TABLE 1-23
RESIDENTIAL AND COMMERCIAL EMISSION CONTROLS PERFORMANCE

Technology	Efficiency Loss[(a)] (%)	CO Reduction (%)	CH_4 Reduction (%)	NO_x Reduction (%)	N_2O Reduction (%)	NMVOCs Reduction (%)	Date Available[(b)]
Catalytic Woodstove	-44	90	90	-27	NAV	NAV	1985
Non-Catalytic Modified Combustion Stove	-30	15	50	-5	NAV	NAV	1985
Flame Retention Burner Head	-9	28	NAV	NAV	NAV	NAV	
Controlled Mixed Burner Head	-7	43	NAV	44	NAV	NAV	
Integrated Furnace System	-12	13	NAV	69	NAV	NAV	
Blueray Burner/Furnace	-12	74	NAV	84	NAV	NAV	
M.A.N. Burner	-13	NAV	NAV	71	NAV	NAV	1980
Radiant Screens	-7	62	NAV	55	NAV	NAV	
Secondary Air Baffle	NAV	16	NAV	40	NAV	NAV	
Surface Comb. Burner	NAV	55	NAV	79	NAV	NAV	
Amana HTM	-21	-55	NAV	79	NAV	NAV	
Modulating Furnace	-7	NAV	NAV	32	NAV	NAV	
Pulse Combuster	-36	NAV	NAV	47	NAV	NAV	
Catalytic Combuster	-29	NAV	NAV	86	NAV	NAV	
Replace Worn Units	NAV	65	NAV	NAV	NAV	NAV	
Tuning, Seasonal Maintenance	-2	16	NAV	NAV	NAV	NAV	
Reduced Excessive Firing	-19	14	NAV	NAV	NAV	NAV	
Reduced Excessive Firing with New Retention Burner	-40	14	NAV	NAV	NAV	NAV	
Positive Chimney Dampers	-8	11	NAV	NAV	NAV	NAV	
Increased Thermostat Anticipator	-1	43	NAV	NAV	NAV	NAV	
Night Thermostat Cutback	-15	17	NAV	NAV	NAV	NAV	
Low Excess Air	-0.8	NAV	NAV	15	NAV	NAV	1970
Flue Gas Recirculation	0.6	NAV	NAV	50	NAV	NAV	1975
Over-fire Air	1	NAV	NAV	20-30	NAV	NAV	1970
Low NO_x Burners	0.6	NAV	NAV	40-50	NAV	NAV	1980

(a) Efficiency loss as a percentage of end-user energy conversion efficiency (ratio of energy output to energy input for each technology) due to the addition of an emission control technology. Negative loss indicates an efficiency improvement.

(b) Date technology is assumed to be commercially available.

Source: Radian, 1990.

TABLE 1-24 NET CALORIFIC VALUES FOR PRECEDING TABLES[(a)] (THESE VALUES SHOULD NOT BE USED TO CALCULATE INVENTORIES, SEE NOTE BELOW)	
Fuel	**Net Calorific Value (TJ/kilotonne)**
GAS	
Butane	44.4
Propane	47.1
Natural Gas	52.3
LIQUID	
Crude Oil	40.9
Crude Shale Oil	42
Diesel/Distillate	42.9
Gasoline	46.5
Residual Oil	42
SOLID	
Bagasse/Agriculture	8.8
Bituminous Coal	28.7
Anthracite	27.2
Lignite	15.9
MSW	10.7
Wood	11.5

NOTE: These values are given for information only and refer to the preceding tables. They should not be used by countries to convert energy data to TJ for the inventories. The default net calorific values used in the *Guidelines* have not been changed and can be found in the *Reference Manual* Tables I-2 and 1-3.

Source: US EPA (1995).

(a) Values in preceding tables were originally based on gross calorific value; they were converted to net calorific value by assuming that net calorific values were 5 per cent lower than gross calorific values for coal and oil, and 10 per cent lower for natural gas. These percentage adjustments are the OECD/IEA assumption on how to convert from gross to net calorific values.

1.5.3 Mobile Combustion

1.5.3.1 OVERVIEW

Emissions of greenhouse gases from mobile sources, including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), methane (CH_4), nitrous oxide (N_2O) and non-methane volatile organic compounds (NMVOCs) are most easily estimated by major transport activity, i.e., road, air, rail, and ships. However, as road transport and aviation account for the majority of mobile-source fuel consumption (e.g., 82 per cent in 1988 for the OECD), followed by air transport (about 13 per cent), greater priority has been attached to the development of emission models and inventories for road vehicles and aircraft.

The diversity of the types of mobile source and the range of characteristics which affect emission factors are amply demonstrated by the tables included in this section for both road and air transport. Recent work has both updated and strengthened the data given and a fuller methodology for estimating aircraft emissions has been introduced based upon the EMEP/CORINAIR work in this field. Despite these advances more work is needed to fill in many gaps in knowledge of emissions from certain vehicle types and on the effects of ageing on catalytic control of road vehicle emissions. Equally, there is very little information on the appropriate emission factors for road transport in developing countries where age of fleet, maintenance and patterns of use are different from those in industrialised countries.

It should be recalled that transport is a significant source of CO_2 emissions and emission factors for CO_2 emissions are provided in the following tables to permit the estimation of CO_2 at this detailed level.

1.5.3.2 RECOMMENDED METHODOLOGY

Estimation of mobile source emissions is a very complex undertaking that requires consideration of many parameters, including:

- transport class
- fuel consumed
- operating characteristics
- emission controls
- maintenance procedures
- fleet age

The need for data on several parameters and the wide variety of conditions that can affect the performance of each category of mobile source makes it very difficult to generalise their emission characteristics. Also, within the transport sector, the primary measure of activity is less likely than in other sectors to be fuel consumption.

The underlying general emissions model may be expressed as:

$$\text{Emissions} = \sum (EF_{abc} \times Activity_{abc})$$

where:

where:	EF	=	emission factor
	Activity	=	amount of energy consumed or distance travelled for a given mobile source activity
	a	=	fuel type (diesel, gasoline, LPG, bunker, etc.)
	b	=	vehicle type (e.g., passenger, light-duty or heavy-duty for road vehicles)
	c	=	emission control

which implies the following steps:

- Determine the amount of energy consumed by fuel type for the major transport modes using national data or, as an alternative, IEA or UN international data sources (all values should be reported in terajoules).
- For each fuel type, determine the amount of energy that is consumed by each vehicle type, e.g., light-duty gasoline vehicles, etc. (all units are in terajoules). If distance travelled is the activity measure, determine the total distance travelled by each vehicle type. In this case, the energy consumption associated with these distance travelled figures should be calculated and aggregated by fuel for comparison

with national energy balance figures. If necessary, further subdivide each vehicle type into uncontrolled and key classes of emission control technology.

