Discussion paper - Review of consistency for Fugitive emissions (1B) – Version 2

1B1a – Fugitive emissions from solid fuels: Coal mining and handling

This chapter has been reviewed in Task 5. Please refer to "Discussion paper - Review of PM for Fugitive emissions (1B)".

1B1b - Fugitive emissions from solid fuels: Solid fuel transformation

Emission factors for coke production refer to a number of different sources; EFs for PMs is based on EC (2001) and US EPA, EFs for HMs are based on Theloke et al. (2008) and EFs for PAHs are based on Berdowski et al. (1995). Further, the GB lacks emission factors for Cr, Cu, Se and Zn.

Wenborn 1999:

PAH EFs from coke production are based on a number of other references (EMEP/CORINAIR GB 1998, Radian Corporation 1995, British Steel 1998, TNO 1995 and Parma et al 1995). Radian EFs are based on calculations only. These represent the upper range for all PAHs. The "best estimate" of BaP is based on EMEP/CORINAIR. The "best estimate" EFs for the remaining PAHs are estimated by scaling the BaP EF from EMEP/CORINAIR to the profile from Radian Corporation. A comparison with older values from Josis (1989) and Smith (1984), show that these are within the range of the PAH EFs by Wenborn 1999.

BbF = 0.2 (0.01 – 9.1) g/t
BkF = 0.1 (0.01 – 4.7) g/t
BaP = 0.16 (0.011 – 7.4) g/t
Indeno = 0.07 (0.01 – 3.4) g/t

Weitkamp et al. (2005)

Weitkamp et al. (2005) is based on measurements carried out in 2002, and is supposed to be representative for coke production under European conditions. The study included both PM, HM, OC and EC, and can thereby contribute to increase the consistency of emission factors for coke production.

$EF_{PM2.5}$ was estimated from the measured and calculated SO_2 emission, as the inventory for SO_2 was assumed to be more certain than for $PM_{2.5}$. Further, the concentration of $PM_{2.5}$ to PM_{10} was measured. By combining these data the following PM EFs was estimated:

Pollutant	EF, g/Mg of coke produced	Uncertainty, g/Mg coke produced
$PM_{2.5}$	40	+-20
PM_{10}*	48	+-24**

* $PM_{2.5}$ contributes 84 ±14 % of PM_{10}

** Combined uncertainty = $\sqrt{(20^2+14^2)}$

Pollutant	**Share of $PM_{2.5}$ mass, %**	**Uncertainty, %**
OC*	40	9
EC*	25	5

As	0,038	0,0028
Cd	0,0039	0,0005
Cr	0,0053	0,0009
Cu	0,023	0,0035
Hg		
Ni	0,0055	0,0011
Pb	0,088	0,0084
Se	0,026	0,0021
Zn	0,12	0,012

1 **US EPA (1998)**

2 EFs for coke production are changed afterwards in US EPA (1998) table 12.2-2 for BSO.

		TSP*	BaP**	BbF**	Bj+kF**	Indeno**	PCDD/F***
		Kg/Mg coal charged	Kg/Mg coal charged	Kg/Mg coal charged	Kg/Mg coal charged	Kg/Mg coal charged	Mg TEQ/Mg coke produced
Charging	Uncontrolled Pre-NESHAP Post-NESHAP	0.60 0.0058 0.00053	6.07E-03 3.37E-05 4.14E-06	7.52E-03 4.62E-005 5.13E-06	5.37E-03 3.29E-05 3.66E-06	2.86E-03 1.76E-05 1.95E-06	
Door leaks	Uncontrolled Pre-NESHAP Post-NESHAP	0.26 0.020 0.0079	3.86E-03 1.52E-04 6.07E-05	4.79E-03 1.88E-04 7.52E-05	3.42E-03 1.34E-04 5.37E-05	1.82E-03 7.15E-05 2.86E-05	
Lid leaks	Uncontrolled Pre-NESHAP Post-NESHAP	0.047 0.0065 0.000086	3.45E-04 4.97E-05 4.14E-06	4.28E-04 6.16E-05 5.13E-06	3.05E-04 4.39E-05 3.66E-06	1.63E-04 2.34E-05 1.95E-06	
Offtake leaks	Uncontrolled Pre-NESHAP Post-NESHAP	0.047 0.0059 0.00029	3.45E-4 4.55E-05 1.38E-05	4.28E-04 5.64E-05 1.71E-05	3.05E-4 4.03E-05 1.22E-05	1.63E-04 2.15E-05 6.50E-06	
Pushing		¤	¤	¤	¤	¤	
Oven Underfiring		¤	¤	¤	¤	¤	
Quenching	Uncontrolled Clean water	¤	¤	¤	¤	¤	
Coke production	No gas cleaning APC with afterburner/dust removal						3 0,3

