TABLE 1-36
ESTIMATED EMISSION FACTORS FOR EUROPEAN GASOLINE PASSENGER CARS

	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Uncontrolled: Assumed Fuel Economy 8.9 km/l (11.2 l/100 km)						
Total **g/km**	2.2	0.07	5.3	46	0.005	270
Exhaust	2.2	0.07	3.9	46	0.005	270
Evaporative[(a)]			1.4			
g/kg fuel	27	0.8	63	550	0.06	3180
g/MJ	0.6	0.02	1.5	13	0.001	73
Early non-catalyst controls: Assumed Fuel Economy 10.6 km/l (9.4 l/100 km)						
Total g/km	2.0	0.08	5.2	29	0.005	225
Exhaust	2.0	0.08	3.8	29	0.005	225
Evaporative[(a)]			1.4			
g/kg fuel	29	1.1	74	405	0.07	3180
g/MJ	0.7	0.03	1.7	9.3	0.002	73
Non-catalyst controls: Assumed Fuel Economy 12.0 km/l (8.3 l/100 km)						
Total **g/km**	2.3	0.07	4.5	19	0.005	200
Exhaust	2.3	0.07	3.2	19	0.005	200
Evaporative[(a)]			1.3			
g/kg fuel	37	1.1	72	300	0.08	3180
g/MJ	0.8	0.03	1.7	6.9	0.002	73
Oxidation catalyst: Assumed Fuel Economy 12.3 km/l (8.1 l/100 km)						
Total **g/km**	1.4	0.07	1.4	7.5	0.005	190
Exhaust	1.4	0.07	1.0	7.5	0.005	190
Evaporative[(a)]			0.4			
g/kg fuel	22	1.2	24	125	0.08	3180
g/MJ	0.5	0.03	0.6	2.9	0.002	73
Three-way catalyst: Assumed Fuel Economy 11.8 km/l (8.5 l/100 km)						
Total **g/km**	0.5	0.02	0.5	2.9	0.05	205
Exhaust	0.5	0.02	0.4	2.9	0.05	205
Evaporative[(a)]			0.06			
g/kg fuel	8.2	0.3	7.1	45.9	0.8	3180
g/MJ	0.12	0.007	0.2	1	0.02	73
2-stroke: Assumed Fuel Economy 9.2 km/l (10.9 l/100 km)						
Total **g/km**	0.8	0.08	12	12	0.005	260
Exhaust	0.8	0.08	10.7	12	0.005	260
Evaporative[(a)]			1.5			
g/kg fuel	9.3	1.0	164	150	0.06	3180
g/MJ	0.2	0.02	3.8	3.4	0.001	73

(a) Including diurnal, soak and running losses

TABLE 1-37 ESTIMATED EMISSION FACTORS FOR EUROPEAN DIESEL PASSENGER CARS						
	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Moderate control: Assumed Fuel Economy 13.7 km/l (7.3 l/100 km)						
Total **g/km**	0.7	0.005	0.2	0.7	0.01	190
g/kg fuel	11	0.08	3.0	12	0.2	3140
g/MJ	0.3	0.002	0.07	0.3	0.004	74

TABLE 1-38 ESTIMATED EMISSION FACTORS FOR EUROPEAN DIESEL LIGHT-DUTY VEHICLES						
	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Moderate control: Assumed Fuel Economy 9.2 km/l (10.9 l/100 km)						
Total **g/km**	1.4	0.005	0.4	1.6	0.02	280
g/kg fuel	16	0.06	4.6	18	0.2	3140
g/MJ	0.4	0.001	0.1	0.4	0.004	74

TABLE 1-39 ESTIMATED EMISSION FACTORS FOR EUROPEAN DIESEL HEAVY-DUTY VEHICLES						
	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Moderate control: Assumed Fuel Economy 3.3 km/l (29.9 l/100 km)						
Total **g/km**	10	0.06	1.9	9.0	0.03	770
g/kg fuel	42	0.2	8.0	36	0.1	3140
g/MJ	1.0	0.006	0.2	0.9	0.003	74

