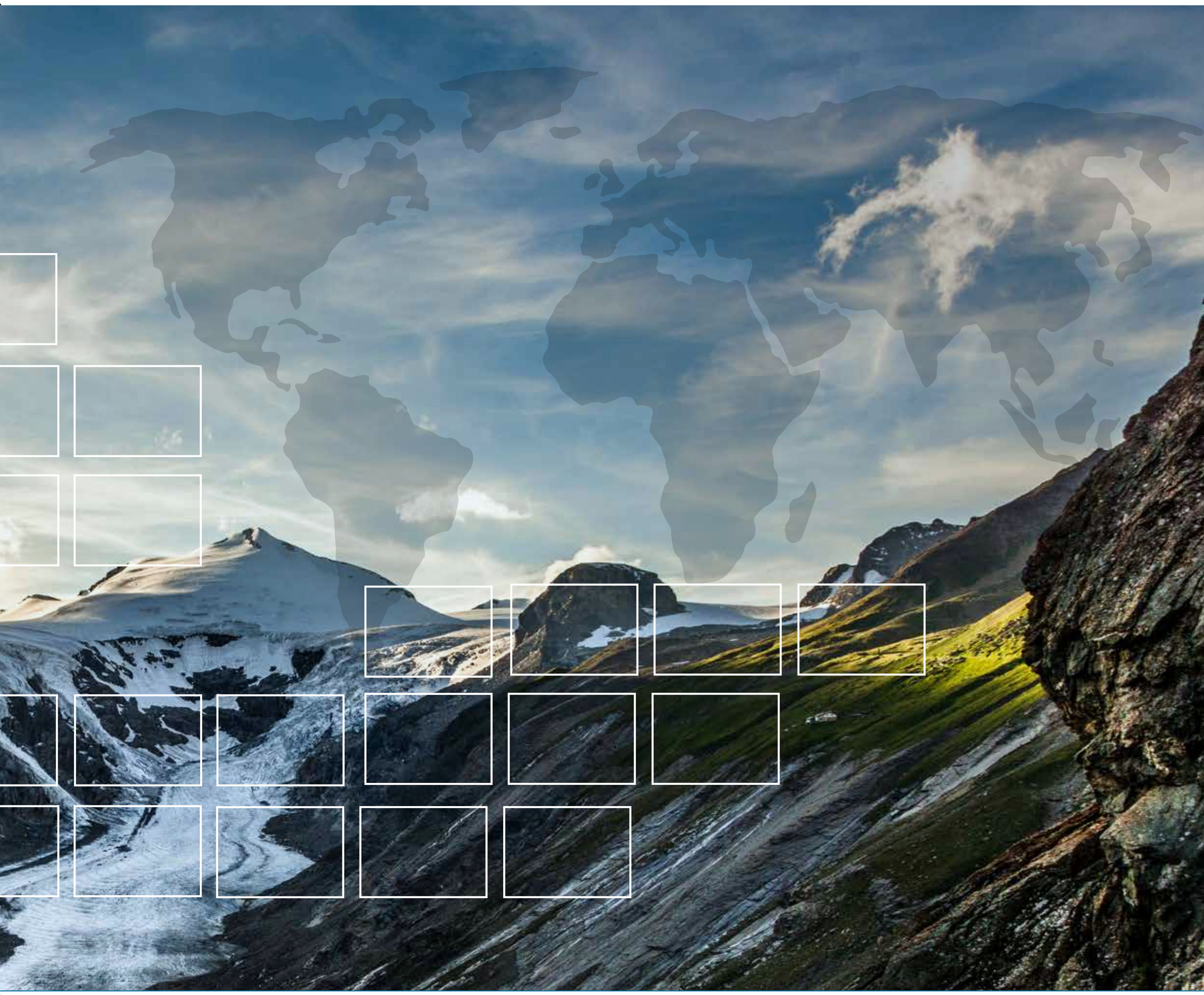
BLACK CARBON

METHODOLOGY FOR THE LOGISTICS SECTOR



SMART FREIGHT CENTRE

GLEC GLOBAL LOGISTICS EMISSIONS COUNCIL

CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

icct THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

SmartWay®

Trade in goods and materials drives global economic growth and development, linking nations and markets through an increasingly interdependent supply chain. The Global Green Freight Project was created by the Climate and Clean Air Coalition (CCAC) as part of a large-scale effort to reduce the climate and health impacts and improve the energy and economic efficiency of transporting those goods and materials. The CCAC funded the development of this methodology to better track black carbon emissions from freight movement as part of its mission to raise awareness of these short-term climate pollutants.

Author

Suzanne Greene, Smart Freight Centre Adviser

Advisors

Eastern Research Group: Rick Baker, John Koupal; International Council on Clean Transportation: Cristiano Façanha, Ray Minjares, Ben Sharpe; Smart Freight Centre: Alan Lewis, Sophie Punte; US Environmental Protection Agency SmartWay: Buddy Polovick, Joshua Silverblatt; and the UN Climate and Clean Air Coalition: Denise Sioson.

Acknowledgments

Benjamin Brown-Steiner (Massachusetts Institute of Technology), Roger Chang, (US Environmental Protection Agency) James Corbett (University of Delaware), Brittany Kelly (Natural Resources Canada), Zbigniew Klimont (International Institute for Applied Systems Analysis), Britney McCoy (US Environmental Protection Agency), Philippe Payen (TK'Blue), Veerabhadran Ramanathan (University of California, San Diego), Stephan Schablinski (Green Freight Asia), Colin Smith (Energy Savings Trust), Darrell Sonntag (US Environmental Protection Agency), and David Yen (US Environmental Protection Agency).

Suggested citation

Smart Freight Centre. *Black Carbon Methodology for the Logistics Sector*. Global Green Freight Project, 2017.

Disclaimer

The contents of the Black Carbon Methodology for Logistics are subject to future change as common practice and scientific knowledge evolves and, in such circumstances, will be reflected in periodic updates. Smart Freight Centre and other partners of the Global Green Freight Project do not guarantee the accuracy of the data included in this publication. Use of the Black Carbon Methodology for Logistics is voluntary; the Global Green Freight Project does not accept responsibility for consequence of its use. The Black Carbon Methodology for Logistics is not intended to replace or supplant any laws or regulations; in the event that this document conflicts with a required regulatory methodology, users should report emissions in adherence to the regulatory requirement.

Contact

Smart Freight Centre
Vijzelstraat 68-78, 1017 HL,
Amsterdam, Netherlands
P.O. Box 11772, 1001 GT,
Amsterdam, Netherlands
Tel office: +31 6 4695 4405
www.smartfreightcentre.org
info@smartfreightcentre.org

BLACK CARBON

METHODOLOGY FOR THE LOGISTICS SECTOR

TABLE OF CONTENTS

List of tables

List of figures

INTRODUCTION AND BACKGROUND

This document is meant to provide guidance to the logistics sector for the voluntary measurement and reporting of black carbon emissions. This report provides guidelines for calculating black carbon emissions resulting from the movement of freight by air, inland waterways, rail, road and sea, as well as transhipment centers. In keeping with the principles of the Global Logistics Emissions Council (GLEC) Framework for Logistics Emissions Methodologies,[1] the Black Carbon Methodology for the Logistics Sector, hereafter referred to as the 'Black Carbon Methodology,' aims to reach the following goals:

- Provide industry and stakeholders with a simple methodology to estimate black carbon emissions with sufficient accuracy for benchmarking, reporting and sustainable decision-making
- Offer a transparent framework characterizing uncertainty within the results via bronze, silver and gold calculation tiers
- Build on existing methodologies to work towards harmonization and standardization of carbon emissions accounting in general
- Raise awareness of black carbon emissions across the global multi-modal supply chain in order to drive innovation and investment in reducing or eliminating emissions

Figure 1 Overview of black carbon methodology requirements

The Black Carbon Methodology can be adapted depending on the data available. As shown in Figure 1, the Black Carbon Methodology can be used to perform a high-level assessment of black carbon emissions (bronze tier) using similar data as required for a greenhouse gas assessment. While these results may be suitable for some decision-making and reporting uses, the accuracy of the values generated greatly improved if more detailed information is available on fuel use, vehicle type and other factors (silver and gold tiers).

Reaching higher levels of accuracy may require the collection of additional data, which can be a difficult task, especially for logistics emissions from subcontracted transport providers (scope 3 emissions). An initial assessment at the bronze level can be used to prioritize data collection efforts for regions, activities or modes with higher emissions.

Defining black carbon

Black carbon are small, dark particles produced from the incomplete combustion of biomass and fossil fuels.[2] If you've ever seen soot coming out of a smokestack or a truck spew black smoke, you've seen black carbon. Black carbon is always emitted alongside other co-pollutants, like organic carbon, brown carbon, ash and sulfates, which are generally classified together under the umbrella category of particulate matter (PM).[3] In terms of air quality regulations, PMs are commonly divided by particle size: under 2.5 micrometers in diameter (PM2.5) and particles under 10 micrometers (PM10). For transport, 98% of PM emissions are within the category of PM2.5.[4]

Elemental carbon is often used interchangeably with black carbon; the primary distinction between elemental and black carbon is based on the measurement technique. Elemental carbon is measured by both thermal heating and optical absorption, whereas black carbon is only measured through optical absorption.[2] For the Black Carbon Methodology, elemental carbon is considered to be the same as black carbon, meaning emissions factors based on measurements of elemental or black carbon can be used. However, as research evolves, the methodology may be updated to further distinguish between black and elemental carbon.

Black carbon can also come from non-exhaust sources, such as wheel and brake wear as well as road abrasion. In regions without advanced tailpipe emissions standards (Euro VI-equivalent), these emissions generally constitute a small share of PM emissions. As more trucks reach a higher engine standard, it might become relevant to consider these emissions.

The Black Carbon Methodology only considers black carbon emissions related to fuel combustion that can be controlled using tailpipe exhaust emissions standards. While they are important to consider from a health impact perspective, co-pollutants and non-exhaust sources are not the focus of this report but could be considered in future iterations. To support this possibility, emissions factors for non-exhaust emissions are included in Appendix 1 to be used on a voluntary basis.[4,5]

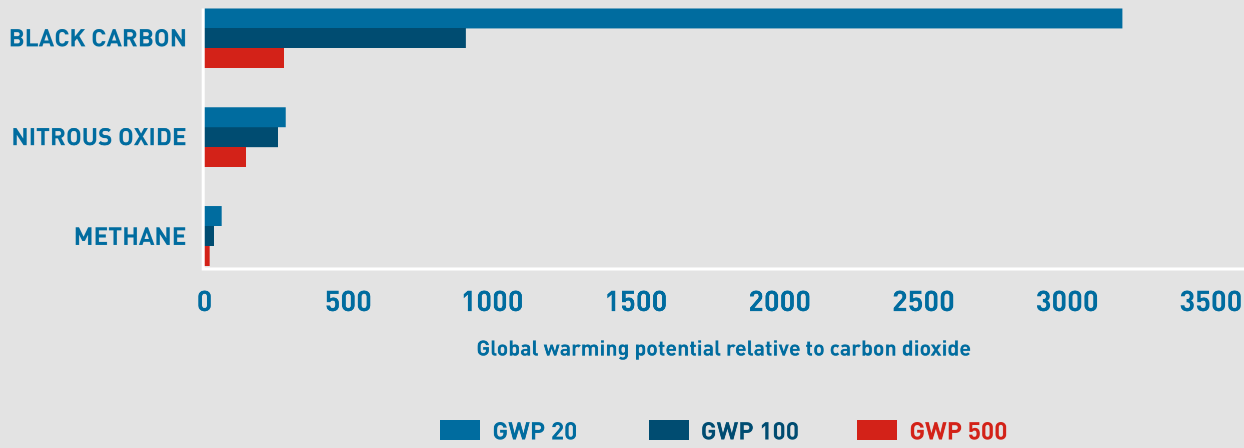


Figure 2 The global warming potential (GWP) of climate pollutants related to transport emissions; the values are relative to carbon dioxide, which has a GWP of 1. The values for nitrous oxide and methane are from the 2014 IPCC Fifth Assessment Report; the black carbon values are taken from Bond et al 2013.

Black carbon and climate

After carbon dioxide, black carbon has the second biggest impact on climate forcing in the atmosphere. Black carbon typically remains in the atmosphere for days to weeks, until it returns to the earth's surface through rain or air deposition.[4,6] Carbon dioxide, in contrast, stays in the atmosphere for decades.

While in the atmosphere, black carbon has over 3,000 times the global warming potential (GWP) of carbon dioxide. Figure 2 shows the GWP black carbon compared with other climate pollutants, nitrous oxide and methane, over a 20, 100 and 500 year time scale.[2,7] The values are relative to carbon dioxide, which has a GWP of 1 over the 500-year time horizon. The short-term impact of black carbon is evident; its impact drops precipitously after 20 years, though still remaining higher than nitrous oxide and methane.

Airborne black carbon absorbs and scatters sunlight, increasing temperatures, melting snow and ice and impacting cloud formation and distribution. It can also influence air circulation and precipitation. For example, black carbon has been implicated in shifts in the global circulations patterns that control large-scale weather systems like the Asian monsoons.[2]

When deposited on the earth's surface, black carbon's impact is particularly relevant in the cryosphere, or regions of frozen water. It reduces reflectivity (albedo), causing sea ice, glaciers and other areas of snow and ice to melt. Black carbon has a disproportionate impact in areas above the 40th parallel, such as the Arctic Sea, where particle deposition can increase the rate at which snow and ice melts, particularly in the local springtime.[4,8] Black carbon also impacts the Himalayan region, where it has increased glacial melt and decreased snowpack.[4]

Black carbon and transportation

As Figure 3 shows, black carbon has a number of harmful qualites, but also the potential for reduction. How does transport contribute to the black carbon problem? On a global scale, the largest sources of black carbon are open burning of grasses, woodlands and forests (as well as agricultural fields to a lesser degree), residential heating and cooking (primarily from wood fires), and diesel engines.[2] On a regional level, the dominant source of black carbon varies. In Africa, Latin America and Southeast Asia, open burning of grasses, woodlands and forests is the most significant contributor to black carbon emissions, while biofuel cooking fires are the largest source in East and South Asia and as well in Africa. East Asia is the only region with a significant black carbon contribution from industrial coal. In Europe and North America, on the other hand, the primary source of black is on-road diesel engines (e.g., diesel trucks, cars, etc.) and off-road diesel engines (e.g., trains, ships, agricultural and construction equipment, generators, etc.).