3 *AP-42 (2008) table 12.2-2. Uncertainty estimates can be defined based on data in US EPA (2008b)
4 **US EPA (1998)
5 *** UNEP (2005)
6 ¤ EFs available in the report

7 **US EPA SPECIATE Version 4.3**

Pollutant	**% of TSP**	**% of PM_{10}**	**% of $PM_{2.5}$**
As	0.023	0.027	0.041
Cd	0.012	0.024	0.05

Cr	0	0.005	0.016
Cu	1.083	0.668	0.516
Hg	0	0.005	0.017
Pb	0.201	0.166	0.249
Zn	0.459	0.338	0.399

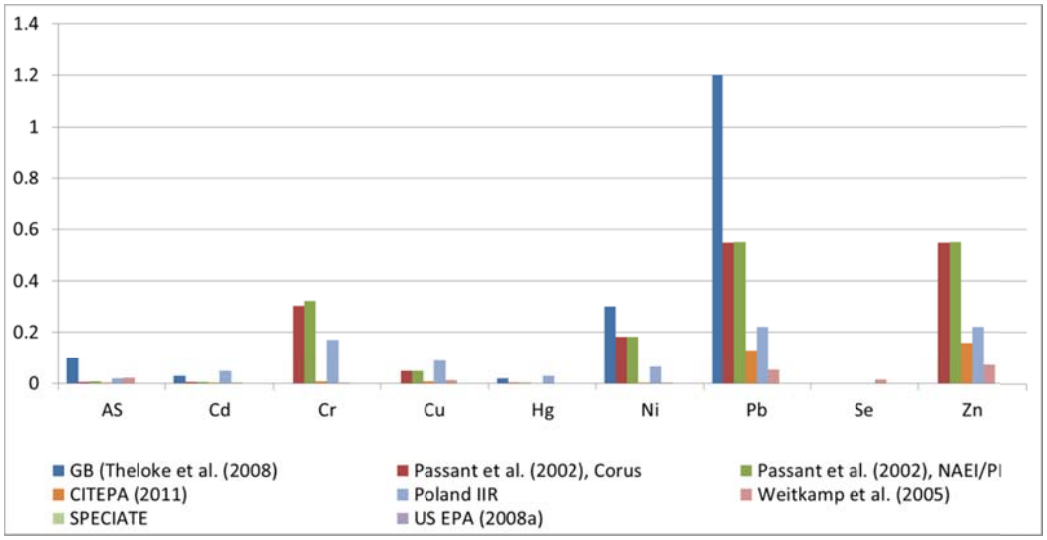
As described in "**Discussion paper - Review of PM for Fugitive emissions (1B) Version 1**", the proposal for updated Tier 1 EFs for solid fuel transformation in the GB are:

Coke oven plant	EF, g/Mg coke	lower	upper	Reference
TSP	150	15	300	EC (2012)
PM_{10}*	80	8	160	EC (2012), Klimont et al. (2002)
$PM_{2.5}$*	60	6	120	EC (2012), Klimont et al. (2002)

* In agreement with the uncertainties for TSP, the lower range is 10 % of EF and the upper range is 200 % of EF.

As the PM EFs cover the whole process of coke production, it is not possible to include abatements at different stages. Therefor the Tier 1 EFs are proposed for Tier 2 as well, like is the case in the present GB chapter.

