

## 1 Discussion paper: BC fractions of PM emissions from navigation

2 The update of the EMEP/EEA Emission Inventory Guidebook with emission data for BC (black carbon), must  
3 be based on studies reporting both total PM and BC in order to derive consistent BC fractions of PM (f-BC).

4 Table 1 presents an overview of the nine studies which have been regarded as relevant for the present  
5 literature review. All studies report emission results from single engine measurements, except one study  
6 for which the results are obtained from plume measurements of a large number of vessels. Apart from f-BC  
7 fractions, for each study the vessel type, fuel type and engine characteristics such as engine speed class,  
8 stroke and engine size is listed, as well as the PM emission sampling conditions as far as information is  
9 available. Some of the following references also report figures for OC which can be input for the further  
10 assessment of OC fractions of PM (f-OC) in a future project.

11 **Agrawal (2010)** reports PM measurement results (including hydrated sulphate), EC and OC, from this  
12 specific study and previous measurements documented in **Agrawal (2008a and 2008b)**. Agrawal et al.  
13 (2010) interpret EC as BC for all three studies.

14 **Petzold (2010)** reports own PM measurement results (including hydrated sulphate) as well as EC, BC, OM  
15 and  $\text{SO}_4^{2-}$ . In addition, Petzold show a result summary table for other measurement studies with  
16 corresponding PM and BC measurements, and hence f-BC to be derived from these measurements. The PM  
17 results from **Murphy et al. (2009)** are listed including hydrated sulphate. The PM results from Lack et al.  
18 (2009) based on plume measurements are listed excluding hydrated sulphate. The latter explains why BC  
19 shares become very high in the Lack et al. (2009) case, as shown in Table 1.

20 In more details, the above mentioned study **Murphy et al. (2009)** reports measurements of total PM  
21 (including hydrated sulphate), EC, OC, and sulphate ( $\text{SO}_4$ ). Calculated hydrated sulphate ( $\text{H}_2\text{SO}_4 \cdot 6.5\text{H}_2\text{O}$ )  
22 figure is also shown. The EC results obtained by Murphy et al. (2009) are interpreted as BC by Petzold et al.  
23 (2010).

24 **Lack et al. (2009 and 2011)** report plume measurements of total PM excluding  $\text{SO}_4$  bound water or ash, and  
25 also reports  $\text{SO}_4$ , POM and BC. As previously mentioned, the BC shares of PM derived from Lack et al.  
26 (2009, 2011) are generally high compared to other measurements studies. The high BC emission shares can  
27 be explained by the fact that the related PM emissions does not include water bound  $\text{SO}_4$ . Lack et al. (2009)  
28 obtain emission results from the plume of 211 commercial vessels during an extensive measurement  
29 campaign. In Lack et al. (2011), the emissions are measured from one vessel before and after fuel switch  
30 between low sulphur and high sulphur fuel.

31 Lack et al (2009) reports f-BC figures derived from measurements made by **Petzold et al. (2004)** and **Kasper**  
32 **et al. (2007)**.

33 A comprehensive literature review has been made by Lack and Corbett (2012) assessing the impact of  
34 engine load, fuel quality and exhaust after treatment systems for engines used by navigation. Although the  
35 work made by Lack and Corbett (2012) contain a lot of detailed information of BC emissions from ship  
36 engines, data on total PM emissions are excluded from the literature review. Hence, it is not possible to  
37 derive consistent f-BC fractions of PM from this source.

1 The f-BC as well as vessel, fuel, engine characteristics as well as sampling conditions from the above  
2 mentioned studies are listed in the following Table 1.

