MARITIME STRATEGIC EVALUATION FOR ISRAEL 2021/22

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Section 4: Dangers in the Maritime Domain

Many dangers are associated with the sea, from security to environment. The two articles in this section deal with issues that deserve attention: the hazards of transferring dangerous goods in ships and black carbon emissions from ships, particularly around ports and port cities. The articles discuss methods to deal with these issues, from regulation that needs to be enforces to practical solutions to limit the damage.

Hazards of Transport of Dangerous Goods in Ships

Aleksander Gerson

Maritime transport constitutes 80 percent of the total global transport of commodities (approximately 11.5 billion tons annually). Due to their significant advantage in size ("economies of scale") over any other mode of transport (whether air- or land-based), ships can transport goods economically and cheaply all over the world. The State of Israel, the Mediterranean Sea's eastern-most country and a "geo-political island," is uniquely dependent on maritime transport for import and export, comprising up to 99 percent of Israeli international trade. Even though bulk seaborne merchandise (liquid or dry), such as ore, grain, crude oil, and all petrochemical products constitute the largest portion of global trade, this article focuses on transport of Dangerous Goods (DG) in container ships, an area in which the most significant increase in vessel size has occurred (approximately sixteen-fold over the past fifty to sixty years), including the volume of goods transported and DG carried.

There is a clear financial incentive for ship owners and operators to transport increasing quantities of containers carrying DG. Carrying this out safely requires in-depth knowledge of the risks involved for any hazardous substance (manufacturing, packaging, loading, and locating on board), and careful consideration of the interface between DGs and the ship and its crew. Carrying DG aboard ships currently involves very sophisticated computations and planning in order to minimize risks to security, safety, and contamination of the marine environment. The world regulator (International Maritime Organization, IMO) and shipping company owners have not yet adapted their policies and procedures sufficiently to keep up with the impact and consequences of the dramatic changes in container ship size.

This article discusses the global changes and trends in transportation of DG in containers in increasingly large ships (mega-ships), their inherent problems, the Israeli perspective, and whether the State of Israel is prepared for the future in this respect.

Background

Container vessels of the 1960s carrying 1,500 TEU (Twenty-foot Equivalent Unit) containers were considered large ships and would typically each carry several to a few dozen containers of hazardous materials. That size is now dwarfed by current container ships carrying 24,000 containers (Ultra Large Container Ships, ULCS), which is the current norm and constitutes a sixteen-fold increase over the past fifty to sixty years. As the cost of transporting a container with DG is relatively high, increasing the quantity of DG containers offers obvious economic benefits for ship owners. The larger the vessels, the greater the quantities of DG they carry, often several hundred such containers per vessel. The downside of this trend is an increase in risks (security, safety, and contamination of the marine environment).

The need for international regulation of transport of DG at sea was already recognized in the 1929 Safety of Life at Sea (SOLAS) Convention, which recommended formulating internationally recognized standards. Classification of DG and initial regulations regarding their carriage ensued and were approved by the 1948 SOLAS Committee. The Committee also decided to continue to develop further international conventions, codes, and regulations.

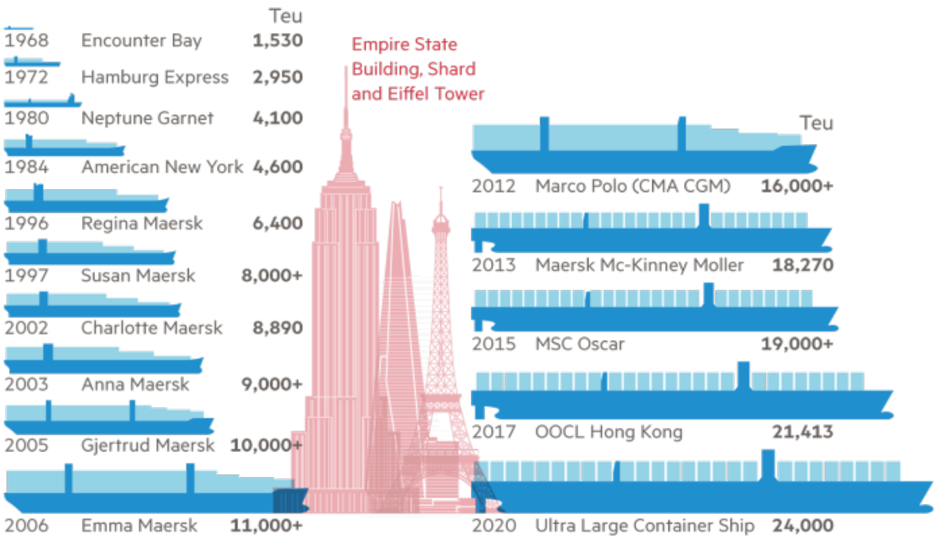

Figure 1: The growth of container ships in the past fifty years[1]

The major achievements in this field are enshrined in the following Conventions:

- SOLAS Chapter VII – Carriage of DG
- SOLAS Chapter II-2 – Construction – fire protection, fire detection, and fire extinction
- International Maritime Dangerous Goods Code (IMDG Code)[2]
- State of Israel legislation – (Ports Regulations 1982), Chapter 16a

Of 250 million containers transporting goods around the world every year, approximately 25 million (10 percent) contain DG of many different types. Hundreds of millions of tons of DG are transported in liquid or dry bulk. These include toxic and corrosive chemicals, substances that release combustible and noxious gases in contact with water or are susceptible to spontaneous combustion, fuels of various kinds, liquified or compressed gases, such as LNG (Liquefied Natural Gas) and LPG (Liquefied Petroleum Gas).

1 "Too big to sail? The debate over huge container ships". *Financial Times*, March 28, 2021.

2 https://imo.org: IMDG Code 40-20.

Preparing DG for transportation, starting at the manufacturer's plant, packaging, loading, transporting them in often unpredictable and rapidly changing and extreme weather conditions—these require highly trained and skilled personnel both ashore and at sea. The IMO has issued multiple regulations and codes to minimize the dangers of transporting DG, alongside regulations issued by other relevant important international bodies such as Lloyds, American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV), Germanische Lloyds (GL), International Association of Independent Tanker Owners (INTERTANCO), The Society of International Gas Tankers (SIGITTO), International Chamber of Shipping (ICS). However, in case of a serious incident occurring at sea involving DG, ships' crews have very limited means at their disposal for tackling such an event.

Case 1 – The burning and foundering of the X-*Press Pearl* with its total cargo of 1,500 containers in May 2021 (fortunately the ship was close to the Sri Lanka shore and the crew was rescued prior to the explosion and spread of the fire) caused not only economic damage but also serious environmental damage in the relatively shallow coastal waters of Sri Lanka, the extent of which has not yet been determined. Although formal results of the inquiry have not yet been published, apparently a leak from a container with nitrous acid caused the huge fire (the mechanism has still not been clarified). The CEO of X-Press Carriers has stated that in view of the total loss and foundering of the vessel itself, the inquiry is likely to take a long time. Due to the extreme temperature, most of the fuels and oils were burned or evaporated, therefore contamination of the sea with fuel and oil was largely limited, a relatively "fortunate" result of the incident. This event raised public awareness (at least locally) to the dangers to life and the environment caused by transport of DG.

Figure 2: The burning and sinking of X-*Press Pearl*, May 2021

Case 2 – In February 2021, Israel suffered an event of contamination of the shore from the release or leak of approximately 1,000 tons of crude oil. However, this damage is incomparable in its significance to the possibility of a marine accident involving a mega container ship (these ships can carry 8,000–6,000 tons of fuel on board) in the vicinity of Israel's shores. Soon, such ships will be arriving regularly at the Haifa and Ashdod ports.

A recent meeting of marine insurance firms that convened in London due to the concerning number of fires on large container ships[3] in the last five years highlighted a possible correlation between the incidence of fires and the substantial number of mis-declarations (aimed at saving shippers' expenses) of containers' contents.[4]

Identification of an oil stain at sea is relatively simple, however contamination with dangerous chemicals, some of which are extremely noxious, may be invisible, difficult to identify, and almost impossible to decontaminate.

Is the State of Israel ready to effectively supervise its marine waters and ports?

Dangerous Goods (DG) are classified into nine categories

1. Explosives (Class 1) 
2. Gases (2.1 Flammable; 2.2 Non-flammable or toxic; 2.3 Toxic) 

3. Flammable Liquids (Class 3) 
4. Solids (4.1 Flammable; 4.2 Liable to spontaneous combustion; Emit flammable gases in contact with water) 
5. Oxidizing Substances (5.1 Oxidizing agent; 5.2 Organic peroxides) 
6. Toxic and Infectious Substances (6.1 Toxic; 6.2 Infectious) 

7. Radioactive (Class 7) 
8. Corrosives (Class 8; Acids and Bases) 
9. Other (Class 9)  and Marine Pollutants 

[3] Insurance Marine News, "Marine Insurance London: Fires on containerships – solutions still elusive", *International Union of Marine Insurance (IUMI)*, December 9, 2020.