	GB (Theloke et al. (2008)	Passant et al. (2002)	Passant et al. (2002)	EC (2012)	Wenborn (1999)	*CITEPA (2011)*	*Poland IIR*	Weitkamp et al. (2005)	SPECIATE	US EPA (2008a)	Unit
		Corus 1998/1999	NAEI/PI			*Source not reviewed*	*Country specific*	Based on proposed $PM_{2.5}$ = 60 g/Mg coke	Based on proposed $PM_{2.5}$ = 60 g/Mg coke	Coke oven leaks and charging	
AS	**0.1**	0.00632	0.00710			*0.00187*	*0.02*	0.0228	0,0246		g/Mg coke
Cd	**0.03**	0.00654	0.00661			*0.00187*	*0.05*	0.00234	0,03		g/Mg coke
Cr		0.304	0.323			*0.00746*	*0.17*	0.00318	0,0096		g/Mg coke
Cu		0.0480	0.0486			*0.00746*	*0.09*	0.0138	0,3096		g/Mg coke
Hg	**0.02**	0.0037	0.00377				*0.03*		0,0102		g/Mg coke
Ni	**0.3**	0.181	0.181			*0.00373*	*0.065*	0.003			g/Mg coke
Pb	**1.2**	0.548	0.551			*0.129*	*0.22*	0.0528	0,1494		g/Mg coke
Se								0.0156			g/Mg coke
Zn		0.548	0.551			*0.157*	*0.22*	0.072	0,2394		g/Mg coke
BaP					0.16					0.1-5.3	g/Mg
BbF					0.20					0.2-10	g/Mg
BkF					0.10					0.1-8.6	g/Mg
indeno					0.07					0.1-5.5	g/Mg
PCDD/F				< 0.1							Ng I-TEQ/Nm^3



The table and chart above show the large differences between HM EFs. For As, Ni and especially Pb the present GB EF have the highest value. For Cr and Zn the values from Passant et al. (2002) are the highest. EFs from Passant et al (2002, NAEI/PI) are based on pollution inventory data for 1999

It is to be decided if the present EFs in the GB should be maintained or updated to another reference. The present values exceed EFs from other sources in many cases, which could indicate that maintaining the present EFs could lead to overestimation. Another reason that speaks in favour of updating the EFs is that other references include more HMs which improves completeness and consistency of the GB.

1B1c – Other fugitive emissions from solid fuels

No EFs

1B2a i – Oil – Exploration, production, transport

Only NMVOC

1B2a iv – Refining/storage

All EFs with reference to CONCAWE are verified in the latest version of the report (CONCAWE (2009)). No inconsistencies are found in the EFs according to the standard checks (∑TSP > ∑pm10 > ∑pm2.5 > ∑HM and ∑pm2.5 > ∑PAH). There are no EFs for TSP, $PM_{2.5}$, Cr, Se and PCDD/F for Catalytic cracking unit regenerators and Fluid coking units and no EF for Cd for Fluid coking units. Many EFs in CONCAWE 2009 refer to other publications it is proposed to change the reference in the guidebook to the original reference. As recalculations of EFs for PAH are carried out in CONCAWE 2009 the current reference should be maintained.

The HM EFs presented in the current GB refer to CONCAWE, 2009. As the EFs in CONCAWE 2009 refer to Environment Australia, 1999 the reference in the GB is proposed to be changed to Environment Australia, 1999 for PM_{10} and HMs.

Environment Australia, 1999 include an emission factor for TSP for FCCU (695 kg /m^3 fresh feed) which is proposed to be added to the GB. It is proposed to apply the PM_{10} EF for $PM_{2.5}$ as no $PM_{2.5}$ EF or size distribution is found in Environment Australia, 1999.

The following emission factors are proposed to be included in the guidebook:

Catalytic cracking unit regeneration

Pollutant	Note	EF	unit	Reference
SO_2		1.413	kg/m^3 feed to the unit	US EPA, 1995
NO_x		0.204	kg/m^3 feed to the unit	US EPA, 1995
NMVOC		0.630	kg/m^3 feed to the unit	US EPA, 1995
CO		39.2	kg/m^3 feed to the unit	US EPA, 1995
NH3		0.155	kg/m^3 feed to the unit	US EPA, 1995
TSP		695	kg/m^3 feed to the unit	Environment Australia, 1999
PM_{10}		549	kg/m^3 feed to the unit	Environment Australia, 1999
$PM_{2.5}$		549	kg/m^3 feed to the unit	A
As		0.0139	g/m^3 feed to the unit	Environment Australia, 1999
Cd		0.06255	g/m^3 feed to the unit	Environment Australia, 1999
Cr		0.329	mg/Mg coke burned	Bertrand & Siegell, 2002; CONCAWE (2009)*
Cu		0.139	g/m^3 feed to the unit	Environment Australia, 1999
Hg		0.0695	g/m^3 feed to the unit	Environment Australia, 1999
Ni		0.6116	g/m^3 feed to the unit	Environment Australia, 1999
Pb		0.3197	g/m^3 feed to the unit	Environment Australia, 1999
Se		0.0139	g/m^3 feed to the unit	Environment Australia, 1999
Zn		0.11815	g/m^3 feed to the unit	Environment Australia, 1999
PCDD/F	Catalytic reforming unit, continuous regeneration mode	1.91E-02	µg/m^3	US EPA (2006) **
BaP		0.71	mg/Mg coke burned	CONCAWE (2009)
BbF		1.22	mg/Mg coke burned	CONCAWE (2009)
BkF		0.82	mg/Mg coke burned	CONCAWE (2009)
Indeno		0.62	mg/Mg coke burned	CONCAWE (2009)

