Discussion paper – Review of consistency for Energy Industries (1A1)

The chapter on energy industries is subdivided into three main parts: public electricity and heat production (1A1a), petroleum refining (1A1b) and manufacture of solid fuels and other energy industries (1A1c). Each part contains both tier 1 and tier 2 emission factors (EFs), especially for 1A1a there are a large number of EF tables to review, therefore the three parts will be described individually below.

Public electricity and heat production

This part of the chapter contains tier 2 EFs for coal, oil, natural gas and wood. In addition there are tier 1 EF tables for coal (hard coal and brown coal), natural gas, derived gases, fuel oil, other liquid fuels and biomass.

The individual fuel categories will be discussed separately in the following.

Coal

There are tier 2 EFs available for hard coal combusted in dry bottom boilers (DBB), brown coal combusted in wet/dry bottom boilers, hard coal combusted in wet bottom boilers (WBB), hard coal combusted in fluid bed boilers (FBB) and brown coal combusted in FBB. In addition there are tier 1 EFs for hard coal and brown coal.

Hard coal

For hard coal there are three tier 2 EF tables provided for DBB, WBB and FBB respectively. The vast majority of EFs refer to US EPA (1998a).

	GB - DBB	GB - WBB	GB - FBB	Reference
NO_x	324	461	83	US EPA, 1998a; US EPA, 1998a; EIPPCB, 2006
CO	10	10	70	US EPA, 1998a; US EPA, 1998a; CITEPA, 1992
NMVOC	1.2	0.8	1.2	US EPA, 1998a
SO_2	820	820	820	Assumed 1 % S
TSP	30	15	15	US EPA, 1998a; expert judgment; expert judgment
PM_{10}	20	12	12	US EPA, 1998a; expert judgment; expert judgment
$PM_{2.5}$	9	6	6	US EPA, 1998a; expert judgment; expert judgment
Pb	8.6	8.6	8.1	US EPA, 1998a
Cd	1	1.1	1	US EPA, 1998a
Hg	1.7	1.7	1.6	US EPA, 1998a
As	8.4	8.4	8	US EPA, 1998a
Cr	5.3	5.3	5	US EPA, 1998a
Cu	7.8	4.8	4.8	Expert judgment
Ni	5.7	5.7	5.4	US EPA, 1998a
Se	27	27	25	US EPA, 1998a
Zn	19	19	19	Expert judgment
PCBs	170	170	170	Kakareka et al., 2004
PCDD/F	10	10	10	UNEP, 2005
Benzo(a)	0.7	0.7	0.7	US EPA, 1998a

Indeno	1.2	1.2	1.2		US EPA, 1998a
HCB	0.62	0.62	0.62		Previous GB

When comparing EFs, it seems that abated EFs have been used unlike in many other parts of the GB. In spite of this the abatement technology in the EF table has been listed as NA. Below the three different technologies will be discussed separately.

Dry bottom boilers

The EFs for DBB in the GB are shown in the table below together with unabated and abated EFs derived from US EPA (1998a). For conversion of the US EPA data the heating value as provided in the reference has been used (26 MMBTU/ton). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	GB - DBB	US EPA - DBB - uncontrolled	US EPA - DBB - uncontrolled - converted	US EPA - DBB - controlled	US EPA - DBB - controlled - converted
NO_x	324	31[1]	513	12[2]	198.4
CO	10	0.5	8.3	0.5	8.3
NMVOC	1.2	0.06	1.0	0.1	1.0
TSP	30	82[3]	1356	0.7[4]	10.8
PM_{10}	20	18.86	312	0.4	7.3
$PM_{2.5}$	9	4.92	81	0.2	3.3
Pb	8.6	507	218	4.20E-04	6.9
Cd	1	44.4	19	5.10E-05	0.8
Hg	1.7	16	7	8.30E-05	1.4
As	8.4	684	294	4.10E-04	6.8
Cr	5.3	1250	537	2.60E-04	4.3
Ni	5.7	1030	443	2.80E-04	4.6
Se	27	1.30E-03	21.5	1.30E-03	21.5
Benzo(a)	0.7	3.80E-08	0.6	3.80E-08	0.6
Indeno	1.2	6.10E-08	1.0	6.10E-08	1.0

[1] PC, dry bottom, cell burner fired, bituminous
[2] PC, dry bottom, wall-fired, bituminous NSPS
[3] Assumes a coal ash weight percent of 8.2
[4] Assumes ESP with an efficiency of 99.2 %

The EFs for Cu and Zn are based on the previous version of the GB where a range is provided of 0.01-0.4 g/Mg for Cu and 0.03-1.3 g/Mg for Zn. In the current GB this has apparently been converted using a heating value of 25 GJ/ton. This is a reasonable assumption and in lack for better data, it is proposed to keep these EFs in the GB.

For PCDD/F the EF refers to UNEP (2005). This is generally a robust reference and it has not been possible within the timeframe of this project to search for better data, so it is proposed to keep the current EF.

Grochowalski & Konieczyński (2008) reports EFs of PCBs and HCB for circulating FBB combusting hard coal in Poland. The average EF for HCB is 6.7 µg/GJ. For PCBs the average EF is 3.3 ng WHO-TEQ/GJ. It is proposed to use this reference for both DBB and WBB (even though the measurements are carried out in

FBB), since they are judged to be better than the current EFs used in the GB. For more discussion on Grochowalski & Konieczyński (2008), please see the chapter on FBB.

Wet bottom boilers

The EFs for WBB in the GB are shown in the table below together with the abated EFs derived from US EPA (1998a). For conversion of the US EPA data the heating value as provided in the reference has been used (26 MMBTU/ton). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	GB - WBB	US EPA - WBB	US EPA – WBB – converted
NO_x	461	14[1]	231
CO	10	0.5	8.3
NMVOC	0.8	0.04	0.7
TSP	15	0.4592[2]	7.6
PM_{10}	12	0.3444	5.7
$PM_{2.5}$	6	0.1804	3.0
Pb	8.6	4.20E-04	6.9
Cd	1.1	5.10E-05	0.8
Hg	1.7	8.30E-05	1.4
As	8.4	4.10E-04	6.8
Cr	5.3	2.60E-04	4.3
Ni	5.7	2.80E-04	4.6
Se	27	1.30E-03	21.5
Benzo(a)	0.7	3.80E-08	0.6
Indeno	1.2	6.10E-08	1.0

[1] PC, wet bottom, tangentially fired, bituminous, NSPS

[2] Assumes ESP with an efficiency of 99.2 % and a coal ash weight percent of 8.2

The EFs for Cu and Zn are based on the previous version of the GB where a range is provided of 0.05-0.4 g/Mg for Cu and 0.5-4 g/Mg for Zn. For DBB it was apparently converted using a heating value of 25 GJ/ton. However, in this case it is not possible to retrace the calculation. Taking the average value as EF leads to EFs of 9 mg/GJ for Cu and 90 mg/GJ for Zn.

For PCDD/F the EF refers to UNEP (2005). This is generally a robust reference and it has not been possible within the timeframe of this project to search for better data, so it is proposed to keep the current EF.

Grochowalski & Konieczyński (2008) reports EFs of PCBs and HCB for circulating FBB combusting hard coal in Poland. The average EF for HCB is 6.7 µg/GJ. For PCBs the average EF is 3.3 ng WHO-TEQ/GJ. It is proposed to use this reference for both DBB and WBB (even though the measurements are carried out in FBB), since they are judged to be better than the current EFs used in the GB. For more discussion on Grochowalski & Konieczyński (2008), please see the chapter on FBB.

Fluid bed boilers

The EFs for FBB in the GB are shown in the table below together with the abated EFs derived from US EPA (1998a). For conversion of the US EPA data the heating value as provided in the reference has been used (26 MMBTU/ton). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	GB - FBB	US EPA - FBB	US EPA - FBB - converted
NOx	83	5[1]	83
CO	70	18	298
NMVOC	1.2	0.05	0.8
TSP	15	0.48[2]	7.9
PM10	12	0.44	7.3
PM25	6	0.3	5.0
Pb	8.1	4.20E-04	6.9
Cd	1	5.10E-05	0.8
Hg	1.6	8.30E-05	1.4
As	8	4.10E-04	6.8
Cr	5	2.60E-04	4.3
Ni	5.4	2.80E-04	4.6
Se	25	1.30E-03	21.5
Benzo(a)	0.7	3.80E-08	0.6
Indeno	1.2	6.10E-08	1.0

[1] Circulating fluid bed

[2] Assuming ESP with an efficiency of 99.22 %

It is seen that the EF from US EPA (1998a) for circulating fluid bed matches the current EF referenced to EIPPCB (2006). For CO the EF derived from the US EPA (1998a) is far higher than the current EF referenced to CITEPA (1992). It is proposed to keep both EFs as currently in the GB.

For PM, it is proposed to change the reference to US EPA (1998a) to ensure the highest degree of consistency between the PM and HM EFs.

The EFs for Cu and Zn are based on the previous version of the GB. However, there is no EFs for FBB in the previous GB therefore it is proposed to use the EFs for WBB for Cu and Zn. For WBB a range is provided of 0.05-0.4 g/Mg for Cu and 0.5-4 g/Mg for Zn. Taking the average value as EF and using a heating value of 15 GJ/ton leads to EFs of 9 mg/GJ for Cu and 90 mg/GJ for Zn.

For PCDD/F the EF refers to UNEP (2005). This is generally a robust reference and it has not been possible within the timeframe of this project to search for better data, so it is proposed to keep the current EF.