[4] Mike Wackett, "Zim develops early detection software for cargo misdeclarations", theloadstar, August 17, 2020; Mike Wackett, "The need for change: container shipping is an 'accident waiting to happen'", theloadstar, November 8, 2021.

An additional list of High Consequence DG (HCDG) includes those with potential for misuse in a terrorist event and may result in serious consequences such as mass casualties and mass destruction, particularly for Class 7 (Radioactive), "mass socio-economic disruption" (IMDG Code Vol I -1.3.4.1.2).

Case 3 – Explosion on board the ammunitions ship SS *Mont Blanc* in the port of Halifax, Nova Scotia, Canada, in 1917 destroyed the port and half of the city and caused 2,000 casualties. If a catastrophe of similar proportions was considered unlikely today, the proof of the contrary was provided by an explosion in the port of Beirut in 2020 when 3,000 tons of ammonium nitrate (a fertilizer) exploded, destroying the Beirut port, and caused 218 fatalities and 7,000 injured.

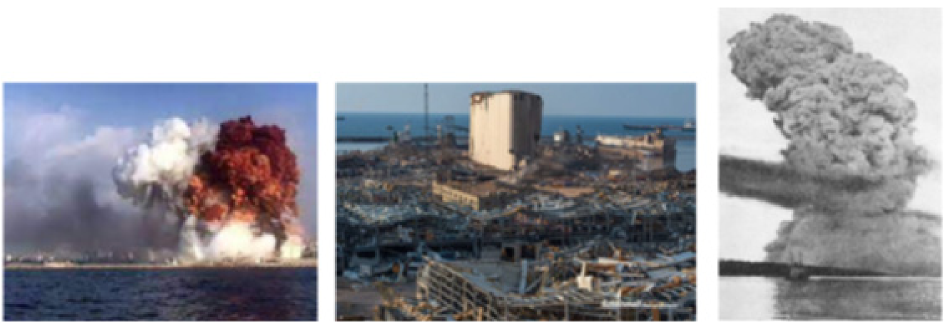

Figure 3: Explosions of DG at Halifax port (1917) and Beirut port (2020)

Table 1:

Types of HCDG		
The following United Nations (UN) numbers are considered HCDG. UN Numbers are a globally recognised way of labelling dangerous goods[5]		
UN Number	Proper shipping names	Class division
3375	Ammonium nitrate emulsion or suspension or gel, intermediate for blasting explosives	5.1
3139	Oxidising liquid, N.O.S.	5.1
1942	Ammonium nitrate with not more than 0.2% total combustible material, including any organic substance calculated as carbon, to the exclusion of another added substance	5.1

The table above lists a few examples of HCDG carried in ships that require special precautions and care during storage, loading, and discharging. Ammonium nitrate poses three main risks:

5 https://imo.org: IMDG Code 40–20. Chapter 1.10.3.1.

- **Decomposition** – Ammonium nitrate melts at 170°C, and above 210°C it decomposes and releases a toxic gas
- **Fire** – Ammonium nitrate, whether solid or liquid, is an oxidizing agent, which can release oxygen to "fuel" burning, even in an oxygen-poor environment
- **Explosion** – In the presence of fire, ammonium nitrate can melt and behave like liquid, which in a confined space may explode, causing a huge shock wave and a cloud of toxic gas capable of spreading thousands of meters around the explosion site. It should never be stored alongside organic substances, fuels, oils, and especially heat sources.[6]

HCDG substances can appear under all classification categories (1–8), depending on their quantity and/or danger category.

Some shipping companies refuse to transport high risk substances such as radioactive materials, substances with wide flammability ranges (very low Flash point, minus 30°C), such as Carbon Disulphide (UN1131), which can auto-ignite at just 100°C.

or substances that have a potential for spontaneous chemical reaction above a certain temperature (SADT – Self Accelerating Decomposition Temperature), such as Class 5.2 organic peroxides.

The above are transported in reefer containers that, in addition to the electrical motor connected to ship's main power supply, are equipped with an autonomous diesel motor. They are also equipped with an audio-visual alarm and a GPS transponder that will send an alarm if the temperature rises above the safety limit.

Most ports also limit transit of explosives and radioactive substances. If permitted, these are transported in limited quantities and need to be managed by specialists. Some ports also limit transport of other kinds of DG, such as especially flammable liquids with a wide flammability range and low SADT Class 4.2 substances, some of

6 https://imo.org: IMDG Code 40-20. Chapter. 1.10.3.1

which may be classified as explosives, for example, nitroglycerin diluted in alcohol (UN 0144).

Case 4 – A ZIM-line ship loaded a container classified as Class 5.1 temperature sensitive in China (Calcium Hypochlorite, UN 1748). This substance is used for sanitizing swimming pools and, on the face of it, is not an especially dangerous substance. The shipper did not report the container's content as required, and it was loaded in a hold adjacent to the engine room bulkhead, which radiates heat from adjacent machinery. After several days at sea, the container exploded and a fire started and spread inside the hold. Fortunately, the ship's crew were alerted, stopped all ventilation to the hold, and released all CO_2 bottles available on board. This stopped the spread of the fire but did not extinguish it. The ship had arrived, in the meantime, at Port Suez (Egypt) and notified the authorities of the incident. In the absence of any remaining CO_2 bottles on board, the ship was not permitted to traverse the Suez Canal, it was detained for a few days until all CO_2 bottles were refilled ashore and returned to the ship and the fire fully extinguished. This case demonstrates the importance of crew alertness and readiness for immediate response, but also the utmost importance of accurate declaration by the shipper regarding the contents of the container. In this case, the ship was saved by the actions of the crew in blocking the spread of the fire.

Following this incident, the ZIM company discontinued their connection with the exporter/shipper of the container. Conclusions following from the event were embedded in the company's regulations for transport of DG (and this type of chemical in particular) and in the safety policy of the company (SMS).

Loading DG Containers on Ships

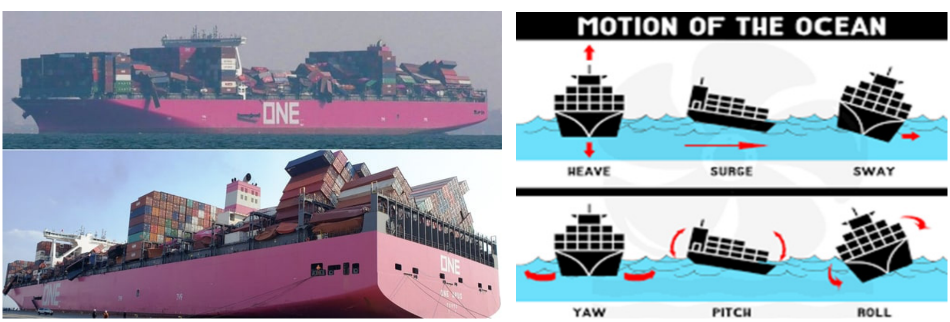

Figure 4: Motion of the ocean (left) and possible results (right)

The international code for transporting DG at sea (IMDG Code) sets out strict and obligatory measures to prevent or minimize risk in case of accident (e.g., collision), structural damage to the vessel, grounding, container collapse due to exceptionally rough sea (parametric rolling), or any other urgent occurrence (especially fire).

IMDG Code requires the following measures (among others):

- Submission of a Shipper's Declaration detailing the industrial/commercial name of the substance, UN Number, packing certificate (signed by a certified packer), classification of the substance and any sub-classification if relevant (main/primary risk and secondary risk), ship's plan and precise location for loading the container and net weight of the dangerous substance.
- Certificate of cleaning containers or washing empty iso-tanks that previously contained dangerous substances. In the absence of such a certificate, the container is considered to contain a dangerous substance.
- Category of packing, instructions for emergency procedures in case of any structural damage to the container's integrity, including contact numbers of the shipper/manufacturer 24/7 in case of urgent need for further advice. The ship is required to carry a Document of Compliance (DoC) detailing which cargoes the ship is certified to carry in each of its cargo holds.
- Loading plan approved by the Israeli Ministry of Transport, detailing horizontal and (vertical) tier separations. Tier separation requirements are very strict for flammable liquids (Class 3) or corrosive liquids (Class 8), due to the concern of possible leak; in some cases, the most stringent "4" (see below) separation is required, where even separation by a continuous steel deck is insufficient, and a significant additional horizontal distance is required.
  - "away from" – minimum 3 meters distance between containers
  - "separated from" – minimum 6 meters distance between containers
  - "separated by a complete compartment or hold from" (on deck, minimum 24 meters apart)
  - "separated longitudinally by an intervening complete compartment or hold from" (horizontally)
- Liquid cargoes or noxious gases are required to be distanced from accommodation and engine room ventilation systems.
- If the ship is carrying flammable or noxious liquids in the holds, it is obliged to have a dedicated system for pumping hold bilges, which is separate from the ship's engine room where all other pumping arrangements are located (SOLAS II-2/19).

