

Taking Stock: Where are we on defining, measuring and controlling black carbon?

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The logo for the International Council on Clean Transportation (icct). It features the lowercase letters 'icct' in a bold, dark blue font. The letter 'i' has a small blue circle above it. Below the letters, the full name 'THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION' is written in a smaller, all-caps, dark blue font.

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My goals for this presentation

- Present you with an overview of progress to date on:
 - Defining BC
 - Measuring BC
 - Controlling BC
 - Estimating BC (inventories)

IMO BC work plan

- MEPC 62 agreed to a work plan to consider the impact on the Arctic of BC emissions from shipping and instructed BLG (now PPR) to:
 - Develop a definition of BC
 - Identify the most appropriate method(s) to measure marine BC
 - Investigate appropriate control measures

Progress on the IMO BC work plan

Year	Meeting	Outcomes
2015	MEPC 68	<ul style="list-style-type: none">• Adopted Bond et al. (2013) definition of BC, as agreed to at 1st BC technical workshop (Ottawa)
2016	PPR 3	<ul style="list-style-type: none">• PPR endorsed EUROMOT measurement reporting protocol refined at the 2nd BC technical workshop (Utrecht) and field tested in subsequent research
2017	PPR 4	<ul style="list-style-type: none">• Canada and the Netherlands submitted a summary of 3rd BC technical workshop (Vancouver) on BC measurement and control• Agreed to identify the most appropriate method for measuring marine BC at PPR 5• Agreed to to finalize appropriate control measures for BC at PPR 6

Upcoming IMO actions on BC

Year	Meeting	Expected Outcomes
2018	PPR 5	<ul style="list-style-type: none">Finalization of BC measurement reporting protocolIdentification of the most appropriate method for measuring BC
2019	PPR 6	<ul style="list-style-type: none">Finalization of appropriate control measures for consideration by MEPC
2019	MEPC 74	<ul style="list-style-type: none">Discussions on BC control measures and policies could begin

The definition of BC is settled

BC is a distinct type of carbonaceous material, formed primarily in flames, is directly emitted to the atmosphere, and has a unique combination of physical properties:

1. BC strongly absorbs visible light with a mass absorption coefficient (MAC) value above $5 \text{ m}^2 \text{ g}^{-1}$ at a wavelength $\lambda = 550$ nanometers (nm)
2. BC is refractory, with a vaporization temperature near 4000 K
3. BC is insoluble in water, in organic solvents including methanol and acetone, and in other components of atmospheric aerosol; and
4. BC exists as an aggregate of small carbon spherules.

How best to measure BC is the critical question at this point

- IMO has asked members to look at 4 methods:
 - Filter Smoke Number (FSN)
 - Photo Acoustic Spectroscopy (PAS)
 - Multi Angle Absorption Photometry (MAAP)
 - Laser Induced Incandescence (LII)
- Many researchers in this room have experience with these instruments.
- Many researchers have found good agreement with FSN and PAS. LII correlated well, but there's limited experimental data. The most BC emission factor data we have to date comes from FSN measurements.
- Several have stated that MAAP is not fit for purpose.

Appropriate BC control measures are also needed – we'll learn more about this today

- Technologies
 - Diesel particulate filters
 - Fuel switching
 - LNG (but need to be careful about life-cycle GHGs)
 - SCR and low-PM engine recalibration (burn hotter to reduce BC, and use SCR to address higher NO_x)
 - Energy efficiency ship designs and retrofits
 - Scrubbers (SO_x reduction w/ BC reduction co-benefits)
 - Alternative fuels and propulsion technologies (biofuels, hydrogen, batteries, etc.)
- Operations
 - Slow steaming
 - Shore power

Inventories – understanding how much (and where) ship BC is emitted

Study	Inventory Year	BC (kilotonnes)	Fuel consumption (million tonnes)	BC EF (g/kg fuel)
Global BC Inventory				
Bond et al. (2013)	2000	100	-	0.17-0.85
Dentener et al. (2006)	2000	130	182	0.69
Fuglestvedt et al. (2010)	2000	197	182	1.08
Eyring et al. (2005)	2001	50	280	0.18
Lack et al. (2008)	2001	133	254	0.53
Dalsøren et al. (2009)	2004	39	216	0.18
Eyring et al. (2010)	2005	160	300	0.53
Buhaug et al. (2009)	2007	120	333	0.36
Comer et al. (2017b)	2015	67	247	0.27
BC in the Arctic				
Corbett et al. (2010)	2004	1.25	3.5	0.35
Peters et al. (2011)	2004	1.15	3.3	0.35
DNV (2013)	2012	0.052	0.3	0.18
Winther et al. (2014)	2012	1.58	4.5	0.35
Comer et al. (2017a)	2015	1.45	4.4	0.30-0.56 (0.34 avg.)

