CHAPTER 5. SOURCES OF AIR POLLUTION: GASOLINE AND DIESEL ENGINES

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The combustion of gasoline and diesel fuel in vehicle engines produces emissions of several potentially harmful substances. These emissions are not solely the result of the combustion process, nor do they come only from the tailpipe of the vehicle; rather, they result from a combination of the engine design and the fuel characteristics. Also apparent is that evaporative emissions from refuelling, spills onto heated engine parts, and so on can equal emissions from the tailpipe. In addition, analyses have indicated that a significant source of emissions from vehicles is abrasion and wear of tyres and metallic components, resulting in emissions of a variety of metals and carbon compounds.

The primary emissions from motor vehicles come in two predominant forms: major gaseous and particulate air pollutants, which can be found in relatively high amounts in the atmosphere, and so-called air toxics, which usually are found in lower amounts in the atmosphere but can have important health implications. The gaseous and particulate pollutants to which motor vehicles contribute include carbon monoxide (CO), ozone (through its atmospheric precursors volatile organic compounds and nitrogen oxides [NO_x]), fine particulate matter PM_{10} and $PM_{2.5}$ (particles < 10 µm and < 2.5 µm in aerodynamic diameter, respectively), and nitrogen dioxide. The air toxics emitted from motor vehicles include aldehydes (acetaldehyde, formaldehyde, and others), benzene, 1,3-butadiene, a large number of substances identified as polycyclic organic matter (including polycyclic aromatic hydrocarbons [PAHs]), and metals.

The various emissions from motor vehicles are also released by other sources, such as industrial processes, electric power generation, and home heating. As a result, the contributions of motor vehicle emissions to ambient levels of major air pollutants vary among pollutants (Table 5.1). For most pollutants, motor vehicles contribute 25–40% of the ambient levels, although in a few cases (e.g. CO, ultrafine particles [$PM_{0.1}$], 1,3-butadiene) motor vehicle contributions are noticeably higher.

Location and season play a role in the amount of motor vehicle emissions. For example, in the USA the estimated contribution of vehicles to ambient PM can vary substantially according to

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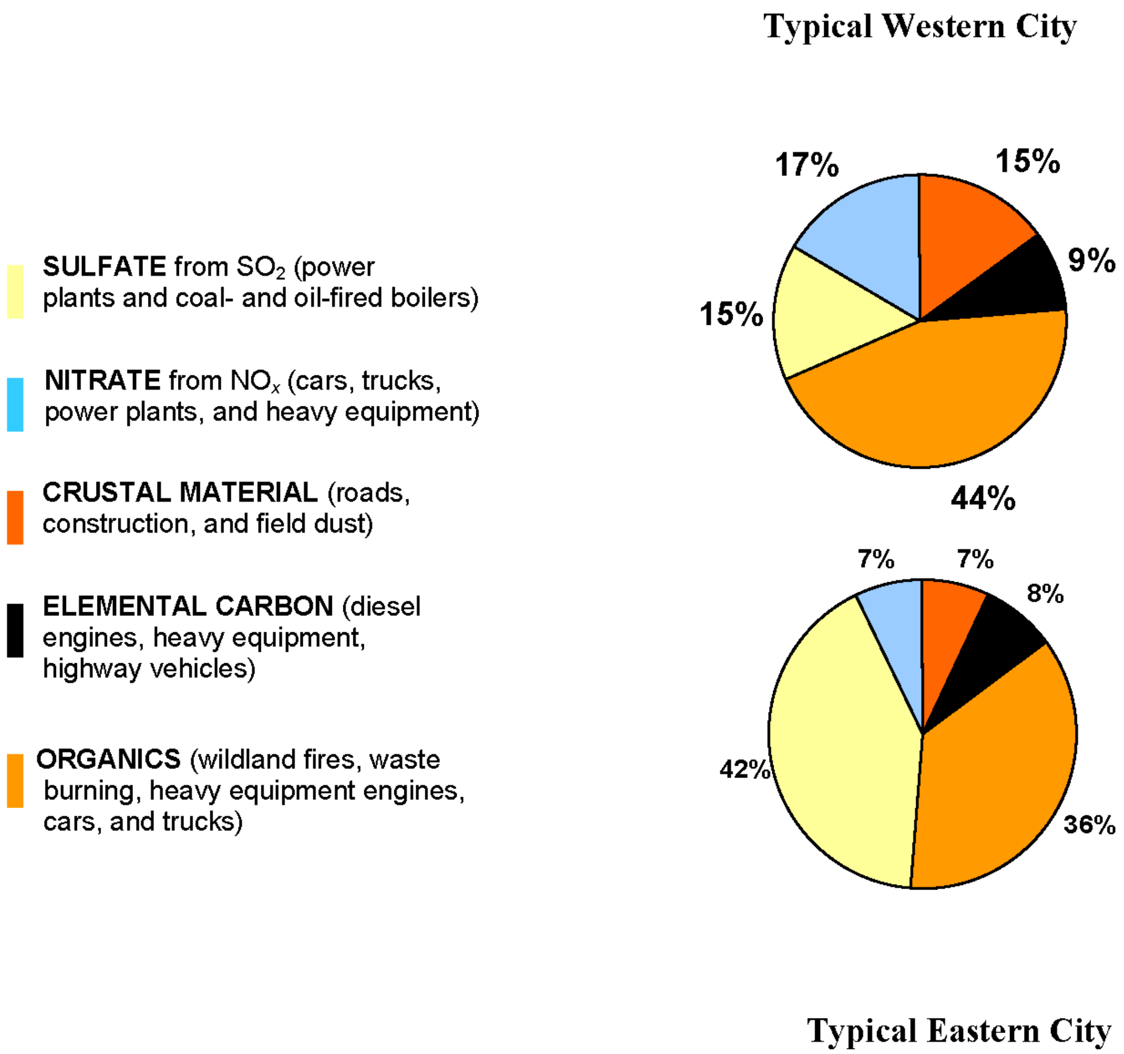
Table 5.1 Estimated average contributions of motor vehicle emissions to ambient levels of major air pollutants in developed countries