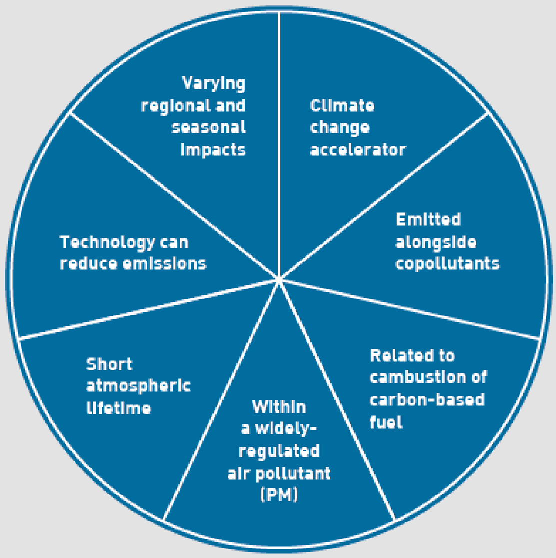


Figure 3 Summary of key characteristics of black carbon

Figure 4 shows the breakdown of emissions by mode of transport as calculated by two leading emissions models, SPEW and GAINS.[9] On-road diesel engines are the primary source of black carbon, followed by off-road diesel engines. Off-road diesel engines include locomotives and other heavy duty equipment, thus the share related to freight transport is expected to be smaller than what is shown in the figure. On-road gasoline engines and international marine vessels follow to a much lesser degree. According to the World Bank, road and sea sector together released nearly 4.8 million tonnes of black carbon in 2000, roughly 20% of global emissions.[10] Air transport takes a larger share in the SPEW model because it includes emissions from the full flight cycle; whereas the GAINS model only includes landing and take-off.

Over the next 30 years, emissions from transport are expected to fall in some regions and grow in others.[10] Developed countries will see black carbon emissions continue to drop in coming years as new vehicle technologies and cleaner, low-sulfur fuels are developed and implemented. In developing countries, however, emissions are expected to grow as transport activities increase and outdated technologies remain in use. Further, diesel fuel standards that allow the use of higher sulfur fuels can negate the gains from some emissions control technologies. This phenomenon can be demonstrated by the US and China. While each country has a similar level of transport activity, China is the source of over 50% of global transport-related black carbon emissions between now and 2050, whereas the US will contribute less than 5%.[11,12]

Black carbon, transport and climate goals

How do transport-related black carbon emissions affect the global temperature? Road transport will have the biggest impact from the sector; black carbon emissions related to road will warm the planet by 0.1° C by 2100, compared with the predicted CO_2-related warming of 0.3° C.[13] Air and sea black carbon emissions together are considered to have a warming impact of 0.1° C.

The co-pollutants associated with black carbon emissions, like organic and brown carbon, can have the opposite affect on the climate, scattering sunlight and providing a cooling effect.[3,14] From a short-lived climate impact perspective, however, their cooling impacts are relatively small. Co-pollutants typically offset less than 5% of the climate benefits of black carbon mitigation from heavy-duty vehicle emissions standards.[15] As cleaner technologies reduce the concentration of black carbon in PM, co-pollutants may contribute more significantly to temperature reduction.

Black carbon and communities

Black carbon and its co-pollutants are linked to numerous negative effects on human health, particularly for the ill or elderly.[16] Exposure to fine particles can cause harmful effects on the respiratory and cardiovascular systems (the lungs, heart, blood, and blood vessels).

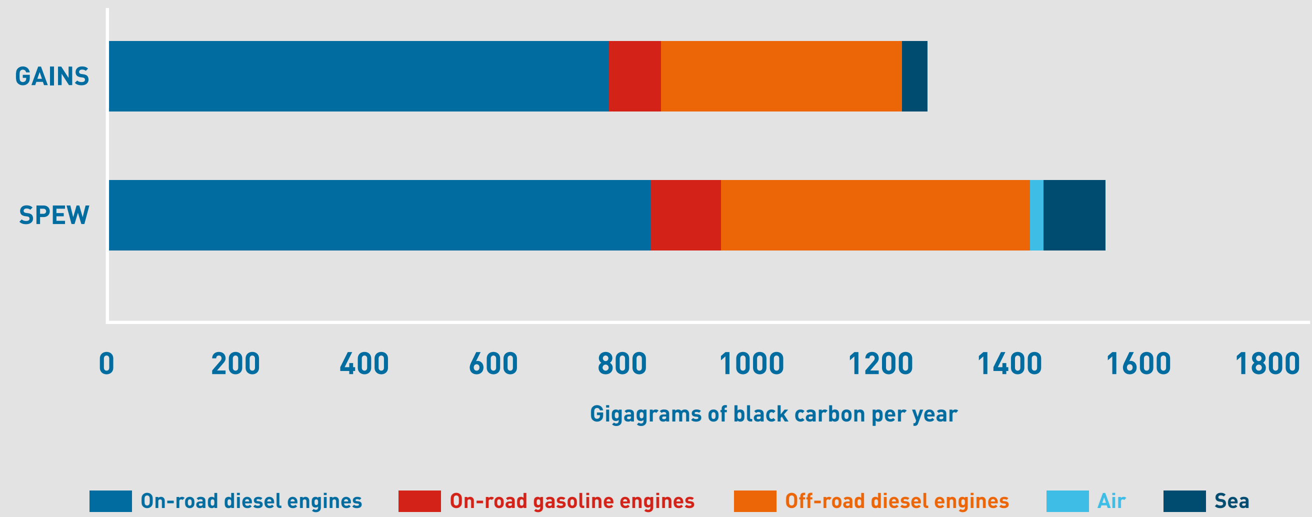


Figure 4 Estimated global black carbon emissions from transportation from the SPEW and GAINS models in Bond's 2013 study. Note that the category of "off-road diesel engines" includes rail and sea transport, as well as other heavy machinery and agricultural vehicles.

In 2005, PM2.5 was implicated in 130,000-320,000 premature deaths in the US, 5.4% of all deaths.[17] The health impacts of PM2.5 emissions are higher in urban areas.

The US EPA estimated the health benefits of reducing PM to be valued at $230,000-$880,000 per ton of black carbon in 2010 .[18] To demonstrate the significance of this value, California is estimated to have reduced their black carbon emissions by 21 million tonnes since the 1980s, primarily through improvements to diesel engines.[3] By the US EPA's metric, the health benefits resulting in these upgrades are worth over four trillion dollars.

Unlike carbon dioxide, black carbon is already included in many country's air quality standards as an ingredient of PM. Black carbon emissions can be considered a "low-hanging fruit" since technology solutions are widely available for the largest transport emitter, diesel trucks. Policy efforts to reduce black carbon will simultaneously reduce the health risks and reduce anthropogenic impacts on the climate. Air quality management policies that control PM2.5 are also used in conjunction with tailpipe emissions standards, fuel quality standards, and other related policies.

Previous work on black carbon accounting

The intent of this Black Carbon Methodology is to align existing efforts on GHG and black carbon accounting, using similar data wherever possible to capitalize on ongoing data collection efforts. This design is meant to work in harmony with the following leading methodologies for GHG accounting:

- World Resources Institute and World Business Council for Sustainable Development Greenhouse Gas Protocol (GHG Protocol)[19]
- Intergovernmental Panel on Climate Change Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC Guidance) [20]
- GLEC Framework[1]

Quantifying black carbon is an evolving science. A number of previous efforts offering guiding principles for black carbon accounting that paved the way for this logistics sector guidance.

For cookstove technologies

Gold Standard. The Gold Standard created a framework for estimating black carbon emissions from cookstoves, one of the major sources of global black carbon. Cookstoves are a common mechanism for carbon offsets, thus proper accounting is important to be sure promised emissions reduction goals are met.[21] Accounting for cookstove emissions is a similar challenge to transport emissions. Emissions are dispersed across a wide area, making it difficult to measure emissions directly. Also, emissions vary greatly depending on cookstove technology.

The Gold Standard approach is based on either actual field measurements or on a standard amount of fuel used to cook a typical meal. The weight of fuel combusted combined with a standard emissions factor for the type of cookstove being used can be used to create an emissions inventory for a set time period. Through these metrics, black carbon reductions resulting from initiatives that provide improved cookstove technologies can be estimated with reasonable accuracy.

Wireless Improved Cookstove Sensors. Ramanathan et al proposed a methodology for measuring cookstove emissions using wireless sensor networks.[23] Inexpensive sensors installed in household kitchens transmit information to both the household and climate finance mechanisms, providing a transparent mechanism for monitoring health impacts and funding carbon offsets. Ramanathan found that the sensor's measurements were much lower than those from estimated using default factors, demonstrating the potential for improving the accuracy of emissions estimates through wireless sensors.

For the transport sector

World Bank. The World Bank outlined an approach for quantifying transport-related black carbon in their report titled Diesel Black Carbon Impacts on Climate and Health.[10] Similar to the Gold Standard, emissions are estimated from the bottom-up, based on the amount of fuel combusted. PM is considered as the basis for estimates, with a set of standard ratios to convent PM to black carbon for various fuel types and engine technologies.

Two top-down approaches to creating black carbon inventories have informed the Black Carbon Methodology. These are typically used to find the total emissions for a geographic area, such as a city or country.

European Environmental Agency and Measurement Evaluation Program. The European Environmental Agency (EEA) and Measurement Evaluation Program (EMEP) created the Air Pollution Emission Inventory Guidebook that allows for a high level of resolution on transport activities.[23] The Guidebook suggests a tiered structure to characterize the availability of activity and emissions factor data, similar to the IPCC approach. Tier 1 represents the simplest approach, with the most default data; where tiers 2 and 3 demand increasing levels of primary data. The Guidebook also includes a repository of PM emissions factors for various vehicle types and activities that is relevant to European activities.

Commission for Environmental Cooperation. The Commission for Environmental Cooperation (CEC) offers guidance for North America, providing a robust structure for treating transport emissions in regional inventories. The CEC North American Black Carbon Guidelines provide step-by-step calculation methods, and includes a library of up-to-date emission factors and BC speciation factors for each major emissions sector contributing to BC, and sources of activity data within Canada, Mexico and the U.S.[24] Related to freight transport, the CEC includes details on heavy trucks, marine vessels, rail and off-road equipment (such as cargo handling equipment).

Consistent with IPCC and EEA, the CEC uses a tier structure to accommodate different levels of data availability. Tier 1 for when only aggregated fuel consumption data or default data are available; Tier 2 when some data on the specific transportation fleet is available; and Tier 3 when there is information available on technologies and operation modes. Sources of fuel consumption, activity inputs, emissions factors and speciation factors are provided for each tier and sector.

Harmonizing methodologies

The methodologies and guidelines described above include many similar principles. First, the amount of fuel burned must be understood, whether through a measured weight/volume or through a standard assumption representing average conditions. Second, most recommend a standard black carbon emissions factor that corresponds to the fuel combusted and the technology used to burn the fuel. The cookstove study shows the potential for wireless sensors to more accurately measure emissions, though sensors for transport need further development before they can be deployed on a wide scale.

Third, most methods include a provision for bounding emissions estimates within a certain time period, typically one year. Finally, a structure to categorize data quality is helpful in interpreting results and understanding accuracy. These principles are carried forward in the Black Carbon Methodology, further propagating a consistent platform for estimation across sectors.

FOUNDATIONS OF THIS METHODOLOGY

This methodology offers a practical approach for calculating black carbon emissions from freight transport regardless of a company's position in the supply chain. Black carbon emissions are estimated based on a measure of actual or estimated freight activity (tonne-kilometer, kilometer or liter fuel) multiplied by a standard emissions factor (black carbon per tonne-kilometer, kilometer or liter fuel), as represented by Equation 1.

$$\textbf{Black carbon emissions} = \textbf{activity} \times \textbf{emissions factor}$$

Equation 1 The basic formula for black carbon emissions from freight transport

Below is a summary of the fundamental aspects of the methodology.

Black carbon. This methodology will provide an estimate of the mass of black carbon emitted from fuel combustion related to freight transport activities using either black carbon or PM2.5 emissions factors. Only combustion-related black carbon is included here; black carbon emissions from non-exhaust emissions are not accounted for at this time. Further, climate and health impacts of black carbon and its co-pollutants are not quantified here.

Black carbon emissions factor. The black carbon emissions factor reflects the average mass of black carbon released from a certain activity. One of the most commonly used units for black carbon is grams per kilogram of fuel, as shown in Equation 2, though grams per kilometer or other appropriate units can also be used.

$$\textbf{Black carbon emissions factor} = \frac{\textbf{black carbon (g)}}{\textbf{fuel (kg)}}$$

Equation 2 A common formula for the black carbon emissions factor

Because of the importance of the vehicle type in emissions, a black carbon emissions factor should be adopted that best represents the actual conditions during which the fuel was burned.

Fuel. This methodology uses a bottom-up approach based on fuel consumption. The term fuel is meant to encompass all energy sources including transport fuels and electricity. Fuel data are most accurately reported by mass (kg), although common liquid fuels are frequently measured by volume for convenience. Conversions are available in Appendix 5.

Emission factors based on fuel are only available for tank-to wheel (i.e., fuel combustion); values for the well-to-tank (i.e., upstream fuel production and distribution) black carbon emissions are not widely available and are thus, unlike the GLEC Framework, are not included in the Black Carbon Methodology at this time. This has been flagged as an area requiring further work; well-to-tank black carbon emissions should be included as values become available.