- The ship must be fitted with a central CO_2 fire extinguishing system for releasing the gas into the engine room or any single hold. Certain chemicals require specific fire extinguishing media, for example, Lithium (UN 1415), which needs to be delivered on board prior to loading that specific cargo.
- If the ship is loading Class 1 explosives, loading is carried out under direct supervision of a Ministry of Transport Inspector. Prior to loading, the container is examined for structural integrity, and it should have regular periodic testing of its integrity (ACEP). Once the cargo is secured in the container and a certified electrician carries out an Electrical Continuity–Megger Test, an appropriate certificate is then issued.
- Flammable materials are loaded into a hold only after ensuring disconnection of the electrical supply to the hold by physically removing fuses from the main electrical board.
- If oxidizing substances (5.1) are loaded in bulk, the ship needs to prove its ability to maintain residual stability in the event of flooding of two holds with water (CO_2 is ineffective in extinguishing a fire cause by oxidizing substances); loading is carried out under supervision of a Ministry of Transport Inspector.
- Highly flammable cargoes (IMDG Code 7.2.7.1.3) cannot be loaded onto a ship carrying Class 1 explosives. These flammable cargoes and other substances susceptible to spontaneous temperature-dependent reaction are subject to a minimal separation from crew accommodation and/or heat or source of possible ignition. Reefer containers come under the category of a potential source of ignition.

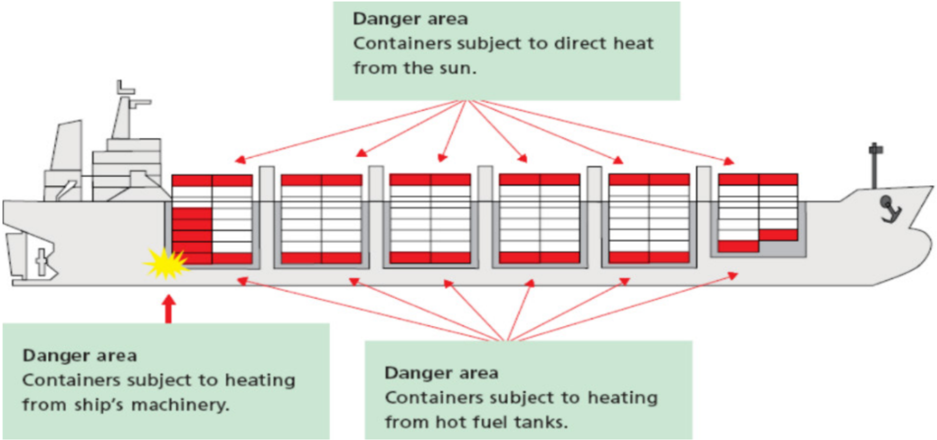

Figure 5: Areas on a ship that could be affected by high temperatures[7]

7 https://www.ukpandi.com

Due to strict separation requirements below deck, loading planners prefer loading containers with DG on the deck (Class 1 containers and flammable substances with susceptibility to spontaneous combustion in particular). Certain substances can only be loaded on the deck and in proximity to the ship's side, where in case of emergency they can be pushed overboard (at least in theory, as container ships have no lifting appliances) or can be isolated more easily in case of explosion or fire.

Loading Above or Below Deck

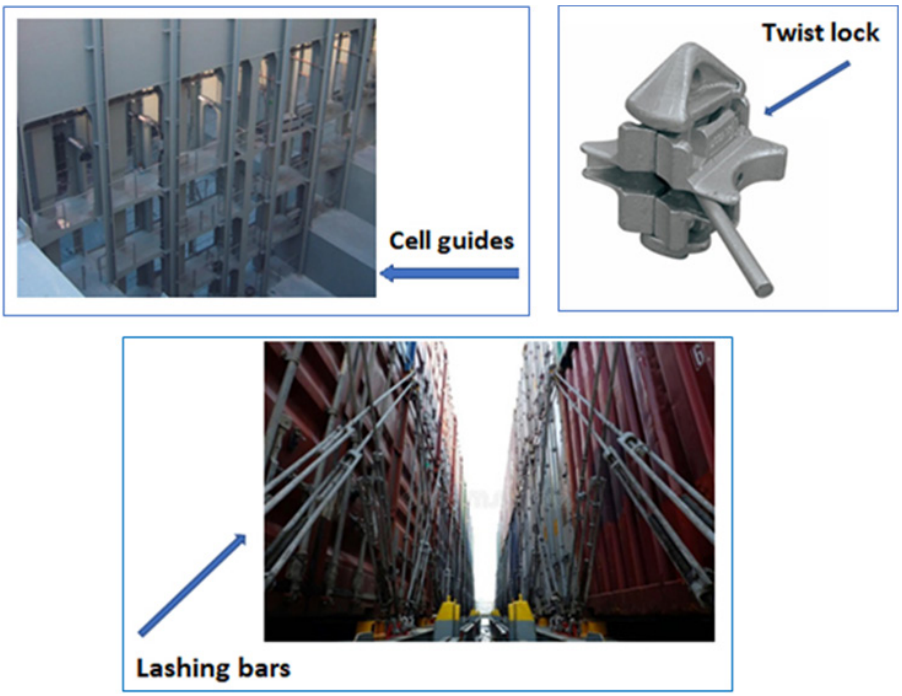

Figure 6: Various tying means to secure containers

There are advantages and disadvantages for loading above or below deck. As already mentioned, segregation rules (Chapter 7.2 of IMDG Code: General segregation provisions)[8] on deck are less stringent and access to containers (at least the lower tiers) is easier. However:

- Lashing bars on deck that connect to the ship's hull can usually reach up only to the fourth tier of containers on deck. Above this height containers are only secured to one another by twist locks at their four corners.

8 The International Maritime Dangerous Goods (IMDG) Code.

- When the sea is very rough, work on deck can be hazardous, especially accessing containers stacked high, in case some fault is suspected.
- In case of strong rolling, container ships are under some circumstances susceptible to parametric rolling and container lashing may fail. If containers containing DG collapse, there is danger of contact between substances that can cause a severe chemical reaction, resulting in potential catastrophe, such as fire or loss of the entire vessel.
- Containers stored inside a ship's hold under deck are stacked within Cell Guides and are therefore more secure in the face of waves and heavy spray in rough weather including all ship's movements at sea. However, transport underdeck may be more costly and segregation more stringent.

When Is Large Too Large and What Can Be Done?

There are many aspects to the problems of transporting dangerous goods containers and particularly in mega-ships. Numerous accidents were caused by collapse of a container stack onto the deck; however, the causes are not always clear. Probable factors may be intrinsic factors of the container, lashing, overloading, sub-optimal spread of weight, incorrect prediction of the ship's movements in rough sea and inadequate lashing calculations.

The current methodology for calculating the forces relies on an assumption of three to five tiers of containers. However, with growth of container ships, these calculations have become overly complex. By the time the ship's software, if at all capable, can calculate all the loading parameters, the ship will have left port and making any adjustment becomes impossible.

Ship operators continue to consult the *Cargo Securing Manual,* which is calculated for ships of Panamax size (maximal ship size that can traverse the Panama Canal), however, this is no longer sufficient for much larger ships with multiple tiers of containers on deck.[9]

Case 5 – While writing this article, news arrived of a fire on board the ZIM *Kingston* with a loss of 109 containers, which fell into the sea opposite the Canadian shore. Apparently, the ship encountered severe weather, which caused collapse of part of the container lashings, some containers contained Xanthates, which ignited.

9 Louise Vogdrup-Schmidt, "Lloyd's Register: 24,000 teu ships on the way". *shippingwatch*, October 16, 2014.

Figure 7: Collapsed containers due to severe rolling

Figure 8: Damage and burn due to collapse of containers, ZIM Kingston, October 2021[10]

Hazards from xanthates include, but are not limited to:

- production of toxic or flammable decomposition products (carbon disulphide* (CS2) and potentially alcohol vapors)
- spontaneous combustion that creates toxic combustion products (sulphur dioxide, carbon monoxide, and carbon dioxide)
- low order explosions from ignition of decomposition products
- acute harm if ingested or significant amounts absorbed through the skin
- acute irritation if inhaled or absorbed on skin surface.

