

Task 1: Review and addition of black carbon methodologies, EFs and reference material (2A, 2B, 2C, 2D, 2F)

Introduction

This paper presents available knowledge on emission of *black carbon* (BC) or *light absorbing carbon* (LAC) from industrial processes. In the literature BC and LAC are synonyms for the same substances. And also *elemental carbon* (EC) is used as synonym for BC. Therefore, BC will be used in this paper. Focus will be on process emissions whereas combustion related emissions are discussed in separate papers.

Surveys on emissions of BC have been done for different countries and areas. In general, the literature mentions combustion as the main source to emission of BC. However, a number of industrial processes are mentioned as minor sources. The characteristics of the potential BC generating processes are high temperature and availability of a carbon source e.g. fossil or biogenic fuel. The relevant industrial processes (Kupiainen & Klimont, 2004) may be e.g.: Iron and steel industry (coke production, sinter plants, pig iron production, open hearth furnace, basic oxygen furnace, electric arc furnace, iron and steel foundries), Non-ferrous metal industry (primary aluminium production, secondary aluminium production, other non-ferrous metals production), Mineral industry (cement production, lime production, glass production), chemical industry (carbon black production), and Other production (paper pulp production).

Many of the published national, regional or global BC inventories are based on GAINS/RAINS eventually combined with local EF e.g. the European emission inventory for elemental and organic carbon for the year 2005 (Visschedijk et al., 2009) or based on different variations of the American database e.g. the U.S PM_{2.5} inventory for 2005 supplemented with EC and OC inventories (Chow et al., 2011)..

Survey

The results of the survey will be presented for the sectors: 2.A Mineral products, 2.B Chemical industry, 2.C Metal production, 2.D Other production, and 2.G Other. So far, the presented EFs are primarily based on Kupiainen & Klimont (2004)/GAINS/RAINS data and supplemented with EFs from other sources e.g. SPECIATE by US EPA. The data sets from the SPECIATE database are identified by file number.

2.A Mineral products

Cement production

Table x Emission factors for BC from cement production (kg/tonne cement) (the table is based on Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Cement production	0-0.14	0.66-2.95	6.5	130	0-2.15	-	-	5.0	Kupiainen & Klimont (2004)
Cement production	-	-	-	-	-	2.93	12.7	-	US EPA, no.: 91127

Chow et al. (2004) have investigated PM_{2.5} from different sources and among these two cement kilns located in Texas. The average content of OC, OP (pyrolysed carbon) and EC in PM_{2.5} were determined to 11.5%, 1.3%, and 4.27% respectively.

1 Recommended EF:

2 EF = 2.9% (BC/PM_{2.5})

3 **Lime production**

4 Table x Emission factors for BC from lime production (kg/tonne lime) (the table is based on Kupiainen &
5 Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Lime production	0.2	1.4	0.46	100	0.43	-	-	0.46	Kupiainen & Klimont (2004)
Lime kiln	-	-	-	-	-	2.32	6.65	-	US EPA, no.: 91138
Lime kiln	-	-	-	-	-	0.46	9.3	-	Chow et al. (2011)

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7 PM₁₀ and PM_{2.5} emitted from a lime kiln operation in connection to a paper pulp mill in South Africa have
8 been investigated. The content of EC was 1.77% and 2.12% in PM₁₀ and PM_{2.5}, respectively. The same
9 figures for OC Were 11.5% and 6.08 % respectively. The present study has been used for establishing the
10 common EF applied in RAINS.

11 Recommended EF:

12 EF = 0.46% (BC/PM_{2.5})

13 **Glass production**

14 Table x Emission factors for BC from glass production (kg/tonne glass) (the table is based on Kupiainen &
15 Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Glass production	0.00195	0.02	0.715	-	0.27	-	-	-	Kupiainen & Klimont (2004)
Glass furnace	-	-	-	-	-	0.062	0.71	-	US EPA, no.: 91143
Fiberglass manufacturing	-	-	-	-	-	2	28	-	US EPA, no.: 91142

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17 Recommended EFs:

18 Glass: EF = 0.062% (BC/PM_{2.5})

19 Glassfiber: EF = 2% (BC/PM_{2.5})

20 **Asphalt**

21 Table x Emission factors for BC from asphalt production (kg/tonne product).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Asphalt manufacturing	-	-	-	-	-	5.72	4.32	-	US EPA, no.: 91159
Asphalt roofing	-	-	-	-	-	0.013	60.3	-	US EPA, no.: 91148