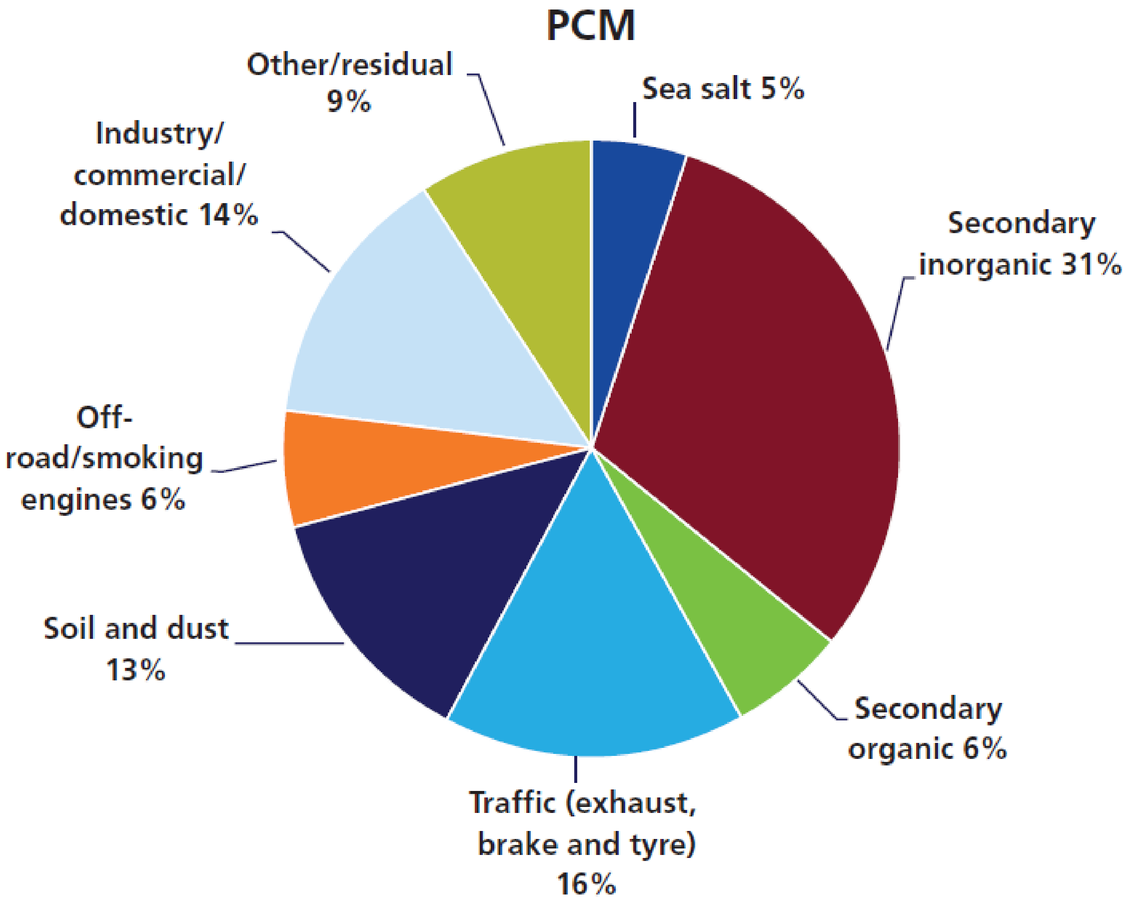
Pollutant	Contribution (%)	Reference
Carbon monoxide	~90	EPA (2000)
$PM_{2.5}$	~25–30	DEFRA (2012)
Nitrogen oxides	~40	EPA (2000)
Volatile organic compounds	~35	EPA (2000)
Average air toxics	~21	EPA (1999)
Urban air toxics	~42	EPA (1999)

Fig 5.1 Sources of $PM_{2.5}$ in typical western and eastern cities in the USA.



Reproduced from EPA (2004).

Fig 5.2 The on-road and nonroad contribution to $PM_{2.5}$ in the United Kingdom.

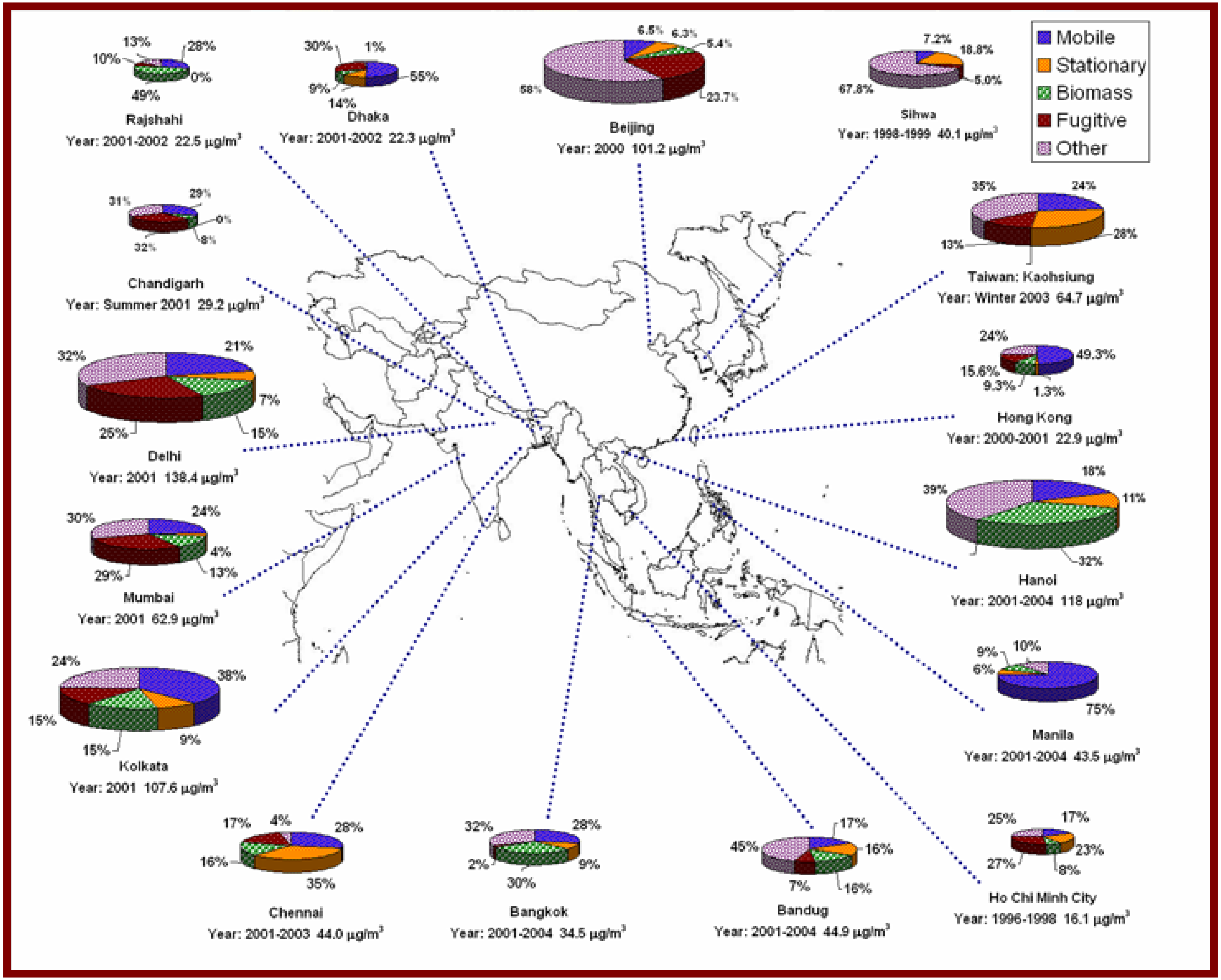


Adapted from DEFRA (2012).

region and depends on the relative contributions of other sources such as coal-burning utilities and their contribution of sulfates (Figure 5.1). Contributions also differ between the USA and Europe (e.g. the United Kingdom; Figure 5.2). In developing countries where biomass burning is often a substantial contributor and overall traffic contributes 20–35%, the contribution of vehicle emissions also varies (Figure 5.3). Seasonal variation can affect the contributions, as illustrated in Figure 5.4 in the case of three Indian cities.