A: Assumption that $PM_{2.5} = PM_{10}$

* EF calculated from the data in Bertrand & Siegell, 2002 based on the formula in CONCAWE (2009) section 5.2

** include EF for Catalytic reforming unit, semi-regenerative mode at 6.35E-06µg/m^3 feed to unit

Fluid coking unit

Pollutant	Note	EF	unit	Reference
SO_2		n.d.	kg/m^3 feed to the unit	Environment Australia, 1999
NO_x		n.d.	kg/m^3 feed to the unit	Environment Australia, 1999
NMVOC		46	kg/m^3 feed to the unit	Environment Australia, 1999
CO		n.d.	kg/m^3 feed to the unit	Environment Australia, 1999
NH3				
TSP		1500	kg/m^3 feed to the unit	Environment Australia, 1999
PM_{10}		765	kg/m^3 feed to the unit	Environment Australia, 1999
$PM_{2.5}$		765	kg/m^3 feed to the unit	A
As		2.16	g/m^3 feed to the unit	Environment Australia, 1999
Cd		n.d.	g/m^3 feed to the unit	Environment Australia, 1999
Cr				
Cu		0.015	g/m^3 feed to the unit	Environment Australia, 1999
Hg		0.03	g/m^3 feed to the unit	Environment Australia, 1999

Ni		0.57	g/m^3 feed to the unit	Environment Australia, 1999
Pb		0.045	g/m^3 feed to the unit	Environment Australia, 1999
Se		0.03	g/m^3 feed to the unit	Environment Australia, 1999
Zn		0.045	g/m^3 feed to the unit	Environment Australia, 1999
PCDD/F				
BaP		n.a.	mg/Mg coke burned	Environment Australia, 1999
BbF		n.a.	mg/Mg coke burned	Environment Australia, 1999
BkF		n.a.	mg/Mg coke burned	Environment Australia, 1999
Indeno		n.a.	mg/Mg coke burned	Environment Australia, 1999

A: Assumption that $PM_{2.5} = PM_{10}$

1B2a v – Distribution of oil products

Only NMVOC

1B2b – Natural gas

Only NMVOC

1B2c – Venting and flaring

The guidebook includes six EF tables for venting and flaring. Two Tier 1 tables for flaring in oil and gas extraction and in refineries, two Tier 2 tables for flaring in well testing and in refineries (same EFs as the corresponding Tier 1 table) and two Tier 3 tables for elevated flaring and enclosed flaring both in refineries.

Table	Type	Tier	PollutantName	Reference
3-1	Flaring in oil and gas extraction	1	NO_x, CO, NMVOC	OLF (1993)
3-2	flaring in oil refineries	1	NO_x, CO, NMVOC, SOx	CONCAWE (2007)
3-3	well testing	2	NO_x, CO	OLF (1993)
3-4	flaring in oil refineries	2	NO_x, CO, NMVOC, SOx	CONCAWE (2007)
3-5	Elevated flaring in oil refinery	3	NO_x, CO, NMVOC, SOx, Benzene	CONCAWE (2007)
3-6	Enclosed flaring in oil refinery	3	NO_x, CO, NMVOC, SOx, PM_{10}, Pb, Cd, Hg, As, Cr, Cu, Ni, Zn	CONCAWE (2007)

All EFs regarding refineries refer to CONCAWE 2007, and EFs regarding oil and gas extraction and well testing refer to OLF (1993). The values referring to CONCAWE 2007 are verified in the latest version of the report (CONCAWE (2009)), but most/all EFs included in CONCAWE refer to other references. The original reference should be applied in the guidebook or new references should be found if the original references are not available.

