter-city buses to determine whether fuller investigation would be warranted.

The Centre's concern about in-vehicle air quality is part of its concern about all adverse impacts of transportation. A sustainable transportation system, according to the Centre's definition, is one that allows the basic access needs of individuals to be met in a manner consistent with human health.[17] If the air within a transportation system's vehicles is hazardous, then the system is not sustainable.

Assessment of in-vehicle exposure to atmospheric pollutants is beyond the resources of the Centre for Sustainable Transportation (CST). For this work, CST collaborated with the Gage Occupational and Environmental Health Unit at the University of Toronto, specifically with Professor James Purdham and his staff. He kindly agreed to undertake the work reported here as an additional feature of ongoing work on occupational exposure to ultrafine particles and its relationship to heart and lung disease. For logistical reasons, his procedures had been restricted to measurement of personal exposure in non-mobile setting. They were adapted to provide for limited assessment of in-vehicle concentrations of carbon monoxide (CO), nitrogen dioxide (NO_2), inhalable particles (PM_{10}) and respirable particles ($PM_{2.5}$).[18] This required the application of well-tried measuring equipment and procedures to new, more challenging situations.

In brief, students carried monitoring equipment on 28 inter-city trips made by Greyhound Canada buses during July and August 2004. The equipment recorded average levels of CO and NO_2, and also concentrations of particulate matter (PM_{10} or $PM_{2.5}$, or both).

PROCEDURES

Bus routes were selected that allowed for about 10 hours of total sampling time in a day. Either two trips of roughly five hours each or four trips of 2-2½ hours were undertaken. All routes involved express buses that for the most part ran along Ontario's 400 series of divided highways with four or more lanes. Outbound routes began at the Toronto Bus Terminal located in the city's downtown. All the equipment detailed below was in or on standard-sized backpacks held on the laps of the students who carried out the sampling. It was not possible to control the location of the students on the bus; they sat wherever seats were available. Data on the pumps used, the run times, and the routes taken were recorded by the students.

Carbon monoxide: CO was measured using Langan Model T15 logging CO monitors, reset the night before each day's trips. The monitors were calibrated using a Thermo Electron Gas Filter Correlation analyzer Model 48. The data were downloaded and recorded after each set of trips. The CO monitors were carried in the mesh portion of the backpack's outer pocket.

Nitrogen dioxide: NO_2 was measured using Gastec #9DL passive dosi-tubes that showed a colour change proportional to NO_2 concentration over time. The colour change was due to the reaction of NO_2 with 2,2-Azinobis (3-ethylbenzothialine-6-sulfonic acid). There are no known interferents listed by Gastec in the product literature. The tubes were opened at the start of the day, and were sealed at the end of the sampling period to prevent further diffusion. The tubes were then read the next morning.

Particulate matter: $PM_{2.5}$ or PM_{10} were measured using Harvard Personal Sampler grease-filled impactors running at four litres per minute. The pumps used were BGI400S 24-hour sampling pumps with nickel metal hydride batteries. The pumps were turned on before each trip, roughly 10 minutes before the scheduled bus departure time. Pumps were turned off in between trips and were turned on again roughly 10 minutes before the bus was scheduled to depart. Filters for the Harvard Samplers were weighed before and after sampling. Filters contained in the Harvard Samplers were conditioned for 24 hours before each weighing in a temperature and humidity controlled chamber. Weighing was conducted using a Perkin-Elmer AD-6 Microbalance with Po-210 anti-static radioactive sources. The grease pots were refilled after each day for the $PM_{2.5}$ sampling heads and after every second day's sampling for the PM_{10} sampling heads. This was because considerably less particulate matter was deposited on the PM_{10} impactor plates.