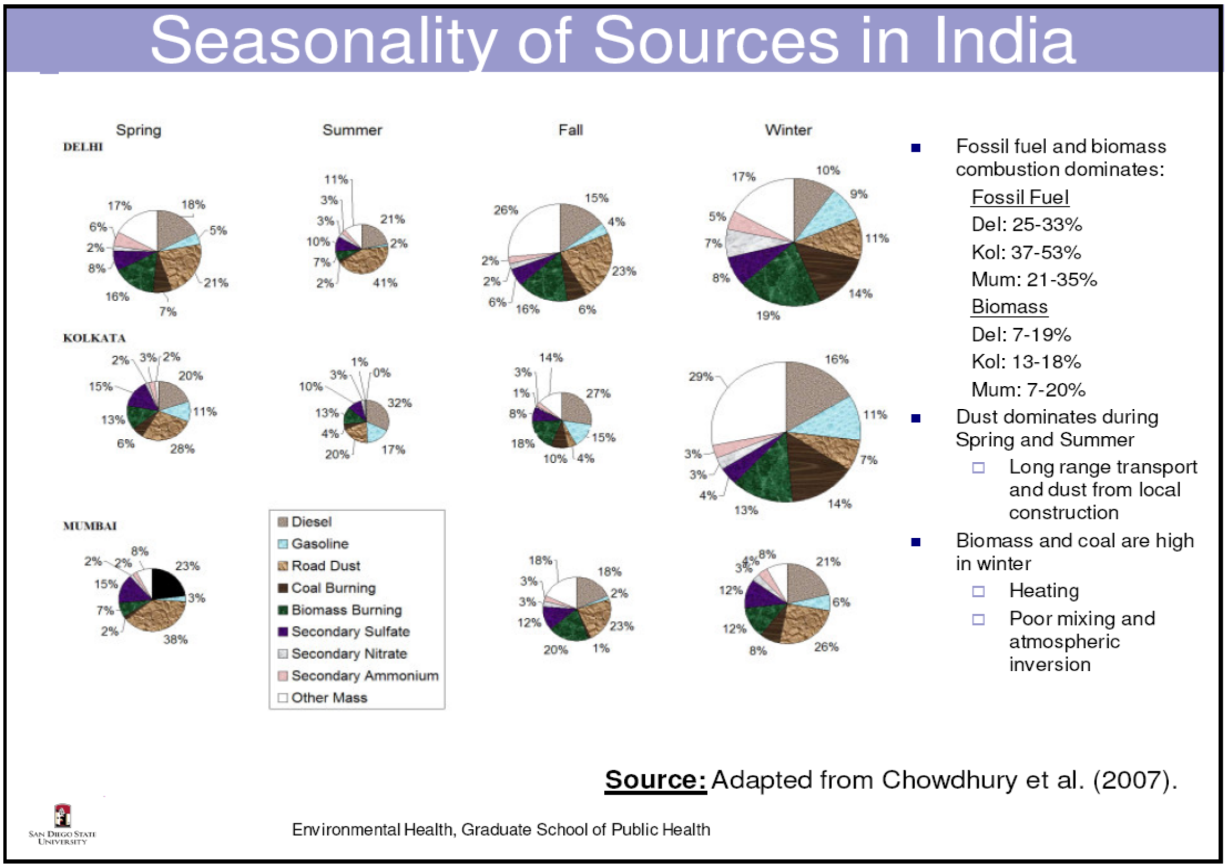
The relative contributions of diesel and gasoline vehicles can also differ depending on location and the method of source apportionment analysis. Figure 5.5, for example, illustrates a source apportionment for Denver, Colorado, USA, which suggests that gasoline vehicles, especially older, poorly maintained vehicles, are a larger contributor to levels of ambient particles than are diesel vehicles. Other analyses (Schauer *et al.*, 1996), however, have found that in Los Angeles, California, USA, close to 90% of the vehicle contribution to particles comes from diesel.

Fig 5.3 Motor vehicles can contribute 25–35% of particulate matter in Asian countries.



Source: HEI (2010a); reproduced with permission from the Health Effects Institute.

Fig 5.4 Seasonal variation in air pollution sources in India.



Seasonality of Sources in India

- Fossil fuel and biomass combustion dominates:
  Fossil Fuel
  Del: 25-33%
  Kol: 37-53%
  Mum: 21-35%
  Biomass
  Del: 7-19%
  Kol: 13-18%
  Mum: 7-20%
- Dust dominates during Spring and Summer
  - ☐ Long range transport and dust from local construction
- Biomass and coal are high in winter
  - ☐ Heating
  - ☐ Poor mixing and atmospheric inversion

Source: Adapted from Chowdhury et al. (2007).

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Adapted from Chowdhury *et al.* (2007).