This severe event demonstrates the hazards related to transport of DG at sea and the susceptibility of container ships to violent and sometimes unpredictable rolling. Spraying water directly into the containers was impossible in this case, as the chemical causing the fire releases a flammable gas when it comes into contact with water. Getting the fire under control took seven days. Pollution of the marine environment occurred, as some containers and debris were washed ashore. If it were not for the proximity to the Canadian shore and immediate assistance from the well-equipped Canadian Coast Guard, this accident could have had dire consequences. The Canadian authorities (CTSB) intend to investigate all of the aspects related to the accident, including the captain's decision not to seek shelter despite all warnings of an imminent storm. Danaos, the operators of the Malta-flagged vessel, have so far declined any comment.

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10 Mike Schuler, "ZIM Kingston Cargo Fire Stabilized and Ship Held Overnight, Canadian Coast Guard Says", *gCaptain*, October 25, 2021.

Robust and Smart Containers

Case 6 – The collision between the container ship *Ever Decent* and the passenger ship *Norwegian Dream* in 1999 in the English Channel triggered a change in the SOLAS Convention. The force of the collision caused containers to detach and land on the prow of the passenger ship; fire broke out in containers containing paints on board the *Ever Decent*. The *Ever Decent* was severely damaged by the collision and the fire and had to be towed to the nearest port.

Figure 9: Damage from collision of container ship *Ever Decent* and passenger ship Norwegian Dream in 1999

Following this incident, since 2016 a water-mist lance is obligatory as part of the fire-fighting equipment on ships. This can penetrate the side of the container, a simple but effective means of combatting fire in a container when every second makes a difference. It has been suggested that in the future each container will be equipped with a fire-extinguishing system, which will be connected to the ship's central fire-fighting system, somewhat similar to the inert gas system in place in every modern tanker. The industry also considers using austenitic steel in container construction.

Figure 10: Water-Mist Lance, capable of penetrating the container's side

Despite all the regulatory improvements, false declarations made by dishonest shippers still constitute a significant problem. Another problem is the tendency of ship operators to ignore the need to recover containers that have dropped into the sea and are considered pollutants according to Annex 5 of MARPOL. Obligatory fitting of containers with a transponder will facilitate their identification and location if they fall into the sea, especially those that contain hazardous, noxious, or polluting substances might help to solve this issue.

Hazards of Transport of Dangerous Goods Containers at Sea and Size of Container Ships — "Communicating Vessels"

As mentioned, economic pressures and the wish to minimize the voyage duration even in stormy weather, are triggers for building ships of ever-increasing size with considerable costs. Delays in arriving at a loading or discharging port within the designated timeframe of a ship that costs 100,000 USD per day to operate will inevitably trigger insurance claims by shippers and recipients when the continuity of the logistic chain is disrupted. Commercial pressures from owners or charterers in turn will be delegated to ships' command.

ISM Code-MSC Resolution MSC.275(85), related to safety management code for ships, states that it is up to the ship's operator to "assess all identified risks to its ships, personnel and the environment and establish appropriate safeguards."

IMO states that masters and deck officers serving on Ultra-Large Container Ships (ULCSs) are required to undergo training in parametric and synchronous rolling, which constitutes a danger to the ship and the cargo (IMO MSC Circ. 1228, 2007), as part of the regulations regarding safety of navigation in unusual weather circumstances.

Recent publications and the numerous adverse incidents involving DG in recent years indicate that the world regulator (IMO) and shipping company owners have not yet updated their approach to consider the dramatic changes in container ship size and the updated training requirements. The recent blockage of the Suez Canal by the ULCS *Ever Given* (March 2021) has highlighted this issue. Even though there was no involvement of DG in this incident, it should serve as a wake-up call to the shipping community as to the extent at which a serious incident in ships of this dimension can be complex and trigger wide-reaching consequences, especially in bottleneck areas such as the Suez Canal.

A large-scale incident involving DG with potential loss of lives and environmental pollution should be pre-empted, especially in ecologically vulnerable areas. A coastal state such as the State of Israel, with heavy marine traffic occurring not far from its shores (to and from the Far East through the Suez Canal), should prepare for the eventuality of an extreme incident with mass casualties and large-scale marine pollution. It is imperative for the State of Israel to introduce a consolidated plan for tackling potential large-scale incidents involving marine pollution and/or loss of life. This should be achieved in collaboration with neighboring countries and as soon as possible.

Acronyms and Abbreviations

Classification Society – A non-governmental organization that establishes and maintains technical standards for the construction and operation of ships and offshore structures.

Class (IMDG) – Classification of Dangerous Goods in accordance with the Code (1–9)

CTSB – Canadian Transportation Safety Board

Flammable Range – The explosive flammable range of a combustible gas or vapor is the range between the lower exposure limit (LEL) and the upper exposure limit (UEL) for that particular gas or vapor

Flash Point – The fire point is the lowest temperature at which the vapours keep burning after the ignition source is removed

IACS – International Association of Classification Societies e.g. American Bureau of Shipping. Lloyds Register, ClassNK, Det Norske Veritas, Germanische Lloyds, Registro Italiano Navale etc.

IBC Code – The International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk

IGC Code – International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk

ICS – International Chamber of Shipping

INTERTANKO – International Association of Independent Tankers Owners

ISM Code – International Management Code for the Safe Operation of Ships and for Pollution Prevention

LC/LD 50 – LD50 (median lethal dose) for acute oral or dermal toxicity, LC50 for acute toxicity on inhalation

MARPOL – The International Convention for Prevention of Marine Pollution from Ships

MSC – Maritime Safety Committee

MEPC – Maritime Environmental Protection Committee

NGOs – Non-Governmental Organizations (see Classification Societies)

SIGTTO – The Society of International Gas Tanker and Terminal Operators

SMS – Safety Management System (ISM Code)

SOLAS – The International Convention for the Safety of Life at Sea

TEU – Twenty foot equivalent

ULCS – Ultra Large Container Ship

UN number – (United Nations number) is a four-digit number that identifies hazardous materials, and articles (such as explosives, flammable liquids, oxidizers, toxic liquids, etc.)

Black Carbon Emissions from Ships in Israeli Ports

***Merav Gonen*[1]**

Introduction

Ships are vital to global trade. They transport approximately 90% of all world trade and are the most efficient means of transport for transporting goods. Despite the advantages and importance of the shipping sector, emissions of air pollutants from ships include substances which are harmful to health and to the environment. The emission of pollutants into the air is partly caused due to the poor quality of fuel used by the shipping sector. The main pollutants emitted from ships include gases such as nitrogen oxides (NO_X), sulfur oxides (SO_X), and particulate matter (PM). One of the particulate substances is black carbon, which is emitted during incomplete combustion of fossil fuels, and is the main component in soot. It is estimated that each year some eight million tons of black carbon are emitted into the atmosphere from different sources of combustion, of which the shipping sector is estimated to emit approximately 130,000 tons. Besides the detrimental impacts on health, black carbon has climate impacts as well. It is the second cause, after carbon dioxide, of global warming from the shipping sector.

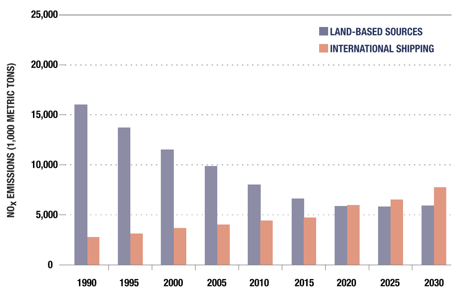
An analysis of global ship traffic shows that a substantial part of ship emissions takes place close to shore or to shipping lanes. The estimate, and it is estimated that 80% of all ship emissions occur within a range of up to 400 km from the coastline. The most significant ship activity segment, in the context of health impacts is the segment in which the ship is berthed in port. Since ports are mostly located close to cities and population centers, ship emissions occurring while the ship is berthed in the port area have a more significant impact on the air quality around the port and on the health of the population living in the nearby city. Studies show that in port cities, the port activity contributes 50% of the total particulate emissions in the urban area.