TABLE 1-40
ESTIMATED EMISSION FACTORS FOR EUROPEAN GASOLINE LIGHT-DUTY VEHICLES

	Emissions					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Moderate control: Assumed Fuel Economy 7.4 km/l (13.6 l/100 km)						
Total **g/km**	2.9	0.08	6.1	37	0.006	325
Exhaust	2.9	0.08	4.8	37	0.006	325
Evaporative(a)			1.3			
g/kg fuel	29	0.8	59	360	0.06	3180
g/MJ	0.7	0.02	1.4	8.3	0.001	73

TABLE 1-41
ESTIMATED EMISSION FACTORS FOR EUROPEAN GASOLINE HEAVY-DUTY VEHICLES

	Emissions					
	NO_x	CH_4	VOC	CO	N_2O	CO_2
Uncontrolled: Assumed Fuel Economy 4.4 km/l (22.5 l/100 km)						
Total **g/km**	6.9	0.1	5.4	58	0.006	535
Exhaust	6.9	0.1	5.4	58	0.006	535
Evaporative(a)						
g/kg fuel	40	0.7	32	346	0.04	3180
g/MJ	0.9	0.02	0.8	7.9	0.001	73

TABLE 1-42
ESTIMATED EMISSION FACTORS FOR EUROPEAN MOTORCYCLES

	Emissions					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
MOTORCYCLES < 50 CC						
Uncontrolled: Assumed Fuel Economy 41.7 km/l (2.4 l/100 km)						
Total **g/km**	0.05	0.1	6.5	10	0.001	57
Exhaust	0.05	0.1	6.2	10	0.001	57
Evaporative(a)			0.3			
g/kg fuel	2.8	5.6	359	550	0.06	3180
g/MJ	0.06	0.1	8.3	13	0.001	73
MOTORCYCLES > 50 CC 2 STROKE						
Uncontrolled: Assumed Fuel Economy 25.0 km/l (4.0 l/100 km)						
Total **g/km**	0.08	0.15	16	22	0.002	95
Exhaust	0.08	0.15	15	22	0.002	95
Evaporative(a)			1.0			
g/kg fuel	2.7	5.0	530	730	0.07	3180
g/MJ	0.06	0.1	12	17	0.002	73
MOTORCYCLES > 50 CC 4 STROKE						
Uncontrolled: Assumed Fuel Economy 19.6 km/l (5.1 l/100 km)						
Total **g/km**	0.30	0.20	3.9	20	0.002	120
Exhaust	0.30	0.20	3.4	20	0.002	120
Evaporative(a)			0.5			
g/kg fuel	7.9	5	105	530	0.05	3180
g/MJ	0.2	0.1	2.4	12	0.001	73

(a) Including diurnal, soak and running losses

Road Vehicles - Alternative Fuels

Alternative motor vehicle fuels such as natural gas, liquefied petroleum gas (LPG), methanol and ethanol are presently being used in a limited way, and are the subjects of a great deal of research and development effort aimed at increasing their usage in the future. This section presents some preliminary estimates of the emissions to be expected from vehicles using these fuels, based on fuel properties and the limited emissions data available.[20]

Natural gas

Because natural gas is mostly methane, natural gas vehicles (NGVs) have lower exhaust NMVOC emissions than gasoline vehicles, but higher emissions of methane. There are no evaporative or running-loss emissions, while refuelling emissions and cold-start emissions are lower. These conditions reduce both NMVOC and CO emissions relative to gasoline vehicles. CO_2 emissions from NGVs will be lower than for gasoline vehicles, since natural gas has a lower carbon content per unit of energy. It is possible to attain increased efficiency by increasing the compression ratio. Optimised heavy-duty NGV engines can approach diesel efficiency levels. NO_x emissions from uncontrolled NGVs may be higher or lower than comparable gasoline vehicles, depending on the engine technology. NO_x emissions from NGVs are more difficult to control using three-way catalysts. N_2O emissions from NGVs were not included.