Exposure

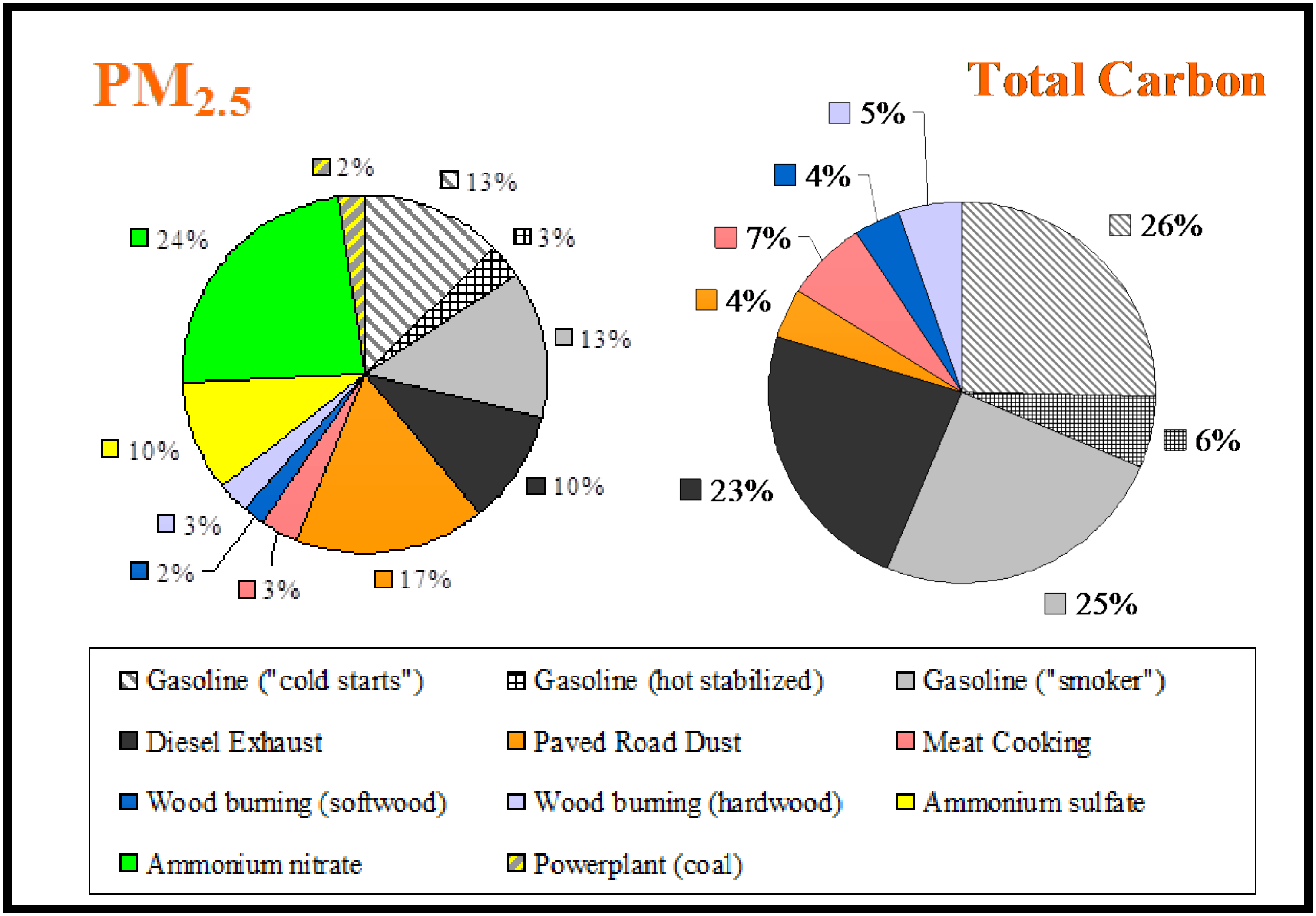
While in general motor vehicles contribute a significant portion, although not the majority, of most air pollutants, there are certain circumstances in which motor vehicles can contribute a substantially higher amount to personal exposure. In particular, in urban centres along roadsides and especially in urban street canyons in crowded business districts, mobile source contributions can contribute 2–10 times as much as in general background situations. (While this

Table 5.2 Contribution of motor vehicle primary emissions to ambient $PM_{2.5}$ in the Los Angeles, California, USA, metropolitan area

Location	Diesel contribution (%)	Gasoline contribution (%)	Total vehicle contribution (%)
Pasadena	18.8	5.7	24.5
Downtown Los Angeles	35.7	6.5	42.2
West Los Angeles	18.0	5.7	23.7
Rubidoux	12.8	0.7	13.5

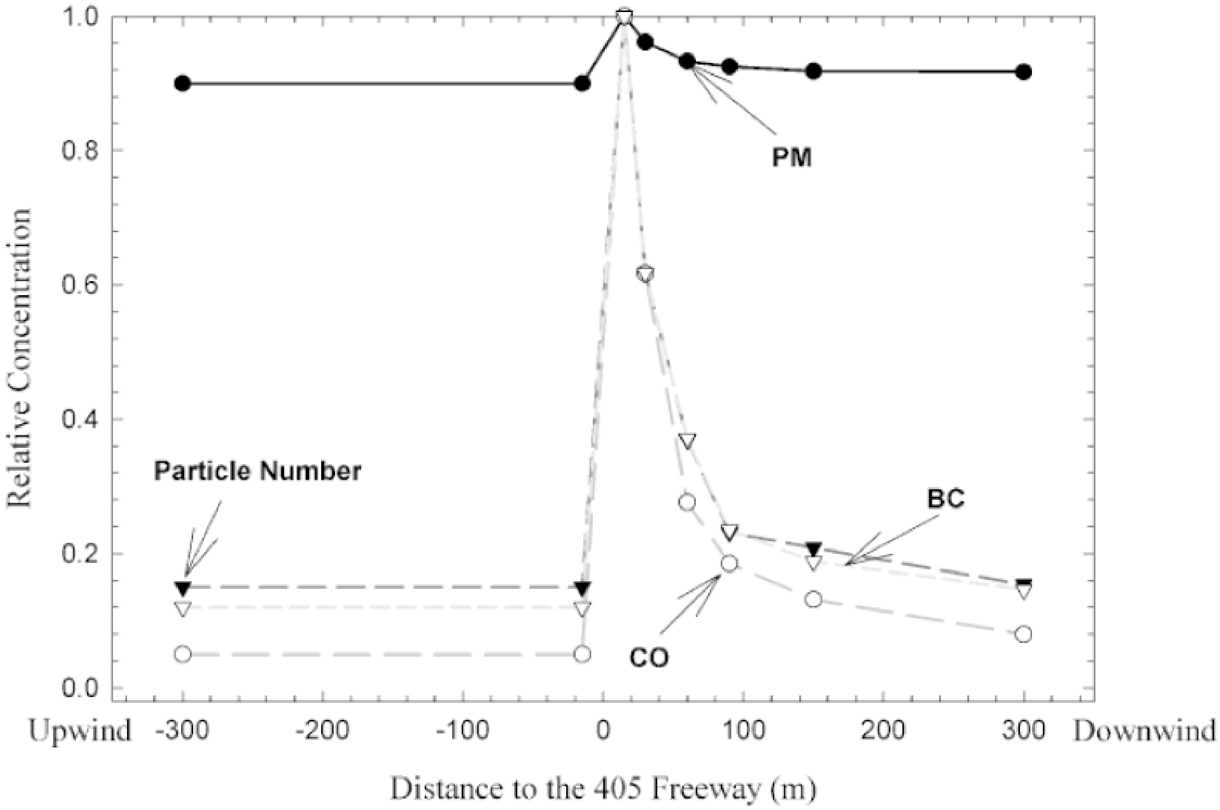
Compiled from Schauer *et al.* (1996).

Fig 5.5 $PM_{2.5}$ and total carbon source contribution estimates in Denver, Colorado, USA.



Source: Northern Front Range Air Quality Study (1998); reproduced with permission from Colorado State University and the Desert Research Institute.