No inconsistencies are found in the EFs according to the standard checks ($\sum TSP > \sum PM_{10} > \sum PM_{2.5} > \sum HM$).

Some inconsistencies are found due to missing EFs for specific pollutants;

- The Tier 1 EF tables include no EFs for PMs, HMs and POPs
- The Tier 2 EF table for well testing includes only NO_x and CO
- The Tier 3 EF table for elevated flaring in refineries includes no EFs for PMs, HMs and POPs for flaring in oil and gas extraction and in refineries

- The Tier 3 EF table for enclosed ground-level flaring in refineries includes no EFs for TSP, $PM_{2.5}$,Se and POPs

Further there is no Tier 2 EF table for flaring in oil and gas extraction.

Flaring in refineries

The EF_{PM10} from CONCAWE (2009) is for combustion of natural gas and not for refinery fuel gas, as is the case for HMs. CONCAWE (2009) recommends to use the EF for natural gas in absence of a specific emission factor for refinery fuel gas. Further, Environment Australia, 1999 (referred in CONCAWE (2009)) gives, that emission of PM_{10} from non-smoking flares can be assumed negligible.

US EPA (1998) and UNEP (2005) have been reviewed for emission factors for PAH and PCDD/F from flaring. They only include EFs for flaring of landfill waste gas and biogas, which have a different composition than refinery gas, and therefore are not applicable for flaring in refineries.

PCDD/F is not assumed to be produced by flaring of refinery gas. CONCAWE gives EFs for combustion of refinery oil, but not for refinery gas, as the amount of chlorine is limited. This is supported by EC (2012) where it is written that "emissions of dioxins from flaring were considered not existing due to the absence of necessary formation conditions." EC (2012) also mention that emissions of PCB from flaring are considered highly unlikely.

The following EFs are proposed to be included in the GB for enclosed flaring in oil refineries:

Source	Pollutant	EF	unit	Reference
Flaring in refineries	TSP	11	g/GJ	CONCAWE (2009), EC (2012)
Flaring in refineries	$PM_{2.5}$	0.24	g/GJ	CONCAWE (2009), EC (2012)
Flaring in refineries *	BaP	0.67	µg/GJ	CONCAWE (2009)
Flaring in refineries *	BbF	1.14	µg/GJ	CONCAWE (2009)
Flaring in refineries *	BkF	0.63	µg/GJ	CONCAWE (2009)
Flaring in refineries *	Indeno	0.63	µg/GJ	CONCAWE (2009)
Flaring in refineries *	PCDD/F	NA		CONCAWE (2009)

* EFs for "refinery fuel gas combustion in boilers and furnaces" are used for flaring as is the case for HM

Further it is proposed to change the reference from CONCAWE 2007 to CONCAWE (2009).

Flaring in oil and gas extraction

Only a limited number of relevant references for emissions from venting and flaring in oil and gas extraction are found.

Well testing

Regarding well testing, the emission factors for NO_x and CO in the current guidebook refer to OLF (1993). The same reference includes emission factors for dioxin, PAH, VOC and soot as well. It is proposed to add the emission factor for dioxin to the guidebook. The emission factor for PAH is assumed to refer to total PAH and is not suitable for use in the guidebook. The VOC emission factor include CH_4 which leads to an overestimation, but in lack of other data, the VOC emission factor might be applied for NMVOC.

PM emission factors for well testing are included in Norway's IIR (Climate and Pollution Agency (2012)) and the reference for TSP is "measurements by OLF". Documentation for the TSP emission factor has been requested to be able to include the factor in the guidebook. In shortage of emission factors for the remaining pollutants, the emission factors for flaring could be applied.

Well testing

Pollutant	Note	EF	unit	Reference
NO_x		3.7	g/kg oil burned	OLF (1993)
NMVOC	VOC including CH_4	3.3	g/kg oil burned	OLF (1993)
CO		18	g/kg oil burned	OLF (1993)
TSP		25		*
PM_{10}		21.5		**
$PM_{2.5}$		14		**
PCDD/F		0.01	mg/kg oil burned	OLF (1993)
PAH	PAH 4	0.24	mg/kg oil burned	Climate and Pollution Agency (2012)

* EF given in Norway's IIR (Climate and Pollution Agency (2012)) with reference to OLF measurements. Request for documentation has been sent to OLF.