RESULTS

The results of the measurements are set out in Table 1, together with an indication of relevant standards.[19]

Table 1 Summary of results of the measurement of in-bus levels of indicated pollutants, together with acceptable levels (as explained in Note 20)

	Carbon monoxide (parts per million)	Nitrogen dioxide (parts per billion)	Particulate matter (micrograms per cubic metre)	
			PM_{10}	$PM_{2.5}$
Lowest value	0.6	25	11	5
Geometric mean	0.9	60	33	16
Highest value	1.2	168	159	47
Acceptable level[20]	13.0	106	50	30

In brief, levels of carbon monoxide in the buses were much lower than (better than) the national standard of an 'acceptable' level for CO. Levels of nitrogen dioxide were on average lower than the acceptable level of this pollutant, but five of the 19 values exceeded the acceptable level (i.e., not including the discarded extreme values). There are presently no national standards for PM_{10}, and $PM_{2.5}$, although there are recommended levels and a formal standard for $PM_{2.5}$ is emerging. The derivation of the 'acceptable' levels for PM_{10} and $PM_{2.5}$ is discussed in Note 20. As in the case of nitrogen dioxide, the average particulate levels recorded in the buses can be considered acceptable. However, in each case two values (out of 19 for PM_{10} and 14 for $PM_{2.5}$) exceeded what might be considered to be the respective acceptable levels.

INITIAL CONCLUSIONS

These results are consistent with the findings reported in the introductory section above. They provide no justification for further work on in-vehicle carbon monoxide levels in inter-city buses. They do suggest that further work on in-vehicle levels of nitrogen dioxide and particulate matter could be warranted. It should be stressed that the results are based on too few assessments[21] to allow a conclusion that there are problems with exposure to these pollutants in inter-city buses.

Several procedural and equipment problems were encountered (see Note 21), all of which were remedied. As thus refined, the methods used appear robust and valid, and suitable for further work on in-vehicle concentrations of these pollutants.

ACKNOWLEDGEMENTS

This work was financially supported by CAW-Canada and Amalgamated Transit Union. The support was much appreciated as was the excellent cooperation provided by Greyhound Canada.

NOTES

[1] The quote is from Page x of Rodes C, Sheldon L, Whitaker D, Clayton A, Fitzgerald K, Flanagan J, DiGenova F, Hering S, Frazier C. *Measuring concentrations of selected air pollutants inside California vehicles*. California Air Resources Board, December 1998, available at the URL below. Data from this study are also analyzed in Fruin SA, Winer AM, Rodes CE, Black carbon concentrations in California vehicles and estimation of in-vehicle diesel exhaust particulate matter exposures. *Atmospheric Environment*, 38, 4123-4133, 2004.
1. http://www.arb.ca.gov/research/abstracts/95-339.htm. Accessed June 28, 2005.

[2] The report for CARB is Fitz DR, Winer AM, Colome S, Behrentz E, Sabin LD, Lee SJ, Wong K, Kozawa K, Pankratz D, Bumiller K, Gemmill D, Smith M, *Characterizing the range of children's pollutant exposure during school bus commutes*. University of California: Riverside, October 2003, available at the URL below. An article based on the report is Sabin LD, Behrentz E, Winer AM, Jeong S, Fitz DR, Pankratz DV, Colome SD, Fruin SA, Characterizing the range of children's air pollutant exposure during school bus commutes. *Journal of Exposure Analysis and Environmental Epidemiology* advance online publication, 8 December 2004; doi:10.1038/sj.jea.7500414. Another article based on this report is Marshall JD, Behrentz E, Vehicle self-pollution intake fraction: Children's exposure to school bus emissions. *Environmental Science & Technology*, 39, 2559-2563, 2005.
1. http://www.arb.ca.gov/research/schoolbus/schoolbus.htm. Accessed June 28, 2005.

[3] This quote is from Page 1 of Solomon GM et al, *No Breathing in the Aisles: Diesel Exhaust inside School Buses*. National Resources Defense Council, Washington DC, January 2001, available at the URL below.
1. http://www.nrdc.org/air/transportation/schoolbus/schoolbus.pdf. Accessed December 10, 2004.

[4] This quote is from Page 5 of Wargo J, *Children's Exposure to Diesel Exhaust on School Buses*. Environment and Human Health Inc., North Haven, Connecticut, February 2002, available at the URL below.
1. http://www.ehhi.org/reports/diesel/. Accessed December 10, 2004.