Fuel consumption factor. Similar to a "miles per gallon" or "liters per 100km" figure, the fuel consumption factor is a fuel efficiency metric for logistics that represents the average amount of fuel used to move one tonne of freight for one kilometer under a specified set of conditions. The consumption factor, shown in Equation 3, is typically calculated by carriers based on their actual activities and reported to green freight programs and/or shippers. Empty running and backhauls should be included in order to ensure the full round trip is considered.

$$\text{Fuel consumption factor} = \frac{\sum_1^n \text{fuel consumption}}{\sum_1^n (\text{mass} \times \text{distance})}$$

Equation 3 The formulaic representation of the fuel consumption factor

Where different fuels are used interchangeably within a fleet, or where more than one fuel is used in a vehicle, then the data for each fuel needs to be kept separately until the emission factor has been applied. A detailed description of the fuel consumption factor and its application in the different modes of transport can be found in the GLEC Framework.

Modes of transport. The following modes of transport are covered by the Black Carbon Methodology: air, inland waterways, rail, road and sea (modes are defined in more detail in the Glossary).

Region. Black carbon may have different impacts depending on where it is emitted or deposited. Black carbon emissions are particularly relevant in areas covered by snow and ice, thus the Arctic region is of particular concern, particularly for sea transport.[8] Companies are recommended to estimate the percentage of emissions occurring in areas north of the 40th parallel. Black carbon may also be more relevant in urban areas, due to human health impacts.

Scopes of accounting. To maintain consistency with GHG accounting principles, the Black Carbon Methodology adopts the same scopes of accounting put forth in the Greenhouse Gas Protocol.[19]

- **Scope 1** refers to a company's direct emissions from controlled or owned assets.
- **Scope 2** refers to emissions from the production of purchased electricity, heat or steam. For freight transport, this will largely relate to electric vehicles and transhipment centers.
- **Scope 3** Other indirect emissions, such as the production of purchased materials and non-electricity based fuels and logistics-related activities in vehicles, vessels

or warehouses not owned or controlled by the reporting entity.

Tonne-kilometer. The tonne-kilometer is the standard metric for freight movement, taking into account not only the distance a shipment travels but the weight of the shipment.

Timeframe for average fuel consumption factors. Because black carbon emissions depend on vehicle technology and level of maintenance, average fuel consumption factors are calculated on an annual basis to account for vehicle technology improvements.

Timeframe for reporting. Black carbon emissions are typically reported on an annual basis, similar to typical GHG reporting cycles. Calculations can be completed on other timescales, so long as it is adequately stated alongside the results.

Transhipment centers. Black carbon emissions related to fuel and electricity use in transhipment centers, such as warehouses, distribution centers and ports, should be included in transport chain emissions.

Transport chain. The transport chain is a series of transport legs carried out by various modes interconnected by stops at transhipment centers. The transport chain should assume the widest possible boundary, beginning with the hand-over of a shipment to the transporting party and ending with the delivery of the good at its final destination.

For each transport leg, the mode of transport and geographic location of the start and end points should be clearly defined. For transhipment centers, the type of center and its geographic location should be defined.

Vehicles. Black carbon emissions can vary greatly depending on the vehicle type, size, engine technology level of maintenance and other factors. As such, relating fuel burn to vehicle type, as suggested in the methodology below, is critical for getting a more accurate estimate of black carbon emissions.

This methodology only includes emissions related to the operation of vehicles involved in freight movement. Emissions from vehicle production, maintenance, and end of life (e.g., recycling) are not included.

STEPS TO CALCULATE BLACK CARBON

Building on the foundations set forth in the previous sections, this section provides a step-by-step guide for calculating black carbon. Following the five steps shown below, black carbon can be estimated for a set of scope 1 or scope 3 activities with variations depending on the level of data available. The steps can also be used as a guideline for setting up data collection structures to improve accuracy or for procurement guidelines to establish expectations for emissions reporting.

1

Plan

- Define the transport chain(s) for analysis
- Determine calculation tier based on data availability

2

Gather fuel and shipment information

- According to the calculation tier:
  Scope 1: Gather fuel use data for each mode, vehicle type, and/or region
  Scope 3: Find or estimate the shipment weight and distance traveled. Find default fuel consumption factors matching the transport activities to estimate fuel burn.

3

Gather black carbon emissions factors

- Find black carbon emissions factors for each mode according to the calculation tier

4

Calculate black carbon emissions

- Convert fuel use into black carbon emissions
- Sum emissions for each mode and transport chain

5

Report and reduce

- Report black carbon emissions
- Use results

1. Plan

This section sets forth the preliminary steps for setting up a black carbon calculation, whether emissions are in a company's scope 1, 2 or 3. For many companies, this will be a similar process as for GHG accounting.

Define the transport chains for analysis

Companies should begin by identifying which transport chains to examine. Depending on the company, this could be a single mode, single transport chain, all modes or transport chains in one region or country, or all transport activities. Each transport chain may have several modes and transhipment centers included, any may have multiple carriers throughout a shipment's journey, as demonstrated by Figure 5.

Determine calculation tier based on data availability

A tiered approach provides a consistent and transparent structure for communicating uncertainty within reported values. It also establishes a pathway for improving data collection in order to improve accuracy. Both primary and default data can be used within the Black Carbon Methodology; companies can apply the calculation most appropriate for their situation. It is the responsibility of each company to determine the best available data it can obtain for each mode with a reasonable amount of effort and resources, and

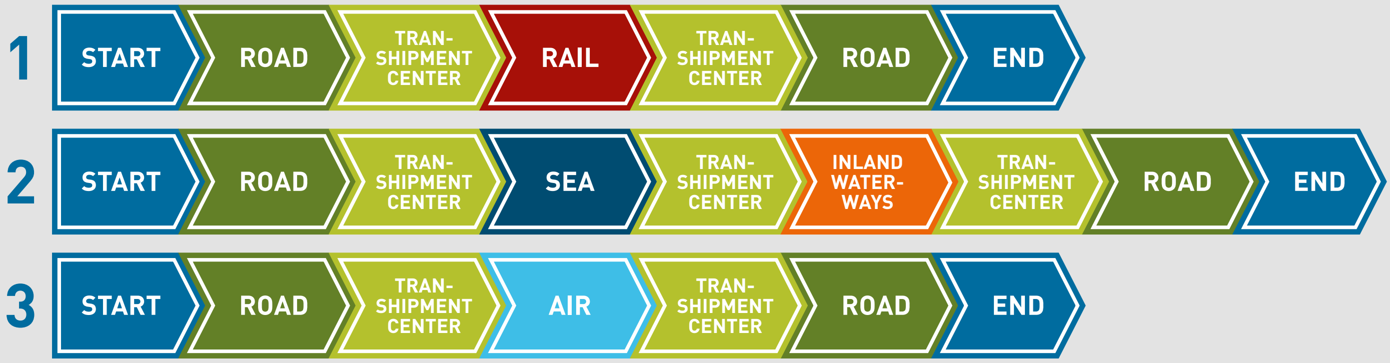


Figure 5 Three sample transport chain maps, including all transport elements and transhipment centers encountered throughout the journey.

make a plan to collect data where it is missing. In the context of the logistics sector, some shippers subcontract their logistics activities to logistics service providers (LSPs), who may further sub-contract some activities to carriers around the globe. As such, shippers and LSPs may have difficulty finding information such as the distance, vehicle type or engine technology used for their shipments. This disconnect can make calculating black carbon emissions a challenge.

Because of these gaps in knowledge, black carbon accounting must take an approach similar to GHG accounting, where less accurate estimates are taken in situations where data are poor and more accurate estimates are taken where data are available. Modeled after the IPCC's tiered emissions calculations approach, three levels of calculation can be undertaken depending on the information known about the shipment conditions.[25] Bronze, like IPCC's tier 1, represents the simplest approach using the most default data; where silver and gold, (IPCC tiers 2 and 3), demand increasingly detailed data. Depending on a company's operations, different modes or regions may report at different tiers.

Companies may choose to begin with a preliminary bronze assessment to understand the primary sources of black carbon within a transport chain, then move towards gold tier data collection for those hotspots in order to refine estimates and strategize around emissions reduction.[26]

Bronze. Requiring the least amount of primary data, the bronze tier is appropriate in settings where detailed data are unavailable and impossible to obtain, such as for some scope 3 activities. Bronze is the least accurate calculation tier and should be considered a stepping stone on the path to silver and bronze tiers.

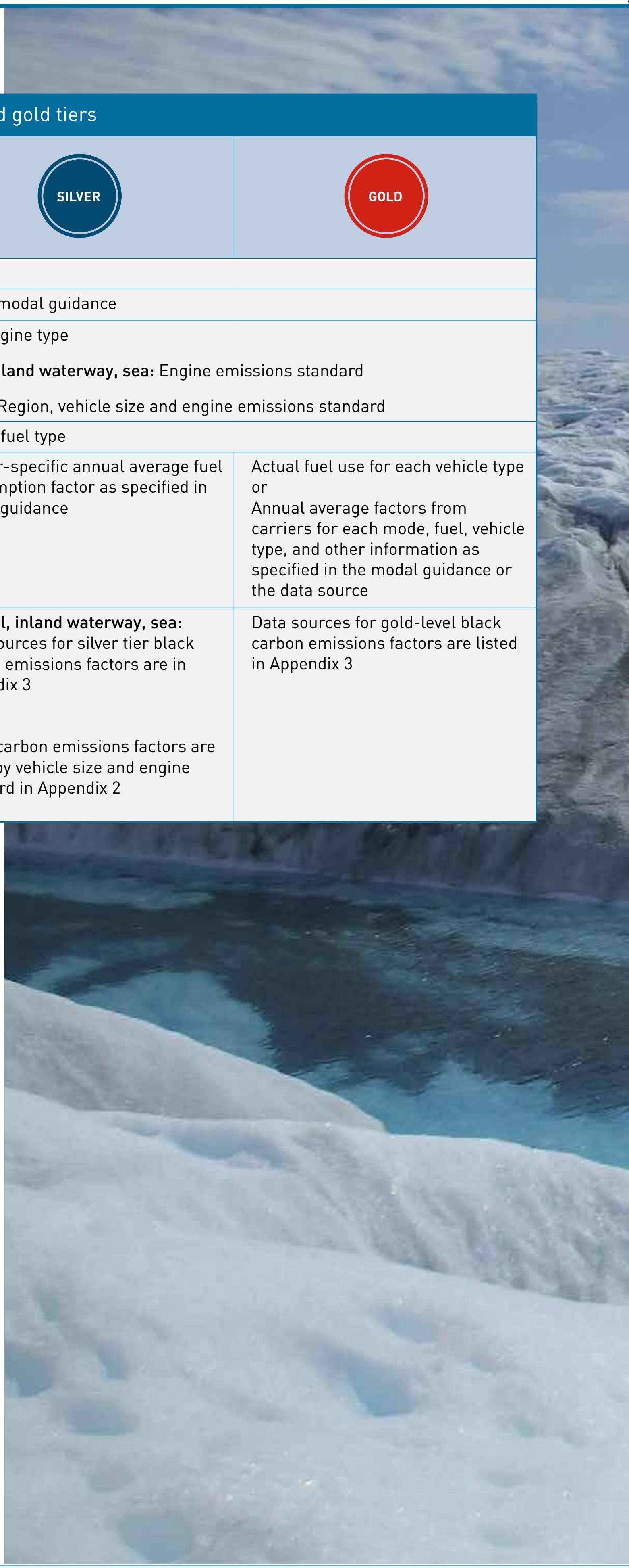
Silver. Silver is for situations where a company has some primary data on fuel consumption tied to vehicle type, but some detailed information on the vehicle and its activities is missing. The required vehicle information to reach the silver tier is specified for each mode.

Gold. Gold represents the most accurate accounting approach, where the most detailed data are known on a shipment's conditions. Carriers are expected to have access to this level of information for their own vehicles, vessels, and/or transhipment centers.

The requirements for each tier is summarized in Table 1; additional details for each mode are included in the following sections and in Appendix 1, 2 and 3.

Table 1 Summary of data requirements for bronze, silver and gold tiers

	BRONZE	SILVER	GOLD
Weight	Actual or estimated	Actual	
Distance	Actual or estimated distance, according to the modal guidance		
Vehicle Information	Default vehicle	**Air:** Engine type **Rail, inland waterway, sea:** Engine emissions standard **Road:** Region, vehicle size and engine emissions standard	
Fuel Type	Default fuel type	Actual fuel type	
Fuel Consumption Factor	Default fuel consumption factor for each mode	Carrier-specific annual average fuel consumption factor as specified in modal guidance	Actual fuel use for each vehicle type or Annual average factors from carriers for each mode, fuel, vehicle type, and other information as specified in the modal guidance or the data source
Black Carbon Emissions Factor	**Air, rail, inland waterway, sea:** Default black carbon emissions factor each mode is in Appendix 1 **Road:** Default black carbon emissions factors for various vehicle sizes and regions are in Appendix 1	**Air, rail, inland waterway, sea:** Data sources for silver tier black carbon emissions factors are in Appendix 3 **Road:** Black carbon emissions factors are listed by vehicle size and engine standard in Appendix 2	Data sources for gold-level black carbon emissions factors are listed in Appendix 3



2

2. Gather fuel data

The combustion of carbon-based fuel is the core issue in finding logistics-related emissions. Fuel use is generally known in scope 1 emissions and estimated for scope 3. For scope 3, an average fuel consumption factor, either reported by the carrier or based on default data, is adopted to estimate average fuel burn.

Scope 1 emissions

For scope 1 calculations, the actual fuel burn can be used, derived either from fuel records or spend. Fuel burn can be considered for a journey or a set of journeys, or it can be used to create a fuel consumption factor reflecting average conditions over the course of one year. The type of vehicle in which the fuel was burned is especially important to understand for black carbon, thus it is important to develop structures for relating fuel burn to vehicle fleets in order to improve the accuracy of results. More information on vehicle types are within the modal sections below.

Scope 3 emissions

Scope 3 emissions are from subcontracted transport providers, where fuel data is often unavailable or incomplete. In this case, emissions can be estimated using actual or estimated shipment weight and distance mixed with a fuel consumption factor best representing actual conditions. Each component is described in more detail below.

Gather shipment weight & distance

For freight transport, it's not only the weight of the shipment that matters, but the distance it travels. In keeping with the GLEC Framework, the tonne-kilometer is a key metric for understanding the fuel efficiency and emissions intensity of the actual work done.