Fig 5.6 Proximity to traffic (60, 90, and 300 m). While $PM_{2.5}$ varies very little (5–10%), ultrafine particles, black carbon (BC), and carbon monoxide (CO) decrease within 100 m to < 20%.



Source: Zhu *et al.* (2002); reproduced with permission from Taylor & Francis.

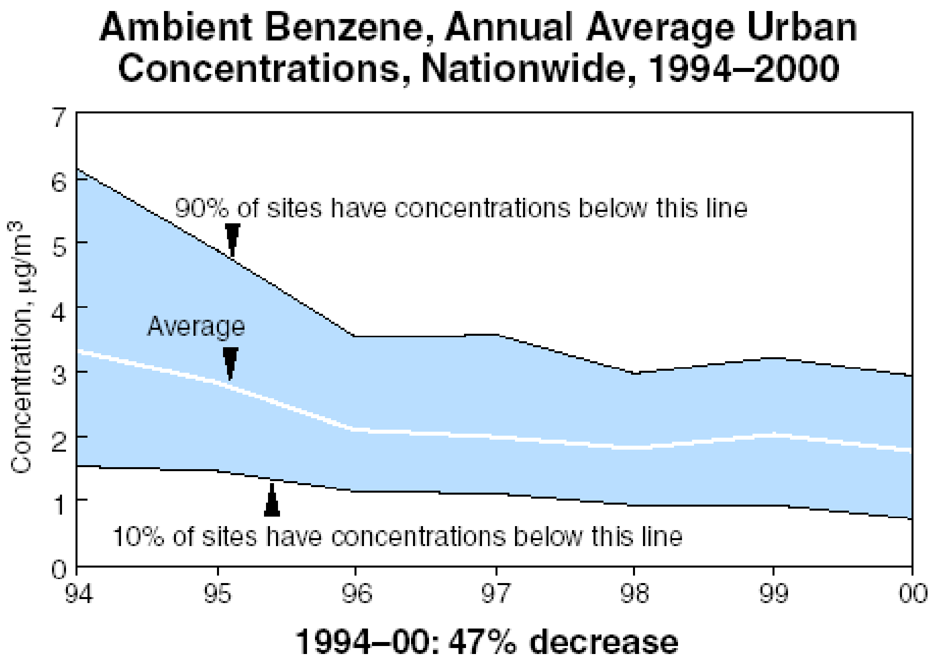
is true in general, there is one instance – the case of ozone – where urban levels are generally lower than those found outside cities, the result of scavenging of the ambient ozone by high levels of ambient NO_x.) For example, Table 5.2 presents data from the Los Angeles metropolitan area that suggest a 3-fold difference in vehicle contributions to $PM_{2.5}$ levels across the basin. These exposures can be especially high in microenvironments, such as roadside locations where concentrations of certain pollutants (e.g. CO and ultrafine particles) can be elevated because of fresh emissions (Figure 5.6). A comprehensive review of the literature on traffic exposure identified the area within 300–500 m of a major road as the most affected by traffic emissions (HEI, 2010b).

Exposure to high concentrations of these pollutants can have important acute and chronic health implications, particularly for individuals who live long-term in areas with congested traffic. This exposure pattern is of special concern in developing countries where large numbers of people from the lowest socioeconomic strata live on or near roadsides in housing that offers little filtering of outside air.

Trends and the future

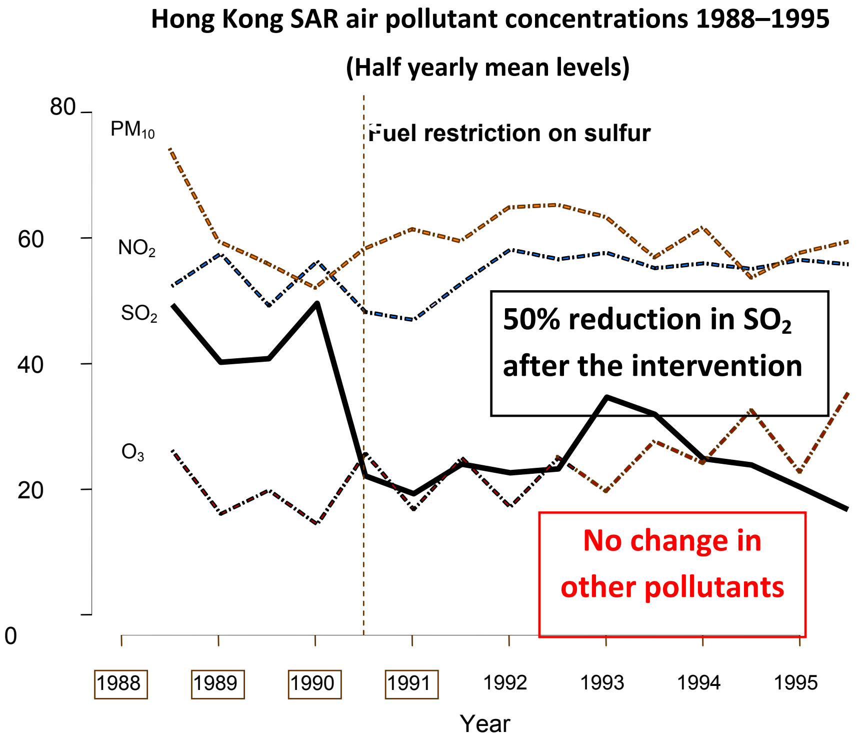
A series of measures have been implemented to reduce components of gasoline and diesel fuels that can lead directly or indirectly to harmful health effects caused by vehicle emissions. These

Fig 5.7 Reductions in ambient benzene levels in the USA.



Reproduced from EPA (2002).

Fig 5.8 Reduction in ambient SO_2 levels in the Hong Kong Special Administrative Region (SAR) after required reduction in fuel sulfur levels.