Grochowalski & Konieczyński (2008) reports EFs of PCDD/F, PCBs and HCB for circulating FBB combusting hard coal in Poland. Measurement were carried out on four plants, of which two were combusting clean coal, while the other two were burning a mixture of coal and coal silt and a mixture of coal and waste coal. Both mixtures were 70 % clean coal on an energy input basis. The reported EFs are shown in the table below.

	Plant 1[1]	Plant 2[2]	Plant 3	Plant 4	Unit
PCDD/F	46.4	23.4	7.51	19.2	ng I-TEQ/GJ
PCBs	4.65	2.42	3.76	2.56	ng WHO-TEQ/GJ
HCB	26.7	16.9	7.2	6.19	µg/GJ

[1] A mixture of coal and coal silt was combusted during the measurements

[2] A mixture of coal and waste coal was combusted during the measurements

For PCDD/F and HCB there seems to be a significant difference between the two plants using clean coal and the two plants using mixtures. However, for PCBs the difference is insignificant. The average EFs for plant 3 and 4 for PCDD/F and HCB are 13.4 ng I-TEQ/GJ and 6.7 µg/GJ respectively. For PCBs the average of the four plants is 3.3 ng WHO-TEQ/GJ. For PCDD/F, the EF is very close to the EF from UNEP (2005), it is therefore proposed to keep the EF as currently in the GB.

For HCB the EF is approximately a factor of ten higher than the current EF. The current EF refers to the previous GB. It is therefore proposed to change the EF to reference Grochowalski & Konieczyński (2008).

For PCBs there is a very large difference between the current EF (170 µg/GJ) and the average of the Polish measurements (3.3 ng WHO-TEQ/GJ). The current reference is Kakareka et al. (2004), which has not been retrieved in this study. In the previous GB values were provided indicating that the EFs from Kakareka et al. (2004) were for residential plants, which could explain the very high value. Furthermore, it is not clear whether the EF for PCBs in the current GB is in toxic equivalents. Therefore, it is proposed to change the EF to reference Grochowalski & Konieczyński (2008).

Proposed tier 2 EFs

The table below summarises the discussions and proposals in the preceding chapters. It contains, mainly the same references, however, with some errors corrected and using the heating values provided in US EPA (1998a) for the conversion.

Currently, there is no EFs in the GB for benzo(b)fluoranthene and benzo(k)fluoranthene. It has not been possible to find detailed data within the available time of this project. However, Wenborn et al. (1999) reports EFs in mg/ton for all 16 PAHs. There is no indication on the combustion technology. In order to ensure the highest degree of consistency it is proposed to keep the US EPA (1998a) EFs for the two PAHs and supplement with EFs from Wenborn et al. (1999) for the remaining two. The EFs for benzo(b)fluoranthene and benzo(k)fluoranthene are reported in Wenborn et al. (1999) as 0.9 mg/ton and 0.7 mg/ton respectively. Based on the Energy Statistics Manual (OECD/IEA, 2005) the average NCV for other bituminous coal is 24.1 GJ/ton. This corresponds to EFs of 37.3 µg/GJ and 29.0 µg/GJ.

	DBB	WBB	FBB	Unit
NOx	198	231	83	g/GJ
CO	8.3	8.3	70	g/GJ
NMVOC	1.0	0.7	0.8	g/GJ
SO2	820	820	820	g/GJ
TSP	10.8	7.6	7.9	g/GJ
PM10	7.3	5.7	7.3	g/GJ
PM25	3.3	3.0	5.0	g/GJ
Pb	6.9	6.9	6.9	mg/GJ
Cd	0.8	0.8	0.8	mg/GJ
Hg	1.4	1.4	1.4	mg/GJ
As	6.8	6.8	6.8	mg/GJ
Cr	4.3	4.3	4.3	mg/GJ
Cu	7.8	9.0	9.0	mg/GJ
Ni	4.6	4.6	4.6	mg/GJ

Se	21	21	21	mg/GJ
Zn	19	90	90	mg/GJ
PCBs	3.3	3.3	3.3	ng WHO-TEQ/GJ
PCDD/F	10	10	10	ng I-TEQ/GJ
Benzo(a)	0.6	0.6	0.6	µg/GJ
Benzo(b)	37	37	37	µg/GJ
Benzo(k)	29	29	29	µg/GJ
Indeno	1.0	1.0	1.0	µg/GJ
HCB	6.7	6.7	6.7	µg/GJ

Tier 1 EFs

It is proposed to use the same EFs for tier 1 as the tier 2 EFs for DBB.

Brown coal

For brown coal there are two tier 2 EF tables provided for DBB/WBB and FBB respectively. The vast majority of EFs refer to US EPA (1998b). The table below shows the current GB EFs for DBB/WBB compared with values from the US EPA (1998b). For conversion of the US EPA data the heating value as provided in the reference has been used (6500 BTU/lb). Furthermore, units have been converted using 1055.0559 J/BTU, 2000 lb/ton and 453.59237 g/lb.

	GB - DBB/WBB	US EPA	US EPA - converted
NO_x	286	7.1[1]	234.8
CO	20	0.25	8.3
NMVOC	1.7	0.04	1.3
TSP	40	0.336[2]	11.1
PM_{10}	30	0.227[3]	7.5
$PM_{2.5}$	14	0.093[3]	3.1
Pb	17.6	4.20E-04	13.9
Cd	2.1	5.10E-05	1.7
Hg	3.5	8.30E-05	2.7
As	17.2	4.10E-04	13.6
Cr	10.9	2.60E-04	8.6
Ni	11.8	2.80E-04	9.3
Se	54.6	1.30E-03	43.0
Benzo(a)	1.6	3.80E-08	1.3
Indeno	2.6	6.10E-08	2.0

[1] Pulverized coal, dry bottom, tangential

[2] Assumes baghouse and a coal ash weight percent of 4.2

[3] Assumes same particle size distribution as for lignite combustion controlled with multiple cyclones, i.e. $TSP:PM_{10}:PM_{2.5}$ = 1.3:0.88:0.36

There are some differences in the calculated EFs compared to the current EFs despite the same reference is being used. Currently, there is no EF for Cu. However, this is available in the previous GB, where a range of 0.004-0.02 g/Mg is provided. For Zn the range is 0.01-0.2 g/Mg. The calorific value of lignite can vary significantly. For the purpose of converting the EFs the default value from the 2006 IPCC Guidelines (IPCC, 2006) is used (11.9 GJ/Mg). This results in EFs of 1.0 mg/GJ for Cu and 8.8 mg/GJ for Zn.

The table below shows the current GB EFs for brown coal combustion in FBB compared with values from the US EPA (1998b). For conversion of the US EPA data the heating value as provided in the reference has been used (6500 BTU/lb). Furthermore, units have been converted using 1055.0559 J/BTU, 2000 lb/ton and 453.59237 g/lb.

	GB - FBB	US EPA	US EPA - converted
NO_x	61	3.6	119
CO	0.07	0.15	5.0
NMVOC	1.7	0.03	1.0
TSP	40	0.294[1]	9.7
PM_{10}	30	0.199[2]	6.6
$PM_{2.5}$	14	0.081[2]	2.7
Pb	18	4.20E-04	13.9
Cd	2.1	5.10E-05	1.7
Hg	3.5	8.30E-05	2.7
As	17	4.10E-04	13.6
Cr	11	2.60E-04	8.6
Ni	12	2.80E-04	9.3
Se	55	1.30E-03	43.0
Benzo(a)	0.8	3.80E-08	1.3
Indeno	1.3	6.10E-08	2.0

[1] Assumes ESP and a coal ash weight percent of 4.2

[2] Assumes same particle size distribution as for lignite combustion controlled with multiple cyclones, i.e. TSP:PM_{10}:$PM_{2.5}$ = 1.3:0.88:0.36

For NO_x and CO the EFs refer to the BREF document on large combustion plants (EIPPCB, 2006). For NO_x the following values are provided in the BREF document: 76.1 g/GJ (capacity 100-300 MW) and a range of 43-60.4 g/GJ (capacity > 300 MW). How the current EF (61 g/GJ) has been derived is somewhat of a mystery. However, taking the arithmetic average of 43 and 76.1 gives an average EF of 60 g/GJ, which is proposed in the GB. The current CO EF in the GB is 0.07 g/GJ, this can be compared to 0.1 g/GJ (capacity 100-300 MW) and a range of 4.5-25.9 g/GJ (capacity > 300 MW) from the BREF document. The current EF is lower than any EF provided in the BREF document. The average EF from the BREF document would be 13 g/GJ. It is somewhat higher than the EF derived from the US EPA (1998b), however, since the BREF data should be better reflecting European conditions, this EF is proposed to be included in the GB.

To ensure some degree of consistency between the EFs for PM and HMs, it is proposed to change the current EFs based on expert judgment (based on Visschedijk et al., 2004) to EFs derived from the US EPA (1998b), from where most of the HM EFs are sourced.

For Cu and Zn, the EFs refer to the previous version of the GB. However, the EFs cannot be recreated. For Cu a range of 0.004-0.02 g/Mg is provided. For Zn the range is 0.01-0.2 g/Mg. The calorific value of lignite can vary significantly. For the purpose of converting the EFs the default value from the 2006 IPCC Guidelines (IPCC, 2006) is used (11.9 GJ/Mg). This results in EFs of 1.0 mg/GJ for Cu and 8.8 mg/GJ for Zn.

Proposed tier 2 EFs

The table below summarises the discussions and proposals in the preceding chapters. It contains, mainly the same references, however, with some errors corrected and using the heating values provided in US EPA (1998a) for the conversion.