Table 1-43 shows three types of NGVs: passenger cars, gasoline-type heavy-duty vehicles, and diesel-type heavy-duty vehicles.[21] Two sets of emission factors are shown for each: uncontrolled (typical of a simple natural gas conversion, without catalytic converter or optimisation for emissions) and advanced control (reflecting an engine and catalytic converter factory-produced and optimised for natural gas). The estimates for the passenger car and gasoline-type heavy-duty vehicle are based on a gasoline-type engine, converted to use natural gas. For the uncontrolled vehicles, no changes in the engine are assumed beyond the fitting of a natural gas mixer and modified spark timing such that the efficiency would be the same. For the vehicles with advanced control, a higher compression ratio is assumed to give 15 per cent better fuel efficiency.

For the diesel-type heavy-duty vehicles, the engine assumed is a diesel-type engine, converted to lean, Otto-cycle operation using natural gas. The uncontrolled case reflects no further optimisation beyond the conversion, while the controlled case includes extensive combustion optimisation for NO_x control and an oxidation catalytic converter.

Liquefied petroleum gas

LPG is primarily propane (or a propane/butane mixture) rather than methane which affects the composition of exhaust VOC emissions, but otherwise is similar to natural gas. Evaporative and refuelling emissions are virtually zero, and CO and exhaust NMVOC emissions are usually lower than gasoline vehicles. The CO_2 emissions should be somewhat lower than gasoline, due to the lower carbon-energy ratio, and the higher

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[20] Actual emission levels from these vehicles may be very different, and further testing is needed to confirm these estimates.

[21] The emissions considered are only those of the vehicle itself – additional emissions due to, e.g., compression or liquefaction of gas for storage on the vehicle, leakage from pipelines, etc. are not included, nor are the potential emissions credits due to, e.g., production of methane from biomass. This is consistent with the treatment of emissions from vehicles using oil-based fuels.

octane level allows some increase in efficiency, although less than for natural gas. NO_x emissions from LPG vehicles tend to be higher than for gasoline, but can also be controlled using three-way catalysts. N_2O emissions were not included.

Table 1-44 shows two types of LPG vehicles. The engines and technologies considered are the same as those for natural gas, except that the lean, diesel-derived natural gas engine with propane is not considered.

Methanol and Ethanol

The two alcohols have similar properties, and are discussed together. Development efforts have focused primarily on mixtures of alcohols with gasoline, in flexible fuel vehicles, capable of running on any combination of gasoline and up to 85 per cent methanol or ethanol. Engines and emission control systems are similar to those for advanced-technology gasoline vehicles, and the overall energy efficiency and emissions properties are similar. Table 1-46 shows estimated emissions for a vehicle of this type using M85 (85% methanol / 15% gasoline) fuel. Also shown are some rough emissions estimates for heavy-duty vehicles equipped with methanol or ethanol engines.