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23 Recommended EFs:

24 Asphalt manufacturing: EF = 5.7% (BC/PM_{2.5})

1 Asphalt roofing: EF = 0.013% (BC/PM_{2.5})

2 2.B Chemical industry

3 Carbon black production

4 Table x Emission factors for BC from carbon black production (kg/tonne carbon black) (the table is based on
5 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Carbon black	1.1	0	1.1	-	100	-	-	-	Kupiainen & Klimont (2004)

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7 Recommended EF:

8 EF = 100% (BC/PM₁)

9 Urea fertiliser

10 Table x Emission factors for BC from urea fertiliser production (kg/tonne urea).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Urea	-	-	-	-	-	2	31	-	US EPA, no.: 91167

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12 Recommended EF:

13 EF = 2% (BC/PM_{2.5})

14 Chemical industry, average

15 Table x Emission factors for chemical industry, average (kg/tonne chemical).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Chemical industry, average	-	-	-	-	-	1.825	9.175	-	US EPA, no.: 91124
Industrial manufacturing	-	-	-	-	-	0.89	7.36	-	US EPA, no.: 91121

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17 Recommended EFs:

18 Industrial manufacturing: EF = 0.89% (BC/PM_{2.5})

19 Chemical industry: EF = 1.8% (BC/PM_{2.5})

20 2.C Metal production

21 Engelbrecht et al. (2002) have investigated the composition of PM₁₀ and PM_{2.5} from a number of sources
22 within the iron and steel industry; see table y. The results have among other been used for establishing the
23 EFs for RAINS as described by Kupiainen & Klimont (2004).

24 Table y

Process	PM ₁₀		PM _{2.5}	
	EC %	OC %	EC %	OC %

Metallurgical sinter plant	0.39	2.00	0.17	2.73
Electric arc furnace	0	2.04	0.33	3.94
Electric arc furnace	0	1.51	0.40	2.53
Ferromanganese furnace	11.7	6.21	13.3	6.74

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2 **Coke production**

3 Table x Emission factors for BC from coke production (kg/tonne coke) (the table is based on Kupiainen &
4 Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Coke production	0.75	0.54	1.535	4.976	48.9	-	-	30.8	Kupiainen & Klimont (2004)
Coke production	-	-	-	-	-	25	40	-	Weitkamp et al. (2005)

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6 Recommended EF:

7 Coke production. EF = 25% (BC/PM_{2.5})

8 **Sinter plants**

9 Table x Emission factors for BC from sinter plants (kg/tonne sinter) (the table is based on Kupiainen &
10 Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Sinter processes	0.005	0.026	0.34	8.563	19.2	-	-	0.30	Kupiainen & Klimont (2004)
Sinter fugitive	-	-	0.06	1.6	-	-	-	3.75	Kupiainen & Klimont (2004)
Pellet plant	-	-	0.03	0.03	-	-	-	100	Kupiainen & Klimont (2004)
Sintering Furnace	-	-	-	-	-	0.17	2.73	-	US EPA, no.: 91139

11

12 Recommended EFs:

13 EF ??

14 EF ??

15 **Pig iron production**

16 Table x Emission factors for BC from pig iron plants (kg/tonne pig iron) (the table is based on Kupiainen &
17 Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Pig iron production	0.018	0	0.04	1.48	45.0	-	-	2.7	Kupiainen & Klimont (2004)
Pig iron fugitive	0	0	0.05	2.5	-	-	-	2.0	Kupiainen & Klimont (2004)

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19 Recommended EF:

1 Pig iron production: EF = 45% (BC/PM₁)

2 Pig iron, fugitive: EF = 0%

3 **Open-hearth furnace**

4 Table x Emission factors for BC from an open-hearth furnace (kg/tonne steel) (the table is based on
5 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Steel production	0	0	2.22	10.55	-	-	-	-	Kupiainen & Klimont (2004)
Open hearth furnace	-	-	-	-	-	ni	20	-	US EPA, no.: 91133

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7 Recommended EF:

8 EF = 0% (BC/PM_{2.5})

9 **Basic oxygen furnace**

10 Table x Emission factors for BC from a basic oxygen furnace (kg/tonne steel) (the table is based on
11 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Steel production	0	2.09	3	20.9	-	-	-	14.4	Kupiainen & Klimont (2004)