It has not been possible to find EFs for PCBs, benzo(b)fluoranthene, benzo(k)fluoranthene and HCB specifically for brown coal combustion. It is proposed to include the EFs for hard coal combustion for brown coal combustion in lack of better data.

	DBB/WBB	FBB	Unit
NO_x	235	60	g/GJ
CO	8.3	13	g/GJ
NMVOC	1.3	1.0	g/GJ
SO_2	820	820	g/GJ
TSP	11.1	9.7	g/GJ
PM_{10}	7.5	6.6	g/GJ
$PM_{2.5}$	3.1	2.7	g/GJ
Pb	14	14	mg/GJ
Cd	1.7	1.7	mg/GJ
Hg	2.7	2.7	mg/GJ
As	14	13.6	mg/GJ
Cr	8.6	8.6	mg/GJ
Cu	1.0	1.0	mg/GJ
Ni	9.3	9.3	mg/GJ
Se	43	43	mg/GJ
Zn	8.8	8.8	mg/GJ
PCBs	3.3	3.3	ng WHO-TEQ/GJ
PCDD/F	10	10	ng I-TEQ/GJ
Benzo(a)	1.3	1.3	µg/GJ
Benzo(b)	37	37	µg/GJ
Benzo(k)	29	29	µg/GJ
Indeno	2.0	2.0	µg/GJ
HCB	6.7	6.7	µg/GJ

Tier 1 EFs

It is proposed to use the same EFs for tier 1 as the tier 2 EFs for DBB/WBB.

Oil

The GB contains three tier 2 EF tables for residual oil in dry bottom boilers, gas oil fired gas turbines and gas oil fired engines. Additionally, there are tier 1 EF tables for heavy fuel oil and other liquid fuels. The tier 2 EFs will be discussed first and afterwards the tier 1 EFs will be addressed.

The GB refers to the US EPA chapter on fuel oil combustion as US EPA (1998). However, this chapter was updated in 2010, therefore it is referenced in this discussion paper as US EPA (2010).

Boilers

EFs are provided for residual oil combusted in dry bottom boilers. The majority of EFs refer to the US EPA (2010). The exceptions are NO_x, which refers to CITEPA (1992), PM, which refers to Visschedijk et al. (2004) and PCDD/F, which refers to UNEP (2005).

For NO_x the reference is quite old and the EF seems rather high compared even with the highest EF (without low-NO_x burners and/or abatement) provided in US EPA (2010). However, it is proposed to maintain it in the GB. There should be substantial measurement data available across Europe to allow for an update of this EF, but nothing appears to be published.

Visschedijk et al. (2004) presents EFs for four different types of installations. Currently the EFs refer to the second lowest emission level. While this indeed is a realistic PM EF level (or maybe even to high), it is inconsistent with the HM EFs presented. The HM EFs referenced to the US EPA (2010) are all unabated and therefore the PM EFs should also be presented as unabated. This will allow inventory compilers using the GB to see the actual relationship between PM and HM emissions. Currently, applying the GB could lead to an overestimation of HM emissions. It is therefore proposed that the EFs for PM are changed to the values from the US EPA (2010).

For PCDD/F, the EF refers to UNEP (2005). It is proposed to maintain this EF.

The EFs derived from the US EPA and the current GB EFs are shown in the table below. For conversion of the US EPA data the heating value as provided in the reference has been used (150 MMBTU/10^3 gal). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	US EPA - original unit	US EPA - converted	GB EF	Proposed EF
NO_x	47[1]	135	210	210
CO	5	14.3	15.1	14.3
NMVOC	0.76	2.2	2.3	2.2
SO_2			485	485
TSP	12.367[2]	35.4	20	35.4
PM_{10}	8.791	25.2	15	25.2
$PM_{2.5}$	6.407	18.4	9	18.4
Pb	1.51E-03	4.3	4.6	4.3
Cd	3.98E-04	1.1	1.2	1.1
Hg	1.13E-04	0.3	0.3	0.3
As	1.32E-03	3.8	4	3.8
Cr	8.45E-04	2.4	2.5	2.4
Cu	1.76E-03	5.0	5.3	5.0
Ni	8.45E-02	242	255	242
Se	6.83E-04	2.0	2.1	2.0
Zn	2.91E-02	83	88	83
PCDD/F			2.5	2.5
Benzo(b)	1.48E-06[3]	4.2		4.2
Benzo(k)	1.48E-06[3]	4.2		4.2
Indeno	2.14E-06	6.1	6.9	6.1

[1] This is the highest EF provided for large boilers (> 100 Million Btu/hr), for smaller boilers the EF is reported as 55 lb/10^3 gal corresponding to 158 g/GJ.
[2] The TSP EF assumes 1 % sulphur content in the fuel, the factor is derived from the equation EF = 8.3 * A, where A = 1.12(S) + 0.37.
[3] The EF reported for benzo(b,k)fluoranthene has been used.

Gas turbines

Currently, the completeness of the EF table for gas oil fired gas turbines is lacking. Several HMs and all POPs are missing from the table. The EFs included refer to the US EPA (2000a) and for PM to Rubenstein (2003). It is not possible to retrieve a copy of Rubenstein (2003), apparently it is a paper/presentation at a conference in 2003, when searching for the title of this reference the only results are the current and previous GB chapters. The reference is therefore considered to be of poor validity.

Recent measurement data are available for NO_x, CO and PM from a Danish study (Nielsen et al., 2010), and even though these data are based on very few measurements, they are proposed to be included in the GB. For NMVOC and SO_2 the current EFs are maintained.

For heavy metals it is proposed to use the data on HM content in European diesel oil as reported by van der Gon and Kuenen (2009). While the data is based on analysis of fuels sold for road transport, it is believed that the data is valid for gas oil used in stationary plants as well. Contact with a Danish refinery has confirmed that there is no difference in HM content between gas oil sold for stationary and mobile combustion.

It is proposed to include an EF for PCDD/F based on Pfeiffer et al. (2000). Even though the EF is referring to small installations (central heating boilers), it is the only dataset available. The EF is derived based on the average of the three new technologies listed by Pfeiffer et al. (2000). The EF is converted using a NCV of 42.8 GJ/ton as specified by Pfeiffer et al. (2000).

	GB EF	Proposed EF	Reference
NO_x	398	83	Nielsen et al., 2010
CO	1.5	2.6	Nielsen et al., 2010
NMVOC	0.2	0.2	US EPA, 2000. Chapter 3.1
SO_2	46	46	Based on 0,1 % S
TSP	3	9.5	Nielsen et al., 2010
PM_{10}	3	9.5	Nielsen et al., 2010 (TSP=PM10=PM2.5)
$PM_{2.5}$	3	9.5	Nielsen et al., 2010 (TSP=PM10=PM2.5)
Pb	6.3	0.012	van der Gon & Kuenen, 2009
Cd	2.2	0.001	van der Gon & Kuenen, 2009
Hg	0.5	0.12	van der Gon & Kuenen, 2009
As		0.002	van der Gon & Kuenen, 2009
Cr	5	0.2	van der Gon & Kuenen, 2009
Cu		0.13	van der Gon & Kuenen, 2009
Ni		0.005	van der Gon & Kuenen, 2009
Se		0.002	van der Gon & Kuenen, 2009
Zn		0.42	van der Gon & Kuenen, 2009
PCDD/F		1.1	Pfeiffer et al., 2000

Engines

The GB contains EFs for large stationary gas fuelled engines. All EFs are referenced to US EPA (1996 & 2010). However, in the EF table it is incorrectly referenced to chapter 3.3, while the correct chapter is 3.4. Furthermore, it seems that the EFs have not been calculated correctly based on the reference.

	US EPA original unit	US EPA converted	GB
NO_x	3.2	1376	1450
CO	0.85	365	385
NMVOC	0.0819	35	37
SO_2	0.101	43	46
TSP	0.0573	24.6	28.1
PM_{10}	0.0496	21.3	22.4
$PM_{2.5}$	0.0479	20.6	21.7
Pb	9	3.9	4.1
Cd	3	1.3	1.4
Hg	3	1.3	1.4
As	4	1.7	1.8
Cr	3	1.3	1.4
Cu	6	2.6	2.7
Ni	3	1.3	1.4
Se	15	6.4	6.8
Zn	4	1.7	1.8
Benzo(a)	2.57E-07	0.11	0.12
Benzo(b)	1.11E-06	0.48	0.50
Benzo(k)	2.18E-07	0.09	0.10
Indeno	4.14E-07	0.18	0.19

The EFs for NO_x and CO are somewhat higher than recent measurements. Measurements reported by Nielsen et al. (2010) showed a NO_x EF of 942 g/GJ and a CO EF of 130 g/GJ. The current CO EF is far above the highest value reported in the Danish measurements. It is proposed to update the EFs for NO_x and CO to reference Nielsen et al. (2010).

The HM EFs and PAHs EFs reported by Nielsen et al. (2010) are significantly lower (except Zn) than the EFs based on US EPA data. However, they are based on a single measurement and there is no PM EFs available. Therefore, the EFs based on US EPA (1996 & 2010) are proposed to be maintained in the GB at present. The comparison is shown in the table below.

mg/GJ	US EPA converted	GB	Nielsen et al., 2010
Pb	3.9	4.1	0.15
Cd	1.3	1.4	0.01
Hg	1.3	1.4	0.11
As	1.7	1.8	0.06
Cr	1.3	1.4	0.2
Cu	2.6	2.7	0.3
Ni	1.3	1.4	0.01

Se	6.4	6.8	0.22
Zn	1.7	1.8	58
Benzo(a)	0.11	0.12	0.0019
Benzo(b)	0.48	0.50	0.0150
Benzo(k)	0.09	0.10	0.0017
Indeno	0.18	0.19	0.0015

Currently, there are no EFs for PCDD/F, PCBs or HCB in the GB. These pollutants were included in the measurements reported by Nielsen et al. (2010). It is therefore proposed to include these in the EF table. The EF for PCDD/F is 0.99 ng/GJ, for PCBs the EF is 0.13 ng/GJ and for HCB the EF is 0.22 µg/GJ.