Global BC inventory, 2015

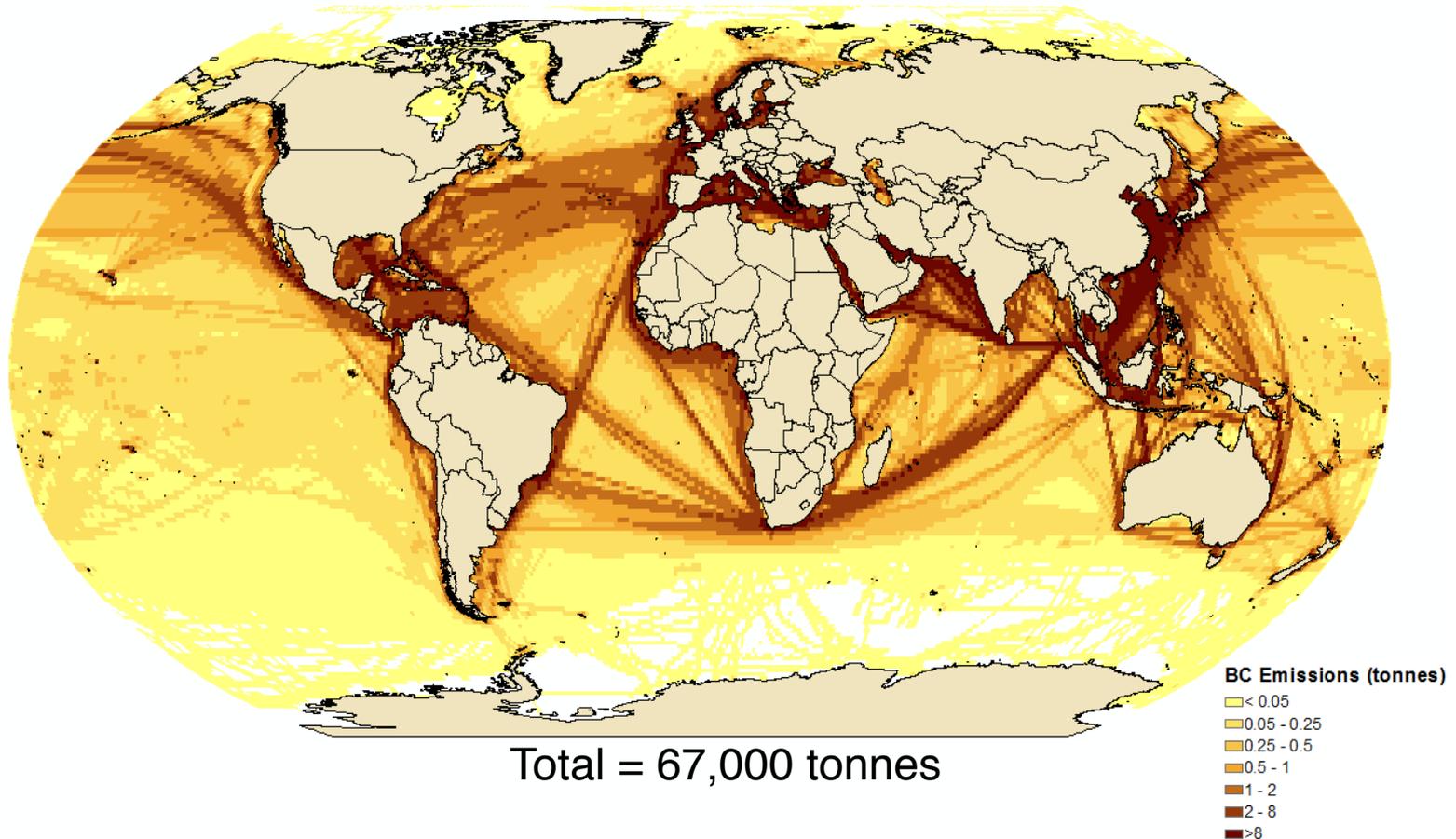