TABLE 1-43 ESTIMATED EMISSION FACTORS FOR US LIGHT- AND HEAVY-DUTY NATURAL GAS VEHICLES						
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Passenger Cars						
Advanced Control; Assumed Fuel Economy: 14.9 km/m^3						
g/km	0.5	0.7	0.05	0.3	NAV	133
g/kg fuel	10.3	14.5	1.0	6.2	NAV	2750
g/MJ	0.21	0.29	0.02	0.12	NAV	56.1
Uncontrolled; Assumed Fuel Economy: 6.5 km/m^3						
g/km	2.1	3.5	0.5	4.0	NAV	305
g/kg fuel	19.0	31.6	4.5	36.1	NAV	2750
g/MJ	0.38	0.63	0.09	0.72	NAV	56.1
Heavy-Duty Vehicles: Stoichiometric Engine (compare with gasoline)						
Advanced Control; Assumed Fuel Economy: 3.6 km/m^3						
g/km	2.6	3.0	0.20	1.0	NAV	550
g/kg fuel	13.0	15.0	1.0	5.0	NAV	2750
g/MJ	0.26	0.30	0.02	0.10	NAV	56.1
Uncontrolled; Assumed Fuel Economy: 2.2 km/m^3						
g/km	5.7	10.0	1.4	12.0	NAV	900
g/kg fuel	17.4	30.6	4.3	36.7	NAV	2750
g/MJ	0.35	0.61	0.09	0.73	NAV	56.1
Heavy-Duty Vehicles: Lean Burn Engine (compare with diesel)						
Advanced Control; Assumed Fuel Economy: 2.4 km/m^3						
g/km	4.0	4.0	0.40	1.5	NAV	825
g/kg fuel	13.3	13.3	1.3	5.0	NAV	2750
g/MJ	0.27	0.27	0.03	0.10	NAV	56.1
Uncontrolled; Assumed Fuel Economy: 2.0 km/m^3						
g/km	23.0	10.0	2.0	8.0	NAV	990
g/kg fuel	63.9	27.8	5.6	22.2	NAV	2750
g/MJ	1.28	0.56	0.11	0.44	NAV	56.1

TABLE 1-44 ESTIMATED EMISSION FACTORS FOR US LIGHT- AND HEAVY-DUTY LPG VEHICLES.						
	NO_X	CH_4	NMVOC	CO	N_2O	CO_2
Passenger Cars						
Advanced Control						
g/km	0.5	0.03	0.25	0.3	NAV	170
g/kg fuel	8.8	0.6	4.4	5.3	NAV	3000
g/MJ(a)	0.19	0.01	0.10	0.11	NAV	63.1
Uncontrolled						
g/km	2.1	0.18	3.5	8.0	NAV	356
g/kg fuel	17.7	1.5	29.5	67.5	NAV	3000
g/MJ	0.38	0.03	0.64	1.45	NAV	63.1
Heavy-Duty Vehicles: Stoichiometric Engine (compare with gasoline)						
Advanced Control						
g/km	2.6	0.15	0.70	1.0	NAV	695
g/kg fuel	11.2	0.6	3.0	4.3	NAV	3000
g/MJ	0.24	0.01	0.07	0.09	NAV	63.1
Uncontrolled						
g/km	5.7	0.4	8.0	24.0	NAV	1020
g/kg fuel	16.8	1.2	23.5	70.6	NAV	3000
g/MJ	0.36	0.03	0.51	1.52	NAV	63.1
(a) Berdowski, et al. (1993a) suggest a CH_4 emission factor of 0.013 g/MJ for this vehicle/technology class.						

TABLE 1-45 ESTIMATED EMISSION FACTORS FOR EUROPEAN LPG PASSENGER CARS						
	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Moderate control: Assumed Fuel Economy 8.9 km/l(a) **(11.2 l/100 km)**						
Total **g/km**	2.2	0.06	1.5	7.1	-	180
g/kg fuel	37	1.0	25	120	-	3030
g/MJ	0.9	0.02	0.6	2.6	-	65
(a) Under 5 bar pressure						

TABLE 1-46 ESTIMATED EMISSION FACTORS FOR US LIGHT- AND HEAVY-DUTY METHANOL VEHICLES						
	EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Passenger Cars (M85 Fuel)						
Advanced Control						
g/km	0.5	0.02	0.66	3.14	NAV	183
g/kg fuel	4.5	0.2	5.9	28.0	NAV	1632
g/MJ	0.19	0.01	0.25	1.19	NAV	69.7
Heavy-Duty Vehicles - Methanol-Diesel Engine - M100 Fuel						
Advanced Control						
g/km	4.0	0.1	1.50	4.0	NAV	908
g/kg fuel	6.1	0.2	2.3	6.1	NAV	1375
g/MJ	0.30	0.01	0.11	0.30	NAV	68.8

1.5.3.4 SURFACE NON-ROAD SOURCES

Emission factors are provided for major non-road vehicle source categories including farm and construction equipment, railway locomotives, boats, and ships (all primarily equipped with diesel engines), jet aircraft, and gasoline-fuelled piston aircraft.