Tier 1

There are two tier 1 EF tables in the GB, one for heavy fuel oil (HFO) and one for other liquid fuels (OLF). The EFs are shown together with the current tier 2 EFs for residual oil combustion in the table below.

	GB – Tier 1 HFO	GB – Tier 1 OLF	GB - Tier 2 residual oil DBB
NO_x	215	180	210
CO	5	15	15,1
NMVOC	0,8	0,8	2,3
SO_2	485	460	485
TSP	25	3	20
PM_{10}	18	2	15
$PM_{2.5}$	13	1	9
Pb	4,9	4,1	4,6
Cd	1,3	1,4	1,2
Hg	0,4	1,4	0,3
As	4,3	1,8	4
Cr	2,7	1,4	2,5
Cu	5,7	2,7	5,3
Ni	273	1,4	255
Se	2,2	6,8	2,1
Zn	94	1,8	88
PCDD/F	2,5	1,5	2,5
Indeno	6,9	6,9	6,9

It is not clear why the tier 1 EFs in some cases are different from the tier 2 EFs for residual oil combustion. In some cases it seems to simply be a mistake, e.g. for CO the tier 1 EF of 5 g/GJ matches the US EPA value of 5 lb/10^3 gal. For PM there is no explanation on why the expert judgment, based on the reference, used to derive PM EFs comes up with different values. For HMs the values are also strangely different in spite of the fact that both sets are referenced to US EPA (2010). Referring to the discussion on the tier 2 EFs, it can also be noted that in neither case have the heating value provided in the reference been used.

It is proposed to change the tier EFs for HFO, so they match the tier 2 EFs for residual oil combustion.

For other liquid fuels, it is not clear from the GB what is covered. If going by Table 3-2, it is everything from gas oil, naphtha, NGL, LPG, orimulsion, shale oil and refinery gas. It is impossible that the EFs would be representative for all the fuels listed.

The current EFs refer to multiple data sources. The EFs for NMVOC, HMs and indeno refer to US EPA (2010), for NMVOC and HMs the EFs are based on gas oil (distillate oil), while the EF for indeno refers to fuel oil. The EF for PCDD/F (1.5 ng/GJ) refers to UNEP (2005) and is taken for shale oil. UNEP (2005) provides an EF for HFO of 2.5 ng/GJ and for light oil of 0.5 ng/GJ. For PM the EFs are expert judgment based on Visschedijk et al. (2004), however, it is completely unclear what assumptions are behind the derivation of the PM EFs.

For NO_x and CO the EFs refer to CORINAIR (1990). The reference is to a working paper for a meeting held in 1991. Based on the first version of the EMEP/CORINAIR Guidebook the following information is provided referenced to CORINAIR (1990).

	NOx	CO
Gas oil	50-269	10-46.4
Kerosene		12
Naphtha	180	15
Black liquor[1]	20-440	11.1-314

[1] This is listed as a liquid fuel in the original GB, but is categorised as biomass.

Based on the EFs, it seems that EFs for naphtha have been chosen as representative for “other liquid fuels”. This seems like an odd choice, since the naphtha consumption will be very small compared to that of other liquid fuels e.g. gas oil.

Since the majority of the current EFs refer to gas oil, it seems more reasonable to change the EFs for NO_x, CO and PM to match. Therefore, it is proposed that these EFs are also referenced to US EPA (2010). The EFs derived from US EPA (2010) are shown in the table below. For conversion of the US EPA data the heating value as provided in the reference has been used (140 MMBTU/10^3 gal). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	US EPA - original unit	US EPA - converted
NO_x	20	61
CO	5	14.3
TSP	2	5.7
PM_{10}	1	2.9
$PM_{2.5}$	0.25	0.7

In the GB the fuel indication in this table will be changed to gas oil. Furthermore, as discussed at the TFEIP meeting in Berne, guidance will be provided on the most suitable EFs for the different fuels, e.g. that for LGP and refinery gas, it is more suitable to use the EFs for natural gas than to use the EFs derived for gas oil.

Natural gas

The GB chapter contains tier 2 EFs for natural gas combusted in boilers, gas turbines and gas engines. In addition the chapter contains tier 1 EFs for natural gas and derived gases.

Boilers

All tier 2 EFs for boilers refer to US EPA (1998c) with the exception of the EFs for Hg and PCDD/F. These EFs refer to van der Most & Veldt (1992) and UNEP (2005) respectively. It has not been possible to retrieve a copy of van der Most & Veldt (1992). For NMVOC there seems to have been an error in the conversion in the GB. The correct EF based on the US EPA (1998c) data is 2.6 g/GJ.

	Based on US EPA		Current EF
	lb/10^6 scf	g/GJ[1]	g/GJ[1]
NO_x	190	89	89
CO	84	39	39
NMVOC	5.5	2.6	1.5
SO_2	0.6	0.3	0.3
TSP	1.9	0.89	0.9
PM_{10}	1.9	0.89	0.9
$PM_{2.5}$	1.9	0.89	0.9
Pb	0.0005	0.2	0.2
Cd	1.10E-03	0.5	0.5
Hg	2.60E-04	0.1	0.1
As	2.00E-04	0.1	0.09
Cr	1.40E-03	0.7	0.7
Cu	8.50E-04	0.4	0.4
Ni	2.10E-03	1.0	1.0
Se	2.40E-05	0.01	0.01
Zn	2.90E-02	13.6	14
PCDD/F			0.5
Benzo(a)	1.20E-06	0.6	0.6
Benzo(b)	1.80E-06	0.8	0.8
Benzo(k)	1.80E-06	0.8	0.8
Indeno	1.80E-06	0.8	0.8

[1] For HMs the unit is mg/GJ and for PAHs µg/GJ.

For HMs data are available regarding the HM content in Danish natural gas. Based on this EFs can be derived. The table below provides a comparison between the HM EFs derived based on fuel analysis of Danish natural gas (Nielsen et al., 2012) and the current EFs based on data from the United States.

Comparison of HM EFs natural gas from Nielsen et al. (2012) with the EFs from US EPA (1998c)

	Nielsen et al., 2012	US EPA, 1998c
Pb	0.0015	0.2
Cd	0.00025	0.5
Hg	0.68	0.1
As	0.12	0.1
Cr	0.00076	0.7
Cu	0.000076	0.4
Ni	0.00051	1.0
Se		0.01
Zn	0.0015	13.6

It is proposed to update the HM EFs for all other HMs than Se to the values provided by Nielsen et al. (2012).

The EF for PCDD/F (0.5 ng/GJ) refers to UNEP (2005). The reference does not distinguish between gas oil fired boilers and natural gas fired boilers. There are very few available data for PCDD/F emissions from gas combustion, UNEP (2005) refers to three sources for their information, but it has not been possible to acquire any of the original references. In the national reporting Austria uses an EF of 0.2 ng/GJ referenced to Wurst & Hübner (1997). The same value is reported by Rentz et al. (2008). Since no better data is available, it is proposed to keep the EF for the moment.

Tier 1 EFs

The tier 1 EFs for natural gas are currently identical to the tier 2 EFs for natural gas combustion in boilers. It is proposed to maintain this, so that the changes implemented for tier 2 boilers will also be implemented in the tier 1 EF table.

The GB also contains tier 1 EFs for derived gases, which according to the GB guidance covers gas works gas, coke oven gas and blast furnace gas. The EFs are an inconsistent mix of expert judgment, old CORINAIR90 EFs and defaults EFs for natural gas from the US EPA (1998c). When examining the data it becomes even more inconsistent. The EFs for CO and NMVOC that refer to CORINAIR90 is not even fitting the definition. The CO EF actually refers to refinery gas, while the NMVOC EF actually is the upper value of the range for blast furnace gas and the lower limit for coke oven gas. The overall range would be 1-167 g/GJ compared to the listed EF of 2.5 g/GJ.

Based on the observations above it is very difficult to see the usefulness of this EF table. Therefore, it is proposed to delete this table as most if not all the EFs are out-of-date or for different fuels than what is supposedly in the table.

Gas turbines

All EFs (except Hg) are referenced to the US EPA. For NO_x, CO, NMVOC and PM the EFs refer to US EPA (2000a), while the remaining EFs are referenced to the general chapter on natural gas combustion (US EPA, 1998c). The EF table does not include an EF for PCDD/F, it is proposed to include the same EF as used for natural gas combusted in boilers.

More recent data are available for the main pollutants from Denmark (Nielsen et al., 2010) and Switzerland (BUWAL, 2001). The values from the studies are provided in the tables below.

	Nielsen et al., 2012	BUWAL	GB
NO_x	48	60	153
CO	4,8	15	39,2
NMVOC	1,6	0,1	1
SO_2		0,5	0,281
TSP		0,2	0,908
PM_{10}		0,2	0,908
$PM_{2.5}$		0,2[1]	0,908

[1] Assumed identical to PM_{10}.

It is suggested to change the EFs for NO_x, CO and NMVOC to the EFs provided by Nielsen et al. (2010) and the EFs for SO_2, TSP, PM_{10} and $PM_{2.5}$ to the EFs provided by BUWAL (2001).