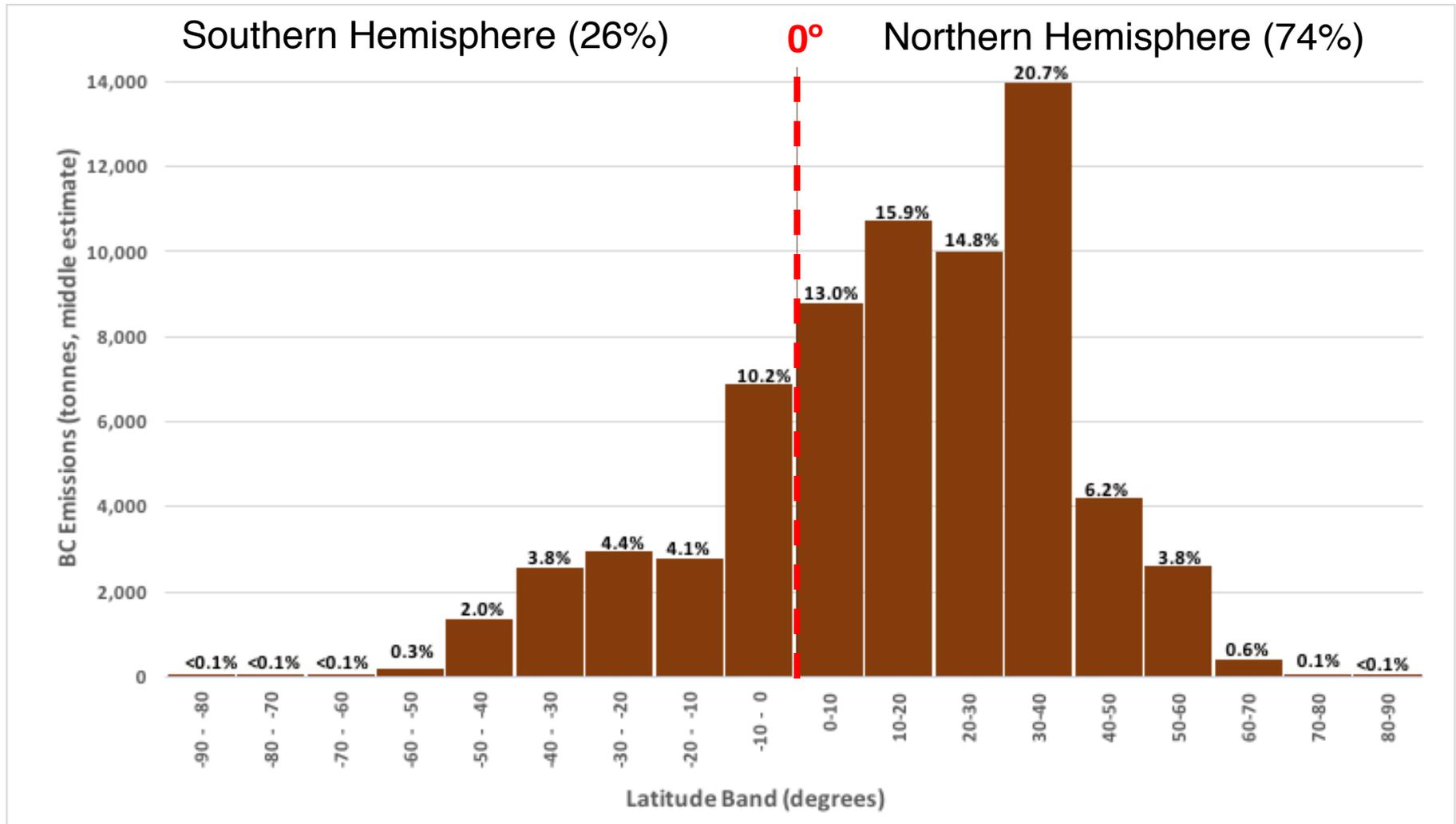