- Multiply the amount of energy consumed, or the distance travelled by each category of vehicle or vehicle/control technology, by the appropriate emission factor for that category. Data presented in the next section (Emission Factors) can be used as a starting point. However, national experts are encouraged to consult other data sources referenced in this chapter or locally available data before determining appropriate factors for a particular country.
- Emissions of each pollutant can be summed across all categories of fuel and technology type, including for all levels of emission control, to determine total emissions from mobile source-related activities.

Emission Factors

The tables given for road transport summarise results of a detailed analysis of mobile-source emission factors covering North American and European vehicles and conditions.

Recently published work has permitted the updating of figures appearing in the 1995 edition of the *Guidelines.* The US emission factors for mobile sources, published in the 1995 edition, were developed using the MOBILE4 model. This was one of a series of emissions models developed and periodically updated by the US Environmental Protection Agency for use in its analysis of motor vehicle regulatory and policy issues. The MOBILE4 model is now out of date. Since the analysis done in 1991, several improvements have been based on new information and vehicle testing results. Emission factors developed using the latest version of the MOBILE model (MOBILE5a) are higher for most pollutants. The US tables included here contain this latest information.

CO_2 factors are derived from the carbon content of the fuels and therefore include the carbon present in other carbon molecule based emissions.

The European data are drawn from the CORINAIR COPERT model. However, for actual calculations of national emissions, users are encouraged to also consult a range of recent and more detailed information sources (see Data Sources in Section 1.5.1). Particularly for indirect GHGs, more comprehensive sources are available based on programmes outside the GHG emissions area.

Emission factor estimates are presented for CO_2, CO, NO_x, N_2O, CH_4 and NMVOCs for several classes of non-road vehicles - railway locomotives, ships and boats, farm and construction equipment.

This section on mobile sources also contains a more comprehensive explanation of a methodology for the estimation of emissions from aircraft and greater specificity of aircraft/engine emission factors for NO_x.

All emission factor data are stated on the basis of full molecular weight of the respective pollutant; NO_x factors are stated as NO_2.

Emission Factors for Mobile Sources in Developing Countries

In highly populated developing countries the estimated emissions per kilometre travelled should be altered. First, there are virtually no catalytic converters on the vehicles. Second, the number of accelerations and decelerations that the vehicle will undergo is much larger than for corresponding travel in countries that are less populated and have well arranged highway systems. The measured pollutant value of NO_x in an engine at constant rpm conditions is about 1.0 g/MJ for the United States and for Europe. However, for highly populated developing countries 1.8 g/MJ should be used.

Further information on emission factors for developing countries is available from Riveros et. al (1995), Bose (1996) and other sources listed in the bibliography.

1.5.3.3 ROAD VEHICLES

United States Emission Estimates

Technical Approach

The US emissions estimates for NO_x, CO, CH_4 and NMVOC from highway vehicles were developed directly from the US EPA's MOBILE5a model. The model calculates exhaust emission factors for gasoline and diesel fuelled US vehicles, based on the year in which they were manufactured. For gasoline vehicles, it also calculates VOC emissions due to evaporative, running and refuelling losses (VOC emissions from diesel vehicles due to these causes are negligible).

Assumptions

To develop emission estimates for different control technology types, calculations were carried out for specific model years during which US vehicles were equipped with the technology in question. Table 1-25 shows the correspondence between the technology types and the US model years used to represent them in the model. Average lifetime emissions were calculated for each vehicle type based on their assumed lifetimes. The model uses a two-step linear function to estimate deterioration rates from vehicle mileage. Linear equations are fitted to vehicle emission estimates at 0 and 50 000 miles and 50 000 and 100 000 miles and from the results lifetime average factors were calculated.

The emission factors calculated by MOBILE5a are affected by assumptions regarding average speeds, ambient temperature, diurnal temperature range, altitude and fuel volatility that are provided to the model. They are also affected by the assumed presence or absence of inspection/maintenance (I/M) programmes and anti-tampering programmes as well as the type of I/M programme used. The model calculates emission factors using three seasonal conditions: Spring/Fall, Winter and Summer. The model was also run with three different I/M scenarios; no I/M programme, basic I/M and enhanced I/M. Where I/M influences emissions, the emission factors given in the tables included here are shown as range estimates with the lower value representing the enhanced I/M and the upper value reflecting no I/M. Since there is no I/M programme for diesel vehicles in the United States the diesel vehicle emission factors generated by the model for different I/M programmes were the same. The average speed assumed by the model is 31.4 km/h - typical of uncongested urban driving (see Table 1-26).

TABLE 1-25
EMISSION CONTROL TECHNOLOGY TYPES AND US VEHICLE MODEL YEARS USED TO REPRESENT THEM

Technology	Model Year
Gasoline Passenger Cars and Light Trucks	
Uncontrolled	1964
Non-catalyst controls	1973
Oxidation catalyst	1978
Early three-way catalyst	1983
Three-way catalyst	1996
Heavy-Duty Gasoline Vehicles	
Uncontrolled	1968
Non-catalyst control	1983
Three-way catalyst	1996
Diesel Passenger Cars and Light Trucks	
Uncontrolled	1978
Moderate control	1983
Advanced control	1996
Heavy-Duty Diesel Vehicles	
Uncontrolled	1968
Moderate control	1983
Advanced control	1996
Motorcycles	
Uncontrolled	1973
Non-catalyst controls	1996

TABLE 1-26
ASSUMED AMBIENT TEMPERATURE, DIURNAL RANGE AND REID VAPOUR PRESSURE FOR DIFFERENT SEASONS

	Ambient Temperature (°C)	Diurnal Range (°C)	Reid Vapour Pressure (kPa)
Spring/Fall	16	7 to 24	62
Winter	2	-7 to 10	103
Summer	29	21 to 38	54

The estimated vehicle fuel economies were also used to calculate fuel specific and energy specific emission factors for all of the pollutants. Energy specific emission factors were based on the net calorific value of the fuel in each case. Since emission and fuel consumption tend to vary in parallel (vehicles and operating modes causing high emission rates also tend to result in high fuel consumption, and vice-versa) these energy specific emission factors are expected to be more generally applicable than the factors in grams per kilometre and their use is to be preferred.