Weight and distance are only required when actual fuel data are not available, typically for scope 3 emissions. However, there are some exceptions. For bronze and silver tier road calculations, only distance is required. For transhipment centers, only the weight is required – electricity and fuel use are allocated by the tonnes of cargo passing through a center on an annual basis.

Shipment weight. Mass, or weight, is the most-widely used metric for freight measurement. Metric tonnes is the most common unit, though other relevant measurements, such as volume or twenty-foot equivalent units (TEU), can be used if converted to mass following standard protocols. Conversion factors are available in Appendix 5.

The included weight should be the actual mass of the cargo in official shipment documents (e.g., bills of lading) and not proxies such as 'chargeable weight.' Additionally, the weight should include the product and packaging provided for transport by the shipper. Passenger weight is not included as freight transport. Standard factors for calculating and excluding the weight of passengers from the GLEC Framework should be applied and clearly indicated.

Distance. Distance, in kilometers, is either measured directly or estimated following the common practice for each mode of transport. Shipments are generally considered to be the point at which a product leaves the manufacturer or producer and arrives at the point of use or retail sale. In some cases, this may vary due to the business model, such as companies that ship directly to households.

Calculating tonne-kilometers. Tonne-kilometers should be calculated separately for each mode, and potentially region, vehicle type or other factors, depending on the calculation tier. To find the total tonne-kilometers, the weight and distance for each trip are multiplied separately then summed. Do not multiply the total tonnes by the total kilometers as this will lead to a significant overestimation.

$$\sum_{trip=1}^{n} \mathbf{tkm} = \mathbf{tonne}_{\ trip\ 1} \times \mathbf{kilometer}_{\ trip\ 1} + \mathbf{tonne} \ldots \times \mathbf{kilometer} \ldots + \mathbf{tonne}_{\ trip\ n} \times \mathbf{kilometer}_{\ trip\ n}$$

Equation 4 Formula to calculate total tonne-kilometers

If the weight or distance are unknown, tonne-kilometers can be estimated by multiplying the total tonnes shipped by the average shipment distance or the total distance by the average shipment weight.

Find fuel consumption factors

Ideally, freight carriers will calculate annual average fuel consumption factors for their vehicles and fleets, and communicate this information to shippers. If carrier data are not available, default factors can be applied, understanding that they could lead to either significantly higher or lower emissions estimates.[27]

Unlike with GHG emissions accounting, the vehicle type and condition can be extremely relevant in determining black carbon. Therefore, wherever possible, a fuel consumption factor should be selected that matches the vehicle type to the greatest specificity possible, though this might be difficult for some modes where less information is available. Companies can consider establishing data sharing protocols with transport partners in order to improve information availability.

Practitioners are encouraged to find the most up-to-date consumption factors that are relevant for their vehicles, activities and regions of operations. Potential sources include but are not limited to the sources listed in Table 2; a set of default fuel consumption factors is also compiled in the GLEC Framework.

Table 2 Examples of sources of default fuel consumption factors	
Regional	**International**
■ GLEC Framework[1] ■ France's ADEME Information for Transport Services[28] ■ US EPA SmartWay[29] ■ Natural Resources Canada[30] ■ European Standard 16258[31] ■ UK Defra[32]	■ Intergovernmental Panel on Climate Change Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Chapter 2: Energy[20] ■ INFRAS Handbook of Emissions Factors for Road Transport[33] ■ European Chemical Industry Council/European Chemical Transport Association Guidelines[34] ■ Life cycle databases, such as those referenced by the GHG Protocol at http://www.ghgprotocol.org/Third-Party-Databases

3

3. Gather black carbon emissions factors

On a high level, the amount of black carbon released from logistics activities depends on the fuel that is combusted. However, there are other factors and variables that will vary the amount of black carbon generated by an engine even with the same quantity of fuel, such as engine wear, fuel system types/management and fuel quality/levels of impurities such as sulfur.

It is important to allocate fuel burn to black carbon emissions factors most closely aligned with operating conditions. This report contains guidance on sources for emissions factors available in 2017, though practitioners are encouraged to find the most up-to-date information available. Appendix 1 contain black carbon emissions factors for bronze tier calculations for all modes, Appendix 2 includes factors for silver tier for road, and Appendix 3 includes links to gold tier factors.

The following formats can be used for black carbon emissions factors:

- Black carbon per unit of fuel, tonne-kilometer, kilometer, kilowatt hour or other useful unit
- PM2.5 per unit of fuel, tonne-kilometer or kilometer converted to black carbon using standard PM2.5 speciation factors
- Optional: Black carbon emissions per kilometer from tires, brake and roads are available for heavy duty vehicles.

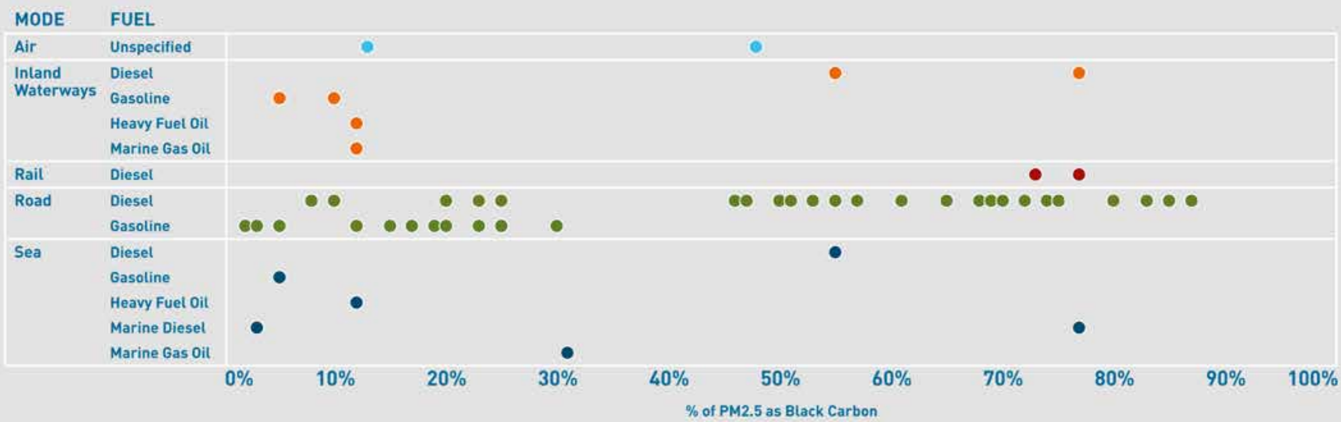


Figure 6 Examples of different PM2.5 to black carbon speciation factors for different modes, vehicle types and fuels. Each point represents a different study and/or vehicle type. A table of speciation factors is available in Appendix 4.

PM2.5 as a proxy for black carbon. Black carbon often makes up a significant portion of PM2.5 emissions, and is commonly used as a proxy measurement to estimate black carbon.[35] PM2.5 is generally measured by mass or particle count over a drive cycle. PM2.5 can be converted to black carbon using standard ratios that define the black carbon content for various fuels, activities and vehicles; as shown in Figure 4, the ratio of black carbon to PM2.5 can be highly variable. It is important to select the black carbon ratio best suited for the region and available data. Appendix 4 includes table of ratios from various sources.

Sources of black carbon emissions factors

Many sources exist for black carbon or PM2.5 emissions factors - the challenge is to find the factor that most closely represents the actual shipment conditions, such as the fuel type, vehicle size, and engine technology. Regional emissions factors should be used whenever possible, though data from developing countries are less commonly available. It is important to select the most detailed factor possible and clearly state the source of the chosen emissions factor.

The appendices of this report include information on black carbon emissions factors. Appendix 1 includes bronze tier black carbon emissions factors for all modes and transhipment centers. Appendix 2 contains silver tier black carbon emissions factors for road. Appendix 3 includes sources for emissions factors for silver- and gold tier emissions factors for air, rail, inland waterways, sea and transhipment centers, and gold tier emissions factors sources for road.

A note on primary measurement data

This methodology adopts standard values for the black carbon content associated with fuel combustion, rather than primary data from company-led emissions testing. At this point, unregulated testing procedures make primary data highly uncertain, and expensive equipment can make measurement cost-prohibitive. While this might change with the advent of wireless sensors, default factors provide an even playing field for companies to report emissions without additional investment. Companies interested in directly monitoring their black carbon or PM2.5 emissions are encouraged to do so by participating in government or academic studies aimed on improving the accuracy of emissions factors such as those adopted by the Black Carbon Methodology.

4

4. Calculate black carbon

The final step in the calculation of black carbon brings the pieces from the previous steps together. Depending on the type of data collected, one of the following equations should be adopted to calculate black carbon for each fuel consumed.

Convert fuel use into black carbon

With actual fuel data. Equation 5 can be used to calculate black carbon emissions with actual fuel burn data. Different fuel types should be calculated separately. Note that the tonne-kilometers are not required for this method.

$$\text{Black carbon (g)} = \text{fuel (kg)} \times \text{black carbon emission factor} \left(\frac{\text{black carbon (g)}}{\text{fuel (kg)}} \right)$$

Equation 5 Formula for calculating black carbon emissions with actual fuel data

With a default fuel consumption factor. The method for finding black carbon emissions using a default fuel consumption factor is shown in Equation 6.

$$\text{Black carbon (g)} = \text{tonne-kilometers} \times \text{fuel consumption factor} \left(\frac{\text{fuel (kg)}}{\text{tkm}} \right) \times \text{black carbon emission factor} \left(\frac{\text{black carbon (g)}}{\text{fuel (kg)}} \right)$$

Equation 6 Formula to calculate black carbon using a fuel consumption factor

With a PM2.5 emissions factor. PM2.5 emissions factors can be converted to black carbon using a PM2.5 speciation factor, as shown in Equation 7. A set of speciation factors for different regions, modes and engine types is available in Appendix 4.

$$\text{Black carbon (g)} = \text{fuel (kg)} \times \left[\text{PM2.5 emissions factor} \left(\frac{\text{g BC}}{\text{g PM2.5}} \right) \times \text{PM2.5 speciation factor} \left(\frac{\text{PM2.5 (g)}}{\text{fuel (kg)}} \right) \right]$$

Equation 7 Formula to calculate black carbon emissions using a PM2.5 emissions factors

With distance (for road). Emissions per distance black carbon emissions factors for road transport are available for bronze and silver tier calculations.

$$\text{Black carbon (g)} = \left(\frac{\text{tonne - kilometer}}{\text{payload (tonne)}}\right) \times \text{black carbon emission factor} \left(\frac{\text{black carbon (g)}}{\text{distance (km)}}\right)$$

Equation 8 Formula to calculate black carbon emissions using distance-based emissions factors

Sum emissions for each mode and transport chain

Once the fuel or distance data are converted to black carbon, they can be can be totaled depending on the reporting needs or analysis goals. Many reporting structures require total emissions per year. Other options may include the sum of a particular transport chain, region, customer or other activity of interest.

5

5. Report and reduce

Once emissions are calculated, they can be used for reporting and to create strategies for reduction. A structure for reporting results is included below, as well as suggestions for possible uses.

Report black carbon emissions

Black carbon emissions reported using the Black Carbon Methodology should include the following information:

- Mass of black carbon in grams, tonnes or other appropriate unit
- Description of activities covered (e.g., individual transport leg, total all transport chains, annual emissions)
- Time period for which the assessment complete (e.g., annual emissions)
- Reporting level (gold, bronze, silver) for each mode
- Assumptions
    - Distance method used for each mode
    - Source of fuel consumption factor
    - Source of black carbon emissions factor
    - Source of PM speciation factor, if used

Optional information that may be useful for understanding results as well as tracking improvements over time. Below provides a number of suggestions that can be adopted at the discretion of the company.

- Breakdown by mode
- % of emissions in polar/glacial regions
- % of fleet not utilizing a diesel engine; % of fleet meeting Euro 6 or US 2007 and later emission standards; and % of fleet retrofitted with DPF
- Transport service categories, as explained in the GLEC Framework

An example of an annual black carbon emissions report is in Table 3.

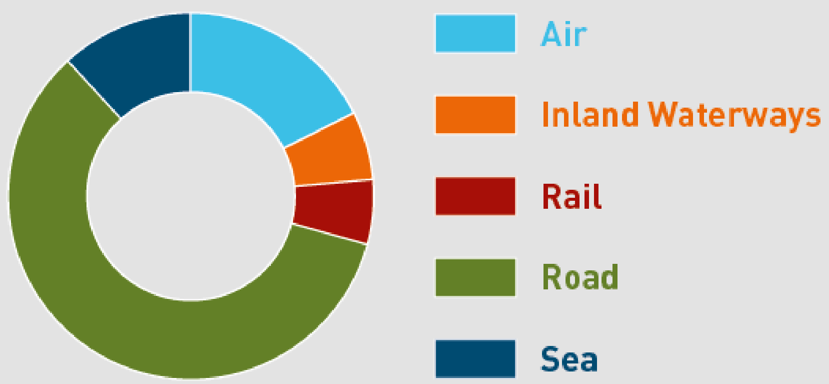


Figure 7 Example: Breakdown of emissions by mode

Table 3 An example of black carbon reporting structure

Mode	2016 Emissions	Tier	Fuel Consumption Factor	Black Carbon Emissions Factor	PM Speciation Factor	Other information
Air	150 kg	Bronze	Defra default factor	Provided bronze tier factor	n/a	
Inland waterways	50 kg	Bronze	GLEC Framework default factor	Provided bronze tier factor	n/a	
Rail	50 kg	Silver	SmartWay annual average data for carrier	MOVES model	n/a	
Road	500 kg	Gold	Carrier-specific data	MOVES model	US EPA	50% of vehicles equipped with DPF
Sea	100 kg	Silver	Carrier reported data from Clean Cargo Working Group	EMEP/EEA Guidebook	EMEP/EEA Guidebook	10% of activities in polar regions

Use results

Estimating black carbon emissions following the Black Carbon Methodology provides a framework for tracking and reporting emissions over time. Results found through the Black Carbon Methodology have many potential uses.