For HMs data are available regarding the HM content in Danish natural gas. Based on this EFs can be derived. The table below provides a comparison between the HM EFs derived based on fuel analysis of Danish natural gas (Nielsen et al., 2012) and the current EFs based on data from the United States.

	Nielsen et al., 2012	US EPA, 1998c
Pb	0.0015	0.2
Cd	0.00025	0.5
Hg	0.68	0.1
As	0.12	0.1
Cr	0.00076	0.7
Cu	0.000076	0.4
Ni	0.00051	1.0
Se		0.01
Zn	0.0015	13.6

It is proposed to update the HM EFs for all other HMs than Se to the values provided by Nielsen et al. (2012).

Currently, there is no EF for PCDD/F. In line with the EFs for natural gas fired boilers it is proposed to use the EF provided by UNEP (2005) of 0.5 ng/GJ.

It has not been possible to find additional references for PAH EFs for natural gas turbines. Therefore, it is proposed to keep the existing values based on US EPA (1998c).

Engines

All EFs (except Hg) are referenced to the US EPA. Most of the EFs are not transparently documented, since they are referenced as expert judgment based on two different chapters of AP42 (US EPA, 1996 & US EPA, 2000b). EFs for many of the pollutants are available from Danish measurements on a large number of stationary natural gas fired gas engines (Nielsen et al., 2010). The remaining EFs are sourced from BUWAL (2001). The EFs are provided in the table below

	GB	Proposed EF	Reference
NO_x	1420	135	Nielsen et al., 2010
CO	407	56	Nielsen et al., 2010
NMVOC	46	89	Nielsen et al., 2010
SO_2	0.281	0.5	BUWAL, 2001
TSP	1.5	2	BUWAL, 2001
PM_{10}	1.5	2	BUWAL, 2001
$PM_{2.5}$	1.5	2	BUWAL, 2001
Pb	0.234	0.04	Nielsen et al., 2010
Cd	0.515	0.003	Nielsen et al., 2010
Hg	0.1	0.1	Nielsen et al., 2010
As	0.0937	0.05	Nielsen et al., 2010
Cr	0.656	0.05	Nielsen et al., 2010

Cu	0.398	0.01	Nielsen et al., 2010
Ni	0.984	0.05	Nielsen et al., 2010
Se	0.0112	0.2	Nielsen et al., 2010
Zn	13.6	2.91	Nielsen et al., 2010
PCDD/F		0.57	Nielsen et al., 2010
Benzo(a)pyrene	2.7	1.20	Nielsen et al., 2010
Benzo(b)fluoranthene	18	9.00	Nielsen et al., 2010
Benzo(k)fluoranthene	2	1.70	Nielsen et al., 2010
Indeno(1,2,3-cd)pyrene	4.7	1.80	Nielsen et al., 2010

It is proposed that the data presented above replaces the current EF table (Table 3-23). If needed a dedicated table for dual fuelled engines can be elaborated based on US EPA (1996). However, only main pollutants are available and the EFs for HMs and PAHs will therefore refer to the EFs for natural gas fired engines.

Wood

The chapter contains tier 2 EFs for wood combustion in dry bottom boilers and fluid bed boilers and tier 1 EFs for generic biomass combustion.

For NMVOC, SO_2, HMs and PAHs the reference is US EPA (2003). For NO_x and CO the reference for fluid bed boilers is Kubica et al. (2003). However, this seems to be a presentation at a previous TFEIP meeting and any published reference has not been found.

When analysing the GB data in comparison to the data that can be derived from the US EPA (2003), it is clear that the GB has a factor 10 error in the EF for indeno(1,2,3-cd)pyrene.

	GB - tier 1	GB - DBB	GB - FBB	US EPA - original unit	US EPA - converted
NO_x	211	211	96	0.49	211
CO	258	258	42	0.6	258
NMVOC	7.3	7.3	7.3	0.017	7.3
SO_2	11	11	11	0.025	11
TSP	51	35	35	0.4	172
PM_{10}	38	23	23	0.36	155
$PM_{2.5}$	33	12	12	0.31	133
Pb	21	21	21	4.80E-05	20.6
Cd	1.8	1.8	1.8	4.10E-06	1.8
Hg	1.5	1.5	1.5	3.50E-06	1.5
As	9.5	9.5	9.5	2.20E-05	9.5
Cr	9	9	9	2.10E-05	9.0
Cu	21	21	21.1	4.90E-05	21.1
Ni	14	14	14.2	3.30E-05	14.2
Se	1.2	1.2	1.2	2.80E-06	1.2
Zn	181	181	181	4.20E-04	180.6
PCBs	60	60	60		
PCDD/F	50	50	50		
Benzo(a)	1.12	1.1	1.1	2.60E-06	1.12

Benzo(b)	0.04	0.04	0.04	1.00E-07	0.04
Benzo(k)	0.02	0.015	0.02	3.60E-08	0.02
Indeno	0.37	0.37	0.37	8.70E-08	0.04
HCB	6	6	6		

The NO_x and CO EFs from US EPA (2003) seem to be very high compared to the values used for FBB from Kubica et al. (2003) and also compared to other recently published data, e.g. Nielsen et al. (2010), which reported NO_x and CO EFs of 81 g/GJ and 90 g/GJ respectively. The BREF document (EIPPCB, 2006) provides a NO_x EF of 57 g/GJ for a plant with primary NO_x reducing measures. The footnote to the table in US EPA (2003) states that for FBB the CO EF is substantially lower (0.17 lb/MMBTU ≈ 73 g/GJ), this value is more in line with the other available references. Even though, the EFs in Nielsen et al. (2010) are based on very few measurements, it is proposed to change the NO_x and CO EFs to this reference. This will mean that the EF tables for DBB/WBB and FBB will be identical. Therefore, it is proposed to merge the tables, so there will only be one EF table for all boilers combusting wood.

The PM EFs are quite curious. The uncontrolled EF form US EPA can be converted to an EF of 172 g/GJ, the EF from US EPA for a plant with ESP is 24 g/GJ, which is more in line with the EFs of 9 g/GJ and 10 g/GJ reported in the BREF document (EIPPCB, 2006) and Nielsen et al. (2010) respectively. The current tier 2 EFs refer to expert judgment based on Visschedijk et al. (2004). However, Visschedijk et al. (2004) reports a TSP EF of 100 g/GJ. The assumption in one of the tier 2 EF tables (Table 3-19) states that a concentration of 50 mg/Nm3 has been assumed. No other information is provided.

Since the HM EFs from the US EPA (2003) are unabated, it should also be the unabated PM EFs that are included in the EF tables. Therefore, it is proposed to change the PM EFs to unabated values and state this in the EF tables.

The EFs for PAH are quite low compared to Nielsen et al. (2010). However, since only one measurement in Nielsen et al. (2010) was above the detection limit, it is proposed to maintain the current EFs.

The HCB EF refers to a previous version of the GB. The EF presented in the previous version is 60 µg/ton for firewood. This is referenced to Pacyna et al. (1999), which is not available online. The EF is identical to the value reported by Bailey (2001) and referenced to Cohen et al. (1995). It has not been possible to acquire a copy of Cohen et al. (1995), wherefore it has not been possible to verify the background of this EF. It is proposed to change the reference and the interval to the values reported by Bailey (2001). Currently the EF has been converted using a NCV of 10 GJ/ton. This seems quite low as it is close to the value of fresh cut wood (8.2 GJ/ton – OECD/IEA, 2005). It is proposed to use the average between fresh cut wood and air dried wood as reported by OECD/IEA (2005) corresponding to 12 GJ/ton.

The reference attributed to the PCB EF in the GB is Kakareka et al. (2004). It is not included in the list of references, but in the chapter on sources of PCB in the previous GB, it is clear that the EF refers to residential combustion. It is therefore not considered suitable for power plants. From US EPA (2003) the following data is provided for PCBs.

	US EPA - original unit	US EPA - converted
Monochlorobiphenyl	2.20E-10	9.46E-02

Dichlorobiphenyl	7.40E-10	3.18E-01
Trichlorobiphenyl	2.60E-09	1.12E+00
Tetrachlorobiphenyl	2.50E-09	1.07E+00
Pentachlorobiphenyl	1.20E-09	5.16E-01
Hexachlorobiphenyl	5.50E-10	2.36E-01
Heptachlorobiphenyl	6.60E-11	2.84E-02
Octachlorobiphenyl	0.00E+00	0.00E+00
Nonachlorobiphenyl	0.00E+00	0.00E+00
Decachlorobiphenyl	2.70E-10	1.16E-01

A simple summation of the EFs gives a total of 3.5 µg/GJ compared to the current EF of 60 µg/GJ. It is proposed to change the EF, since the current refers to residential wood combustion. Unless better data becomes available, the PCBs EF will be updated to 3.5 µg/GJ.

The PCDD/F EF refers to UNEP (2005), it has not been possible to find more reliable data within the timeframe available.

The tier 1 EF table for biomass will be identical as the tier 2 EFs.

Petroleum refining

This chapter contains tier 1 EFs for refinery gas and tier 2 EFs for residual oil, gas oil, LPG and natural gas used in process furnaces as well as EFs for natural gas and gas oil used in reciprocating engines.

For refinery gas the GB for tier 2 EFs refer to the tier 1 EFs. The vast majority of the EFs refer to US data predominantly from the US EPA.

No information has been found on emissions of NH_3, HCB and PCBs. As a result these pollutants are still listed as NE for all EF tables.