BOX 4
LIMITATIONS OF MOBILE5A RESULTS

Emission factors for many greenhouse gases from road vehicles have been developed using the MOBILE5a Model[a] as presented in Tables 1-27 to 1-33. This model is one of a series of emissions models developed and periodically updated by the US Environmental Protection Agency for use in its analysis of motor vehicle regulatory and policy issues. The model has been used to derive average emission factors for NO_x, CO, and NMVOC by class of vehicle and for gasoline and diesel fuel. Calculations for other gases and for alternative fuels were done separately.

All "global" average emission factors like these should be considered illustrative and should not be directly used in national emissions calculations. Such values are by necessity based on "global" average assumptions in several key areas. Average emission factors by class of vehicle are sensitive to very specific assumptions including those about

- vehicle models, average age and accumulated mileage
- per cent driving in cold start, hot start and stabilised conditions
- average driving speed
- ambient temperature
- fuel comparison
- rates of tampering with control systems
- proper maintenance

Obviously, many of these assumed conditions will vary significantly from country to country and even by region within countries. For example, the light-duty gasoline vehicle class does not include two-stroke engines, which are not used in the United States, but are important in Central and Eastern Europe. Therefore, "global" illustrative factors should not be used to calculate actual emissions in a specific country.

For the above reasons, **illustrative emission factors** should not be directly used for national calculations. National inventory experts should consult the more detailed references on mobile source emission factors and use these sources to develop or adapt emission factors which are appropriate for their specific conditions. The expert group on GHG emissions from fuel combustion has identified the need for more detailed guidance and assistance to national experts on the development of locally applicable emission factors as a priority for future work.

(a) The MOBILE5a Model and its User Guide can be obtained from Terry Newell, US EPA Office of Mobile Sources, 2565 Plymouth Road, Ann Arbor MI 48105, USA; tel: (313) 668-4462, Email: Newell.Terry@epamail.epa.gov or access the latest information on mobile sources on the world wide web at http://www.epa.gov/OMSWWW/omshome.htm.

N_2O emission from internal combustion engines is not well understood and data on emissions are scarce. The 1995 edition of the *Guidelines* contained supplementary information used by the Canadian Government, based on a review of data available in 1994 (Ballantyne et al., 1994). The Canadian estimates show that N_2O emissions from vehicles with three-way catalysts increased markedly during the first 15 to 20 000 km, so that earlier estimates based on tests of low mileage vehicles are too low. These results are summarised in Box 5. The US tables, included in this section, use the Canadian data to estimate N_2O emissions from gasoline passenger cars. For light-duty gasoline trucks and motorcycles, fuel specific N_2O emissions were assumed to be the same as for the corresponding passenger car technology. N_2O emissions per kilometre were then calculated from the fuel specific emissions and the fuel consumption characteristics for each class.

In the absence of direct data, N_2O emissions from heavy-duty gasoline trucks were estimated by assuming that their fuel specific emissions were similar to those for passenger cars with similar technology. N_2O emission factors for heavy-duty diesel trucks were derived from emissions for these vehicles reported by Dietzmann, Parness and Bradow (1980). The corresponding fuel specific emission rates were used to estimate N_2O emissions from light-duty diesel vehicles in the absence of information on this class.

BOX 5
RECENT INFORMATION ON N_2O MEASUREMENTS

Since the initial illustrative emission factors were estimated in 1991, a number of measurement studies have been carried out to improve understanding of vehicle N_2O emissions. A paper by Ballantyne, et al., (1994) summarised measurements in Canada, the United States and Europe.

	Canadian Measurements (Ballantyne, et al., 1994)		US Measurements (Dasch, 1992)		European Measurements (De Soete, 1989)		Values Used in Canadian National Inventory	
	mg/miles	g/km	mg/miles	g/km	mg/miles	g/km	mg/miles	g/km
New three-way catalysts	21-126	0.013-0.078	13-101	0.008-0.06	60-170	0.037-0.106	60	0.04
Aged three-way	72-211	0.045-0.131	-	-	260-356	0.162-0.221	280	0.17
Oxidation catalyst	-	-	3-66	0.002-0.04	120	0.075	120	0.075
No catalyst	-	-	2.4-4.8	0.001-0.003	8-32	0.005-0.02	32	0.02

Results of this analysis are presented by categories defined by the US EPA as listed below:

Table 1-27: Light-duty gasoline passenger cars - vehicles with rated gross weight less than 8 500 lb (3 855 kg) designed primarily to carry *12 or fewer passengers*. Six levels of gasoline-vehicle control technology are shown:

1 Uncontrolled (still typical of most vehicles around the world).

2 Non-catalyst emission controls - including modifications to ignition timing and air-fuel ratio to reduce emissions, exhaust gas recirculation (EGR), and air injection into the exhaust manifold.

3 Oxidation catalyst systems normally including many of the same techniques, plus a two-way catalytic converter to oxidise hydrocarbons and CO.

4 "Early" three-way catalyst results representative of vehicles sold in the United States in the early to mid-1980s, which were mostly equipped with carburettors having electronic "trim".

5 "Advanced" three-way catalyst values based on current US technology vehicles, using electronic fuel injection under computer control.

6 Low Emission Vehicles (LEV) are expected to include sequential multi-port fuel injection with adaptive learning, more sophisticated computer diagnostics and heated catalysts with secondary air injection.

Table 1-28: Light-duty gasoline trucks - vehicles having rated gross vehicle weight less than 8 500 lb (3 855 kg), and which are designed primarily for transportation of cargo or more than 11 passengers at a time, or which are equipped with special features for off-road operation. They include most pickup trucks, passenger and cargo vans, four-wheel drive vehicles, and derivatives of these. The technology classifications used are the same as those for gasoline passenger vehicles.