Emissions of Air pollutants from the shipping sector

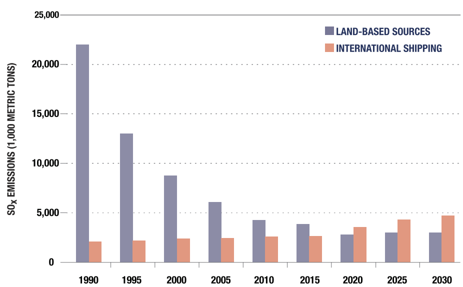
Ships are considered to be the most efficient means of transport in terms of tons of goods transported per ton of fuel. Also, compared with other means of transport such as trucks or airplanes, ships emit the least carbon dioxide in terms of gram per

1 This article is based on research done as part of Master's Degree studies in the Department of Natural Resources and Environmental Management. The author wishes to thank Prof. Ofira Ayalon and Chief Engineer Asher Kadosh for their assistance this article.

ton cargo transported per kilometer. However, when it comes to air pollutants, the shipping sector's contribution is greater. Ship emissions equal, and even exceed, the emissions from land transport: sulfur dioxide emissions from ships are 1.6 to 2.7 times greater than the same emissions from land transport, and nitrogen dioxide and particulate emissions are slightly lower or equal to those from road vehicles (Corbett et al., 1999). Generally speaking, total ship emissions are increasing due to the growth in the volume of global trade, where approximately 90% of the global trade is transported by sea. In addition, regulatory measures taken in the land transport sector (emissions standards for cars and trucks) to reduce air pollutants have resulted in the relative decline in emissions from the land transport sector. Therefore, the relative contribution of the shipping sector to the total greenhouse gas emissions and other pollutant emissions of the whole transport sector has increased. In the European Union, regulations led to reduced emissions from land transport over the past two decades, thus it is estimated that the total emissions of SO_X and NO_X from the shipping sector will exceed the total emissions from land-based sources (figure 1a). The United States' Environmental Protection Agency (EPA) also estimates that shipping contributes 14% to the total NO_X emissions in the USA and that the contribution of the shipping sector to particulate emissions from diesel is approximately 45% (ICCT, 2007).



NO_X emissions estimate in the EU – land-based sources versus international shipping



SO_X emissions estimate in the EU - land-based sources versus international shipping

Figure 1: Estimated land-based emissions versus international shipping in the European Union (NO_X, SO_X). Source: Air Pollution and Greenhouse Gas Emissions from Ocean-going Ships ICCT 2007

Globally, ships are responsible for 14–31% of all nitrogen oxides (NO_X) emissions and for 4–9% of all sulfur oxides (SO_X) emissions. It should be noted that in the past decade, the International Maritime Organization has adopted regulations intended to reduce air emissions of sulfur oxides and nitrogen oxides from ships. The regulations adopted, as part of the MARPOL Convention, gradually limited the sulfur content in fuels used by ships to 3.5% sulfur beginning in 2012 and subsequently to 0.5% sulfur from 2020. In addition, limits on the nitrogen oxide emissions from ship engines were also imposed, depending on the year the ship was built. Moreover, in areas declared as "emission control areas", a more stringent emission limit is imposed (0.1% sulfur). These restrictions on the shipping sector have been introduced gradually over many years but did not yield a significant emissions reduction due to the growth in the shipping sector. It is hoped that we will see the effects of the regulations after 2020, in SO_x emissions reductions, following the coming into effect of the sulfur content limit in fuels as well as the introduction of emissions control areas in North America and Europe (the Baltic Sea, the North Sea).

Particulate air emissions from the shipping sector

In addition to the air pollutants emitted from ships, which include gases such as nitrogen oxides (NO_x) and sulfur oxides (SO_x), ships also emit particles. Particulate Matter (PM) air pollution usually consists of metals, black carbon, organic carbon, ammonia, sulfates, nitrates, and soil particles (dust). Particulate air pollution from Diesel engines is considered to be more harmful than other sources and it contains a relatively large quantity of black carbon.

One of the reasons for the pollutant emissions from ships is the fact that ships use a relatively poor quality of fuel, known as Heavy Fuel Oil (HFO) or Residual Oil. This type of fuel, (also known as "mazut") is produced at the bottom of the refining process. It is the heaviest commercial fuel that can be extracted from crude oil. It is heavier than gasoline and kerosene. HFO is cheaper than other fuels but it is considered the most polluting. This type of fuel contains more sulfur, aromatic hydrocarbons and ash, which reduce the efficiency of the combustion, and cause increased pollutant emissions, including black carbon (IMO BLG 17/Inf 7, 2012). According to data from the International Maritime Organization, in 2018 the global shipping fleet consumed 339 million tons of fuel, 79% of which were Heavy Fuel Oil. (223 million tons HFO, 102 million tons MDO,[2] 11 million tons LNG[3]), (IMO MEPC 75/7/15, 2020).

The particulate air pollution is classified by the diameter of the particles, which may vary from tenths of a micron to tens of microns. Particles smaller than 10 microns in diameter are called PM10. There is another classification of PM1 for finer particles less than 1 micron in diameter. Black carbon belongs in this category. The smaller

2 Marine Diesel Oil – MDO

3 Liquefied Natural Gas – LNG

the diameter of the particles, the deeper they penetrate the respiratory tracts. The black carbon particles are very fine particles, sometimes even having a diameter of 0.1 microns. They are able to penetrate into the lungs and into the bloodstream.

Black carbon and its effects on climate, agriculture, and health

Black Carbon (BC) is a carbonaceous substance consisting of particles less than 1 micron (PM1) in diameter. It is produced during incomplete combustion of carbon-based fossil fuels. In scientific literature, the definition of black carbon differentiates it from other forms of carbon due to its unique physiological properties: 1) it strongly absorbs visible light; 2) it is refractory; 3) it is insoluble in water or in organic solvents; 4) it exists in the air as an aerosol (aggregates of small carbon spherules), (Bond et al., 2013). Black carbon has been declared by the United Nations World Health Organization to be carcinogenic.

In the western world, Diesel engines are the main source of particulate emissions. Diesel engines have a relatively high proportion of particulate emission per unit of energy, and the black carbon component in these emissions is high. An estimate of the total global emissions of black carbon for 2013 totaled 7,500,000 tons (Bond et al., 2013). On a global scale, the transport sector is responsible for 19% of all black carbon emissions, mostly (90%) from diesel engines. The share of shipping sector in diesel engine emissions is 3.9% to 5.7%. It is estimated that the annual emissions of black carbon from the shipping sector is approximately 130,000 tons per year (Eyring et al., 2010). Both the IMO and the researchers agree that black carbon emissions from ships are being underestimated. It is estimated that black carbon emissions from shipping will continue to increase and will even triple by 2050 compared with 2004, despite the low-sulfur fuel regulations (Corbett et al., 2010).

The effects of black carbon on climate

Black carbon exists in the atmosphere as particles. It is the main component in soot. Although it is not a greenhouse gas (GHG), it still has an impact on the Earth's radiation balance: black carbon particles have a warming effect due to its property to absorb solar radiation. In addition, when it deposited on snow, it darkens it and alters the melting patterns due to a reduction of the "albedo effect", which is the reflectivity of solar radiation (white surfaces have a high albedo effect). Black carbon also affects the creation of clouds and atmospheric stability in the high strata (Hansen & Nazarenko, 2004). The global warming potential (GWP) of 1 ton black carbon over a period of 100 years is 900 (the range is between 120 and 1800 due to uncertainty over the effect on climate) (Bond et al., 2013). In other words, in order to achieve the same effect as 1 ton of black carbon on global warming for a period of 100 years, 900 tons of carbon dioxide are required. The global warming potential of 1 ton of black carbon over a period of 20 years is much higher, 3,200 (3,200 times more than CO_2). (Figure 2)

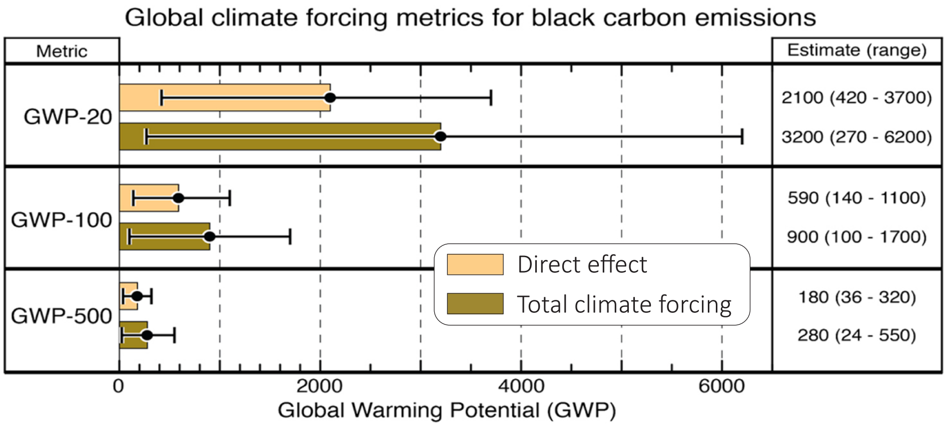


Figure 2: The potential global warming contribution of black carbon, Source: Bond et al., 2013

A recent study done by the International Maritime Organization on greenhouse gas emissions from ships, found that the total greenhouse gas emissions of the shipping sector in terms of ton of CO_2 Equivalent, (meaning the impact of a specific pollutant relative to the impact of 1 ton of carbon dioxide), totaled 1076 million tons in 2018, reflecting an increase of 9.6% compared with 2012. The shipping sector's share of the total global emissions from anthropogenic sources increased from 2.76% to 2.89%.