A more robust climate footprint. Voluntary reporting/disclosure of black carbon alongside GHGs to give a more robust accounting of climate impact.

Pathway for policy. Adopting a black carbon methodology can provide a harmonized mechanism for regulating black carbon from a policy perspective. Results can also be used to estimate the impact of an existing or proposed emissions reduction technology or policy.

Strengthening regional and global black carbon inventories. Better data on freight transport-related emissions may serve to improve inventories, improving inputs to climate change models.

Hotspot assessment. High-level results can be used to pinpoint parts of a transport chain with higher black carbon emissions.

Supply chain optimization. Black carbon measurements can be used as a metric for supply chain decisions.

Carrier selection. Giving companies a tool for selecting transport carriers with lower black carbon emissions.

Risk assessment. Understanding the primary sources of black carbon in the transport chain will allow companies to understand which carriers, modes or routes might be affected if black carbon policy is enacted.

ADDITIONAL INFORMATION FOR MODES AND TRANSHIPMENT CENTERS

This section offers details for details specific to each mode of transport as well as transhipment centers. More detailed information on each mode can also be found in the GLEC Framework.

AIR

Air

This method covers freight transport by dedicated cargo planes and passenger planes with belly cargo. There is less information on air transport compared with road, and most has focused on the landing and take-off (LTO) cycle of aircraft since that is the most relevant for place-based emissions inventories. Airplanes reach high altitudes where emissions are more difficult to measure and monitor, and studies show that high altitude black carbon may not have the same behavior as emissions close to the earth's surface.[2] However, there is evidence that emissions from the climb, cruise and descent (CCD) phases also have an impact on both climate and human health.[36]

In light of this, and in keeping with the GLEC Framework, the Black Carbon Methodology adopts the broadest range of emissions accounting – the full flight cycle (LTO + CCD). At this time, reaching silver or gold calculation tiers are more difficult because there is a lack of detailed information on fuel burn or emissions for the full flight cycle of different aircrafts or engine types. It is expected that more data will become available soon with the adoption of new International Civil Aviation Organization (ICAO) aircraft engine emissions standards for PM.[37]

There are, however, a wide range of aircraft-specific data on LTO black carbon emissions. To make use of these detailed LTO emissions factors, the fuel burn for LTO and cruising phases must be differentiated. Guidance on characterizing average values for the distance of various flight stages for different aircraft types can be found in following sources:

- IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, Chapter 2 (Energy), Appendix 2.5 A.1[20]
- European Environment Agency Guidance on Aviation[23]

If the fuel use for the LTO and cruise phases cannot be differentiated, but details on the airplane type are known, the difference between the LTO phase for the silver or gold tier black carbon emissions factors and the bronze tier value full flight emissions can be used to estimate CCD emissions.[24] Then, the silver or gold tier LTO factor can be added to the estimated CCD phase emissions to estimate the full flight cycle. This is demonstrated in Equation 9.

Cruise phase emissions = full flight cycle (fuel × bronze BC emissions factor) - LTO (silver or gold BC emissions factor)

Silver or gold tier emissions = LTO + cruise phase

Equation 9 The formula by which detailed LTO data can be used to find full flight emissions

Table 4 Calculation tiers for air transport

	BRONZE	SILVER	GOLD
Weight	Actual or estimated	Actual	Actual
Distance	Distance should be the great circle distance (GCD) between the origin and destination airports. The option to add a 95-km correction factor as recommended by EN 16258 is accepted as long as it is clearly documented. The latitude and longitude of the aerodromes can be taken either from aerodrome data published in the national Aeronautic Information Publication or from a source using such data (e.g ICAO).		
Vehicle Information	Default aircraft type	Engine type (e.g., piston, gas turbine)	Engine type and/or make and model
Fuel Type	Jet fuel assumed	Actual fuel type	Actual fuel type
Fuel Consumption Factor	Default fuel consumption factor	Carrier-specific annual average fuel consumption factor for each fuel and engine type	Actual fuel use for each vehicle type Annual average factors from carriers for each fuel, engine type or make/model
Black Carbon Emissions Factor	Emissions factor for the full flight cycle in g/kg fuel provided in Appendix 1	Black carbon or PM2.5 emissions factors for the full flight cycle, organized by aircraft engine type as shown in the data sources listed in Appendix 3 Engine-specific LTO emissions factors can be combined with the bronze-level default factors using Equation 9	Black carbon or PM2.5 emissions factors for the full flight cycle, based on additional factors in data sources listed in Appendix 3, such as aircraft make/model, altitude, activity data and other relevant factors Engine-specific LTO emissions factors can be combined with the bronze-level default factors using Equation 9

INLAND WATER-WAYS

Inland waterways

This methodology covers the operation of waterborne vessels, including tow/tug vessels, to transport cargo along rivers and canals, including empty running. Limited information is available for inland waterways vessels; future versions of the Black Carbon Methodology may offer additional black carbon data points.

In the EU, inland waterway vessels are classified as non-road mobile machinery, the same as locomotives.[38] Inland waterways vessels have emissions standards classified in stages related to the age of manufacture. In the US, inland waterways are classified as marine vessels, however the engine standards are aligned with those of EU inland waterway vessels.

Inland waterway ships, barges and vessels can run on different types of fuels. The eventual black carbon emissions can vary widely by fuel type and engine efficiency, so gaining resolution on the types of vessels and engines is particularly relevant for increasing the accuracy of estimates for inland waterways.

Table 5 Calculation tiers for inland waterways transport

	BRONZE	SILVER	GOLD
Weight	Actual or estimated	Actual	Actual
Distance	Actual distance: Recorded in ship log-books, or Estimated distance: Distances estimated based on established start and end points on the network		
Vehicle Information	Standard vessel	Engine emissions standard (stage or tier)	
Fuel Type	Marine diesel oil assumed	Actual fuel type	Actual fuel type
Fuel Consumption Factor	Default fuel consumption factor	Carrier-specific annual average fuel consumption factor for each mode, fuel type and region	Actual fuel use for each vehicle type Annual average factors from carriers for each mode, fuel, activity, and vessel type
Black Carbon Emissions Factor	Emissions factor in g/kg fuel provided in Appendix 1	Black carbon or PM2.5 emissions factors organized by fuel and engine type, as shown in the data sources listed in Appendix 3	Black carbon or PM2.5 emissions factors based on additional factors in data sources listed in Appendix 3, such as vessel type, engine type and other relevant factors.

Rail

Rail made up 2% of global transport GHG emissions (in terms of total tonnes) as of 2000, including both freight and passenger transport.[9] In the EU, 80% of rail transport is electrified; however the average for the rest of the world is 30% electrified - with the lowest rates of electrification in North America, Africa and China. As a result, many countries rely on diesel fuel, with the exception of China where trains are primarily powered by coal.[9,39] China, Russia and North America rely the most heavily on rail for freight transport, which are most likely powered by fossil fuels. Most locomotives fall under the heavy duty diesel vehicle or off-road engine category, similar to some trucks or ships.[23,40] Locomotives are generally categorized by their engine emissions standard, in stages (EU) or tiers (US), with newer engines emitting less black carbon.[38,41]

Road

Road transport is the largest source of transport-related black carbon. Since diesel trucks form the backbone of many freight transport operations, diesel-powered road transport will likely be of high importance to many shippers. Emissions from different types of trucks can vary greatly, with newer trucks generally emitting significantly less black carbon than older models.

Table 6 Calculation tiers for rail transport

	BRONZE	SILVER	GOLD
Weight	Actual or estimated	Actual	
Distance	Distance refers to the planned distance reflecting the actual rail network infrastructure		
Vehicle Information	Standard locomotive	Engine emissions standard (stage or tier)	
Fuel Type	Diesel fuel assumed	Diesel or electric	
Fuel Consumption Factor	Default fuel consumption factor	Carrier-specific annual average fuel consumption factor for each fuel and engine standard	Actual fuel use for each fuel and engine standard Annual average factors from carriers for each fuel, and engine standard
Black Carbon Emissions Factor	Emissions factor in g/kg fuel provided in Appendix 1	Black carbon or PM2.5 emissions factors organized by fuel type and engine standard, as shown in the data sources listed in Appendix 3	Black carbon or PM2.5 emissions factors based on additional factors in data sources listed in Appendix 3, such as freight density, hours of operation, nominal power output, temperature control equipment, train size, and other relevant factors

Perhaps because of this, road transport is the most well-studied mode in terms of black carbon emissions. There are more emissions factors available for road than any other mode. There is greater detail on vehicle type, engine technology and activities, , allowing for the selection of more precise values. Beyond fuel type, the truck's size, engine type, maintenance level, region and presence of emissions control retrofits are the key factors for characterizing road emissions.

Emissions from electric vehicles owned by the reporting company will fall into that company's scope 2 emissions. Black carbon emissions factors for electricity depend greatly on geography and may be difficult to obtain for some regions. Default black carbon emissions factors for common electricity sources can be found in the US EPA GREET model.[42]

Truck size. Truck sizes are categorized under the Black Carbon Methodology into the following classes: heavy duty truck (HDT), medium HDT and heavy HDT. Table 7 shows vehicle names type alongside the weight and categories defined in COPERT, the EEA's Calculation of Emissions from Road Transport software tool.[43]

Table 7 Road vehicle size classification

Vehicle Type	Fuel Type	Categories	Subcategories
Light HDT (8,501-14,000 lbs.) (3.836-6,364 kg)	Gasoline	Gasoline >3.5t	n/a
	Diesel	Rigid <=7.5t	n/a
Medium HDT (14,000-33,000 lbs.) (6,364-15,000 kg)	Diesel	Rigid	Diesel 7.5-12t,12-14t
Heavy HDT (>33,000 lbs.) (>15,000 kg)	Diesel	Rigid	Diesel, 14-20t, 20-26t, 26-28t, 28-32t, >32t
		Articulated	Diesel, 14-20t, 20-28t, 28-34t, 34-40t, 40-50t, 50-60t

Region. Many older trucks remain on the road, especially in developing countries where best available emissions technology are more slowly adopted.[44] Of particular concern are so-called high-emitters – vehicles that release particularly high levels of black carbon and other co-pollutants. Understanding where high-emitters lie in the supply chain and taking measures to mitigate their emissions will have a great effect in reducing overall transport emissions.

Engine type. Newer engine emission control technologies have greatly reduced emissions. For some countries, air quality standards have progressively reduced the amount of PM that is allowed to be emitted for an engine to be placed on the market.[45] For example, Euro VI and US 2007 trucks are equipped with diesel particulate filters (DPFs), that, when used with low-sulfur fuel (less than 10ppm sulfur), reduce 90-99% of black carbon compared with uncontrolled levels.

This technology may also be applied (or retrofitted) after the vehicle or vessel has been originally placed on the market, for example a vehicle originally fitted with a Euro III engine may be retrofitted with a full flow DPF and actually have equivalent PM emissions of a Euro VI. It is important to take note of vehicles in the fleet that have been retrofitted for emissions control so those upgrades can be properly accounted for in sustainability reporting.

Fuel type. Fuel type is also an important factor. Trucks utilizing gas-powered engines or other diesel alternatives can also produce very low black carbon emissions.

Table 8 Calculation tiers for road transport

	BRONZE	SILVER	GOLD
Weight	Actual or estimated	Actual	
Distance	Scope 1: Actual distance Scope 3, or where distance is unknown: Planned distance For collection and delivery rounds: GCD or shortest feasible distance between the individual loading and unloading points within the round.[32]		
Vehicle Information	Truck size: Light, medium or heavy HDT	Truck size: Light, medium or heavy HDT and Euro- and US-equivalent class	Trucks organized Euro- and US-equivalent class
Fuel Type	Diesel or gasoline	Actual fuel type	
Fuel Consumption Factor	Default fuel consumption factor	Carrier-specific annual average fuel consumption factor for each fuel, engine type and vehicle size	Actual fuel use for each fuel type and engine type Carrier-specific annual average factors for each fuel, region and engine type
Black Carbon Emissions Factor	Emissions factors in g/km for • Diesel • LHDT, MHDT and HHDT • Region provided in Appendix 1	Emissions factors in g/km for • Fuel • LHDT, MHDT and HHDT • Engine type provided in Appendix 2	Black carbon or PM2.5 emissions factors based on additional factors in data sources listed in Appendix 3, such as activity level, load factor, road conditions, traffic and other relevant factors

SEA

Sea

A number of factors impact the rate of emissions from sea transport. In general, black carbon emissions increase with the size of the vessel, largely due to the use of marine diesel oil in large vessels.[40] The speed at which the vessel travels also impacts emissions – slower speeds emit less black carbon.[46] As such, information on the fuel burned by the engine types and speeds (e.g., gas turbine, high-speed diesel, medium-speed diesel, slow-speed diesel and steam turbine) is required at the silver and gold tier.[47]

Fuel type is important, namely its sulfur content.[48] Shipping fuels with higher sulfur content are more effective in heating low altitude clouds prevalent in remote ocean areas, contributing to climate change.[49] Global regulations, such as IMO's Emission Control Areas and 2020 sulfur cap of 0.5%, continue to limit the use of high sulfur fuel, though some regions lag behind in terms of fuel standards.[50]

The climate impact of shipping is particularly relevant due to the increasing ship traffic in the Arctic region.[8] Black carbon emissions have a disproportionate effect on areas covered by ice and snow, such as the Himalayas, Greenland and the Arctic. As trade lanes through the Arctic remain open for longer periods each year, limited black carbon emissions is an important consideration for preserving sensitive ice areas.[51]

Table 9 Calculation tiers for sea transport

	BRONZE	SILVER	GOLD
Weight[a]	Actual or estimated	Actual	
Distance	Actual distance: Recorded in ship log-books, or Estimated distance: Distances estimated based on established port-to-port distances		
Vessel Information	Standard vessel	Engine type or IMO engine tier	
Fuel Type	Marine diesel oil assumed	Actual fuel type	
Fuel Consumption Factor	Default fuel consumption factor Use values for each trade lane if using Clean Cargo Working Group (CCWG) factors	Carrier-specific annual average fuel consumption factor for each fuel and engine type or IMO tier, and trade lane if using CCWG factors	Actual fuel use for each fuel, vessel type and region Annual average factors from carriers for each fuel, vessel type and trade lane
Black Carbon Emissions Factor	Emissions factor in g/kg fuel provided in Appendix 1	Black carbon or PM2.5 emissions factors organized by fuel and engine type or IMO tier, from sources provided in Appendix 3	Black carbon or PM2.5 emissions factors included in the data sources listed in Appendix 3, such as for each fuel

a: TEUs can be converted to tonnes using the standard conversion factor listed in the GLEC Framework: Metric tonnes = TEU ×10 – however, actual weight will lead to more accurate results.