Table 1-29: Heavy-duty gasoline vehicles - manufacturer's gross vehicle weight rating exceeding 8 500 lb (3 855 kg). This includes large pickups, vans and specialised trucks using pickup and van chassis, as well as the larger "true" heavy-duty trucks, which have gross vehicle weights of eight short tons or more. In the United States, the large pickups and vans in this category greatly outnumber the heavier trucks, so that the emission factors calculated by MOBILE5a, and fuel economy estimates, are more representative of these vehicles. Three levels of emission control technology are shown:

1 Uncontrolled.

2 Non-catalyst emission controls, including control of ignition timing and air-fuel ratio to minimise emissions, EGR, and air injection into the exhaust manifold to reduce hydrocarbons and CO emissions.

3 Three-way catalyst technology presently used in the United States includes electronically-controlled fuel injection, EGR, air injection, and electronic control of ignition timing, as well as the catalyst itself.

Table 1-30: Light-duty diesel passenger cars - a diesel passenger car designed primarily to carry fewer than 12 passengers, with gross vehicle weight less than 8 500 lb (3 855 kg). Three levels of emission control technology are shown:

1 Uncontrolled.

2 Moderate emissions control (achieved by changes in injection timing and combustion system design).

3 Advanced emissions control utilising modern electronic control of the fuel injection system, and exhaust gas recirculation.

Table 1-31: Light-duty diesel trucks - light-duty diesel trucks defined like their gasoline counterparts, including weight, utility, and off-road operation features. The technology classifications are the same as those for diesel passenger cars.

Table 1-32: Heavy-duty diesel vehicles - the classification for heavy-duty diesel vehicles is the same as for gasoline vehicles, but the characteristics of US vehicle fleets are different. Heavy-duty diesel vehicles are primarily large trucks, with gross vehicle weight ratings of 10 to 40 tons. Therefore, the MOBILE5a emission factors are more representative of large trucks (and buses) than the smaller pickup and van-type vehicles, and this is reflected in the fuel economy estimates. Three levels of control are presented:

1 Uncontrolled.

2 Moderate control (typical of 1983 US engines).

3 Advanced control (for engines meeting US 1991 emissions standards).

Table 1-33: Motorcycles - The MOBILE5a emission factors for these vehicles are based on the US motorcycle population, which probably reflects higher average power ratings and fuel consumption than for many developing countries. The factors for uncontrolled motorcycles include a mixture of two-stroke and four-stroke engines, with the VOC emissions due primarily to the two-strokes, and the NO_x to the four-stroke engines. The factors for motorcycles with non-catalyst emission controls reflect four-stroke engines only, as US emission control regulations have essentially eliminated two-stroke engines from the market.

Table 1-27 Estimated Emission Factors For US Gasoline Passenger Cars						
	EMISSIONS					
Season	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Low-Emission Vehicle Technology;(a) Assumed Fuel Economy: 8.5 km/litre (11.8 l/100 km)						
Spring/Fall	0.26-0.34	0.02-0.03	0.30-0.46	3.15-5.30	-	-
Summer	0.25-0.32	0.02-0.03	0.32-0.47	2.69-4.67	-	-
Winter	0.31-0.39	0.03-0.04	0.29-0.51	4.78-7.60	-	-
Average (g/km)	0.27-0.34	0.02-0.03	0.30-0.47	3.44-5.72	0.040	280
Average (g/kg fuel)	3.07-3.91	0.25-0.38	3.42-5.35	38.96-64.77	0.453	3172.31
Average (g/MJ)	0.070-0.089	0.006-0.009	0.078-0.122	0.885-1.472	0.010	72.098
Three-Way Catalyst Control;(a) Assumed Fuel Economy: 8.3 km/litre (12.0 l/100 km)						
Spring/Fall	0.41-0.48	0.02-0.03	0.49-0.66	3.62-5.78	-	-
Summer	0.39-0.46	0.02-0.03	0.80-0.95	2.90-4.89	-	-
Winter	0.47-0.56	0.03-0.04	0.37-0.60	6.35-9.14	-	-
Average (g/km)	0.42-0.50	0.03	0.54-0.72	4.12-6.40	0.170	285
Average (g/kg fuel)	4.67-5.53	0.28-0.39	6.00-7.99	45.92-71.22	1.892	3172.31
Average (g/MJ)	0.106-0.126	0.006-0.009	0.136-0.182	1.044-1.619	0.043	72.098
Early Three-Way Catalyst;(a) Assumed Fuel Economy: 8.0 km/litre (12.5 l/100 km)						
Spring/Fall	0.41-0.51	0.03-0.04	0.63-0.81	4.77-7.08	-	-
Summer	0.39-0.49	0.03-0.04	1.44-1.62	4.46-6.87	-	-
Winter	0.50-0.63	0.04-0.06	0.45-0.70	7.75-10.42	-	-
Average (g/km)	0.43-0.54	0.03-0.05	0.79-0.99	5.44-7.86	0.170	298
Average (g/kg fuel)	4.55-5.71	0.37-0.48	8.41-10.52	57.93-83.73	1.810	3172.31
Average (g/MJ)	0.103-0.130	0.008-0.011	0.191-0.239	1.317-1.903	0.041	72.098
Oxidation Catalyst; Assumed Fuel Economy: 6.2 km/litre (16.1 l/100 km)						
Spring/Fall	1.10-1.17	0.05-0.07	1.26-1.76	8.79-14.96	-	-
Summer	0.84-0.90	0.06-0.08	2.58-3.25	12.16-20.79	-	-
Winter	1.29-1.38	0.07-0.09	1.07-1.66	12.28-19.72	-	-
Average (g/km)	1.08-1.16	0.06-0.08	1.54-2.11	10.51-17.61	0.075	383
Average (g/kg fuel)	8.97-9.58	0.50-0.63	12.77-17.48	87.08-145.95	0.622	3172.31
Average (g/MJ)	0.204-0.218	0.011-0.014	0.290-0.397	1.979-3.317	0.014	72.098
Non-Catalyst Control; Assumed Fuel Economy: 4.5 km/litre (22.2 l/100 km)						
Spring/Fall	1.33-1.37	0.10-0.12	1.97-2.36	14.76-21.63	-	-
Summer	1.06-1.09	0.11-0.13	4.06-4.61	20.59-30.70	-	-
Winter	1.35-1.40	0.13-0.15	1.62-2.05	17.53-26.09	-	-
Average (g/km)	1.27-1.31	0.11-0.13	2.41-2.84	16.91-25.01	0.020	531
Average (g/kg fuel)	7.56-7.82	0.65-0.75	14.38-17.00	101.06-149.45	0.125	3172.31
Average (g/MJ)	0.172-0.178	0.015-0.017	0.327-0.386	2.297-3.397	0.003	72.098
Uncontrolled; Assumed Fuel Economy: 4.7 km/litre (21.3 l/100 km)						
Spring/Fall	1.54	0.12-0.14	5.72-6.06	28.23-38.04	-	-
Summer	1.31	0.11-0.12	9.76-10.07	28.22-38.04	-	-
Winter	1.83	0.16-0.17	4.24-4.66	30.89-41.63	-	-
Average (g/km)	1.56	0.13-0.14	6.36-6.71	28.89-38.94	0.020	506
Average (g/kg fuel)	9.76	0.82-0.90	39.88-42.09	181.14-244.14	0.130	3172.31
Average (g/MJ)	0.222	0.019-0.020	0.906-0.957	4.117-5.549	0.003	72.098