The main contributor in terms of climate-affecting emissions from the shipping sector is carbon dioxide – 91% of the total emissions, and the second in its effect is black carbon, which amounts to 6.8% of the emissions. Black Carbon emissions from shipping increased by 12% between 2012-2018 (IMO MEPC 75/7/15, 2020). Therefore, black carbon is regarded as the second contributor to global warming, after carbon dioxide, from the shipping sector.

Recently, climate scientists have begun focusing research not only on greenhouse gases but also on aerosol particles (solid or liquid particles suspended in the air), and in particular black carbon, as one of the anthropogenic sources of global warming. Understanding the full range of impacts of black carbon on global warming is still a work in progress, however as opposed to carbon dioxide, which remains in the atmosphere for hundreds of years, black carbon has a relatively short life span in the atmosphere – between days and weeks. Therefore, black carbon is considered to be an SLCF (short lived climate forcer). This means that the measures for reducing black carbon emissions could have an immediate contribution towards reducing global warming (UNEP & WMO UNEP/GC/26/INF/209, 2011).

The effects of black carbon on health

Black carbon is a particulate air pollutant, meaning air pollution which is caused by microscopic particles of a fluid or solid (as opposed to gaseous air pollution). Particulate air pollution severely affects health since the smaller the diameter of the particles, the deeper they penetrate the respiratory tracts, damaging the lung tissue, degrading respiratory function and increased morbidity of cardiopulmonary disease and cancer. The World Health Organization has defined particulate matter pollution of PM2.5 as being the environmental factor which poses the greatest health hazard (WHO, 2012). Black carbon is one of the components of particulate pollution and it is a universal indicator of the amount of harmful particles from combustion sources. There is scientific evidence of the negative health impacts of the carbonaceous component of the particles. It has been found that black carbon is a better indicator than PM for measuring the negative health impacts of respiratory particles. (Schaap & Denier van der Gon, 2007). Studies show that black carbon has negative health impacts compared with other PM2.5 components (Smith et al., 2009). To date there are not enough toxicological or epidemiological studies able to quantitatively estimate the difference between the health impacts of particles in general and those of black carbon. It is estimated that particulate emissions cause approximately 60,000 premature deaths per year as a result of cardiopulmonary diseases and cancer (Eyring et al., 2010). The average risk of premature death from cardiac diseases is 0.6% per 10 microgram exposure to black carbon (COMEAP, 2006).

To conclude, black carbon is the second most important cause of global warming from the shipping sector, and in terms of warming potential, it causes thousands of times greater warming than a ton of CO_2. Black carbon also has negative health impacts. It is the main harmful component in particulate air pollution and is a cause of illness and death. In addition, black carbon is the main climatic pollutant, harming agricultural crops. Therefore, decision-makers need to address black carbon emissions.

International regulation on black carbon

Until recently, black carbon has not been addressed separately in international conventions or regional agreements, neither were its emissions measured separately.

Instead, it was included generally under particulate air pollution. Following the growing interest over the health impacts of black carbon as a particulate air pollutant, as well as a climate factor, black carbon has begun to receive specific reference as an air pollutant in several frameworks. At the moment, this is evident only in recommendations and there are no regulations yet which specifically reduce or limit black carbon emissions. The International Maritime Organization has been holding discussions on this issue for several years as part of the Marine Environment Protection Committee. It is worth noting that black carbon emissions were addressed for the first time in a study conducted by the International Maritime Organization to estimate the greenhouse gas emissions from international shipping for 2020, due to recognition of its impacts. Following is a review of the current references to black carbon in some international conventions and agreements:

The Gutenberg Protocol was amended in 2012 so that countries' commitments to emissions reduction will also include black carbon. This protocol is part of the UNECE CLRTAP – Convention on LongRange Transboundary Air Pollution. This means the setting of a new standard in the international policy on air pollution, which for the first time includes reference to black carbon. Once the protocol came into effect, the parties to the convention were required to report their national inventory of black carbon emissions. Although the Protocol includes a recommendation to countries to take measures to reduce black carbon emissions, there is no actual commitment to reduce emissions. The United States and the European Union countries are also signatories to this convention.

Annex VI to MARPOL 73/78 Regulations for the Prevention of Air Pollution from Ships, 1997, deals with reduction of air emissions from ships and includes reference to SO_x and NO_x emissions. The annex to the convention does not refer to the required reduction of particulates at all or to black carbon specifically. Limiting the sulfur content in fuels reduces sulfur particulate emissions.

In 2011, the Arctic Council (an intergovernmental forum of the countries bordering the Arctic: Canada, Denmark, Finland, Iceland, Sweden, Norway, Russia and the United States) recommended that member states implement measures to reduce emissions of black carbon. The recommendations include reference to several sectors, which emit black carbon, including the shipping sector. These are voluntary technical measures to reduce emissions from shipping in the Arctic region.

Following numerous position papers that were submitted to the International Maritime Organization regarding black carbon emissions from shipping, and the growing concern with the effects of black carbon on the Arctic region, in November

2020 the Marine Environment Protection Committee approved an amendment to the MARPOL Convention. The amendment prohibits the use and carriage of Heavy Fuel Oil in ships sailing in the Arctic region. Heavy Fuel Oil is regarded to be an environmental hazard both in terms of a potential oil spill and in terms of the emissions of air pollutants, including black carbon, which is also one of the causes of global warming and melting of snow and ice. The prohibition is expected to come into effect in 2024, however it includes many exemptions, which enable certain types of ships to use Heavy Fuel Oil until 2029. This is a first step towards limiting black carbon emissions from ships and reducing its environmental impacts in sensitive regions like the Arctic.

Working groups were formed within the Environment Committee of the International Maritime Organization to identify possible reduction measures for black carbon. It will take a few years (if ever) before an operational regulatory decision is reached on emissions of black carbon.

As discussed, the shipping sector uses large diesel engines, which emit many pollutants, including black carbon. To better understand the emissions from the shipping sector, we shall review which features of a ship influence these emissions.

Ship characteristics which influence black carbon emissions

The ship emissions of black carbon particles are influenced both by the type of engine and the engine load (as a function of the ship's activity) and by the type of fuel being used. Black carbon emission levels are by the following factors:

1. The type of engine installed on the ship: slow speed diesel (SSD), medium speed diesel (MSD), high speed diesel (HSD). 2-stroke engine or 4-stroke engine.
2. The specific engine load as a function of ship activity. The engine load is affected by the cargo and the weather conditions (winds and currents).
3. The vessel type – container ships, bulk carriers, tankers, cruise ships etc.
4. The type of fuel used on the ship – Heavy Fuel Oil (HFO), marine diesel oil (MDO) or liquefied natural gas (LNG).
5. Source of the emissions – main engine/auxiliary engine/boiler.

An overall calculation of the total black carbon emissions of the global fleet by type of ship (figure 4) shows that the container ship category accounts for 26% of the total emissions, the bulk carriers account for 18.6% of the total emissions, the oil tanker category accounts for 15% of the total emissions and the cruise ships account for 6.1% of the total emissions.

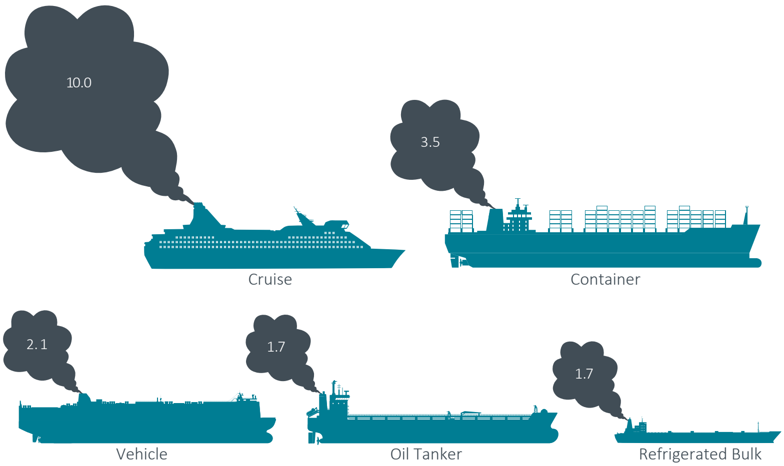


Figure 3: "Emission intensity" of black carbon (tons) per ship per year. Source: ICCT, 2017. Cruise ship, container ship, vehicle ship, oil tanker, refrigerated bulk

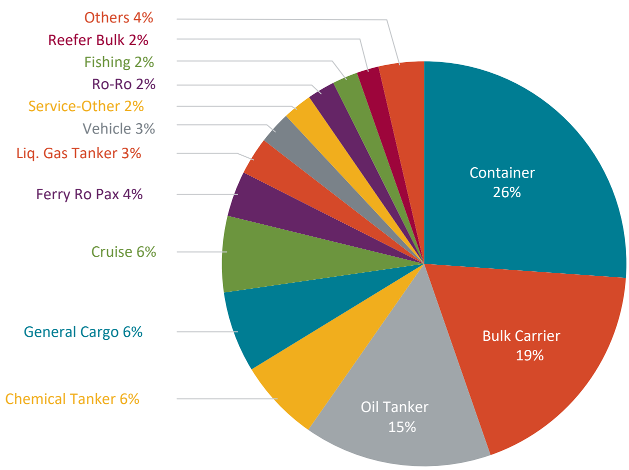


Figure 4: Share of black carbon emissions by ship type. Source: ICCT, 2017

Cruise ships are responsible for 6% of black carbon emissions (the relative contribution of cruise ships to the total emissions is disproportionate to their part of the global fleet as they account for only 1% of all the ships in the global fleet). It is estimated that a cruise ship emits on average 0.34 kg black carbon per ton of fuel it consumes while container ships and tankers emit on average 0.26 kg black carbon per ton of fuel consumed. When looking at the "emission intensity", which is calculated as the total amount of black carbon one ship emits per year, it was found that a cruise ship emits the most black carbon per year – 10 tons black carbon per ship per year, three times as much as a container ship, which emits 3.5 tons of black carbon per ship per year. In comparison, one cruise ship emits a quantity of black carbon in one year equals to 4,200 trucks under the Euro 5 standard, which travel 100,000 km per year.