Table 1-47 presents emission factors specific to the United States, but may be applicable to other regions as well. The emission factors for diesel engines used in railway locomotives, farm equipment such as tractors and harvesters, construction equipment such as bulldozers and cranes, and diesel boats, are from Weaver (1988). N_2O emission factors for off-road diesels are assumed to be the same as those for heavy-duty on-highway diesel engines.

Large ocean-going cargo ships are driven primarily by large, slow-speed and medium-speed diesel engines, and occasionally by steam turbines and gas turbines (the latter in high power-weight ratio vessels such as fast ferries and warships). The number of vessels equipped with steam or gas-turbine propulsion is small, however, since these vessels are unable to compete with the more efficient diesels in most applications. The results shown for NO_x and CO are from Hadler (1990)[22]. N_2O emissions for these engines were assumed to be the same, on a fuel-specific basis, as those for other heavy-duty diesels, and VOC emissions from these large diesels are probably negligible.

[22] Other sources consulted for comparison are Melhus (1990), Bremnes (1990), Alexandersson (1990).

TABLE 1-47
ESTIMATED EMISSION FACTORS FOR US NON-ROAD MOBILE SOURCES

	UNCONTROLLED EMISSIONS					
	NO_x	CH_4	NMVOC	CO	N_2O	CO_2
Ocean-Going Ships						
g/kg fuel	87	NAV	NAV	1.9	0.08	3212
g/MJ	2.1	NAV	NAV	0.046	0.002	77.6
Boats						
g/kg fuel	67.5	0.23	4.9	21.3	0.08	3188
g/MJ	1.6	0.005	0.11	0.50	0.002	75.0
Locomotives						
g/kg fuel	74.3	0.25	5.5	26.1	0.08	3188
g/MJ	1.8	0.006	0.13	0.61	0.002	75.0
Farm Equipment						
g/kg fuel	63.5	0.45	9.6	25.4	0.08	3188
g/MJ	1.5	0.011	0.23	0.60	0.002	75.0
Construction and Industrial Equipment						
g/kg fuel	50.2	0.18	3.9	16.3	0.08	3188
g/MJ	1.2	0.004	0.09	0.38	0.002	75.0
Jet and Turboprop Aircraft						
g/kg fuel	12.5	0.087	0.78	5.2	NAV	3149
g/MJ	0.29	0.002	0.018	0.12	NAV	72.8
Gasoline (Piston) Aircraft						
g/kg fuel	3.52	2.64	24	1034	0.04	3172
g/MJ	0.08	0.06	0.54	24	0.0009	72.1

A detailed experimental assessment of exhaust emissions from a broad cross section of ship categories including bulk carriers, container ships, dredgers, ferries, tankers and tugs has recently been completed by Lloyd's Register (1995). The vessels evaluated by Lloyd's Register were powered by in-service diesel engines of various vintages and sizes, and tested without modification.

A total of sixty engines on fifty vessels were tested under steady-state conditions, and a further eight vessels were tested under transient engine loads by Lloyd's Register (1995). Emission factors reported by Lloyd's Register for medium and slow speed diesel engines are considered to be the best available to date and have been adopted in this study (see Table 1-48).

In the absence of data on the relative time spent under steady state versus transient engine loads, steady state engine emission rates are adopted in this study for ocean-going ships. For detailed regional studies, it is recommended that surveys of engine type and mode of operation be undertaken to establish fleet emission rates for non-CO_2 gases.