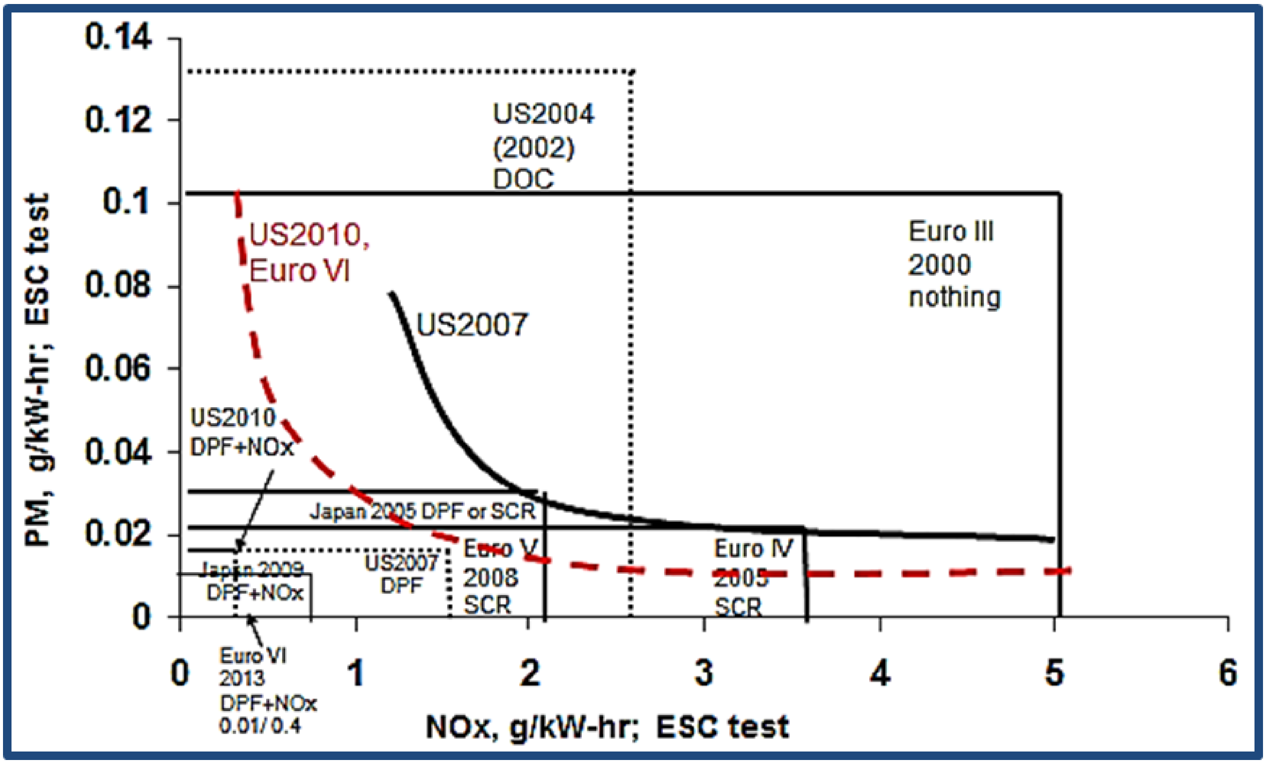


50% reduction in SO_2 after the intervention

No change in other pollutants

Source: Hedley *et al.* (2002); adapted with permission from Elsevier.

Fig 5.9 Transition in USA, European, and Japanese rules for heavy-duty diesel engines, 1975–2010.

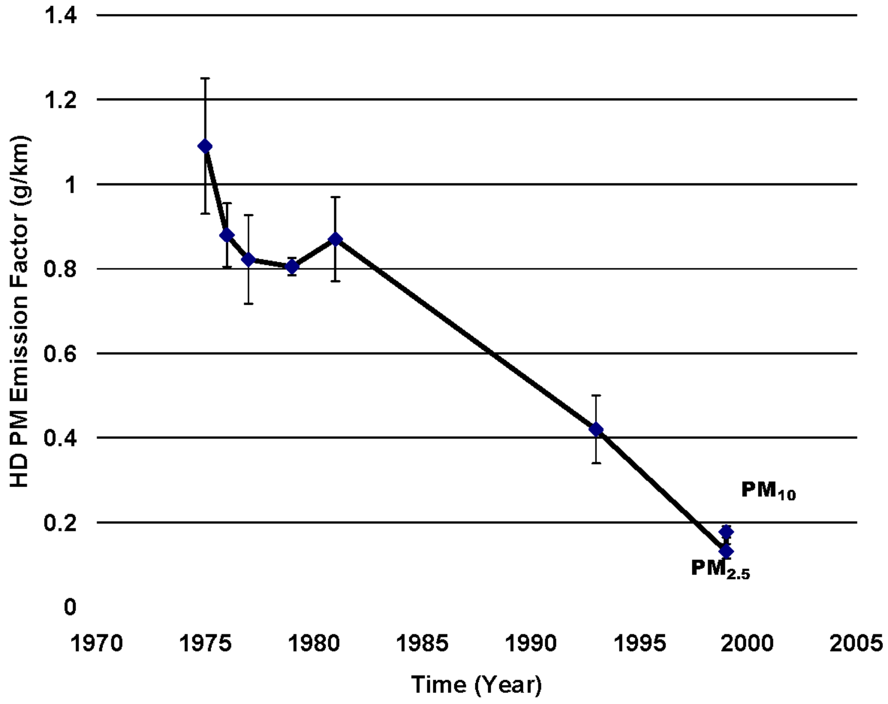


Source: Johnson (2009); adapted with permission from SAE International.

actions include the elimination of lead from fuel in much of the world, substantial reductions in benzene content (resulting, for example, in a nearly 50% reduction in ambient levels in the USA; Figure 5.7), and efforts to reduce sulfur in fuel, which can substantially reduce sulfur dioxide (SO_2) ambient levels (e.g. Hong Kong Special Administrative Region; Figure 5.8). In addition to direct reductions of emissions, fuel changes can also facilitate the introduction of advanced emission control technologies (e.g. particle filters).

In 1999, the United States Environmental Protection Agency took steps to further improve fuel formulation and reduce emissions of light-duty vehicles and, in 2000 and 2004, to impose stringent new fuel and emissions standards for on-road and nonroad heavy-duty vehicles (Figure 5.9). Earlier such actions have resulted in substantial reductions in on-road emissions from diesel vehicles, for instance (Figure 5.10). These new efforts are projected to provide considerable reductions in emissions in coming decades as new model engines are phased into the fleet (Figure 5.11). Comprehensive testing of the newest diesel technology (Figure 5.12) has demonstrated a > 90% reduction in PM emissions (Khalek *et al.*, 2011). However, in the USA, the wide-ranging benefits of the newest standards are not expected to be realized until 2030. Figure 5.9 also illustrates that the European Union and Japan are on a similar path, which is expected to substantially reduce emissions over the 20 years beginning in 2015. Developing countries, especially in Asia and Latin America, have also adopted earlier versions of United States or European vehicle emissions and fuel standards, and, in some cases, are progressively instituting the later, more stringent stages of those rules (Figure 5.13).

Fig 5.10 On-road diesel reductions in the Tuscarora Tunnel, Pennsylvania, USA, 1975–2000.