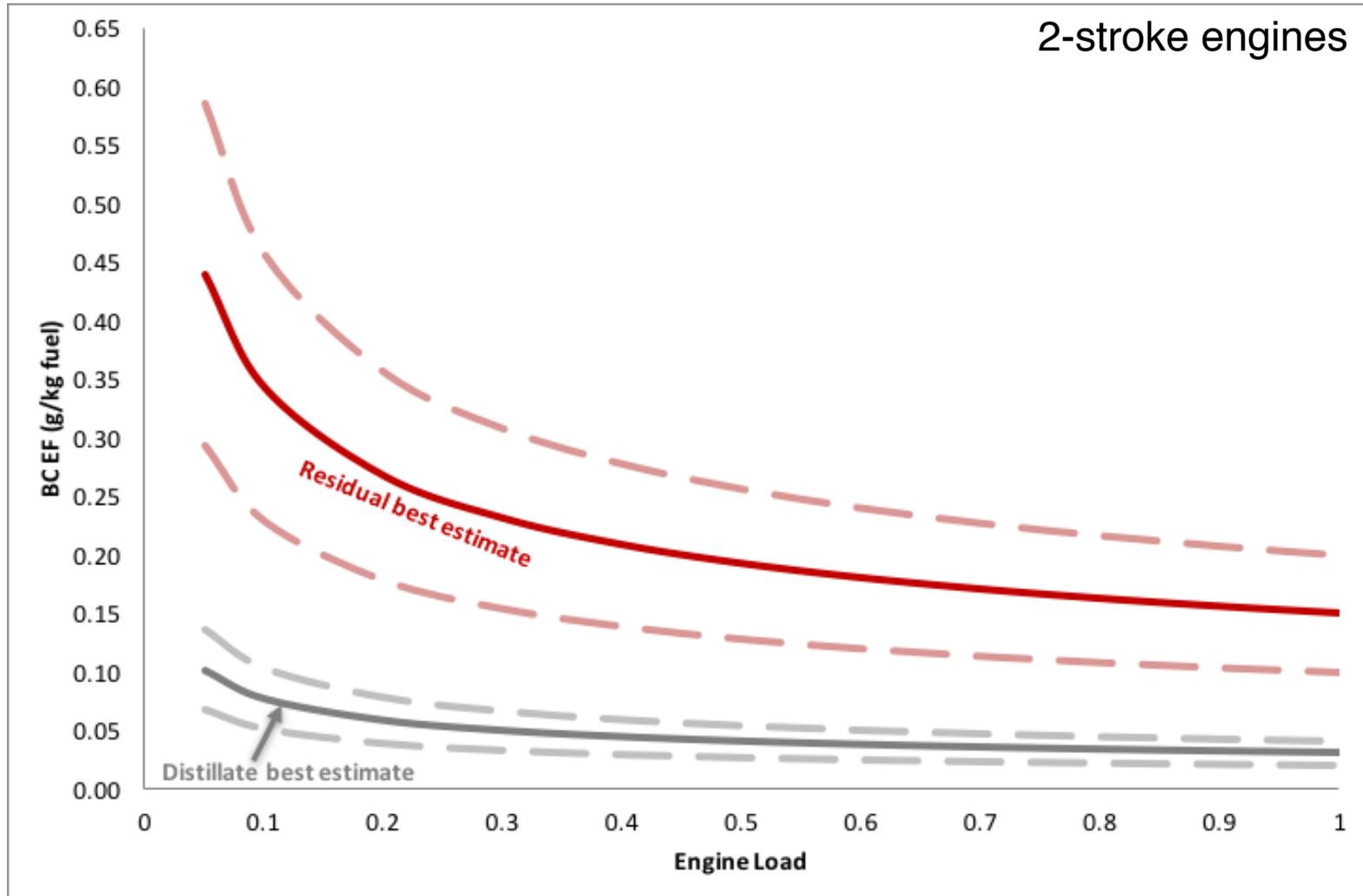