For slow to medium speed diesel engines, considered to be representative of large ocean-going cargo ships, Lloyd's Register (1995) reported NO_x emission rates of 57 and 87 kg/tonne of fuel, respectively. In the absence of data on the fleet composition of slow versus medium speed diesel engines for ocean going fleets, a NO_x emission factor of 72 kg/tonne of fuel is recommended. The corresponding emission rate documented by IPCC (1995) was 87 kg/tonne of fuel. Emission rates for CH_4 and NMVOC for ocean-going ships were not reported by IPCC (1995). In this study, CH_4 and NMVOC emission rates are estimated from hydrocarbon (HC) data reported by Lloyd's Register according to $CH_4 = 0.12 \times HC$ and $NMVOC = HC - CH_4$.

Lloyd's Register reported a CO emission rate of 7.4 kg/tonne of fuel for slow to medium speed diesel engines. In this study, the value of 7.4 kg CO/tonne of fuel is adopted for slow to medium speed diesel engines on ocean-going ships.

Emission factors for small engines mainly used in pleasure crafts and small fishing boats can be found in Table 1-49 under the heading "Inland waterways" for diesel engines as well as for 2-stroke and 4-stroke gasoline engines.

The difference in emission rates noted above, illustrates the importance of characterising fleet engine types and fuel use for regional scale emissions from marine and other non-road sources.

TABLE 1-48
DEFAULT MARINE EMISSION FACTORS

	CH_4	N_2O	NO_x	CO	NMVOC
Ocean-going Ships (diesel engines*)					
g/MJ	0.007	0.002	1.8	0.18	0.052

* Mostly using heavy fuel oil.

Table 1-49 presents emission factors for non-road vehicles in Europe. These estimates were produced for CORINAIR using national data and information compiled by Andrias et al., 1994.

TABLE 1-49
ESTIMATED EMISSION FACTORS FOR
EUROPEAN NON-ROAD MOBILE SOURCES AND MACHINERY

PART 1: DIESEL ENGINES

	Emissions											
	NO_x		CH_4 (a)		NMVOC(a)		CO		N_2O		CO_2	
Diesel Engines												
	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ
Agriculture	50	1.2	0.17	0.004	7.3	0.17	16	0.37	1.3	0.03	3140	73
Forestry	50	1.2	0.17	0.004	6.5	0.15	15	0.35	1.3	0.03	3140	73
Industry	49	1.1	0.17	0.004	7.1	0.16	16	0.37	1.3	0.03	3140	73
Household	48	1.1	0.17	0.004	10	0.23	23	0.53	1.2	0.03	3140	73
Railways	40	0.9	0.18	0.004	4.7	0.11	11	0.25	1.2	0.03	3140	73
Inland waterways	42	1.0	0.18	0.004	4.7	0.11	11	0.25	1.3	0.03	3140	73

PART 2: GASOLINE ENGINES

	Emissions											
	NO_x		CH_4 (a)		NMVOC(a)		CO		N_2O		CO_2	
Gasoline 4-stroke												
	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ
Agriculture	7.6	0.17	3.7	0.08	74	1.7	1500	33	0.07	0.002	3200	71
Forestry	-	-	-	-	-	-	-	-	-	-	3200	71
Industry	9.6	0.21	2.2	0.05	43	1.0	1200	27	0.08	0.002	3200	71
Household	8.0	0.18	5.5	0.12	110	2.5	2200	79	0.07	0.002	3200	71
Railways	-	-	-	-	-	-	-	-	-	-	-	-
Inland waterways	9.7	0.22	1.7	0.04	34	0.76	1000	22	0.08	0.002	3200	71
Gasoline 2-stroke												
	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ	g/kg	g/MJ
Agriculture	1.7	0.04	6.2	0.14	620	14	1100	25	0.02	0.0004	3200	71
Forestry	1.6	0.04	7.7	0.17	760	17	1400	31	0.02	0.0004	3200	71
Industry	2.1	0.05	6.0	0.13	600	13	1100	31	0.02	0.0004	3200	71
Household	1.8	0.04	8.1	0.18	810	18	1600	36	0.02	0.0004	3200	71
Railways	-	-	-	-	-	-	-	-	-	-	-	71
Inland waterways	2.7	0.06	5.1	0.11	500	11	890	20	0.02	0.0004	3200	71

(a) Including diurnal, soak and running losses.