(a) Recent measurement results (De Soete, 1993, Ballantyne, et al., 1994) have shown that N_2O emissions from aged catalysts, e.g., tested after driving 15 000 - 25 000 km, are substantially higher than from new catalyst-equipped cars. Tests on comparable models show aged catalysts emitting from roughly 30% more to almost 5 times the rate of new equipment. As indicated in Box 5, Environment Canada has used a value almost 5 times as high for aged catalysts in its national inventory calculations.

TABLE 1-28
ESTIMATED EMISSION FACTORS FOR US LIGHT-DUTY GASOLINE TRUCKS.

Season	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Low-Emission Vehicle Technology;[(a)] Assumed Fuel Economy: 6.0 km/litre (16.7 l/100 km)						
Spring/Fall	0.31-0.40	0.02-0.04	0.30-0.50	3.57-6.03	-	-
Summer	0.29-0.38	0.02-0.03	0.31-0.50	2.87-5.11	-	-
Winter	0.37-0.47	0.03-0.05	0.34-0.62	6.02-9.33	-	-
Average (g/km)	0.32-0.41	0.02-0.04	0.31-0.53	4.01-6.62	0.058	396
Average (g/kg fuel)	2.50-3.23	0.18-0.29	2.43-4.13	31.30-51.71	0.450	3172.31
Average (g/MJ)	0.057-0.073	0.004-0.007	0.055-0.094	0.711-1.175	0.010	72.098
Three-Way Catalyst Control;[(a)] Assumed Fuel Economy: 6.0 km/litre (16.7 l/100 km)						
Spring/Fall	0.49-0.59	0.02-0.04	0.47-0.69	4.45-7.08	-	-
Summer	0.47-0.56	0.02-0.03	0.66-0.87	3.64-6.05	-	-
Winter	0.57-0.69	0.04-0.05	0.47-0.77	7.68-11.22	-	-
Average (g/km)	0.50-0.61	0.03-0.04	0.52-0.76	5.06-7.86	0.236	396
Average (g/kg fuel)	4.04-4.86	0.21-0.30	4.14-6.06	40.46-62.87	1.890	3172.31
Average (g/MJ)	0.092-0.111	0.005-0.007	0.094-0.138	0.920-1.429	0.043	72.098
Early Three-Way Catalyst;[(a)] Assumed Fuel Economy: 4.8 km/litre (20.8 l/100 km)						
Spring/Fall	0.63-0.76	0.05-0.07	0.74-1.04	6.49-9.97	-	-
Summer	0.60-0.73	0.05-0.07	1.34-1.65	5.97-9.52	-	-
Winter	0.76-0.93	0.08-0.10	0.76-1.19	9.58-13.54	-	-
Average (g/km)	0.65-0.80	0.06-0.08	0.90-1.23	7.13-10.75	0.227	396
Average (g/kg fuel)	5.23-6.36	0.47-0.63	7.16-9.82	56.96-85.86	1.810	3172.31
Average (g/MJ)	0.119-0.144	0.011-0.014	0.163-0.223	1.294-1.951	0.041	72.098
Oxidation Catalyst; Assumed Fuel Economy: 4.8 km/litre (20.8 l/100 km)						
Spring/Fall	1.15-1.28	0.07-0.09	1.48-2.31	9.56-18.76	-	-
Summer	0.77-0.86	0.09-0.11	2.70-3.85	13.72-27.86	-	-
Winter	1.34-1.50	0.10-0.12	1.30-2.30	13.47-26.33	-	-
Average (g/km)	1.10-1.23	0.08-0.10	1.74-2.69	11.58-22.93	0.097	498
Average (g/kg fuel)	7.03-7.84	0.52-0.66	11.08-17.16	73.77-146.07	0.620	3172.31
Average (g/MJ)	0.160-0.178	0.012-0.015	0.252-0.390	1.677-3.320	0.014	72.098
Non-Catalyst; Assumed Fuel Economy: 4.0 km/litre (25.0 l/100 km)						
Spring/Fall	1.62-1.68	0.12-0.14	3.09-3.55	18.41-27.08	-	-
Summer	1.28-1.32	0.13-0.15	5.80-6.39	23.76-35.80	-	-
Winter	1.67-1.72	0.15-0.17	2.29-2.83	23.08-34.24	-	-
Average (g/km)	1.55-1.60	0.13-0.15	3.57-4.08	20.92-31.05	0.023	601
Average (g/kg fuel)	8.17-8.45	0.69-0.80	18.85-21.55	110.41-163.90	0.120	3172.31
Average (g/MJ)	0.186-0.192	0.016-0.018	0.428-0.490	2.509-3.725	0.003	72.098
Uncontrolled; Assumed Fuel Economy: 4.1 km/litre (24.4 l/100 km)						
Spring/Fall	1.84	0.12-0.14	6.87-7.24	29.92-40.29	-	-
Summer	1.56	0.11-0.12	11.07-11.41	29.91-40.29	-	-
Winter	2.18	0.16-0.17	5.31-5.77	33.17-44.09	-	-
Average (g/km)	1.85	0.13-0.14	7.53-7.92	30.73-41.24	0.024	579
Average (g/kg fuel)	10.16	0.71-0.79	41.26-43.37	168.36-225.95	0.130	3172.31
Average (g/MJ)	0.231	0.016-0.018	0.938-0.986	3.826-5.135	0.003	72.098

(a) Recent measurement results (De Soete, 1993, Ballantyne, et al., 1994) have shown that N_2O emissions from aged catalysts, e.g., tested after driving 15 000 - 25 000 km, are substantially higher than from new catalyst-equipped cars. Tests on comparable models show aged catalysts emitting from roughly 30% more to almost 5 times the rate of new equipment. As indicated in Box 5, Environment Canada has used a value almost 5 times as high for aged catalysts in its national inventory calculations.