TRAN-
SHIPMENT
CENTERS

Transhipment centers

Transhipment centers are a vital part of the transport chain, where shipments are transferred from one mode to another or stored for future delivery. Transhipment centers range from ports, warehouses, distribution centers, rail hubs or air terminals, among others. This methodology applies to the electricity or fuel consumed within a transhipment center related to freight movement activities only. Emissions may come from electricity to power or heat facilities as well as fossil fuels used to power generators, cranes, service vehicles, etc. Emissions related to non-freight movement activities, such as administrative offices, are not included here.

Transhipment center emissions for logistics is a growing area of study. Transhipment center fuel consumption factors can be challenging to find; thus, high level estimates may be needed at this time. Also, centers handle freight from numerous customers, making emissions allocation and reporting a challenge, particularly for scope 3 reporting.

It is widely accepted that these estimates will improve over time as data collection and sharing become more common. The GLEC Framework has put forth a methodology for calculating their emissions, and continues to conduct research to establish best practices for calculating and reporting emissions from transhipment centers. Future revisions of the GLEC Framework, and the Black Carbon Methodology, will continue to add detail to this mode and work to refine default factors that can be used for reporting.

Table 10 Calculation tiers for transhipment centers

	BRONZE	SILVER	GOLD
Weight	Actual or estimated	Actual	Actual
Distance	N/A		
Center Type	Actual center type		
Fuel Type	Actual fuel type		
Fuel Consumption Factor	Default fuel consumption factor	Carrier-specific annual average fuel use, allocated as fuel / tonne of outgoing cargo	Actual fuel use for the center, or Carrier-specific annual average fuel use
Black Carbon Emissions Factor	Default factors from the GREET model provided in Appendix 1	**For electricity emissions.** A black carbon grid factor should be used that best represents the region's energy mix. Grid factors for black carbon or PM2.5 may be available from government agencies, or a value can be adopted from a different region employing the same energy source, such as GREET, if clearly noted. **For fossil fuels.** For mobile transport, follow guidelines for the mode of transport. For stationary sources, use the best available information on local conditions to select the best black carbon emissions factor. Life cycle databases may offer the most detailed information for machinery.	

SOURCES OF UNCERTAINTY

Results found using the Black Carbon Methodology inherently contain a number of uncertainties, especially at the bronze and silver calculation tiers. Most notably, imprecise information on fuel use, vehicle, distance, among other things, may lead to less precise estimates. Different types of vehicles and engines emit vastly different black carbon emissions, thus relating fuel burn to vehicle type is essential for obtaining an accurate result.

Missing data. Practitioners just beginning to calculate black carbon emissions should begin with the bronze tier with the goal of moving towards the silver and gold tiers, understanding that they may need set up structures to collect data to improve accuracy. The bronze tier is a good tier to use if the company does not have access to sufficient or complete data, but this tier comes with the largest uncertainties, and thus the largest chance of incorrectly estimating black carbon emissions.

Efforts to gather emissions data will take time and investment. Default figures can be used to develop an understanding of the intensity of emissions for a certain mode, activity or region. Data collection can then be prioritized in the areas with the highest emissions.[26,52] Companies may also look to improve accuracy around activities, modes or regions where it has developed specific emissions reductions targets.

Default factors. Uncertainty may also come from the default fuel consumption, black carbon emissions and PM2.5 speciation factors themselves, including those listed in this report. Default factors are often developed in laboratories, where different sampling methods and definitions of black carbon (e.g. including elemental carbon) may add to uncertainty. Aggregated emissions factors, such as the bronze tier factors included here, mix various engine types together, reducing accuracy. The limits of sulfur and other impurities in fuel vary around the world so there may not be a common globally accepted conversion factor for calculating black carbon emissions for a certain fuel type.

Lab vs. real-world conditions. Actual driving conditions will be different from the laboratory setting. While less studied, emissions may vary due to a vehicle's activities and condition; driving cycle, idling conditions mis-fueling, mal-maintenance, and vehicle overloading can also create a difference in emissions profiles. External conditions may affect emissions, such as ambient air temperature, road surface, traffic conditions, highway vs side roads, and urban vs rural areas.[53]

Black carbon and PM. PM2.5 speciation factors are highly variable and must be applied carefully in order to accurate represent the ratio of carbon for different modes or vehicles. The PM2.5 ratio is also important for understanding the prevalence of co-pollutants that could be offsetting climate impacts. In future reports, black carbon from brake and tire wear should be considered for inclusion in emissions factors, particularly for road transport.

Research needed. Furthermore, there is less information and emissions factors for air, inland waterway, rail, sea and transhipment centers, though this may begin to change in the coming years. There is a need for further research in order to validate factors for different regions, vehicle types and other relevant characteristics that might impact the rate of black carbon emissions. The application of wireless sensors to track black carbon emissions may be a promising solution to issues of uncertainty, and could more definitively associate quantities of black carbon emissions with different vehicles, regions and activities.

SUMMARY

The Black Carbon Methodology provides guidance for calculating black carbon emissions resulting from freight movement. The guidance is meant to provide a detailed methodology for those that have access to primary data, while also providing a framework for companies with less specific information. The calculation tiers allow companies to begin the process of measuring black carbon using data common in GHG calculations in order to raise awareness of black carbon emissions in the transport chain and how they can be targeted for reduction.

The climate change and human health impacts of black carbon are significant. Investing in reduction efforts will have wide-ranging benefits for society and the ecosystem. Improved air quality improves public health, especially in urban areas where exposure to diesel exhaust can have disproportional impacts. Emissions also linked to glacial melt in the Himalayas, earlier spring melt in the Arctic, shifting circulation patterns, and decreasing sea ice.

Leadership from both companies and governments is needed to affect change. As shippers and carriers gain understanding on the location and quantity of their transport-related black carbon emissions, it will become clearer as to how and where they can be reduced. Progress may lag in developing countries, as transportation activities increase and technology is more slowly adopted. This is furthered exacerbated by less stringent fuel quality standards, which limit the effectiveness of filtration technologies.

Tracking black carbon emissions will help stakeholders to make transport choices throughout the supply chain that emit less black carbon. Shippers can consider transport providers, modes or routes emitting less carbon, and carriers can know where best to prioritize emissions reduction technologies. Companies are encouraged to begin to calculate their black carbon emissions and share your experiences with the Global Green Freight Project.

LIST OF ABBREVIATIONS

BC	Black carbon
CCAC	Climate and Clean Air Coalition
CCD	Climb, cruise and descent cycle
CEC	Commission for Environmental Cooperation
DPF	Diesel particulate filter
EEA	European Environmental Agency
EMEP	European Measurement Evaluation Program
GHG	Greenhouse gas
GLEC	Global Logistics Emissions Council
GWP	Global warming potential
HDT	Heavy duty truck
ICAO	International Civil Aviation Organization
ICCT	International Council on Clean Transportation
IPCC	Intergovernmental Panel on Climate Change
LSP	Logistics service provider (equivalent to 3rd party logistics provider (3PL) or freight forwarder)
LTO	Landing and take-off cycle
PM	Particulate matter (PM2.5 and PM10 refer to the diameter of particles)
SFC	Smart Freight Centre
tkm	tonne-kilometer
US EPA	United States Environmental Protection Agency

REFERENCES

[1] Smart Freight Centre. GLEC Framework for Logistics Emissions Methodologies. (2015).

[2] Bond, T. C. et al. Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research Atmospheres 118, 5380–5552 (2013).

[3] Ramanathan, V. Black Carbon and the Regional Climate of California: Report to the California Air Resources Board. (2013).

[4] US EPA. Report to Congress on Black Carbon. 388 (2010). doi:10.1016/j.icrp.2009.12.007

[5] Klimont, Z. et al. Global anthropogenic emissions of particulate matter including black carbon. doi:10.5194/acp-2016-880

[6] Bond, T. C. et al. A technology-based global inventory of black and organic carbon emissions from combustion. Journal of Geophysical Research D: Atmospheres 109, (2004).

[7] IPCC. in (eds. Stocker, T. et al.) 1535 (Cambridge University Press, 2013).

[8] IMO. Investigation of Appropriate Control Measures (Abatement Technologies) to Reduce Black Carbon Emissions from International Shipping. (2015).

[9] Uherek, E., Halenka, T., Borken-Kleefeld, J., Balkanski, Y., Berntsen, T. & Borrego, C., Gauss, M., Hoor, P., Juda-Rezler, K., Lelieveld, J., Melas, D., Rypdal, K., Schmid, S. Transport Impacts on Atmosphere and Climate: Land Transport. Atmospheric Environment (2010).

[10] World Bank. Reducing Black Carbon Emissions from Diesel Vehicles: Impacts, Control Strategies, and Cost-Benefit Analysis. (2014).

[11] Mehndiratta, S., Fang, K. & Darido, G. World Bank Case Studies on Green Trucks / Freight Transport Initiatives. (2011).

[12] ICCT. Global Transportation Energy and Climate Roadmap.

[13] Olivié, D. J. L. et al. Modeling the climate impact of road transport, maritime shipping and aviation over the period 1860-2100 with an AOGCM. Atmospheric Chemistry and Physics 12, 1449–1480 (2012).

[14] V. Ramanathan and G. Carmichael. Global and regional climate changes due to black carbon. Nature Geoscience 1, 221–227 (2008).

[15] ICCT. Impacts of World-Class Vehicle Efficiency and Emissions Regulations in Select G20 Countries. (2017).

[16] United States Congress. Clean Air Act. (1970).

[17] Pope, C. A., Ezzati, M. & Dockery, D. W. Fine-Particulate Air Pollution and Life Expectancy in the United States. New England Journal of Medicine 360, 376–386 (2009).

[18] US EPA. Health Effects of Particulates and Black Carbon. (2013).

[19] WRI & WBCSD. Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (Revised Edition). (2004).

[20] IPCC. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. (2006).

[21] The Gold Standard. Quantification of climate related emission reductions of black carbon and co-emitted Species due to the replacement of less efficient cookstoves with improved efficiency cookstoves. 12 (2015).

[22] Ramanathan, T. et al. Wireless sensors linked to climate financing for globally affordable clean cooking. Nature Climate Change 7, 44–47 (2016).

[23] European Environmental Agency & European Monitoring Evaluation Programme. EMEP/EEA Air Pollutant Emission Inventory Guidebook. (2016).

[24] CEC. North American Black Carbon Emissions Estimation Guidelines: Recommended Methods for Estimating Black Carbon Emissions. (Commission for Environmental Cooperation, 2015).

[25] Garg, A., Kazunari, K. & Pulles, T. Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy. (2006). doi:10.1111/j.1440-1843.2006.00937_1.x

[26] Olivetti, E., Patanavanich, S. & Kirchain, R. Exploring the viability of probabilistic under-specification to streamline life cycle assessment. Environmental Science and Technology 47, 5208–16 (2013).

[27] Blanco, E. E. & Craig, A. J. The Value of Detailed Logistics Information in Carbon Footprints. (2009).

[28] ADEME. CO_2 Information for Transport Services. (2012).

[29] US EPA. SmartWay Transport Partnership: Driving Data Integrity in Transportation Supply Chains. (2013). at ←http://www3.epa.gov/smartway/forpartners/documents/dataquality/420b13005.pdf→

[30] Natural Resources Canada. The Addition of Freight Emissions to GHGenius. (2010).

[31] CEN. EN 16258: Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers). (2012).

[32] Defra. Greenhouse gas reporting - Conversion factors 2016. (2016).

[33] INFRAS. Handbook Emission Factors for Road Transport. (2017).

[34] ECTA. Guidelines for Measuring and Managing CO_2 Emission from Freight Transport Operations. (2011).

[35] Snyder, E. G. et al. The changing paradigm of air pollution monitoring. Environmental Science & Technology 47, 11369–11377 (2013).

[36] Barrett, S. R. H., Britter, R. & Waitz, I. A. Global Mortality Attributable to Aircraft Cruise Emissions. Environmental Science and Technology 44, 7736–7742 (2010).

[37] ICAO. Addressing Aircraft Noise and Local Air Quality Impacts (A39-WP/210). (2016).

[38] European Commission. Regulation (EU) 2016/1628 of the European Parliament and of the Council. (2016).

[39] International Union of Railways. Railway Statistics: 2015 Synopsis. (2015).

[40] US EPA. Black Carbon Emissions Inventory Methods and Comparisons. (2012).

[41] US EPA. Emission Standards for Locomotives and Locomotive Engines. (1998). at ←https://www.gpo.gov/fdsys/pkg/FR-1998-04-16/pdf/98-7769.pdf→

[42] Argonne National Laboratory. Estimation of Emission Factors of Particulate Black Carbon and Organic Carbon from Stationary, Mobile and Non-Point Sources in the United States for Incorporation into GREET. (2014).

[43] European Topic Centre on Air Air and Climate Change. COPERT 4: Computer programme to calculate emissions from road transport. (2017).

[44] Shah, S. D., Cocker, D. R., Miller, J. W. & Norbeck, J. M. Emission Rates of Particulate Matter and Elemental and Organic Carbon from In-Use Diesel Engines. Environmental Science and Technology 38, 2544–2550 (2004).

[45] European Commission. Motor vehicles with trailers: polluting emissions. (1970).

[46] Lack, D. A. et al. Particulate emissions from commercial shipping: Chemical, physical, and optical properties. Journal of Geophysical Research Atmospheres 114, (2009).

[47] IMO. Third IMO Greenhouse Gas Study. (2014).