Figure from our upcoming report *Black carbon emissions and fuel use in global shipping, 2015*.
Soon to be available at: <http://theicct.org/black-carbon-emissions-global-shipping-2015>

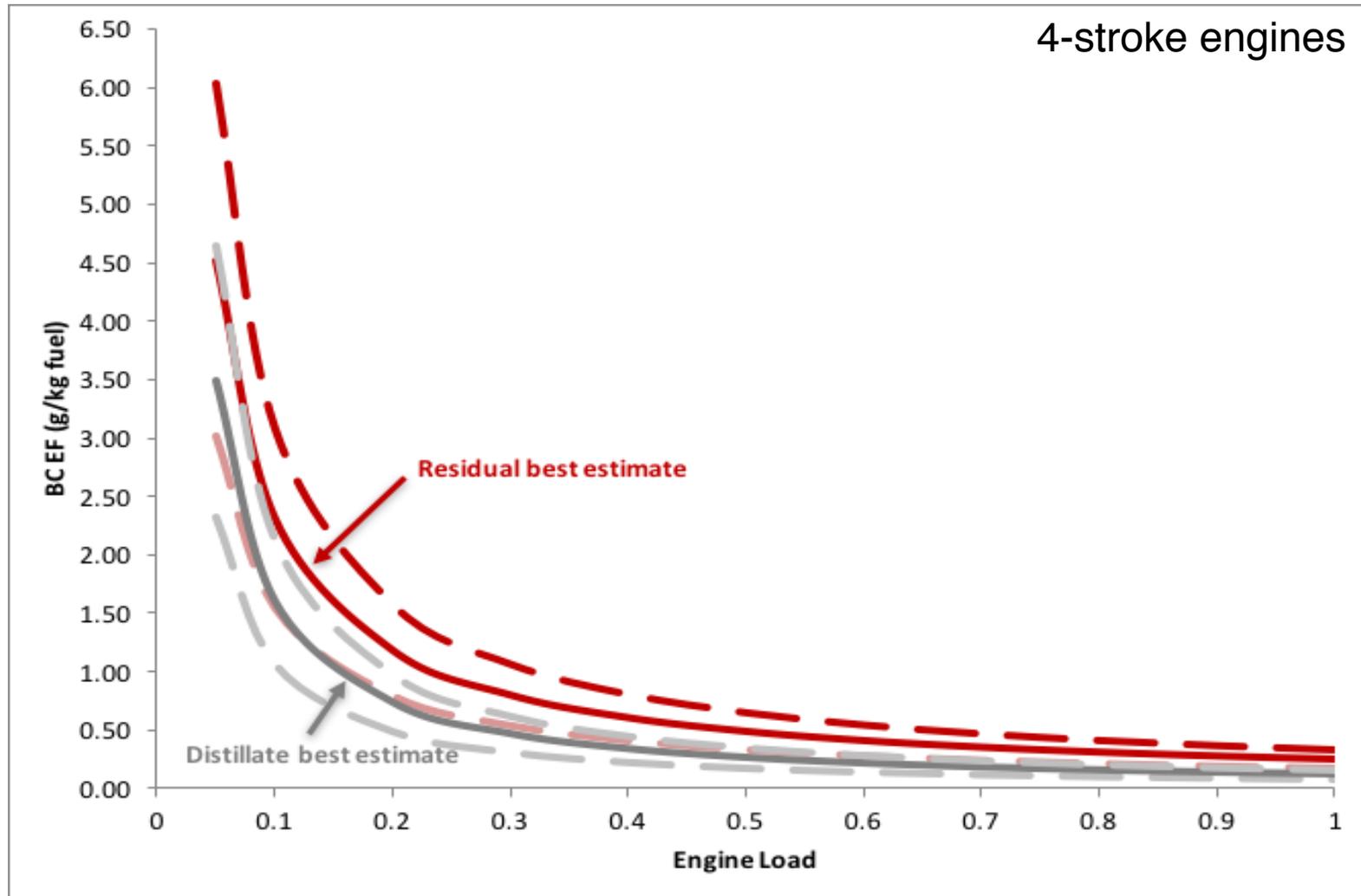
74% of BC emitted in the Northern Hemisphere



Global BC inventory uses BC EFs based on recent testing data and can be updated over time



4-stroke engine BC EFs (note the order of magnitude increase on the y-axis)



Conclusions

- We've defined BC
- We've measured BC
- We've identified many ways to control BC
- We've estimated BC in Arctic and global inventories
- Now we, the community interested in this topic, will need to share our expertise to help IMO make progress on BC by:
 - Identifying the most appropriate method(s) to measure marine BC
 - Identify appropriate control measures for marine BC

Thank you!

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