Tier 1

For refinery gas the EFs for the main pollutants refer to US EPA data for natural gas boilers. For heavy metals and PAHs the EFs refer to two references from the American Petroleum Institute (API) (API, 1998 and API, 2002). None of these are freely available online and have therefore not been checked. The values are also referenced by Concawe (2009).

The EFs of the main pollutants are consistent with the information in the reference (US EPA, 1998c). However, for NO_x it is not clear how the current EF (60 g/GJ) has been derived. US EPA provides values ranging from 76 lb/10^6 scf for controlled tangential-fired boilers to 190 lb/10^6 scf for large wall-fired boilers (uncontrolled post-NSPS). This corresponds to an interval of 36 g/GJ to 89 g/GJ. Taking the arithmetic average of these corresponds to an EF of 63 g/GJ, which is proposed as an updated NO_x EF.

As mentioned it has not been possible to check the original references for the HMs and PAHs EFs. However, a comparison of the EFs with the EFs for natural gas combustion from the US EPA shows a general good agreement. Therefore, it is considered reasonable to continue the use of these EFs. However, it should be investigated whether copies of the original references can be obtained by the TFEIP.

For Se and Zn there are currently no EFs provided. It is proposed to use the EFs for natural gas from the US EPA for refinery gas. This means a Se EF of 0.01 mg/GJ and a Zn EF of 13.6 mg/GJ.

Tier 2

As mentioned four tier 2 EF tables are provided for process heaters. These cover residual oil, gas oil, LPG and natural gas.

Residual oil

The EFs refer mainly to the US EPA (2010), however the PM EFs and four of the HMs refer to expert judgment (based on Visschedijk et al., 2004) and API (1998 and 2002) respectively. The table below presents the data as derived from the US EPA (2010) compared to the current EFs. For conversion of the US EPA data the heating value as provided in the reference has been used (150 MMBTU/10^3 gal). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	Based on US EPA		Current EF
	lb/10^3 gal	g/GJ[1]	g/GJ[1]
NO_x	47	135	123
CO	5	14	15
NMVOC	0.76	2.2	2.3
SO_2	157	450	485
TSP	12.41	36	20
PM_{10}	10.7	31	15
$PM_{2.5}$	7.0	20	9
Pb	1.51E-03	4.3	4.6
Cd	3.98E-04	1.1	1.2
Hg	1.13E-04	0.3	0.11
As	1.32E-03	3.8	4
Cr	8.45E-04	2.4	15
Cu	1.76E-03	5.0	12
Ni	8.45E-02	242	1030
Se	6.83E-04	2.0	NE
Zn	2.91E-02	83.4	49
Benzo(b,k)	1.48E-06	4.2	NE
Indeno	2.14E-06	6.1	NE

[1] For HMs the unit is mg/GJ and for PAHs µg/GJ.

The small differences for the pollutants previously referenced to US EPA (2010) can possibly be attributed to the use of a different heating value instead of the one provided in the reference. For PM the EFs calculated based on US EPA are higher than the current EFs. The current PM EFs in the GB are referenced as "Expert judgment based on Visschedijk et al. (2004)". However, Visschedijk et al. (2004) reports PM EFs for heavy oil used in refineries as 50 g/GJ, 40 g/GJ and 35 g/GJ respectively for TSP, PM_{10} and $PM_{2.5}$. To have the highest degree of consistency, it is proposed that the PM EFs are changed to the ones derived from US EPA data.

The EFs for Cr, Cu, Ni and Zn refer to API (1998 and 2002). For Cr, Cu and Ni these EFs are significantly higher than the EFs for residual oil combustion from US EPA (2010). Similarly to refinery gas it is proposed to keep these EFs for the time being, but in the future the original reference should be sourced and checked.

EFs for Se and PAHs are currently not included in the GB. It is proposed to include EFs for Se and the available PAHs from US EPA (2010).

Gas oil

All of the EFs provided in the GB refer to US EPA (2010). A comparison of the values as calculated based on the information from US EPA (2010) and the EFs in the GB is provided in the tables below. For conversion of the US EPA data the heating value as provided in the reference has been used (140 MMBTU/10^3 gal). Furthermore, units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	Based on US EPA		Current EF
	lb/10^3 gal	g/GJ	g/GJ
NO_x	20	61	60
CO	5	15	16
NMVOC	0.2	0.6	1.1
SO_2	14.2	44	46
TSP	2	6.1	6.5
PM_{10}	1	3.1	3.2
$PM_{2.5}$	0.25	0.8	0.8

As can be seen there is a generally good agreement, and the small differences can probably be attributed to not using the heating value as provided in the reference when recalculating the values. For NMVOC the difference is larger and is not explainable. It is proposed to change the EFs to match the current calculations based on US EPA (2010).

For HMs the comparison is shown in the table below. The units have been converted using 1055.0559 J/BTU and 453.59237 g/lb.

	Based on US EPA		Current EF
	lb/10^12 BTU	mg/GJ[1]	mg/GJ[1]
Pb	9	3.9	4.1
Cd	3	1.3	1.4
Hg	3	1.3	1.4
As	4	1.7	1.8
Cr	3	1.3	1.4
Cu	6	2.6	2.7
Ni	3	1.3	1.4
Se	15	6.4	6.8
Zn	4	1.7	1.8
Benzo(b,k)	9	3.9	NE
Indeno	3	1.3	NE

[1] For PAHs the unit is µg/GJ.

The small differences are probably due to rounding during the unit conversions. It is proposed to revise the EFs to the ones presented in the table above. Furthermore, it is proposed to include EFs for benzo(b)fluoranthene, benzo(k)fluoranthene and Indeno(1,2,3-cd)pyrene based on the data from US EPA (1998c).

LPG

Currently only the EFs of NO_x, CO, NMVOC and PM are specific to LPG, since the rest of the EFs refer to natural gas. The reference (US EPA, 2008a) provides EFs for propane and butane, the assumed composition of LPG is not provided in the GB. Furthermore, the reference (US EPA, 2008a) states that PM, CO and NMVOC are the same as for natural gas on a heat input basis. If it is assumed that LPG is 50 % propane and 50 % butane, the EFs can be calculated as seen in the table below. The EFs are recalculated using 91.5 $MMBtu/10^3$ gal for propane, 102 $MMBtu/10^3$ gal for butane, 1055.0559 J/BTU and 453.59237 g/lb.

	Based on US EPA				
	$lb/10^3$ gal		g/GJ	g/GJ	Current EF
	Propane	Butane	LPG	Natural gas	
NOx	13	15	62	63	64
CO	7,5	8,4	35	39	37
NMVOC[1]	1	1,1	4,7	2,6	4
TSP	0,2	0,2	0,89	0,89	0,99

[1] For LPG the EF is provided for TOC while for natural gas the EF is provided for VOC. When comparing TOC the values are practically identical.

As can be seen there is practically no difference between the LPG EFs and the natural gas EFs. The only exception is for NMVOC, which is due to the different definitions.

Therefore, it seems redundant to have a separate EF table for LPG since all EFs are identical or very similar to those of natural gas. It is therefore proposed that the table (Table 4-7) is removed from the GB. A sentence will be added to chapter 4.4.3.2 stating that if LPG is used the EFs for natural gas should be used to calculate emissions.

Natural gas

The EFs of the pollutants are consistent with the information in the reference (US EPA, 1998c). However, for NO_x it is not clear how the current EF (60 g/GJ) has been derived. US EPA provides values ranging from 76 $lb/10^6$ scf for controlled tangential-fired boilers to 190 $lb/10^6$ scf for large wall-fired boilers (uncontrolled post-NSPS). This corresponds to an interval of 36 g/GJ to 89 g/GJ. Taking the arithmetic average of these corresponds to an EF of 63 g/GJ, which is proposed as an updated NO_x EF.

	Based on US EPA		Current EF
	$lb/10^6$ scf	g/GJ[1]	g/GJ[1]
NO_x	76-190	63 (36-89)	60
CO	84	39	39
NMVOC	5.5	2.6	2.6
SO_2	0.6	0.3	0.3
TSP	1.9	0.89	0.89
PM_{10}	1.9	0.89	0.89
$PM_{2.5}$	1.9	0.89	0.89
Pb	0.0005	0.2	0.2

Cd	1.10E-03	0.5	0.5
Hg	2.60E-04	0.1	0.1
As	2.00E-04	0.1	0.09
Cr	1.40E-03	0.7	0.7
Cu	8.50E-04	0.4	0.4
Ni	2.10E-03	1.0	1.0
Se	2.40E-05	0.01	0.01
Zn	2.90E-02	13.6	14
Benzo(a)	1.20E-06	0.6	0.6
Benzo(b)	1.80E-06	0.8	0.8
Benzo(k)	1.80E-06	0.8	0.8
Indeno	1.80E-06	0.8	0.8

[1] For HMs the unit is mg/GJ and for PAHs µg/GJ.

Currently the Hg EF refers to van der Most & Veldt (1992). However, it has not been possible to find this reference. For HMs data are available regarding the HM content in Danish natural gas. Based on this EFs can be derived. The table below provides a comparison between the HM EFs derived based on fuel analysis of Danish natural gas (Nielsen et al., 2012) and the current EFs based on data from the United States.

	Nielsen et al., 2012	US EPA, 1998c
Pb	0.0015	0.2
Cd	0.00025	0.5
Hg	0.68	0.1
As	0.12	0.1
Cr	0.00076	0.7
Cu	0.000076	0.4
Ni	0.00051	1.0
Se		0.01
Zn	0.0015	13.6

It is proposed to update the HM EFs for all other HMs than Se to the values provided by Nielsen et al. (2012).