TABLE 1-29
ESTIMATED EMISSION FACTORS FOR US HEAVY-DUTY GASOLINE VEHICLES

Season	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Three-Way Catalyst Control;[a] Assumed Fuel Economy: 2.3 km/litre (43.5 l/100 km)						
Spring/Fall	1.69-1.74	0.07-0.08	0.88-1.03	6.06-7.49	-	-
Summer	1.76-1.81	0.07	1.64-1.80	6.22-7.67	-	-
Winter	1.81-1.86	0.07-0.08	0.65-0.79	6.75-8.35	-	-
Average (g/km)	1.74-1.78	0.07-0.08	1.01-1.16	6.27-7.75	0.606	1017
Average (g/kg fuel)	5.42-5.56	0.21-0.24	3.17-3.62	19.57-24.19	1.890	3172.31
Average (g/MJ)	0.123-0.126	0.005	0.072-0.082	0.445-0.550	0.043	72.098
Non-Catalyst Control; Assumed Fuel Economy: 2.3 km/litre (43.5 l/100 km)						
Spring/Fall	2.37-2.39	0.12-0.13	3.97-4.20	27.04-32.15	-	-
Summer	1.85-1.88	0.12-0.13	9.92-10.20	40.28-47.89	-	-
Winter	2.54-2.56	0.12-0.13	1.71-1.97	30.12-35.81	-	-
Average (g/km)	2.28-2.31	0.12-0.13	4.89-5.14	31.12-37.00	0.591	1036
Average (g/kg fuel)	6.98-7.06	0.36-0.41	14.98-15.75	95.28-113.28	1.810	3172.31
Average (g/MJ)	0.159-0.161	0.008-0.009	0.341-0.358	2.166-2.575	0.041	72.098
Uncontrolled; Assumed Fuel Economy: 1.8 km/litre (55.6 l/100 km)						
Spring/Fall	3.48-4.13	0.26-0.29	13.38-14.55	97.66-115.91	-	-
Summer	2.83-3.38	0.25-0.29	19.97-21.11	111.10-131.87	-	-
Winter	4.11-4.88	0.26-0.29	12.01-13.38	103.06-122.33	-	-
Average (g/km)	3.47-4.13	0.25-0.29	14.68-15.90	102.37-121.51	0.054	1320
Average (g/kg fuel)	8.35-9.92	0.61-0.70	35.30-38.21	246.08-292.08	0.130	3172.31
Average (g/MJ)	0.190-0.226	0.014-0.016	0.802-0.868	5.593-6.638	0.003	72.098

(a) Recent measurement results (De Soete, 1993, Ballantyne, et al., 1994) have shown that N_2O emissions from aged catalysts, e.g., tested after driving 15 000 - 25 000 km, are substantially higher than from new catalyst-equipped cars. Tests on comparable models show aged catalysts emitting from roughly 30% more to almost 5 times the rate of new equipment. As indicated in Box 5, Environment Canada has used a value almost 5 times as high for aged catalysts in its national inventory calculations.

TABLE 1-30 ESTIMATED EMISSION FACTORS FOR US DIESEL PASSENGER CARS						
	EMISSIONS					
Season	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Advanced Control; Assumed Fuel Economy: 10.0 km/litre (10 l/100 km)						
Spring/Fall	0.42	0.01	0.17	0.56	-	-
Summer	0.42	0.01	0.17	0.56	-	-
Winter	0.44	0.01	0.19	0.58	-	-
Average (g/km)	0.43	0.01	0.17	0.56	0.007	237
Average (g/kg fuel)	5.68	0.06	2.32	7.54	0.09	3172.31
Average (g/MJ)	0.129	0.001	0.053	0.171	0.002	72.098
Moderate Control; Assumed Fuel Economy: 9.6 km/litre (10.4 l/100 km)						
Spring/Fall	0.54	0.01	0.17	0.56	-	-
Summer	0.54	0.01	0.17	0.62	-	-
Winter	0.54	0.01	0.17	0.56	-	-
Average (g/km)	0.54	0.01	0.17	0.58	0.01	248
Average (g/kg fuel)	6.88	0.08	2.17	7.35	0.13	3172.31
Average (g/MJ)	0.156	0.002	0.049	0.167	0.003	72.098
Uncontrolled; Assumed Fuel Economy: 7.5 km/litre (13.3 l/100 km)						
Spring/Fall	0.67	0.01	0.24	0.61	-	-
Summer	0.67	0.01	0.24	0,.61	-	-
Winter	0.67	0.01	0.24	0.61	-	-
Average (g/km)	0.67	0.01	0.24	0,.61	0.014	319
Average (g/kg fuel)	6.62	0.12	2.39	6.04	0.14	3172.31
Average (g/MJ)	0.150	0.003	0.054	0.137	0.003	72.098

TABLE 1-31
ESTIMATED EMISSION FACTORS FOR US LIGHT-DUTY DIESEL TRUCKS

Season	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Advanced Control; Assumed Fuel Economy: 7.2 km/litre (13.9 l/100 km)						
Spring/Fall	0.49	0.01	0.24	0.64	-	-
Summer	0.49	0.01	0.24	0.64	-	-
Winter	0.49	0.01	0.24	0.64	-	-
Average (g/km)	0.49	0.01	0.24	0.64	0.024	330
Average (g/kg fuel)	4.70	0.08	2.35	6.11	0.23	3172.31
Average (g/MJ)	0.107	0.002	0.053	0.139	0.005	72.098
Moderate Control; Assumed Fuel Economy: 7.2 km/litre (13.9 l/100 km)						
Spring/Fall	0.68	0.01	0.24	0.64	-	-
Summer	0.68	0.01	0.24	0.64	-	-
Winter	0.68	0.01	0.24	0.64	-	-
Average (g/km)	0.68	0.01	0.24	0.64	0.063	331
Average (g/kg fuel)	6.52	0.08	2.34	6.10	0.60	3172.31
Average (g/MJ)	0.148	0.002	0.053	0.139	0.014	72.098
Uncontrolled; Assumed Fuel Economy: 5.7 km/litre (17.5 l/100 km)						
Spring/Fall	0.92	0.01	0.49	1.01	-	-
Summer	0.92	0.01	0.49	1.01	-	-
Winter	0.92	0.01	0.49	1.01	-	-
Average (g/km)	0.92	0.01	0.49	1.01	0.031	415
Average (g/kg fuel)	7.02	0.10	3.76	7.73	0.24	3172.31
Average (g/MJ)	0.159	0.002	0.086	0.176	0.005	72.098