3 Table 1 f-BC fractions from the references considered in the present literature review

Reference	Vessel	Fuel <sup>a</sup>	Engine <sup>b</sup>	Stroke	Size (kW)	Sampling	f-BC	Comment
Petzold et al. (2004)	-	HFO	SS				7	From Lack et al. (2009)
Kasper et al. (2007)	Tanker	HFO	SS	2-stroke	8500	-	17	From Lack et al. (2009)
	Tanker	MDO	SS	2-stroke	8500	-	17	
Lack et al. (2009)		HFO	SS			Plume	12	Table 3, and Petzold et al. (2010), Table 1
		MDO	MS			Plume	40	
		MDO	HS			Plume	22	
		MDO, avg				Plume	31	
Lack et al. (2011)		HFO	SS			Plume	6	Table 1
		MDO	SS			Plume	33	
Agrawal et al. (2008a)	Container	HFO	SS	2-stroke	50270	8178-1	1.3	From Petzold et al. (2010), Table 2
Agrawal et al. (2008b)	Tanker	HFO	SS	2-stroke	15750	8178-1	1.1	From Agrawal et al. (2010), Table 6
Agrawal et al. (2010)	Container	HFO	SS	2-stroke	54840	8178-4	0.3	Table 6
Murphy et al. (2009)	Container	HFO	SS	2-stroke	54840	8178-1	0.3	
Petzold et al. (2010)	-	HFO	MS	4-stroke	10000		2.6	Engine test rig results
Jayaram et al. (2011)								Harbor craft. Only measures EC and OC

4 a: HFO: heavy fuel oil; MDO: marine diesel oil

5 b: SS: Slow speed; MS: Medium speed; HS: High speed

## 6 Recommendation

7 The recommendation is to use the f-BC fractions derived from the plume measurements made by Lack et  
8 al. (2009) and to distinguish only between fuel types. The main reason for selecting the data from Lack et  
9 al. (2009) is that the latter study is very comprehensive having measured the emissions from 211  
10 commercial vessels. In opposition, the remaining studies referenced above are single engine experiments.  
11 The data for slow speed engines from Lack et al. (2009) is used to represent HFO (f-BC = 0.12) , whereas the  
12 average of the emissions from medium and high speed engines is used to represent MDO (f-BC = 0.31). A  
13 +/- uncertainty range of 20 % for the BC emission factor is stated by Lack et al. (2009), and this uncertainty  
14 range is used for the present study as well.

15 The tables in the Guidebook being updated with f-BC (or BC factors calculated from the existing PM factors  
16 and the examined f-BC fractions) are listed in Table 2. These fractions must then be combined with the  
17 existing PM factors in GB in order to establish the final BC emission factor in each case.

18 Table 2 relevant for f-BC updates in the GB navigation chapter

Table no.	Tier	Detail	BC:PM data source
3-1	1	HFO	Present survey
3-2	1	MGO	Present survey
3-3	1	Gasoline (boats)	Winther et al. (2011) – IIASA
3-4	2	Engine type x Fuel type	Present survey
3-5	2	Boats (D/G2/G4) x Fuel type	Winther et al. (2011) – IIASA
3-9	3	Phase x Engine type x Fuel type	Present survey
3-10	3	Phase x Engine type x Fuel type	Present survey
3-11	3	Boats (D/G2/G4) x Vessel type x Fuel type	Winther et al. (2011) – IIASA

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1 For diesel fuelled boats, f-BC = 0.55 are taken from road transport conventional car engines available from  
2 the COPERT model. For gasoline fuelled boats, f-BC = 0.05 are taken from Winther and Nielsen (2011) based  
3 on information from Kupiainen and Klimont (2004).

#### 4 **Inclusion of f-BC values in the guidebook**

5 The inclusion of the new f-BC information in the guidebook can be made in several ways and needs to be  
6 agreed by the transport expert panel prior to the update of the individual chapters. For navigation, one  
7 approach can be to place the final version of the present note as an annex to the guidebook chapter, and  
8 make references to the relevant PM emission factor tables in the chapter. Another approach can be to  
9 include directly the f-BC fractions in the relevant PM emission factor tables, or as foot notes to the tables.  
10 References can then be made to the annex description, or alternatively a brief summary of the discussion  
11 note can be put somewhere central in the chapter.

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#### 14 **References**

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