[5] Chertok M, Voukelatos A, Sheppeard V Rissel C, *Comparison of personal exposures to air pollutants by commuting mode in Sydney: BTEX & NO_2*. Prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the New South Wales Department of Health, 2004. (ISBN 073473672X)

[6] Chan LY, Liu YM, Carbon monoxide levels in popular passenger commuting modes traversing major commuting routes in Hong Kong. *Atmospheric Environment, 35*, 2637-2646, 2001.

[7] Chan LY, Liu YM, Lee SC, Chan CY, Carbon monoxide levels measured in major commuting corridors covering different landuse and roadway microenvironments in Hong Kong. *Atmospheric Environment*, *36*, 255-264, 2002.

[8] Gómez-Perales JE, Colvile RN, Nieuwenhuijsen MJ, Fernández-Bremauntz A, Gutiérrez-Avedoy VJ, Páramo-Figueroa VH, Blanco-Jiménez S, Bueno-López E, Bernabé-Cabanillas R, Ortiz-Segovia E, Commuters' exposure to $PM_{2.5}$, CO, and benzene in public transport in the metropolitan area of Mexico City. *Atmopheric Environment*, *38*, 1219-1229, 2004.

[9] Batterman SA, Peng C-Y, Braun J, Levels and composition of volatile organic compounds on commuting routes in Detroit, Michigan. *Atmospheric Environment*, *36*, 6015-6030, 2002.

[10] Karman D, Ogus O, Akay G, *Measurement of air toxics in the cabins of commuter vehicles under summer and winter conditions in Ottawa, Canada*. Presentation on a report for Environment Canada, 2001. Available at the URL below.
1. http://www.carleton.ca/~dkarman/research.html. Accessed December 10, 2004.

[11] Gee IL, Raper DW, Commuter exposure to respirable particles inside buses and by bicycle. *The Science of the Total Environment*, 235, 403-405, 1999.

[12] Adams HS, Nieuwenhuijsen MJ, Colville RN, McMullen MAS, Khandelwal P, Pin particle ($PM_{2.5}$) personal exposure levels in transport microenvironments, London, UK. *The Science of the Total Environment*, 279, 29-44, 2001.

[13] Praml G, Schierl R, Dust exposure in Munich public transportation: a comprehensive 4-year survey in buses and trams. *International Archives of Occupational and Environmental Health*, 73, 209-214, 2000.

[14] Gulliver J, Briggs DJ, Personal exposure to particulate air pollution in transport microenvironments. *Atmospheric Environment*, 38, 1-8, 2004.

[15] Riediker M, Cascio WE, Griggs TR, BHerbst MC, Bromberg PA, Neas L, Williams RW, Devlin RB. Particulate matter exposure in cars in associated with cardiovascular effects in healthy young men. *American Journal of Respiratory and Critical Care Medicine*, 169, 934-940, 2004.

[16] Briscoe M, *In-car pollution: the hidden threat to automobile drivers*. International Center for TechnologyAssessment, Washington DC, July 2000, available at the first URL below. Additional sources are listed at the second URL below and in the sources cited in Notes 1, 3 and 4.
1. http://www.icta.org/projects/trans/incar.pdf. Accessed December 10, 2004.
2. http://www.ph.ucla.edu/ese/faculty/winerlab/literature_school.htm. Accessed December 10, 2004.

[17] The Centre's definition of a sustainable transportation system is this:
A sustainable transportation system is one that:

- Allows the basic access needs of individuals to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.
- Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

A slightly amended version of this definition was adopted as a working definition of sustainable transport by the transport ministers of the 15 countries of the European Union at the 2340th meeting of the European Council (transport/telecommunications), as indicated at the URL below.
1. http://corporate.skynet.be/sustainablefreight/trans-counci-conclusion-05-04-01.htm. Accessed December 10, 2004.