TABLE 1-32
ESTIMATED EMISSION FACTORS FOR US HEAVY DUTY DIESEL VEHICLES

Season	EMISSIONS					
	NO_X	CH_4	NMVOC	CO	N_2O	CO_2
Advanced Control; Assumed Fuel Economy: 2.4 km/litre (41.7 l/100 km)						
Spring/Fall	3.52	0.04	0.86	4.36	-	-
Summer	3.52	0.04	0.86	4.36	-	-
Winter	3.52	0.04	0.86	4.36	-	-
Average (g/km)	3.52	0.04	0.86	4.36	0.025	987
Average (g/kg fuel)	11.32	0.14	2.78	14.01	0.08	3172.31
Average (g/MJ)	0.257	0.003	0.063	0.318	0.002	72.098
Moderate Control; Assumed Fuel Economy: 2.4 km/litre (41.7 l/100 km)						
Spring/Fall	7.96	0.05	1.13	5.01	-	-
Summer	7.96	0.05	1.13	5.01	-	-
Winter	7.96	0.05	1.13	5.01	-	-
Average (g/km)	7.96	0.05	1.13	5.01	0.025	1011
Average (g/kg fuel)	24.96	0.16	3.55	15.71	0.08	3172.31
Average (g/MJ)	0.567	0.004	0.081	0.357	0.002	72.098
Uncontrolled; Assumed Fuel Economy: 2.2 km/litre (45.5 l/100 km)						
Spring/Fall	10.30	0.06	1.63	4.85	-	-
Summer	10.30	0.06	1.63	4.85	-	-
Winter	10.30	0.06	1.63	4.85	-	-
Average (g/km)	10.30	0.06	1.63	4.85	0.031	1097
Average (g/kg fuel)	29.79	0.18	4.70	14.03	0.09	3172.31
Average (g/MJ)	0.677	0.004	0.107	0.319	0.002	72.098

TABLE 1-33
ESTIMATED EMISSION FACTORS FOR US MOTORCYCLES

Season	EMISSIONS					
	NO_X	CH_4	NMVOC	CO	N_2O	CO_2
Non-catalytic Control; Assumed Fuel Economy: 10.8 km/litre (9.3 l/100 km)						
Spring/Fall	0.37	0.12	2.26	13.77	-	-
Summer	0.31	0.12	2.59	16.74	-	-
Winter	0.43	0.14	2.47	18.01	-	-
Average (g/km)	0.37	0.13	2.39	15.57	0.002	219
Average (g/kg fuel)	5.40	1.83	36.60	225.14	0.03	3172.31
Average (g/MJ)	0.123	0.042	0.786	5.117	0.001	72.098
Uncontrolled; Assumed Fuel Economy: 8.9 km/litre (11.2 l/100 km)						
Spring/Fall	0.19	0.25	5.87	21.78	-	-
Summer	0.16	0.24	5.96	21.55	-	-
Winter	0.22	0.31	6.93	24.09	-	-
Average (g/km)	0.19	0.26	6.16	22.30	0.002	266
Average (g/kg fuel)	2.29	3.13	73.33	265.51	0.02	3172.31
Average (g/MJ)	0.052	0.071	1.667	6.034	0.001	72.098

European Emission Estimates

The European emission estimates for NO_x, CH_4, NMVOC (total VOC minus CH_4), CO, N_2O and CO_2 are based on the COPERT90 model, developed for the Commission of the European Communities.[19] The calculation is based on five main types of input parameters:

- total fuel consumption
- vehicle park
- driving condition
- emission factors
- other parameters

For these main types of input parameters, additional information (e.g., on vehicle classes, production years etc.) is needed in order to carry out the calculations.

The methodology is defined in such a way that it uses the firm technical data and that national variations among European countries can be incorporated. The variations may include such things as composition of vehicle park, vehicle age, driving patterns, some fuel parameters and a few climatic parameters. Other variations which may exist, for example, variations in vehicle maintenance, mountain driving etc., are not accounted for because there is not enough data available to do so.

Vehicle categories

The vehicle categories chosen by CORINAIR 1990 do not meet all the requirements for modelling vehicle emissions considered important by the working group. In particular the age of vehicle (year of production) and the engine technology are not sufficiently reflected. Thus, for the purpose of the COPERT work only, a more detailed vehicle category split has been developed.

Hot Emissions

These emissions depend on a variety of factors including the distance that each vehicle travels, its speed (or road type), its age and engine size.

The basic formula for estimating hot emissions using an experimentally obtained emission factor is:

$$\text{Emissions [g]} = \text{emission factor [g/km]} \cdot \text{vehicle kilometres per year [km]}$$

The emission factors and vehicle kilometres are in most cases split into certain classes of road types and vehicle categories.

However, for many countries the only data known with any certainty are the total fuel consumption of gasoline, diesel and LPG, not vehicle kilometres. It is therefore suggested that fuel consumption data are used to check vehicle mileage where they are known and to make a final fuel balance.

Cold Start Emissions

Cold starts result in additional emissions. They take place under all three (urban, rural and highway) driving conditions, but seem to be most significant for urban driving. In

[19] As is the convention throughout these *Guidelines*, CO_2 emissions are calculated to include the carbon emitted as CO and as VOC.

principle they occur for all vehicle categories. However, emission factors are available or can be reasonably estimated only for gasoline, diesel and LPG passenger cars and - assuming that these vehicles behave like passenger cars - light-duty vehicles. Consequently, only these categories are covered by the methodology. Moreover, cold start emissions are considered not to be a function of vehicle age.