[49] Winebrake, J. J., Corbett, J. J., Green, E. H., Lauer, A. & Eyring, V. Mitigating the health impacts of pollution from oceangoing shipping: An assessment of low-sulfur fuel mandates. Environmental Science and Technology 43, 4776–4782 (2009).
[50] Lauer, A., Eyring, V., Corbett, J. J., Wang, C. & Winebrake, J. J. Assessment of near-future policy instruments for oceangoing shipping: Impact on atmospheric aerosol burdens and the earth's radiation budget. Environmental Science and Technology 43, 5592–5598 (2009).
[51] IMO. International Convention for the Prevention of Pollution from Ships (MARPOL): Annex IV, Regulation 14. (2010).
[52] Corbett, J. J. et al. Arctic shipping emissions inventories and future scenarios. Atmospheric Chemistry and Physics 10, 9689–9704 (2010).
[53] Zgola, A. M. L. et al. Environmental Assessment of Information Technology Products Using a Triage Approach. 2011 IEEE International Symposium on Sustainable Systems and Technology (ISSST) (2011).
[54] Duan, H. et al. Quantification of carbon emissions of the transport service sector in China by using streamlined life cycle assessment. Journal of Cleaner Production 95, 109–116 (2015).
[55] UNECE. Glossary for Transport Statistics. (2009).
[56] IMO. Definition and measurement of black carbon in international shipping. (2012).
[57] Wagner, F. & Amman, M. GAINS (Greenhouse gas-air pollution interactions and synergies): analysis of the proposals for GHG reductions in 2020 made by UNFCCC Annex 1 countries by mid-August 2009: IIASA. Laxenburg, Austria (2009).
[58] ICCT. Black Carbon Measurement Methods and Emission Factors from Ships. (2016). at
[59] Deru, N. & Torcellini, P. Source Energy and Emission Factors for Energy Use in Buildings. (2007).
[60] Klimont, Z. et al. Global anthropogenic emissions of particulate matter including black carbon. Atmospheric Chemistry and Physics Discussions, 1–72 (2016).

GLOSSARY

Air. Any movement of goods on an aircraft movement, including take-off, cruising and landing, between a place of loading and unloading. Aircraft is defined as any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of air against the earth's surface.[54]

Black carbon. The Black Carbon Methodology uses the International Maritime Organization's 2012 definition of black carbon: *Black carbon is strongly light absorbing carbonaceous material emitted as solid particulate matter created through incomplete combustion of carbon-based fuels. Black carbon contains more than 80% carbon by mass, a high fraction of which is sp2-bonded carbon, and when emitted forms aggregates of primary spherules between 20 and 50nm in aerodynamic diameter. Black carbon absorbs solar radiation across all visible wavelengths and freshly emitted black carbon has a mass absorption efficiency of 5 m/g1 at the mid-visible wavelength of 550 nm. The strength of this light absorption varies with the composition, shape, size distribution, and mixing state of the particle.*[55]

Calculation tier. In the Black Carbon Methodology, calculation tiers refer to the data requirements needed to meet a set level of accuracy (bronze, silver and gold). A tier can also refer to engine standard or class.

Default data. Generic data based on sets of measurements or simulations that represent standard conditions.

Elemental carbon. A descriptive term for carbonaceous particles that is based on chemical composition rather than light-absorbing characteristics. Often used as a synonym for black carbon.[4] Elemental carbon is the primary focus of most black carbon inventories.

Inland waterways. Any movement of goods using inland waterway transport vessels that is undertaken wholly or partly on navigable inland waterways between a place of loading and unloading. A navigable inland waterway is defined as a stretch of water, not part of the sea, which by natural or manmade features is suitable for navigation, primarily by inland waterway vessels. This covers navigable rivers, lakes, canals and estuaries.[54]

Organic carbon. The mix of compounds containing carbon bound with other elements; e.g., hydrogen and oxygen. Organic carbon may be a product of incomplete combustion, or formed through the oxidation of VOCs in the atmosphere. Both primary and secondary organic carbon possess radiative properties that fall along a continuum from light-absorbing to light-scattering.[4]

Primary data. Measurement data gathered for actual activities.

Rail. Any movement of goods transported using mobile equipment operating exclusively on rails, moving either under its own power or hauled by another vehicle, between a place of loading and unloading.[54]

Road. Any movement of goods using a road vehicle on a given road network between a place of loading and unloading. A road vehicle is defined as a vehicle running on wheels and intended for use on roads.[54]

Scopes. Scopes of accounting refer to the business activities being covered in a carbon assessment. According to the GHG Protocol, scope 1 refers to a company's direct emissions from controlled or owned assets. Scope 2 refers to emissions related to the production of purchased electricity, heat or steam. Scope 3 covers indirect emissions, such as the transport-related activities subcontracted to logistics service providers and/or carriers and emissions related to the production of fuel.

Sea. Any movements of goods transported by a seagoing vessel, or a floating marine structure with one or more surface displacement hulls, which are undertaken wholly or partly at sea between a place of loading and unloading.

Speciation factor. A conversion factor capturing the amount of black carbon within the particulate matter emissions of a certain fuel or vehicle type.

Tonne. A metric system unit equivalent to 1,000 kilograms, also known as the metric ton.

Transhipment center. A self-contained facility for handing freight, including freight acceptance and release, secure storage, security and documentation, that connects freight within or to other modes of transport. Transhipment centers include, but are not limited to, the following types: intermodal rail transport terminals, airports, container terminals, ports, distribution centers, and storage facilities.[54]

APPENDIX 1:
BRONZE TIER BLACK CARBON EMISSIONS FACTORS

Air, inland waterways, rail and sea

The following emissions factors are recommended for use under bronze calculation tier, where little or no information is available on actual operating conditions.

Table 11 Bronze tier black carbon emissions factors for air, inland waterways, rail and sea in grams black carbon / kilogram fuel

Mode	Standard Vehicle Assumption	g BC / kg fuel	Source
Air	Standard jet fuel-powered aircraft	0.1	Global standard value for fuel burned through the entire flight cycle listed in Bond's 2004 study
Inland Waterways	Standard inland waterway vessel under average conditions	0.0007	Standard value for inland waterways listed in the 2016 EEA & EMEA Air Pollutant Emission Inventory Guidebook[24]
Rail	Standard diesel-powered locomotive under average conditions	1.0	Median value for all rail types in the GAINS model[57]

Road

The following black carbon emissions factors are recommended for fleet average bronze tier emissions calculations for road transport. These factors are an estimate for a whole fleet in 2015, accounting for the share of activity in each region by vehicle type and standard. These factors applicable directly to calendar year 2015 but also reasonably approximates emissions within one or two years of 2015. Note that the share of activity by vehicles meeting more-advanced standards like Euro VI is expected to increase over time.

Table 12 Bronze tier black carbon emissions factors for road in grams black carbon / kilometer

Type	Region	Gasoline	Diesel		
		Light HDT (g BC/km)	Light HDT (g BC/km)	Medium HDT (g BC/km)	Heavy HDT (g BC/km)
Country	Australia	0.002	0.0093	0.0128	0.0223
	Brazil	0.002	0.0143	0.02	0.0351
	Canada	0.0014	0.0035	0.0048	0.0082
	China	0.0023	0.0143	0.0201	0.0345
	EU-28	0.0014	0.0057	0.008	0.0141
	India	0.0026	0.0194	0.0267	0.0458
	Japan	0.0015	0.0045	0.0063	0.011
	Mexico	0.0015	0.0195	0.0272	0.0465
	Russia	0.0023	0.0158	0.022	0.0376
	South Korea	0.0015	0.0066	0.0092	0.0161
	United States	0.0014	0.0035	0.0048	0.0082
Region	Africa	0.0095	0.0889	0.1166	0.2
	Middle East	0.0079	0.0834	0.1146	0.1995
	Non-EU Europe	0.004	0.057	0.0808	0.144
	Other Asia-Pacific	0.0085	0.0826	0.1079	0.1849
	Other Latin America	0.0049	0.062	0.086	0.1522
	Global	0.0038	0.0183	0.026	0.0339

Emissions from tire wear, brake wear and road abrasion

Though optional for inclusion in the Black Carbon Methodology, bronze tier values for black carbon emissions heavy duty vehicle brake and tire wear as well as road abrasion are included below. Values are taken from the emissions factors listed in the Supplement of the Global Anthropogenic Emissions of Particulate Matter Including Black Carbon, the values adopted by the GAINS model. The average value is recommended for use.

Table 13 Emissions factors for brake wear, tire wear and road abrasion for heavy duty vehicles in grams black carbon / kilometer

	Low	High	Average
Brake wear	0.00025	0.0005	0.00038
Tire wear	0.0006	0.0007	0.0065

Electricity generation

The following default factors are recommended for common types of electricity production, separated between larger electricity production and diesel-based electricity engines, such as generators. The factors are taken from the US EPA GREET model; additional types of engines are available in the report: Estimation of Emission Factors of Particulate Black Carbon and Organic Carbon from Stationary, Mobile and Non-Point Sources in the United States for Incorporation into GREET.[42] A weighted average should be calculated for a country or region's specific grid mix based on the categories below. Information on grid mix is available from the International Energy Agency and local government data such as US EPA eGRID.

Table 14 black carbon emissions factors for transhipment centers electricity sources from the US EPA GREET model

Electricity Source	lb BC /MMBtu	g BC /kWh
Biogas-fueled turbine	0.0084	0.00112
Coal-fired utility boilers	0.0019	0.009
Diesel-fueled turbine	0.0022	0.00029
Natural gas-fired single-cycle turbines	0.0049	0.00065
Natural gas-fired combined-cycle turbine	0.0021	0.00028
Median Value for Non-Biogas Turbines	0.0022	0.00029
2013 Diesel-fueled Stationary Internal Combustion Engine	0.092	0.01223
2020 Diesel-fueled Stationary Internal Combustion Engine	0.032	0.00425
Gasoline-fueled Stationary Internal Combustion Engine	0.012	0.00160

For a region with electricity production based on various fuel sources, use a weighted average to find the average emissions factor for a region. For example, Alaska's grid mix in 2003 was roughly 55% natural gas, 12% diesel fuel and the remainder renewable.[58]

Example of weighted average emissions for electric grid-related BC in Alaska, USA

= (0.55 * 0.0049 lb. BC /MMBtu) + (0.12 * 0.0022) + (0.37 * 0.0)

= 0.00296 lb. BC /MMBtu

APPENDIX 2:

SILVER TIER BLACK CARBON EMISSIONS FACTORS FOR ROAD

This methodology provides silver tier black carbon emissions factors for road only. These lifetime average emissions factors are applicable specific to vehicle types and standard and can be applied to any calendar year. If a truck has been retrofitted, use the factor that corresponds with the updated DPF.

Table 15 Black carbon emission factors by euro-equivalent standard in grams black carbon / kilometer

Vehicle Size	Fuel	Uncon-trolled	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
Light HDT	Gasoline	0.0279	0.0072	0.0016	0.0014	0.0012	0.0012	0.0012
Light HDT	Diesel	0.1554	0.0810	0.0423	0.0431	0.0117	0.0107	0.0002
Medium HDT	Diesel	0.1403	0.1138	0.0656	0.0608	0.0165	0.0154	0.0003
Heavy HDT	Diesel	0.2052	0.1993	0.1230	0.1040	0.0260	0.0287	0.0005

APPENDIX 3:
SILVER AND GOLD TIER BLACK CARBON EMISSIONS FACTORS SOURCES FOR ALL MODES

The following data sources provide more detailed black carbon emissions factors which may be suitable for silver and gold calculation tiers. Other sources may exist or become available over time, so this should not be considered an exhaustive list. Also, as technologies improve, black carbon emissions will likely continue to reduce over time. As such, practitioners are encouraged to seek the most up-to-date emissions factors available.

Table 16 Silver and gold tier black carbon emissions factor sources

Tier	Data Source	Year	Modes	Relevant Pollutant	Unit	Region	Notes
Silver **Gold**	Air Pollutant Emissions Factor Database link	Regularly updated	Air Inland waterways Rail Road Sea	PM2.5 Black carbon	Various	Various	Repository of regional emissions factors available from various sources
Gold	Argonne National Laboratory: Updated Emission Factors of Air Pollutants from Vehicle Operations in GREET Using MOVES link	2013	Road	Black carbon	g / mile	North America	Extensive list of default black carbon emissions factors for numerous vehicle types and ages Information on using g BC/mile data can be found in Road section.
Silver **Gold**	Coordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance (CEPMEIP) link	Up-to-date	Air Inland waterways Rail Road Sea Transhipment Center	PM2.5	g / PJ g / million km	Europe	Emissions factors available for various fuels, compiled from literature. Some data available by vehicle type and activity type
Silver **Gold**	COPERT: Computer programme to calculate emissions from road transport link	Up-to-date	Road	PM2.5 PM10	g / km	Europe	Tool for calculating PM emissions for various engines and activities.

Tier	Data Source	Year	Modes	Relevant Pollutant	Unit	Region	Notes
Silver **Gold**	European Environmental Agency Air Pollutant Emission Inventory Guidebook link	2016	Air Inland waterways Rail Road Sea	PM2.5	g / kg fuel g / LTO (air only)	Europe	Extensive list of PM2.5 emissions factors for transport fuels with various levels of detail per mode, vehicle/engine type and activity level.
Silver **Gold**	GAINS Supplement: Global anthropogenic emissions of particulate matter including black carbon link	2013	Rail Road	Black carbon PM2.5	g / kg fuel	Global	Global average value for various vehicle and locomotive engine standards are available
Gold	Handbook of Emission Factors for Road Transport (HBEFA) link	2014	Road	PM	g / km	Europe	Emissions factors for detailed road activities, regions and fleet compositions
Silver **Gold**	International Maritime Organization Third IMO GHG Study link	2014	Sea	PM2.5	kg / tonne fuel	Global	Emissions factors for various ship types and activity levels
Gold	US EPA Motor Vehicle Emissions Simulator (MOVES) link	2014	Rail Road	PM2.5	g / mile	North America	Interactive model for estimating emissions using detailed activity data
Silver **Gold**	North American Black Carbon Emissions Estimation Guidelines: Recommended Methods for Estimating Black Carbon Emissions link	2015	Air Rail Road Sea	EC PM2.5	g / gallon fuel	North America	Various emissions factors for different modes and level of detail
Silver	UK National Atmospheric Emissions Inventory link	2014	Air Inland Waterways Rail Road Sea	PM2.5	kilotonne / Mt fuel kiloton / billion vehicle kilometers	UK	Database compiling emissions factors for the UK from various sources
Silver	US EPA SmartWay link	Updated annually	Air Inland Waterways Rail Road	PM2.5	g / ton-mile	North America	Carrier-specific data are available

APPENDIX 4:
PM2.5 SPECIATION FACTORS

Three widely available sources for speciation factors included below: World Bank, US EPA and EEA. Whichever method of conversion is applied; it should be clearly stated in the assumptions regarding the calculation. The US EPA SPECIATE database may provide other speciation factors for specific activities.