Natural gas powered engines

It is proposed to change the EFs to the same as for natural gas powered engines in 1A1a, please see that chapter for further information.

Gas oil powered engines

It is proposed in line with the recommendations for category 1A1a that the EFs for NO_x and CO are changed to Nielsen et al. (2010). Additionally, it is proposed to add EFs of PCDD/F, PCBs and HCB to the EF table based on the data reported in Nielsen et al. (2010).

Manufacture of solid fuels and other energy industries

This part of the chapter contains two tier 2 EF tables for coke ovens with and without by-product recovery where the EFs are expressed in units of mass per Mg of coal charged and a tier 1 EF table where the EFs are expressed in units of mass per GJ.

Tier 2

The two tier 2 EF tables for coke ovens with and without by-product recovery are based on US EPA (2008b) except the PCDD/F EF, which is based on UNEP (2005).

It is not very clear how the EFs presented have been derived and what specific processes included in the US EPA reference that have been considered.

Based on analysis of the US EPA (2008b) data, it is impossible to explain some of the current EFs. For some EFs it seems to be that the unabated value has been used as upper limit and the abated value as lower limit. The US EPA (2008b) chapter contains information on many processes within coke production. In the tables below available EFs for the following processes are included: charging, coke oven pushing, combustion stacks, soaking, decarbonization, preheater, quenching, non-recovery combustion stacks and non-recovery charging.

The first table contains uncontrolled/high EFs as presented in US EPA (2008b) and the second table presents EFs based on the most advanced control/lowest EFs provided in the reference. There are different EFs available for the following processes: charging, coke oven pushing (PM, HMs and PAHs), combustion stacks (PM), quenching and non-recovery charging. For the remaining pollutants/processes the US EPA data do not provide a range of EFs.

Data from US EPA (2008b). Where available the uncontrolled/highest values are presented.

kg/Mg	Charging	Coke oven pushing	Combustion stacks	Soaking	Decarbo nisation	Preheater	Quenching	Non-recovery combustion stacks	Non-recovery charging	Total with recovery[1]	Total without recovery[1]
NO_x		0.0097	0.82	0.0005				0.36		830	370
CO		0.032	0.34	0.001	15			0.025		15373	15058
NMVOC		0.05	0.047	0.003						100	53
SO_2		0.049	1.47	0.05				4.7		1569	4799
NH_3		0.006								6	6
TSP	0.600	0.695	0.200	0.008		1.800	2.600	0.900	0.013	5903	6016
PM_{10}	0.293	0.301	0.192	0.008		1.755	0.593	0.863	0.006	3142	3526
$PM_{2.5}$	0.235	0.116	0.187	0.008		1.071	0.502	0.842	0.005	2118	2543
Pb		2.74E-05	2.22E-06					0.0016	1.70E-07	30	1628
Cd		1.92E-07	9.95E-08					9.00E-05		0.29	90
Hg		1.69E-07						0.0017	1.30E-09	0.17	1700
As		1.75E-05	1.64E-06					0.00063	4.00E-07	19	630
Cr		5.70E-06	3.60E-06					0.00032	1.70E-07	9.3	320
Cu		9.85E-06	1.71E-06					0.0014		12	1400
Ni		2.00E-05	9.35E-07					0.00029	2.50E-07	21	290
Se		4.50E-06	1.76E-06					0.00016		6.3	160
Zn		5.15E-05	7.55E-06					0.0026		59	2600
Benzo(a)		1.50E-06	8.15E-06					5.00E-07		9.7	2.0
Benzo(b)		5.25E-06	9.70E-08							5.3	5.3
Benzo(k)		2.82E-06	3.35E-08							2.9	2.8
Indeno		3.12E-06	2.06E-08							3.1	3.1

[1] The columns with the totals are the same unit as in the current GB, i.e. g/Mg for main pollutants and mg/Mg for HMs and PAHs

Data from US EPA (2008b). Where available the controlled/lowest values are presented.

kg/Mg	Charging	Coke oven pushing	Combustion stacks	Soaking	Decarbon isation	Preheater	Quenching	Non-recovery combustion stacks	Non-recovery charging	Total with recovery[1]	Total without recovery[1]
NO_x		0.0097	0.82	0.0005				0.36		830	370
CO		0.032	0.34	0.001	15			0.025		15373	15058
NMVOC		0.05	0.047	0.003						100	53
SO_2		0.049	0.12	0.05				4.7		219	4799
NH_3		0.006								6	6
TSP	0.00053	0.19	0.031	0.008		1.800	0.15	0.900	0.0041	2180	3052
PM_{10}	0.00026	0.1653	0.030	0.008		1.755	0.0147	0.863	0.0020	1973	2808
$PM_{2.5}$	0.00021	0.13965	0.029	0.008		1.071	0.009	0.842	0.0016	1257	2071
Pb		7.65E-06	2.22E-06					0.0016	5.00E-08	9.9	1608
Cd		7.85E-08	9.95E-08					9.00E-05		0.18	90
Hg								0.0017	4.00E-10	0.00	1700
As		4.69E-06	1.64E-06					0.00063	1.20E-07	6.3	630
Cr		2.49E-06	3.60E-06					0.00032	5.00E-08	6.1	320
Cu		3.83E-06	1.71E-06					0.0014		5.5	1400
Ni		5.60E-06	9.35E-07					0.00029	7.50E-08	6.5	290
Se		1.30E-06	1.76E-06					0.00016		3.1	160
Zn		1.74E-05	7.55E-06					0.0026		25	2600
Benzo(a)		5.60E-07	8.15E-06					5.00E-07		9	1
Benzo(b)		1.55E-06	9.70E-08							1.6	2
Benzo(k)		1.63E-06	3.35E-08							1.7	2
Indeno		9.95E-07	2.06E-08							1.0	1

[1] The columns with the totals are the same unit as in the current GB, i.e. g/Mg for main pollutants and mg/Mg for HMs and PAHs

The overall comparison between the data gathered from US EPA (2008b) as provided in the two previous tables and the current EFs in the GB is provided in the table below.

	GB - recovery	EPA - recovery	GB - non-recovery	EPA - non-recovery
NO_x	880	830	420	370
CO	15000	15373	15000	15058
NMVOC	96	100	41	53
SO_2	515	586	2700	4799
NH_3	39	6	39	6
TSP	1810	3587	2700	4285
PM_{10}	905	2490	1900	3147
$PM_{2.5}$	653	1632	1600	2295
Pb	17.1	17.1	1600	1618
Cd	0.18	0.23	90	90
Hg	0.17	0.17	1700	1700
As	11	11.0	640	641
Cr	7.5	7.5	320	324
Cu	7.4	8.0	1400	1407
Ni	12	11.7	300	303
Se	3.7	4.4	160	163
Zn	38	38.4	2600	2634
Benzo(a)	19	9.2	19	1.5
Benzo(b)	8.9	3.0	8.9	2.9[1]
Benzo(k)	7.6	2.2	7.6	2.1[1]
Indeno	5.1	1.8	5.1	1.8[1]

[1] There are no PAH EFs in US EPA (2008b) for non-recovery combustion stacks.

Generally, the EFs calculated based on US EPA (2008b) data are consistent with the EFs in the current GB. However, there are some notable differences. For NO_x there seems to be a consistent error of 50 g/Mg between the two datasets, it has not been possible to find the explanation for this. There are also large differences for SO_2 and PM where it has not been possible to find the explanation for the differences. For HMs the EFs calculated are generally consistent with the current EFs, however, some errors have been identified, e.g. for Cu and Se for plants with by-product recovery.

For PCDD/F the GB lists an EF of 230 ng/Mg coal charged. The reference (UNEP, 2005) provides an unabated EF of 3 µg/Mg coke and an abated EF of 0.3 µg/Mg coke. According to the GB (referenced to the BREF document (EIPPCB, 2012)) the ratio between coal consumption and coke production is 1.285 Mg coal/Mg coke. This means that the unabated EF can be calculated to 2335 ng/Mg coal and the abated EF to 234 ng/Mg coal. This implies that the abated EF has been used in the GB, which is inconsistent with the other EFs presented in the EF tables. It is therefore proposed that the EF for PCDD/F is changed so that the lower limit is the abated value, the upper limit the unabated value and the EF will then be the geometric mean value.

The proposed EFs are included in the table below.

Proposed new tier 2 EFs for coke ovens

	With by-product recovery	Without by-product recovery	Unit
NO_x	830	370	g/Mg coal
CO	15373	15058	g/Mg coal
NMVOC	100	53	g/Mg coal
SO_2	586	4799	g/Mg coal
NH_3	6	6	g/Mg coal
TSP	3587	4285	g/Mg coal
PM_{10}	2490	3147	g/Mg coal
$PM_{2.5}$	1632	2295	g/Mg coal
Pb	17	1618	mg/Mg coal
Cd	0.23	90	mg/Mg coal
Hg	0.17	1700	mg/Mg coal
As	11	641	mg/Mg coal
Cr	7.5	324	mg/Mg coal
Cu	8.0	1407	mg/Mg coal
Ni	12	303	mg/Mg coal
Se	4.4	163	mg/Mg coal
Zn	38	2634	mg/Mg coal
PCCD/F	738	738	ng I-TEQ/MG coal
Benzo(a)	9.2	9.2	mg/Mg coal
Benzo(b)	3.0	3.0	mg/Mg coal
Benzo(k)	2.2	2.2	mg/Mg coal
Indeno	1.8	1.8	mg/Mg coal

Tier 1

According to the GB text the tier 1 EFs are derived from the tier 2 EFs. However, it is not clear what assumptions have been made in deriving the EFs. By analysing the data for the tier 1 EFs in comparison with the two set of tier 2 EFs, it is possible to determine the process of deriving the tier 1 EFs.