Cold start emissions are calculated as emissions additional to emissions that would be expected if all vehicles had only hot engines. A factor, the ratio of cold to hot emissions, is used and applied to the fraction of kilometres driven with cold engines. These factors may vary from country to country. Different driving behaviour, road conditions and climate as well as trip length affect the warm up time and the fraction of distance travelled with cold engines. These factors can be taken into account, but again information may not be available to do this thoroughly in all countries, so that estimates have to close identified gaps.

Evaporative VOC Emissions

There are three primary sources of evaporative emissions from vehicles:

i) diurnal (daily) emissions;
ii) hot soak emissions; and
iii) running losses.

These are estimated separately. Again they are affected by factors that vary from country to country.

All three types of evaporative emissions are significantly affected by the volatility of the gasoline being used, the absolute ambient temperature and temperature changes, and vehicle design characteristics. For hot soak emissions and running losses the driving pattern is also of importance.

In general, the estimation of evaporative emissions from gasoline vehicles involves a large number of uncertainties which can not be resolved without carrying out further measurements.

Application of the baseline methodology to the different vehicle categories and pollutants

Due to gaps in knowledge, the baseline methodology can not be applied in full and in the same way to all vehicle categories. Moreover, there are variations depending on the pollutant considered. In general, one can distinguish between four methods:

Method A	*Hot emissions* are calculated based on: - the total annual kilometres driven per vehicle; - the share of kilometres driven under the driving modes "urban", "rural" and "highway"; - the average speed of the vehicles under the driving modes "urban", "rural" and "highway"; - speed-dependent hot emission factors. *Cold start emissions* are calculated based on: - the average trip length per vehicle trip; - the average monthly temperature; - temperature and trip length dependent cold start correction factor. *Evaporative emissions* are calculated based on: - the fuel volatility (RVP); - the average monthly temperature and the average monthly temperature variation; - fuel volatility and temperature dependent emission factors.

Method B	The total annual emissions per vehicle are calculated based on: - the total annual kilometres driven per vehicle; - the share of kilometres driven under the driving modes "urban", "rural" and "highway"; - the average speed of the vehicles under the driving modes "urban", "rural" and "highway"; - speed-dependent emission factors. Note: for diesel passenger cars, cold start extra emissions for CO, NO_x and NMVOC, as well as extra fuel consumption, are added using the method described under A. For LPG passenger cars a simplified method is used.

Method C	The total annual emissions per vehicle are calculated based on: - the total annual kilometres driven per vehicle; - the share of kilometres driven under the driving modes "urban", "rural" and "highway"; - driving mode dependent emissions factors. Note: for gasoline and diesel light-duty vehicle, cold start extra emissions for CO, NO_X and NMVOC, as well as fuel consumption, are added using the method described under A. For gasoline light-duty vehicles, NMVOC evaporative emissions are added using the method described under A.

Method D	The total annual emissions per vehicle category are calculated based on: - the total annual fuel consumption of the vehicle category and/or the total annual kilometres driven by the vehicle category; - fuel consumption and/or kilometre related emission factors. Note: For two wheelers NMVOC evaporative emissions are added using the method described under A.

TABLE 1-34

SUMMARY OF PRECISION INDICATORS OF THE EMISSION ESTIMATES AND OF CALCULATION METHODS APPLIED FOR THE DIFFERENT VEHICLE CATEGORIES AND POLLUTANTS
(A, B, C, D: Method Indicators - 1, 2, 3, 4: Precision Indicators)

Vehicle Category	NO_X	CO	NMVOC	CH_4	N_2O	CO_2	Fuel
Passenger Cars							
Gasoline	A/1	A/1	A/1	C/1	C/3	D/1	A/1
Diesel	B/1	B/1	B/1	C/2	C/3	D/1	B/1
LPG	B/1	B/1	B/1	-	-	D/1	B/1
Two stroke	C/2	C/2	C/2	C/4	C/4	D/2	C/2
Light-Duty Vehicles	C/1	C/1	C/1	C/3	C/4	D/1	C/1
Heavy-Duty Vehicles	C/2	C/2	C/2	C/4	D/4	D/2	C/2
Two Wheelers	D/2	D/2	D/2	D/4	-	D/2	D/2
Evaporation							
Passenger Cars	-	-	A/3(a)	-	-	-	-
Light-Duty Vehicles	-	-	C/4(a)	-	-	-	-
Two Wheelers	-	-	D/4	-	-	-	-
Cold Start							
Passenger Cars							
Conventional Gas.	A/2	A/2	A/2	-	-	A/2	A/2
Catalyst Gasoline	A/3	A/3	A/3	-	-	A/2	A/3
Diesel	A/3	A/3	A/3	-	-	A/3	A/3
LPG	B/3	B/3	B/3	-	-	B/3	B/3
Light Duty Vehicles	C/4	C/4	C/4	-	-	C/4	C/4

1: Statistically significant emission factors based on a sufficiently large set of measured and re-evaluated data.
2: Emission factors non-statistically significant based on a small set of measured and re-evaluated data.
3: Emission factors estimated on the basis of available literature.
4: Emission factors estimated applying similarity considerations and/or extrapolation.
(a) Only for gasoline engine vehicles.

For the IPCC *Guidelines*, the emission factors from the COPERT model are presented using the American vehicle and control type categories, for ease of comparison. The emission factors have been calculated using data from 15 western and eastern European countries. Therefore the vehicle usage pattern, such as average speed and frequency of cold starts, climatic conditions like the monthly average temperature, and the fuel characteristics of these countries are incorporated in the figures. The emission factors provided are therefore valid for an average European situation.

In developing the following tables, a net calorific value of 43.5 TJ/kt was assumed for gasoline, 42.4 TJ/kt for diesel and 46.1 TJ/kt for LPG.

TABLE 1-35
EUROPEAN EMISSION CONTROL TECHNOLOGY TYPES AND CORRESPONDING EU LEGISLATION AND MODEL YEARS

TECHNOLOGY	LEGISLATION (MODEL YEAR)
Uncontrolled	Pre ECE (up to 1970)
Early non-catalyst controls	ECE 15 00 to 02 (1971-1979)
Non-catalyst controls	ECE 15 03 to 04 (1980-early 1990s)
Oxidation catalyst	88/76/EEC (1988-1991)
Three-way catalyst	91/441/EEC (1989-1995)