Table 17 A compilation of speciation factors for all modes of transport from various sources

Mode	Fuel type	Vehicle Type	BC/ PM 2.5	Region	Source
Air	Jet fuel	Aircraft	0.13	North America	US EPA
	Unspecified	Old/average fleet; LTO and CCD	0.48	Europe	EMEP/EEA Guidebook
	Unspecified	Piston-engine aircraft	0.48	Europe	EMEP/EEA Guidebook
Inland Waterways	Diesel	Non-road	0.77	North America	US EPA
	Diesel	All diesel ships	0.55	Global	World Bank
	Gasoline	All gasoline ships	0.05	Global	World Bank
	Gasoline	Non-road	0.10	North America	US EPA
	Heavy Fuel Oil	All HFO ships	0.12	Global	World Bank
	Marine Gas Oil	All MGO ships	0.12	Global	World Bank
Rail	Diesel	Locomotive	0.73	Global	World Bank
	Diesel	Non-road	0.77	North America	US EPA
	Diesel	2013 Locomotive	0.68	North America	CEC
	Diesel	Default locomotive	0.65	Europe	EMEP/EEA Guidebook
	Diesel	Average line haul or shunting locomotive or rail car	0.65	Europe	EMEP/EEA Guidebook
	Diesel	Locomotive with DPF	0.15	Europe	EMEP/EEA Guidebook
Road	Gasoline	On-road	0.19	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: uncontrolled	0.03	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: Euro 1	0.23	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: Euro 2	0.17	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: Euro 3	0.17	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: Euro 4	0.17	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: Euro 5	0.17	Global	World Bank
	Gasoline	Lightweight Heavy Duty Truck: Euro 6	0.17	Global	World Bank
	Gasoline	Medium weight Heavy Duty Truck: uncontrolled	0.03	Global	World Bank

Mode	Fuel type	Vehicle Type	BC/ PM 2.5	Region	Source
Road	Gasoline	Medium weight Heavy Duty Truck: Euro 1	0.23	Global	World Bank
	Gasoline	Medium weight Heavy Duty Truck: Euro 2	0.17	Global	World Bank
	Gasoline	Medium weight Heavy Duty Truck: Euro 3	0.17	Global	World Bank
	Gasoline	Medium weight Heavy Duty Truck: Euro 4	0.17	Global	World Bank
	Gasoline	Medium weight Heavy Duty Truck: Euro 5	0.17	Global	World Bank
	Gasoline	Medium weight Heavy Duty Truck: Euro 6	0.17	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: uncontrolled	0.03	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: Euro 1	0.23	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: Euro 2	0.17	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: Euro 3	0.17	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: Euro 4	0.17	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: Euro 5	0.17	Global	World Bank
	Gasoline	Heavy weight Heavy Duty Truck: Euro 6	0.17	Global	World Bank
	Gasoline	Passenger Cars	0.12	Global	World Bank
	Gasoline	Light Duty Vehicles	0.05	Global	World Bank
	Gasoline	Light Commercial Vehicle: PRE-ECE	0.02	Global	World Bank
	Gasoline	Light Commercial Vehicle: ECE 15 00/01	0.05	Global	World Bank
	Gasoline	Light Commercial Vehicle: ECE 15 02/03	0.05	Global	World Bank
	Gasoline	Light Commercial Vehicle: ECE 15 04	0.20	Global	World Bank
	Gasoline	Light Commercial Vehicle: Open loop	0.30	Global	World Bank
	Gasoline	Light Commercial Vehicle: Euro 1	0.25	Global	World Bank
	Gasoline	Light Commercial Vehicle: Euro 2	0.25	Global	World Bank
	Gasoline	Light Commercial Vehicle: Euro 3	0.15	Global	World Bank
	Gasoline	Light Commercial Vehicle: Euro 4	0.15	Global	World Bank
	Diesel	On-road	0.74	Global	World Bank
	Diesel	Lightweight Heavy Duty Truck: uncontrolled	0.47	Global	World Bank
	Diesel	Lightweight Heavy Duty Truck: Euro 1	0.70	Global	World Bank
	Diesel	Lightweight Heavy Duty Truck: Euro 2	0.80	Global	World Bank
	Diesel	Lightweight Heavy Duty Truck: Euro 3	0.72	Global	World Bank
	Diesel	Lightweight Heavy Duty Truck: Euro 4	0.69	Global	World Bank
	Diesel	Lightweight Heavy Duty Truck: Euro 5	0.25	Europe	EMEP/EEA Guidebook
	Diesel	Lightweight Heavy Duty Truck: Euro 6	0.25	Europe	EMEP/EEA Guidebook
	Diesel	Medium weight Heavy Duty Truck: uncontrolled	0.46	Europe	EMEP/EEA Guidebook
	Diesel	Medium weight Heavy Duty Truck: Euro 1	0.70	Europe	EMEP/EEA Guidebook
	Diesel	Medium weight Heavy Duty Truck: Euro 2	0.80	Europe	EMEP/EEA Guidebook
	Diesel	Medium weight Heavy Duty Truck: Euro 3	0.72	Europe	EMEP/EEA Guidebook
	Diesel	Medium weight Heavy Duty Truck: Euro 4	0.68	Europe	EMEP/EEA Guidebook
	Diesel	Medium weight Heavy Duty Truck: Euro 5	0.23	Europe	EMEP/EEA Guidebook

Mode	Fuel type	Vehicle Type	BC/ PM 2.5	Region	Source
Road	Diesel	Medium weight Heavy Duty Truck: Euro 6	0.25	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: uncontrolled	0.51	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: Euro 1	0.65	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: Euro 2	0.65	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: Euro 3	0.61	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: Euro 4	0.83	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: Euro 5	0.83	Europe	EMEP/EEA Guidebook
	Diesel	Heavy weight Heavy Duty Truck: Euro 6	0.08	Europe	EMEP/EEA Guidebook
	Diesel	Passenger Cars	0.57	Europe	EMEP/EEA Guidebook
	Diesel	Light Duty Vehicles	0.55	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicles	0.53	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Conventional	0.55	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Euro 1	0.70	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Euro 2	0.80	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Euro 3	0.85	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Euro 4	0.87	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Euro 3, Euro 4, Euro 5 with DPF and fuel additive	0.10	Europe	EMEP/EEA Guidebook
	Diesel	Light Commercial Vehicle: Euro 3, Euro 4, Euro 5 with catalyzed DPF	0.20	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: conventional	0.20	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: Euro 1	0.50	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: Euro 2	0.65	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: Euro 3	0.65	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: Euro 4	0.70	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: Euro 5	0.75	Europe	EMEP/EEA Guidebook
	Diesel	Heavy Duty Vehicle: Euro 6	0.75	Europe	EMEP/EEA Guidebook
	Diesel	On-road	0.74	US	US EPA
	Gasoline	On-road	0.19	US	US EPA
Sea	Marine Diesel	Commercial Marine (C1 & C2)	0.77	US	US EPA
	Marine Diesel	Commercial Marine (C3)	0.03	US	US EPA
	ECA-compliant Diesel	Marine vessel	0.77	North America	CEC
	Residual Oil	Marine vessel – global	0.06	North America	CEC
	Gasoline	All gasoline ships	0.05	Europe	EMEP/EEA Guidebook
	Diesel	All diesel ships	0.55	Europe	EMEP/EEA Guidebook
	Heavy Fuel Oil	All HFO ships	0.12	Europe	EMEP/EEA Guidebook
	Marine Gas Oil	All MGO ships	0.31	Europe	EMEP/EEA Guidebook

APPENDIX 5:
UNIT CONVERSIONS

Distance

To convert from	To	Multiply By
Foot (ft)	Meter (m)	0.3048
Yard (yd)	Meter (m)	0.9144
International mile (mi)	Kilometer (km)	1.6093
Nautical mile (nmi)	Kilometer (km)	1.852
gram (g) /ton-mile (tm)	gram (g) /tonne-kilometer (tkm)	1.609

Weight, Distance, and Volume

To convert from	To	Multiply By
Kilogram (kg)	Metric tonne (tonne)	0.001
Ton (long, 2240lb)	(Metric tonne (tonne)	1.016
Ton (short, 2000lb)	(Metric tonne (tonne)	0.9072
Pound (US lb.)	Kilogram (kg)	0.4536
Twenty-foot Equivalent (TEU)	Metric tonne (tonne)	10
US Gallon	Liter	3.7854

Fuel Densities of Common Transport Fuels

Fuel type	US Gallons / kg	Liters / kg
Aviation gasoline	0.373	1.411
Aviation turbine fuel	0.331	1.252
Crude oil	0.315	1.192
Diesel	0.315	1.194
Gas oil	0.309	1.168
Gasoline	0.360	1.362
Heavy fuel oil (more than 1% sulfur)	0.338	1.281
Heavy fuel oil (1% or less sulfur)	0.267	1.011
Marine diesel oil	0.309	1.168

Source: Energy Institute Knowledge Service. Petroleum Average Conversion Factors. 2011.

APPENDIX 6:
SAMPLE CALCULATIONS

This section attempts to demonstrate black carbon calculations using the methodology and data provided in the Black Carbon Methodology. Three examples are shown below. The first is a bronze tier calculation from the perspective of a shipper who subcontracts their transport and does not have information on the specific shipment conditions – fitting the bronze tier standard. The second calculation is for a set of road shipments where information is known about the distance driven by each vehicle and engine type.

The third set is a mixed supply chain, where an LSP uses their own vehicles for the road transport and subcontracts the air transport. In this case, the calculation includes both the bronze and silver tiers. For the road transport, distance is allocated to vehicle type/engine size based on the average fleet make-up.

Bronze tier calculation

A company subcontracts the transport of a one shipping container from Verona, Italy to New York City. No details are known on the vehicles or actual fuel burn, so the calculations should be done at the bronze tier. The fuel consumption factors are from the GLEC Framework default consumption factors and the black carbon emissions factors are from the bronze tier values in the Black Carbon Methodology.

	Weight (metric tonne)	Distance (km)	Fuel Consumption Factor (kg heavy fuel oil / tkm)	Total Fuel (kg)	Black Carbon Emissions Factor (g / kg Fuel)	Black Carbon (g)
Rail: Verona, Italy to Port of Livorno, Italy	10	350	0.009	32	1.0	32
Sea: Port of Livorno to Port of New Jersey	10	7535	0.006	452	0.1	45

	Distance (km)	Black Carbon Emissions Factor (g / km)	Black Carbon (g)
Road: Port of New Jersey to Pitts-burgh, USA	560	0.016	9.016
	Total Black Carbon (g) per Shipping Container		85.7

Silver tier calculation for road

A carrier took 10 trips with a fleet of trucks with different conditions. In this case, information on the kilometers driven by each type of truck is known, so calculations can be done at the silver tier. The black carbon emissions factor are from the Black Carbon Methodology.

Trip	Fuel Type	Truck Size	Engine Type	Distance (km)	Black Carbon Emissions Factor (g / km)	Black Carbon (g)
1	Diesel	Medium HDT	Euro III	500	0.061	30.4
2	Diesel	Medium HDT	Euro III	750	0.061	45.6
3	Diesel	Heavy HDT	Euro IV	**1000**	0.104	104.0
4	Diesel	Heavy HDT	Euro IV	600	0.104	62.4
5	Diesel	Light HDT	Euro V	500	0.001	0.6
6	Diesel	Heavy HDT	Euro IV	250	0.104	26.0
7	Diesel	Heavy HDT	Euro IV	750	0.104	78.0
8	Diesel	Medium HDT	Euro III	1000	0.061	**60.8**
9	Diesel	Medium HDT	Euro III	500	0.061	30.4
10	Diesel	Light HDT	Euro V	800	0.001	1.0
				Total Black Carbon (g)		**439**

A multi-modal supply chain with mixed tiers

An LSP wants to know the total carbon emissions for the transport of 100 tonnes of product between China to Phoenix, USA. In this case, silver tier information is known for road and bronze for air.

Air: Bronze Tier

The fuel consumption factors are from the GLEC Framework and the black carbon emissions factor are from the bronze tier values in the Black Carbon Methodology.

	Weight (metric tonne)	Distance (km)	Fuel Consumption Factor (kg / tkm)	Total Fuel (kg)	Black Carbon Emissions Factor (g / kg Fuel)	Black Carbon (g)
Shanghai to Los Angeles - air freight as belly cargo	10	10500	0.350	36,750	0.1	**3,675**

Road: Silver Tier

- A road carrier travels 6,000 kilometers
- The fleet is made of different types of trucks - the distance travelled by each truck is unknown.
- To estimate black carbon, the distance is allocated based on the fleet make up: 30% Euro III Heavy HDT, 40% Euro III Heavy HDT, 30% Euro IV.
- The black carbon emissions factor is from Appendix 2.

Fuel Type	Truck Size	Engine Type	Distance (km)	Black Carbon Emissions Factor (g / km)	Black Carbon (g)
Diesel	Heavy HDT	Euro III	1,800	0.104	187.2
Diesel	Heavy HDT	Euro IV	2,400	0.026	62.4
Diesel	Heavy HDT	Euro V	1,800	0.029	51.7
			Black Carbon (g)		**301**

Total: Air & Road	
	Black Carbon (g)
Air	3,675
Road	301
Black Carbon (g)	**3,976**


www.smartfreightcentre.org