Comparison of the implied NCV used to convert tier 2 EFs to tier 1 EFs.

	Table 5-3 [mass]/Mg coal	Table 5-4 [mass]/Mg coal	Table 5-2 [mass]/GJ	Table 5-3 GJ/ton	Table 5-4 GJ/ton	Average GJ/ton
NO_x	880	420	22	40.00	19.09	29.55
CO	15000	15000	525	28.57	28.57	28.57
NMVOC	96	41	2.4	40.00	17.08	28.54
SO_2	515	2700	55	9.36	49.09	29.23
NH_3	39	39	1.3	30.00	30.00	30.00
TSP	1810	2900	81	22.35	35.80	29.07
PM_{10}	905	1900	49	18.47	38.78	28.62
$PM_{2.5}$	654	1600	38	17.21	42.11	29.66
Pb	17.1	1600	28.2	0.61	56.74	28.67
Cd	0.18	90	1.56	0.12	57.69	28.90
Hg	0.17	1700	29.3	0.01	58.02	29.01
As	11	640	11.24	0.98	56.94	28.96

Cr	7.5	320	5.72	1.31	55.94	28.63
Cu	7.4	1400	24.4	0.30	57.38	28.84
Ni	12	300	5.42	2.21	55.35	28.78
Se	3.7	160	2.87	1.29	55.75	28.52
Zn	38	2600	46.1	0.82	56.40	28.61
PCDD/F	230	230	8.9	25.84	25.84	25.84
Benzo(a)	19	19	0.64	29.69	29.69	29.69
Benzo(b)	8.9	8.9	0.31	28.71	28.71	28.71
Benzo(k)	7.6	7.6	0.26	29.23	29.23	29.23
Indeno	5.1	5.1	0.18	28.33	28.33	28.33

Based on the table the average of the tier 2 EFs appears to have been used. According to the BREF document (EIPPCB, 2012) by-product recovery is the most common technique used in Europe. For some pollutants the difference in EFs is very substantial, e.g. for HMs where there is up to a factor 10000 difference. Furthermore, it would appear that a NCV of approximately 29 GJ/Mg has been used for the conversion. According to the IEA Energy Statistics Manual (OECD/IEA, 2005) the net calorific value (NCV) for coking coal is between 26.6 GJ/Mg and 29.8 GJ/Mg. The average value is 28.2 GJ/Mg and it is proposed to use this value to convert the tier 2 EFs to tier 1 EFs.

The average value for the tie 2 EFs has been calculated and converted to energy by using a NCV of 28.2 GJ/Mg. The resulting EFs are shown in the table below.

Proposal for revised tier 1 EFs.

	Revised tier 1 EFs	Unit
NO_x	21	g/GJ
CO	540	g/GJ
NMVOC	2.7	g/GJ
SO_2	95	g/GJ
NH_3	0.21	g/GJ
TSP	140	g/GJ
PM_{10}	100	g/GJ
$PM_{2.5}$	70	g/GJ
Pb	29	mg/GJ
Cd	1.6	mg/GJ
Hg	30	mg/GJ
As	12	mg/GJ
Cr	5.9	mg/GJ
Cu	25	mg/GJ
Ni	5.6	mg/GJ
Se	3.0	mg/GJ
Zn	47	mg/GJ
PCCD/F	26	ng I-TEQ/GJ
Benzo(a)	0.33	mg/GJ
Benzo(b)	0.11	mg/GJ
Benzo(k)	0.077	mg/GJ

Indeno	0.063	mg/GJ

References

API, 1998: Air toxics emission factors for combustion sources using petroleum based fuels, Volume 1: Development of emission factors using API/WSPA approach, No 348, Washington DC: American Petroleum Institute, 1.8.1998.

API, 2002: Comparison of API and EPA toxic air pollutant emission factors for combustion sources, No 4720, Washington DC: American Petroleum Institute, 1.9.2002.

Bailey, R.E., 2001: Global hexachlorobenzene emissions. Chemosphere, Volume 43, Issue 2, April 2001, Pages 167–182.

BUWAL 2001: Massnahmen zur Reduktion der PM_{10}-Emissionen. Umwelt-Materialen Nr. 136, Luft. Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern (in German).

CITEPA, 1992: CORINAIR Inventory-Default Emission Factors Handbook (second edition); CEC-DG XI (ed.), 1992.

Cohen, M., Commoner, B., Eisl, H., Bartlett, P., Dickar, A., Hill, C., Quigley, J., Rosenthal, J., 1995. Quantitative estimation of the entry of dioxins, furans and hexachlorobenzene into the Great Lakes from airborne and waterborne sources. CNBS – Center for the Biology of Natural Systems, Queens College, CUNY, Flushing, New York.

CORINAIR, 1990: CORINAIR 90 Emission Inventory (Proposals) — working paper for the 19–20 September 1991 meeting — Annex 4: Definition of Large Point Sources.

EIPPCB, 2006: Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants. European IPPC Bureau available at http://eippcb.jrc.es/.

EIPPCB, 2012: Best Available Techniques (BAT) Reference Document for Iron and Steel Production, Industrial Emissions Directive 2010/75/EU. European IPPC Bureau available at http://eippcb.jrc.es/.

Grochowalski, A. & Konieczyński, J., 2008: PCDDs/PCDFs, dl-PCBs and HCB in the flue gas from coal fired CFB boilers. Chemosphere 73 (2008) 97−103.

IPCC, 2006: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

Nielsen, M., Nielsen, O.-K. & Thomsen, M. 2010: Emissions from decentralised CHP plants 2007 - Energinet.dk Environmental project no. 07/1882. Project report 5 – Emission factors and emission inventory for decentralised CHP production. National Environmental Research Institute, Aarhus University. 113 pp. – NERI Technical report No. 786. http://www.dmu.dk/Pub/FR786.pdf.

OECD/IEA, 2005: Energy Statistics Manual.

Pacyna J. M. et al. (1999) Technical Report. Appendix 1. To the Executive Final Summary Report. Environmental Cycling of Selected Persistent Organic Pollutants (POPs) in the Baltic Region (POPcycling-Baltic project). Contract No. ENV4-CT96-0214.

Pfeiffer, F., Struschka, M., Baumbach, G., Hagenmaier, H. & Hein, K.R.G., 2000: PCDD/PCDF emissions from small firing systems in households. Chemosphere 40 (2000) 225-232.

Rentz, O., Karl, U., Haase, M. & Koch, M., 2008: Nationaler Durchführungsplan unter dem Stockholmer Abkommen zu persistenten organischen Schadstoffen (POPs). Umweltsbundesamt, Forschungsbericht 205 67 444. (In German)

Rubenstein, G. 2003: Gas turbine PM emissions — Update. Sierra Research, June 2003 Paper to ASME/IGTI Turbo-Expo, Atlanta 2003.

UNEP, 2005: Standardised toolkit for identification and quantification of dioxin and furan releases, Edition 2.1, UNEP Chemicals, Geneva, December 2005.

US EPA, 1996: AP 42, Fifth Edition, Volume I, Chapter 3: Stationary Internal Combustion Sources, Chapter 3.4: Large Stationary Diesel and All Stationary Dual-fuel Engines.

US EPA, 1998a: AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, Chapter 1.1: Bituminous and Subbituminous Coal Combustion.

US EPA, 1998b: AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, Chapter 1.7: Lignite Combustion.

US EPA, 1998c: AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, Chapter 1.4: Natural Gas Combustion.

US EPA, 2000a: AP 42, Fifth Edition, Volume I, Chapter 3: Stationary Internal Combustion Sources, Chapter 3.1: Stationary Gas Turbines.

US EPA, 2000b: AP 42, Fifth Edition, Volume I, Chapter 3: Stationary Internal Combustion Sources, Chapter 3.2: Natural Gas-fired Reciprocating Engines.

US EPA, 2008a: AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, Chapter 1.5: Liquefied Petroleum Gas Combustion.

US EPA, 2008b: AP 42, Fifth Edition, Volume I, Chapter 12: Metallurgical Industry, Chapter 12.2: Coke Production.

US EPA, 2010: AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, Chapter 1.3: Fuel Oil Combustion.

van der Gon, H.D. & Kuenen, J., 2009: Improvements to metal emission estimates. Presentation at The TFEIP/EIONET Meeting in Vienna on 11-12 May 2009.

van der Most, P.F.J. & Veldt, C., 1992: Emission Factors Manual PARCOM-ATMOS, Emission factors for air pollutants 1992, Final version; TNO and Ministry of Housing, Physical Planning and the Environment, Air and Energy Directorate Ministry of Transport and Water Management, The Netherlands, Reference No 92–235, 1992.

Visschedijk, A.J.H., Pacyna, J., Pulles, T., Zandveld, P. and van der Gon, H.G., 2004: Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP), P. Dilara et. Al (eds.), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004, EUR 21302 EN, JRC, pp. 163–174.

Wenborn, M.J., Coleman, P.J., Passant, N.R., Lymberidi, E., Sully J. & Weir R.A., 1999: Speciated PAH inventory for the UK. AEAT-3512/REMC/20459131/ISSUE 1

Wurst, F. & Hübner, C., 1997: Erhebung des PCDD/F-Emissionspotentials für Österreich. Studie im Auftrag des BMWFA (in German).