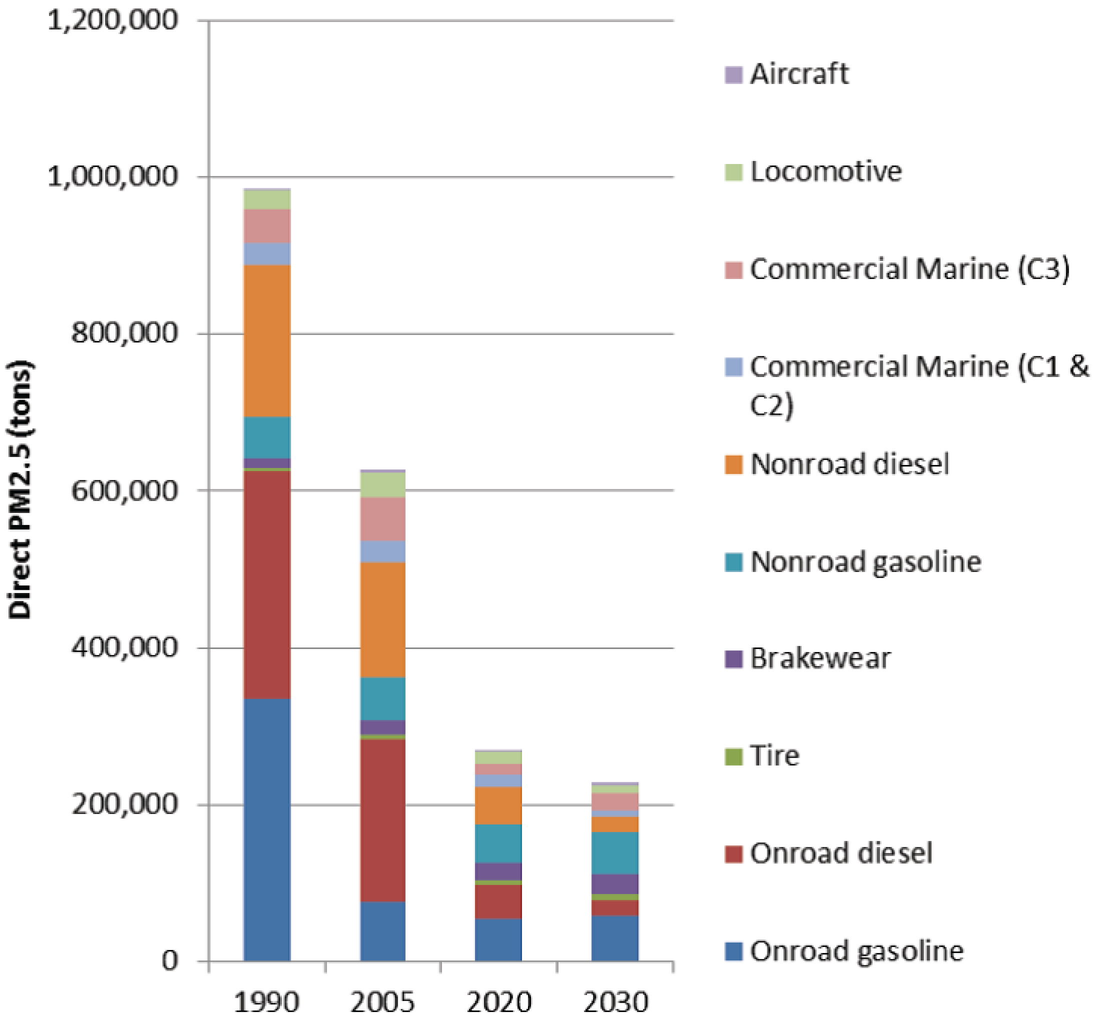
Source: HEI (2002); reproduced with permission from the Health Effects Institute.

This progress in standards for new vehicles, however, is only possible in countries where the quality of fuel has been improved enough to implement the cleanest technologies (e.g. ultra-low-sulfur diesel). In most developing countries, that progress has slowed significantly as refineries, often government-owned, struggle with the costs of substantially reducing sulfur. This will inevitably slow the introduction of the newest, cleanest technologies (now available in the USA and soon to be available in Europe) and will result in continued and growing use of older diesel and gasoline technologies and the accompanying significant exposures.

In addition to standards for fuels and vehicle emissions using existing technologies, increasing attention has focused on use of alternative fuels, such as ethanol and other plant sources (e.g. biodiesel), natural gas, alternative diesel fuels converting gas to liquid (e.g. the Fischer–Tropsch process), and hydrogen. Also, advanced and new vehicle technologies, which include natural gas vehicles, electric and electric hybrid vehicles, and fuel cell vehicles, are in development or beginning to appear on the market.

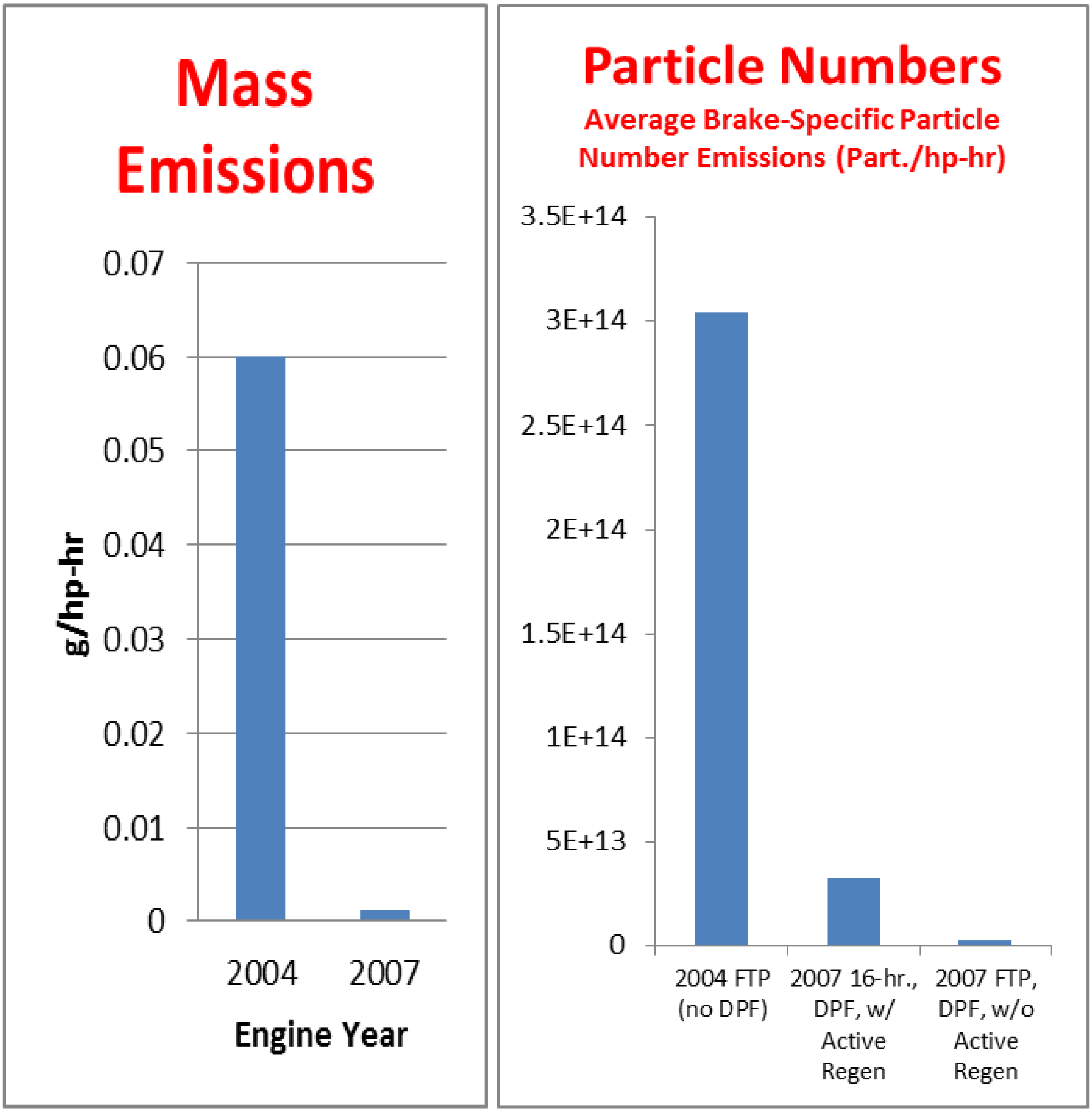
While these fuels and technologies may have certain air quality advantages, they have not all been subjected to rigorous assessment of their emissions benefits. For example, claims of emissions benefits for biodiesel have thus far exceeded the supporting data, and new health-related questions are emerging (e.g. the use of methanol to produce the hydrogen to power fuel cells). In emissions characterization tests of advanced diesel and natural gas bus technologies, conducted by the California Air Resources Board, the newest diesel technologies have appeared to have emissions characteristics that are comparable to, and in some cases better than, those of natural gas buses (Holmén and