[18] Particles larger than about 10 microns (micrometres, often written as µm) are usually caught in the nose and throat and do not reach the lungs. Particles smaller than about 10 µm (PM_{10}) reach further into the bronco-pulmonary system and are thus known as *inhalable* particles. Of these, particles larger than about 2.5 µm are caught by cilia lining the wall of the bronchial passage, which act to expel these particles. Smaller particles, known as *respirable* particles ($PM_{2.5}$), penetrate deeper into the lungs. The present assessment concerned only PM_{10} and $PM_{2.5}$. The ultrafine particles being studied by Professor Purdham in non-mobile setting have a diameter of

less than 0.1 µm. They are believed to be more harmful than $PM_{2.5}$ for two reasons. One is that being smaller they penetrate more deeply into the lungs. The other is that for a given weight they have a larger surface area and thus are potentially more reactive and hazardous. The surface area of a sphere is proportional to the square of its diameter. A gram of spherical ultrafine particles of diameter 0.1 µm has 625 times the surface area, and thus the potential reactivity, of a gram of such particles of diameter 2.5 µm ($PM_{2.5}$). Ultrafine particles are mostly products of combustion processes, including those in internal combustion engines. Compression ignition (diesel) engines are known to produce many more ultrafine particles than spark ignition (gasoline) engines, when the latter are naturally aspirated. Direct-injection gasoline engines may produce similar numbers of ultrafine particles to those produced by diesel engines. See, for example, Färnlund J, Holman C, Kågeson P, *Emissions of Ultrafine Particles from Different Types of Light Duty Vehicle*. Swedish National Road Administration, January 2001, available at the URL below. This report also indicates that particle traps can be effective in removing ultrafine particles from exhaust gases.

1. http://www.vv.se/filer/publikationer/particle.pdf. Accessed December 11, 2004.

[19] The data in Table 1 aggregate recordings from trips between Toronto and London, Ottawa, and Windsor. No weighting for the different distances of these trips was applied. For each pollutant, the lowest two and the highest two recorded values were discarded.

[20] Acceptable levels for CO and NO_2 in Table 1 are taken from the Maximum Acceptable Concentration levels for these substances in the National Ambient Air Quality Objectives (NAAQO), available at the first URL below. Note that the "8-hour" level is provided here for CO and the "24-hour" level is provided for NO_2. These are regarded as more appropriate for the present case than the respective "1-hour" levels, which are 31 parts per million and 213 parts per billion, respectively.

Regarding particulate matter, the only NAAQO concerns total suspended particulates (TSP), for which the 24-hour Maximum Acceptable Concentration is 120 micrograms per cubic metre ($\mu g/m^3$; see the first URL below). According to Environment Canada, at the second URL below, at this concentration of TSP the concentration of PM_{10} would likely be near 60 $\mu g/m^3$, and that of $PM_{2.5}$ would likely be near 30 μ/m^3. The same Environment Canada document speaks to "recommended ambient PM exposure levels" of 25-40 $\mu g/m^3$ for PM_{10} and 15-25 $\mu g/m^3$ for $PM_{2.5}$. The Canadian Council of Ministers of the Environment has adopted a Canada-wide standard for $PM_{2.5}$ of 30 $\mu g/m^3$, 24 hour averaging time, for the year 2010 (see the third URL below). The acceptable level of 50 $\mu g/m^3$ for PM_{10} in Table 1 is taken from the foregoing considerations and from the fourth URL below (the standard used by the Greater Vancouver Regional District). This is also the standard in California (see the fifth URL below).

1. http://www.ec.gc.ca/soer-ree/English/Indicators/Issues/Urb_Air/Tech_Sup/uasup5_e.cfm. Accessed December 11, 2004.
2. http://www.msc-smc.ec.gc.ca/saib/smog/docs/ECapm3/sections/3_e.html#d. Accessed June 28, 2005.
3. http://www.ccme.ca/assets/pdf/pmozone_standard_e.pdf. Accessed June 28, 2005.
4. http://www.gvrd.bc.ca/air/pdfs/QueensboroughAirQualityStudy.pdf. Accessed June 28, 2005.
5. http://www.arb.ca.gov/aqs/aaqs2.pdf. Accessed June 28, 2005.

[21] The actual numbers of assessments—i.e., trips for which a proper reading was gained—were these: 19 for CO, 23 for each of NO_2 and PM_{10}, and 18 for $PM_{2.5}$. Measurement was constrained by faulty equipment (mostly for the CO recording), improper use of equipment (mostly for the NO_2 recording), and the occasional ability to record only one or the other of PM_{10} and $PM_{2.5}$.