The explanation is that a cruise ship consumes large quantities of energy to provide its electricity needs since it is a "floating hotel" serving thousands of passengers that need electricity to operate electricity systems, such as air conditioning in the rooms etc.

Emissions while in port

A ship's activity can be divided into four main operational stages:

1. Cruising between ports, usually on the high seas
2. Maneuvering – entering/departing from port
3. Berthing/Hoteling at port to load or unload
4. Anchorage outside port, usually while waiting before entering the port

As figure 5 shows, ships spend on average half of the time in non-cruising operational modes, i.e., maneuvering, anchorage or berthing – these stages take place in or near the port area.

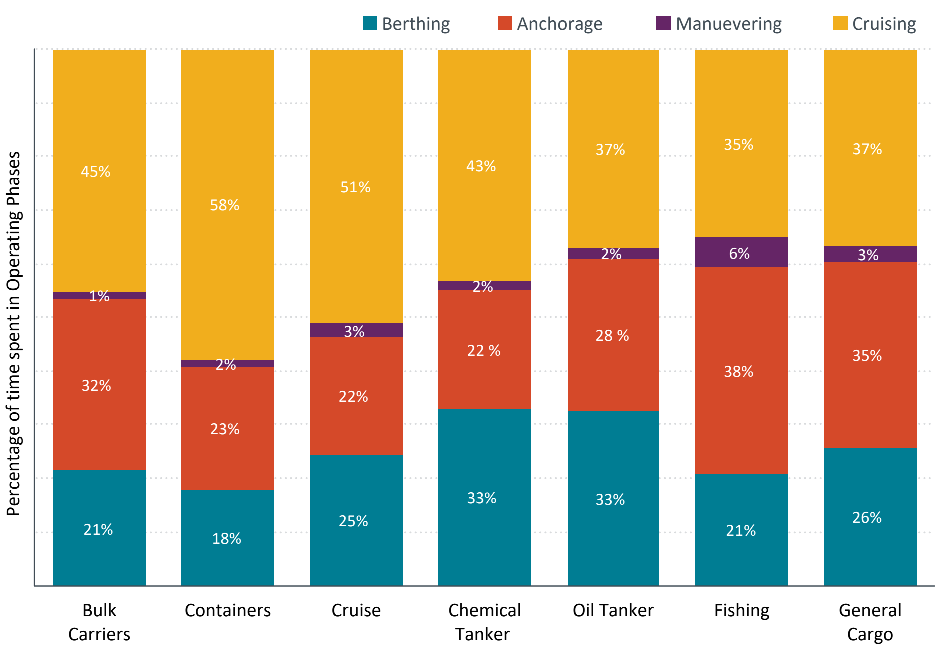


Figure 5: Dwell time in each operational mode by ship type Source: 2020 GHG STUDY IMO

Most commonly, ship emissions are measured during their cruise mode, where most of the fuel consumption takes place and, therefore, also a large proportion of the emissions. At the same time, the emissions which occur in the other operational modes – while in or near the port, are worth examination due to their potential impact on the port surroundings.

In the context of its health impacts on the population near the port, the most significant operational mode, is the Berthing/Hoteling stage due to air emissions from ships therefore it is very important to understand the emissions profile throughout this stage. First, for most of the ship's dwell time in the port (except during maneuvering), the main engine is turned off and therefore emissions are mainly from the auxiliary engine and the boiler. Although the share of emissions from the auxiliary engines while berthing is between 2% and 6% of the total ship emissions, when looking regionally and locally at the port area, studies have shown that emissions from the auxiliary engines while berthing in port account for 40% of the total particulate emissions in port (Xiao et al., 2018).

We shall describe the nature of the emissions according to emission source (type of engine) in each of the ship's operational modes:

Cruising – the ship mainly uses its main engine at cruise speed. In this mode, the engine, the auxiliary engine and the boiler are at optimal operating load and there are less emissions.

Maneuvering – when the ship approaches port, it slows and the main engine operates at low load, the auxiliary engines run at maximum load to provide the electricity needs for the ship's systems. The boiler, too, starts running. The fuel consumption in this mode is highest for the auxiliary engine and low for the main engine and the boiler. Studies show that due to non-optimal load on the engines, the maneuvering mode can create 3 to 6 times as much pollution compared to cruise mode or hoteling mode.

Berthing and anchorage – while the ship is berthing in port to load or unload and also while the ship is at anchorage outside port waiting to enter the port, the main engines are turned off, the auxiliary engine and the boiler continue running to deliver electricity to the refrigerators, lighting, pumps, air conditioning etc., and for heating the fuel. In general cargo ships and tankers, which are required to run the ship's own installations and pumps when unloading, the auxiliary engine runs at high load and so does the boiler, if steam is used for the pumps. The fuel consumption in this mode is medium to high for the auxiliary engine and medium to high for the boiler.

Depending on the type of ship, while on anchorage the ship uses 30% to 50% of the energy used while cruising (Gobbi et al., 2020; Tzannatos, 2010).

A significant part of the global shipping traffic runs near trade routes and ports. 80% of the emissions of the shipping sector take place at distances of no more than 400 km from shore, therefore shipping traffic affects the coastal and port cities air quality (Corbett et al., 1999).

At the local and regional level, the shipping sector has a significant effect on air quality and health near trade routes and ports (Lack et al., 2008). The Mediterranean Sea is considered one of the global hot spots in terms of pollution from shipping due to the large volume of ship traffic. Therefore, air pollution caused by ships has a considerable impact on air quality in port cities in the Mediterranean (Eyring et al., 2010).

A study done in the Port of Barcelona (Pérez et al., 2016) found that the port activity contributes to 50–55% of the particulate emissions in the city. The fuel combustion-related emissions were higher in the port compared to the rest of the city (2.9 nanograms per cubic meter compared with 1 nanogram per cubic meter). Another study estimated that between 10% and 30% of the PM2.5 particulate emissions in Mediterranean port cities are originated from the shipping sector (Thunis et al., 2018). Ship and vehicle diesel engines in ports make a large contribution to the fine particulate emissions and to high concentrations of black carbon near the ports (Gobbi et al., 2020). Due to the proximity of the city to the port, it is expected that the maneuvering, loading/unloading and berthing activities of ships in the port will contribute to air pollution in the nearby city (Castells Sanabra et al., 2014).

The most relevant emissions to the area near the port are particulate emissions and SO_X emissions due to the harm these may cause while in their original form (meaning as a primary pollutant). The health impacts caused by these emissions are dependent on the proximity of the emission source and the receptor. For this reason, the population density around the emission source is critical (Castells Sanabra et al., 2014).

A report published by the Air Resources Board in California's Environmental Protection Agency (Air Resources Board, 2005) on the health impacts of emissions from ships' auxiliary engines at berth, found that communities near ports are exposed to elevated risks of cancer and other health impacts from diesel engines particulate emissions (Diesel PM) from ships at berth. An estimate made specifically for the ports of Los Angeles and Long Beach found that 20% of the total particulate emissions from diesel engines originated from ships in the port (Hoteling emissions). In addition, when comparing the health impacts of the various types of activities near the port, which emit diesel particles, it was found that the impact of hoteling ships is the most significant in terms of the area impacted and in terms of the health risk to the population. The estimation of health risk to the population near the port is that 34% of the risk (61 deaths per year) is attributed to emissions caused by the activities of hoteling ships, compared with other activities in the port which emit diesel particles, such as emissions from ships while maneuvering in port or while cruising near the port, emissions from cargo handling equipment in the port and from the activities of trucks and trains in the port.