1.5.3.5 AIRCRAFT

Background information

While the emission factors for aircraft in the Tier 1 approach are fleet average factors for NO_x, CO and NMVOC as derived from global inventories compiled by NASA, ECAC/ANCAT and others, this section presents a more refined Tier 2 method. The methodology includes four sub-activities:

Box 6	
OVERVIEW OF THE ACTIVITIES INCLUDED IN THE PRESENT METHODOLOGY	**CORINAIR94 CLASSIFICATION(A)**
Domestic airport traffic (LTO[b] -cycles < 914m (3000 ft) altitude)	SNAP[c] code 080501
International airport traffic (LTO-cycles < 914m (3000 ft) altitude)	SNAP code 080502
Domestic cruise traffic (> 914m (3000 ft) altitude[d])	SNAP code 080503
International cruise traffic (> 914m (3000 ft) altitude[d])	SNAP code 080504

(a) CORINAIR uses a round figure of 1000 metres (for 3000 feet) as the cut-off.

(b) LTO is short for the Landing and Take-Off cycle.

(c) SNAP codes refer to the joint EMEP/CORINAIR Methodology, used in Europe.

(d) Including further climbout from and descent to 914 metres (3000 feet) altitude.

Activities include all civil commercial use of airplanes consisting of scheduled and charter traffic of passengers and freight. This also includes taxiing. Military and private aviation activities are not included because respectively, it is unlikely that detailed information is available and fuel usage is proportionately very small. However, theoretically this method could also be used for the estimation of the emissions of military aircraft. In that case, these emissions should be reported under 1A5 "Other" and not with domestic or international aviation.

Operations of aircraft are divided into two parts:

- *The Landing/Take-Off (LTO) cycle* [23] which includes all activities near the airport that take place under the altitude of 914 metres (3000 feet). This includes engines running idle, taxi-in and out, and climbing and descending under this altitude. In aircraft industry-related literature (e.g., the ICAO), the cut-off altitude is often 3000 feet which corresponds to 914 metres.
- *Cruise* is defined as all activities that take place at altitudes above 914 metres (3000 feet). No upper limit is given. This also includes further climb-out from and descent to an altitude of 914 metres.

Activities

For the purposes of the emissions inventory a distinction is made between domestic and international flights[24].

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[23] Some statistics count either a landing or a take-off as one operation. **However it is *both* one take-off and one landing, that together define one LTO-operation.**

[24] If an aircraft goes from one airport in one country to another in the same country and then leaves to a third airport in another country, the first flight stage is considered a domestic trip while the second is considered an international trip. It is not important whether the airport is a domestic or an international airport. In addition, the type of

- *Domestic aviation* (1 A 3 a ii) includes all civil domestic passenger and freight traffic inside a country. All flight stages between two airports in one country are considered domestic no matter the nationality of the carrier or the subsequent destination of the aircraft.
- *International aviation* (1 A 3 a i) includes all civil air traffic coming to or leaving a country. It is assumed that the number of out-bound flights equals the number of in-bound flights.
- LTOs take the classification (domestic or international) of the flight stage to which they belong. As most flights are regarded as return flights, fuel used during landing and take-off will be regarded as equal to a take-off and landing.