** EF given in Norway's IIR (Climate and Pollution Agency (2012)). Based on EF_{TSP} and size distribution for combustion of heavy fuel oil in industry (EPA 2002).

Flaring in oil and gas extraction

The following shortly resume the results from the literature study on flaring in oil and gas extraction:

E&P Forum (1994) include the EFs for flaring listed in the table below.

Pollutant	EF	unit
CO	2.61	Mg/Mg gas burned
NO_x	0.0015	Mg/Mg gas burned
SOx	0.0000128	Mg/Mg gas burned
NMVOC	0.015	Mg/Mg gas burned

Australian Government (2010) includes the following EFs for flaring. Further a number of EFs are included in the reference for combustion of associated and non-associated gas, which is recommended for flaring in lack of EFs for flaring:

Pollutant	EF	unit
CO	8.7	kg/Mg throughput
NO_x	1.5	kg/Mg throughput
Total VOC	15	kg/Mg throughput
NMVOC *	4.5	kg/Mg throughput
PM_{10}	0.12 /	kg/Mg throughput
As **	3.2E-06 / 4.0E-06	kg/Mg throughput
Cd **	1.8E-05 / 2.2E-05	kg/Mg throughput
Cr **	1.1E-06 / 1.4E-06	kg/Mg throughput
Cu **	1.4E-06 / 1.7E-06	kg/Mg throughput
Hg **	4.1E-06 / 5.2E-06	kg/Mg throughput

Ni **	3.4E-05 / 4.2E-05	kg/Mg throughput
Pb **	4.3E-06 / 5.4E-06	kg/Mg throughput
Se **	3.8E-07 / 4.8E-07	kg/Mg throughput
Zn **	4.6E-04 / 5.8E-04	kg/Mg throughput

* Estimated using the assumption from E&P Forum (1994) of 30 % NMVOC of total VOC

** associated gas combustion / non-associated gas combustion

Finstad et al. (2001) include EFs for some HMs for flaring as listed below.

Pollutant	Note	EF	unit	Reference
Cd	anden gas	0	g/ton	Finstad et al. (2001)
Hg	anden gas	0	g/ton	Finstad et al. (2001)
Pb	naturgas / anden gas	0	g/ton	Finstad et al. (2001)
PAH	PAH 4 naturgas/anden gas	0	g/ton	Finstad et al. (2001)

The EFs are proposed for implementation in the guidebook for flaring in oil and gas extraction is listed in the table below. PCDD/F is assumed not applicable as for flaring in refineries.

Pollutant	Note	EF	unit	Reference
SO2		1.28E-08	kg/Mg gas burned	US EPA (1991)
NOx		1.5	kg/Mg throughput	Australian Government (2010)
NMVOC		4.5	kg/Mg throughput	Australian Government (2010)
CO		5.7	kg/Mg throughput	Australian Government (2010)
TSP		1.48		**
PM_{10}		0.12	kg/Mg throughput	Australian Government (2010)
$PM_{2.5}$		0.03		**
As		3.75E-06	kg/Mg throughput	Australian Government (2010) *
Cd		2.0E-05	kg/Mg throughput	Australian Government (2010) *
Cr		1.3E-06	kg/Mg throughput	Australian Government (2010) *
Cu		1.6E-06	kg/Mg throughput	Australian Government (2010) *
Hg		4.7E-06	kg/Mg throughput	Australian Government (2010) *
Ni		3.8E-05	kg/Mg throughput	Australian Government (2010) *
Pb		4.9E-06	kg/Mg throughput	Australian Government (2010) *
Se		4.3E-07	kg/Mg throughput	Australian Government (2010) *
Zn		5.2E-04	kg/Mg throughput	Australian Government (2010) *
PCDD/F		n.a.		CONCAWE (2009)
PAH - 4		0	kg/Mg throughput	Finstad et al. (2001)
BaP		0	kg/Mg throughput	Finstad et al. (2001) ***
BbF		0	kg/Mg throughput	Finstad et al. (2001) ***
BkF		0	kg/Mg throughput	Finstad et al. (2001) ***
Indeno		0	kg/Mg throughput	Finstad et al. (2001) ***

* Mean of EF for combustion of associated and non-associated gas

** Based on PM_{10} and the size distribution applied for flaring in refineries from EC (2012) – please refer to Discussion paper - Review of PM for Fugitive emissions (1B) for PM EFs proposed for flaring and venting

*** Only PAH-4 listed in the reference

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