Fig 5.11 Projected reductions in diesel emissions of $PM_{2.5}$ from the United States Environmental Protection Agency's on-road and nonroad diesel rules.



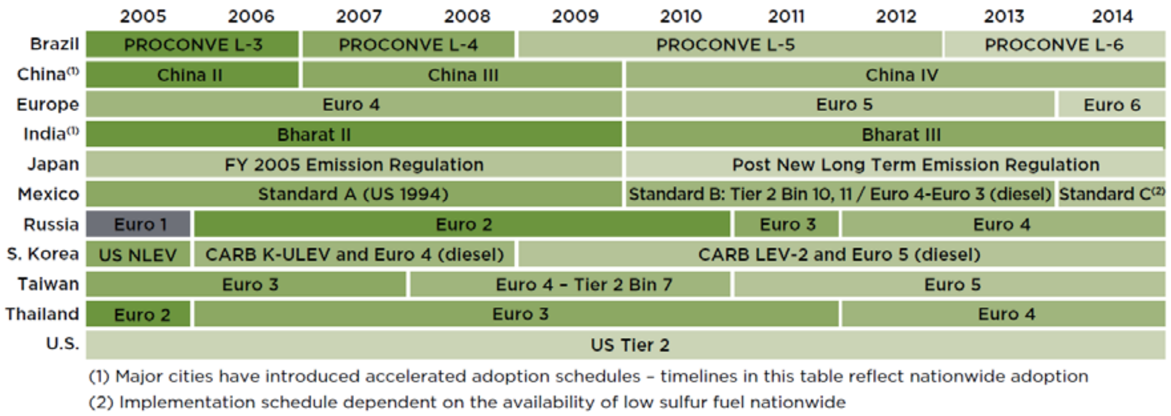
C1, commercial marine engines < 5 liters/cylinder; C2, commercial marine engines 5–30 liters/cylinder; C3, commercial marine engines > 30 liters/cylinder. Reproduced from EPA (2012).

Fig 5.12 Substantial reductions in the mass and number of particles emitted from 2007-compliant heavy-duty diesel engines.



Compiled from Khalek *et al.* (2011).

Fig 5.13 Current and planned requirements for light-duty vehicle emission standards in Asia and worldwide.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Brazil	PROCONVE L-3		PROCONVE L-4		PROCONVE L-5				PROCONVE L-6	
China(1)	China II		China III			China IV				
Europe	Euro 4					Euro 5				Euro 6
India(1)	Bharat II					Bharat III				
Japan	FY 2005 Emission Regulation					Post New Long Term Emission Regulation				
Mexico	Standard A (US 1994)					Standard B: Tier 2 Bin 10, 11 / Euro 4-Euro 3 (diesel)				Standard C(2)
Russia	Euro 1	Euro 2					Euro 3	Euro 4		
S. Korea	US NLEV	CARB K-ULEV and Euro 4 (diesel)			CARB LEV-2 and Euro 5 (diesel)					
Taiwan	Euro 3			Euro 4 - Tier 2 Bin 7			Euro 5			
Thailand	Euro 2	Euro 3						Euro 4		
U.S.	US Tier 2									

(1) Major cities have introduced accelerated adoption schedules - timelines in this table reflect nationwide adoption

(2) Implementation schedule dependent on the availability of low sulfur fuel nationwide

Reproduced from Sanchez *et al.* (2012).

Ayala, 2002). These new fuels and technologies are also subject to the challenges of introducing a substantially different commodity. With a few exceptions – hybrids, natural gas (in urban areas), and ethanol – these new fuels and technologies are not currently in widespread use and are likely to take a long time to develop.

Even as emissions from conventional technologies have declined and more efficient technologies are being developed, continued growth in travel is expected to offset a portion of these reductions (Greenbaum, 1997). As a result, reducing emissions will remain a priority and will likely come about in three ways:

1. Financing, economic incentives, and some regulatory efforts to accelerate replacement and/or retrofitting of existing fleets of vehicles, especially older diesel vehicles;
2. Continued tightening of fuel and emissions standards for petrol and diesel vehicles, especially in developing countries; and
3. Policies to discourage growth in personal automobile use – potentially the most important and challenging future direction. Recent efforts in this area have included the London Congestion Charging Scheme, alternate day driving plans in European and Latin American cities, development of rapid transit systems (e.g. in Bangkok and Delhi), and efforts at growth planning and management to minimize vehicle travel (e.g. Portland, Oregon, USA, and several European cities).

In conclusion, the emissions of a variety of pollutants from vehicles account for approximately 20–40% of the ambient levels of air pollution (depending on the pollutant), with higher contributions in some microenvironments. These pollutants have been demonstrated to have a measurable negative effect on public health. As a result, the long-term trend towards reducing emissions from motor vehicles is likely to continue, albeit at a slower pace in developing countries where fuel quality is a barrier to implementing the cleanest technologies now available elsewhere. In addition, continued growth in vehicle travel is likely to offset a portion of the expected reductions, suggesting the need for continued research on viable alternatives and strategies to reduce the emissions and their impact on public health.

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