In view of the abovementioned findings, it appears that emissions from ships while hoteling in port have considerable effect on the air quality in the area surrounding the port. Therefore, a specific study on ship emissions during their operational mode while in port can be valuable. Another important aspect is that emissions from ships are not distributed evenly throughout the country. Rather, they are concentrated in port cities – and in Israel's case these are Haifa and Ashdod. Therefore ship-generated air pollution is of greater impact in the port cities.

Air pollution from ships in Israel

The Ministry of Environmental Protection conducts an "air emission inventory" which estimates all emissions sources that emit pollutants into the air. The air emission inventory is calculated for sectors that are significant sources of emissions. One of these is the transport sector. The methodology for preparing an emission inventory (Ministry of Environmental Protection, 2019) is based on the Pollutant Emission Inventory Guidebook, published by the European Environmental Protection Agency (EEA, 2020).

From Israel's air pollutant emission inventory of 2018, update 2020 we can examine the relative contribution of the shipping sector to the total air pollutant emission inventory in Israel. Table 1 details the share of vessels related emissions out of the total air pollutant emission inventory in Israel. Vessels in ports are responsible for 16% of the total air emissions of SO_X, and 8% of NO_X. For PM2.5, the shipping sector is responsible for 7% of all the emissions in Israel. It is important to note that in Israel there is no specific estimate for emissions of black carbon.

Table 1: Share of vessels out of the total air pollutant emission inventory in Israel

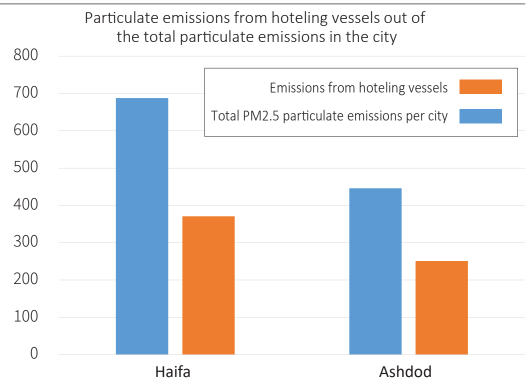
Air pollutant emission inventory	NO_X	SO_X	CO	Particulate matter, diameter less than 10 microns	Particulate matter, diameter less than 2.5 microns	Volatile organic compounds excluding Methane
Emissions from vessels (tons per year)	9,093	7,871	1,240	779	779	604
% of emissions from ships out of the total emissions of this pollutant	8%	16%	1%	5%	7%	2%

Source: air pollutant emission inventory 2018 update September 2020, the Ministry of Environmental Protection

The Ministry of Environmental Protection's emission inventory is detailed by cities in which the emission sources are located. To better understand the local effect of emissions from vessels in ports, the total emissions for the port cities of Haifa and Ashdod were examined, and the relative share of the emissions from vessels were calculated out of the total emissions in the city. As table 2 shows, particulate emissions PM2.5 in Haifa totaled 688 tons, of which 371 tons are attributed to emissions from vessels (54%). In Ashdod particulate emissions PM2.5 totaled 446 tons, of which 251 tons are attributed to emissions from vessels (56%).

Table 2: The relative contribution of vessels to the total emissions of PM2.5 particulate emissions in the port cities of Haifa and Ashdod

	Haifa	Ashdod
Total PM2.5 particulate emissions per city (tons)	688	446
Emissions from hoteling vessels (tons)	371	251
% contribution of vessels to the total PM2.5 particulate emissions per city	54%	56%



Source: air pollutant emission inventory 2018 update September 2020, the Ministry of Environmental Protection

From the above data it can be concluded that in Israel's port cities, emissions from vessels have an extremely significant contribution to air pollution – over half of the PM2.5 particulate emissions are attributed to vessel emissions.

In a study conducted in Israel for the Ministry of Environmental Protection (Barak et al., 2018), the extent of air pollution from vessels in the ports of Haifa and Ashdod was estimated. The study found that the air pollution generated by the vessels in the Haifa and Ashdod ports amounts to heavy pollution, similar in magnitude to a large, diesel-powered power station. This study found that the majority of air pollution from ships in ports is caused from the hoteling stage due to the electricity consumption from the auxiliary engines. The study did not examine black carbon emissions. Only PM2.5 particulate emissions were measured and it was found that the hoteling stage in a terminal is responsible for 48–59% of the PM2.5 emissions, the maneuvering and waiting stage is responsible for 27 to 34% of these emissions, and the cruise stage is responsible for 14–18% of the emissions. This means that approximately 80% of the emissions take place within the port area (anchorage, maneuvering and waiting at distances of up to 10 km from port).

Measures for Reducing Black Carbon Emissions from Ships

In view of the negative impacts of black carbon on health and climate, as reviewed in this article, and the specific effect of ship emissions on air quality in port cities, it is necessary to address appropriate measures to reduce black carbon emissions from ships in general and in particular while ships are hoteling in ports.

There are several possible measures for reducing black carbon emissions. These include measures which will be taken on the ship and measures which will be taken on the shore or at the port. Following is a review of the possible measures for reducing black carbon emissions from ships:

Possible reduction measures on ship

Reduction measures on the ship can be divided into several categories: changes in types of fuels used or treatment of fuels, changes in the engine systems or in the ship structure and treatment of exhaust gases:

1. Fuel type – changing the fuel type used by the ships, using a less-polluting fuel such as distillate fuels, liquid natural gas (LNG), biodiesel and methanol, or treating the fuel.
2. Structure and engine systems – adaptation of the ship structure and engine systems to improve the efficiency of the fuel consumption, and operational means, such as Slow Steaming.
3. Treatment of exhaust gases – the gases emitted from the ship funnel can be treated by installing scrubbers, diesel particulate filters (DPF) (combined with low-sulfur and low-ash distillates) or by installing an electrostatic precipitator.

Possible reduction measures on shore or at port

In addition to the reduction measures above operated on the ship, there are additional measures which can be taken on the shore or at the port, and which are relevant to the reduction of emissions while the ship is hoteling in the port:

Possible emission reduction measures during the ship's hoteling in port include connecting the ship to an electricity power supply from the shore (Electric Shore Power) while docked in port, and on-shore capture & control systems which connects to the ship funnel to treat the ships exhaust emissions. In addition, it is possible to take regulatory measures at the regional level, for example prohibition on the use of Heavy Fuel Oil, and declaration of Emission Control Areas – ECA.

In addition, some voluntary practices on the part of the ports themselves are also possible. For example, reducing port fees for ships using clean fuels while hoteling (Hong Kong) as well as improving the operational interfaces between the ship and the port, such as optimization of JIT ship calls and reducing the ship's hoteling time in the port or on anchorage.

Recommendations for reducing emissions in Israeli Ports

In view of the health risks posed to the population living close to ports and shipping lanes due to emissions of black carbon from ships berthing in the ports or sailing nearby them, measures should be taken to reduce emissions from ships. The most efficient reduction measure which is aimed to reduce emissions from ships during the hoteling stage in the port, and which effectively reduces all types of emissions from ships, is to connect them to electric shore power. This measure can be aimed to the most polluting types of ships, for example cruise ships and container ships. As for bulk carriers, which have high emission rates due to their long hoteling time, other measures can be used to reduce emissions, such as connecting to a capture & control system. In addition, ports can take some operational measures to accelerate and improve the efficiency of unloading operations in order to reduce ships' hoteling time in port.

Regarding reduction measures which are operated on the ship – although the International Maritime Organization has been discussing the issue of black carbon emissions reduction from ships, there are no regulations in place. Some ships have already installed exhaust gas scrubber (EGS) systems to reduce emissions of sulfur particles. While this is a less efficient option in terms of reducing black carbon emissions, it is technologically available and is already in use on ships. A more efficient option for reducing black carbon emissions is a Diesel particulate filter (DPF), however it is not currently in commercial use on ships.

The type of fuels used by ships are also very relevant to emissions: Academic literature data indicates that the heavy fuel oil is four times as polluting than distillate fuels. Therefore, switching ships to using less polluting fuels is of extreme importance for emissions reduction. Switching to using LNG as a fuel is one of the most promising possibilities both in terms of the potential reduction in particulate emissions and in terms of technological availability, although currently there are very few such ships. Regarding alternative fuels such as biodiesel, methanol and ammonia – at this stage the technology has not sufficiently matured for commercial application in ships. The fuels are not available in the necessary quantities required nor does the coastal infrastructures required.

As part of the regulatory measures the State of Israel can take to reduce emissions, it is highly important that the Mediterranean Sea be designated an Emissions Control Area (ECA), which would enable imposition of more stringent restrictions on the fuels in use in the Mediterranean area in general and in Israel in particular. Thus, it is necessary to accelerate Israel's joining MARPOL Convention's Annex VI.

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