Techniques

In general, there exist two types of engines (Olivier, 1991):

- *reciprocating piston engines*, where energy is extracted from a combustion chamber by means of a piston and crank mechanism which drives the propellers to give the aircraft momentum; and
- *gas turbines*, where compressed air is heated by combustion in a combustion chamber and the major part of the released energy is used for propulsion of the aircraft. Part of the energy contained in the hot air flow is used to drive the turbine which in turn drives the compressor. Turbojet engines use energy only from the expanding exhaust stream for propulsion, whereas turbofan and turboprop engines use energy to drive an extra turbine which drives a fan or propeller respectively, for propulsion.

Emissions

Air traffic as a source of combustion emissions varies with respect to the type of fuel which is being used, the location (altitude) of the exhaust gases, the types and the efficiency of the engines, and the length of the flight. Emissions come from jet kerosene and aviation gasoline which are used as fuel on the aircraft.

This Tier 2 methodology is only applicable for jet fuel used in jet engines. Aviation gasoline is only used in small aircraft (often referred to as "general aviation") and generally represents less than 1 per cent of fuel consumption for aviation. As a result, no attempt has been made to estimate emission factors for private aviation as this represents such a small proportion of global consumption.

Use of energy, and therefore emissions, is dependent on the aircraft operations and the time spent at each stage[25]. A substantial part of the fuel consumption takes place outside

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activity (LTO, cruise, domestic, international) is independent of the nationality of the carrier. This treatment of domestic and international differs from that recommended to states by the International Civil Aviation Organization (ICAO,1994). ICAO defines as domestic all flight stages flown between domestic points by an airline registered in that state and therefore excludes flights between domestic points by foreign airlines.

[25] Note: The reference LTO cycle that was used to estimate the emission factors has a cycle time of 32.9 minutes made up of the four individual Times in Mode (TIM) according to ICAO recommendations. Depending on whether there is more or less congestion at the airport this time may be shorter or longer. In particular, taxi times may differ substantially between large metropolitan airports and small airports. This can be

the LTO-cycle. Studies indicate that in national airspace 60-80 per cent of NO_x and 80-90 per cent of SO_2 and CO_2 is emitted at altitudes above 914 metres (3000 feet). For CO it is about 50 per cent and for VOC it is about 20-40 per cent (Olivier, 1991). Globally, however, 80 to 90 per cent of these emissions are emitted above an altitude of 914 metres (3000 feet) (Olivier, 1995).

Besides the combustion of fuel in the LTO and cruise activities, fuelling and fuel handling in general, maintenance of aircraft engines and fuel jettisoning to avoid accidents are emission sources. In the wintertime, anti-ice and de-ice treatment of wings and aircraft is a source of emissions at airport complexes. Many of the substances used flow off the wings when planes are idling, taxiing, and taking off, and then evaporate. These emissions are, however, not included in the methodology.

Emission factors

For LTO cycles, Table 1-50 gives relevant examples from the ICAO Engine Exhaust Emissions Databank (ICAO, 1995). This provides emission factors for LTO cycles for a large number of engines treated under standard conditions. Another useful source of aircraft emission factors is the FAA Aircraft Emission database, US Office of Environment and Energy (1991), derived from an early draft version of the ICAO database.

For cruise activities, average NO_x emission factors related to fuel consumption have been estimated and are displayed in Table 1-51. The cruise emission factors take into account the number of engines fitted to each specific aircraft.

Where aircraft types used in a country are not displayed in Tables 1-50 or 1-51, data for the nearest equivalent type in either of those tables can be used or alternatively the average emission factors displayed in Table 1-52 can be used.

Please note that when using the emission factors, the assumptions on sulphur content in the fuel should be taken into account. The factors have been calculated assuming a weight percentage of 0.05 per cent[26]. Actual values of sulphur content in jet kerosene vary between 0.0001 and 0.3 per cent.

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calculated for individual airports and individual aircraft as a Tier 3 methodology (see last paragraph of Section 1.3).

[26] For example, if the sulphur content of fuel used is 0.01 per cent, the emission factor for SO_2 should be divided by 5 to show the corresponding factor.