12

13 Recommended EF:

14 EF = 0% (BC/PM_{2.5})

15 **Electric arc furnace**

16 Table x Emission factors for BC from an electric arc furnace (kg/tonne steel) (the table is based on
17 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Steel production	0	0.18	4.04	17.55	-	-	-	23.0	Kupiainen & Klimont (2004)
Steel production	-	-	-	-	-	0.36	3.23	-	US EPA, no.: 91153

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19 Recommended EF:

20 EF = 0.36% (BC/PM_{2.5})

21 **Iron and steel foundries**

22 Table x Emission factors for BC from iron and steel foundries (kg/tonne iron) (the table is based on
23 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Iron foundries	0	0.27	2.8	15.05	-	-	-	18.6	Kupiainen & Klimont (2004)
Iron foundries fugitive	0	0	0.4	5.75	-	-	-	6.96	Kupiainen & Klimont (2004)
Cast iron, cupola	-	-	-	-	-	0.91	6.37	-	US EPA, no.: 91157
Cast iron, induction	-	-	-	-	-	ni	ni	-	US EPA, no.: 282012.5

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2 Recommended EFs:

3 Cast iron, cupola: EF = 0.91% (BC/PM_{2.5})

4 Cast iron, inductive: EF = 0% (BC/PM_{2.5})

5 *Ferro-manganese furnace*

6 Table x Emission factors for BC from a ferro-manganese furnace (kg/tonne steel).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Ferro-manganese	-	-	-	-	-	10.1	5.14	-	US EPA, no.: 91151

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8 Recommended EF.

9 EF = 10% (BC/PM_{2.5})

10 *Aluminium production*

11 Table x Emission factors for BC from aluminium production (kg/tonne aluminium) (the table is based on
12 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Aluminium production, primary	0	0	8.46	47.00	-	-	-	18.0	Kupiainen & Klimont (2004)
Aluminium production, secondary	0.0012	0.013	1.428	11.9	0.084	-	-	12.0	Kupiainen & Klimont (2004)
Aluminium production	-	-	-	-	-	2.30	3.90	-	US EPA, no.: 91137
Aluminium processing	-	-	-	-	-	0.19	1.5	-	US EPA, no.: 91132

13

14 Recommended EFs:

15 Aluminium, primary: EF = ??

16 Aluminium, secondary: EF = ??

17 Aluminium, processing: EF = 0.19% (BC/PM_{2.5})

18 *Copper production*

19 Table x Emission factors for BC from copper production (kg/tonne copper).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Copper processing	-	-	-	-	-	0.099	1	-	US EPA, no.: 91158

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1 Recommended EF:

2 EF = 0.099% (BC/PM_{2.5})

3 **Non-ferrous metal production**

4 Table x Emission factors for BC from non-ferrous metal production (kg/tonne metal) (the table is based on
5 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Non-ferrous metal production	0	0	3.6	15.0	-	-	-	24.0	Kupiainen & Klimont (2004)

6

7 Recommended EF:

8 EF = 0% (BC/PM₁)

9 **2.D Other processes**

10 **Paper pulp production**

11 Table x Emission factors for BC from paper pulp production (kg/tonne air dried pulp) (the table is based on
12 Kupiainen & Klimont (2004)).

Sector	BC	OC	PM ₁	TSP	BC/PM ₁ %	BC/PM _{2.5} %	OC/PM _{2.5} %	PM ₁ /TSP %	Reference
Paper pulp production	2	10	41.4	134	4.83	-	-	30.9	Kupiainen & Klimont (2004)
Kraft process, recovery furnace	-	-	-	-	-	1.53	5.23	-	US EPA, no.: 91119
Pulp and paper mills	-	-	-	-	-	0.10	ni	-	US EPA, no.: 91144
Pulp And Paper Industry	-	-	-	-	-	2.64	29.7	-	US EPA, no.: 900152.5

13

14 Recommended EF:

15 Pulp and paper mill: EF = 0.10% (BC/PM_{2.5})

16 Kraft recovery process: EF = 1.5% (BC/PM_{2.5})

17 Pulp and paper industry: EF = 2.6% (BC/PM_{2.5})

18 **Recommendations**

19

20 To be included

21

22 **References**

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