

**IMO Train the Trainer (TTT) Course**  
**on**  
**Energy Efficient Ship Operation**

**Module 5 – Ship Port Interface for**  
**Energy Efficiency**



**I M O**

**ACKNOWLEDGEMENTS**

The “Train the Trainer” course presented herein is based on material originally developed by WMU in 2013 under contract for the IMO. This current edition represents a major upgrade of the training package by Dr Zabi Bazari of Energy and Emissions Solutions, UK (EnEmSol) under contract for the IMO.

IMO wishes to express its sincere appreciation for WMU and EnEmSol expert assistance

Printed and published by the  
International Maritime Organisation,  
London, January 2016

# MODULE 5

## Ship-Port Interface for Energy Efficiency

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### Module Aims and Learning Objectives

The aim of this module is to deal with ship-port interface and how ship in-port operation can influence the ship energy efficiency and port air quality. It includes all aspects of ship operation in ports and relevant technologies, fuels and operational measures for reducing the ship-in-port fuel consumption and air pollutants.

Apart from introductory section on port structure and services, the main operational aspect of ship-port interface in terms of just-in-time operation is covered in detail first. Next, a full review of various technological, fuels and operational measures for reduction of ships' emissions to ports are investigated. The concept of Onshore Power Supply (OPS) or cold ironing is discussed as the main way of reducing air pollutant in ports. Finally, port-related green initiatives and port environmental programs are introduced and sample initiatives are introduced.

By the completion of this module, the trainees will be able to:

- Explain the main activities of a port and the ports' significance in maritime industry;
- Recognise the importance of "ship port time" in the energy efficient ship operation context;
- Describe the way that a ship's just-in-time operation in a port may be realised;
- Identify factors in port-side management that affect efficient ship operations;
- Explain why onshore power supply can reduce the ship's port-related pollutions;
- Discuss the requirements at port-side and ship-side for OPS and the barriers for its implementation;
- Be able to analyse the impact of OPS on ship-at-berth air emissions and energy efficiency;
- Become familiar with port-related green initiatives and port environmental programs;
- Explain in general term, the Environmental Ship Index and how it works; and
- Be able to name and give a brief explanation of other green port specific initiatives.

To support your learning process, a list of references is provided at the end of each section. Referring to them will allow you to go deeper in areas that may be of most interest to you.

The material presented herein is current at the time of preparations of this document. Because of the evolving nature of regulations, technologies and future studies in area of MARPOL Annex VI and in particular energy efficiency of ships, some aspects may require updating over time.

The views expressed in this document are purely those of the author(s) and may not in any circumstances be regarded as stating an official position of the organizations involved or named in this document.

This document is subject to change by the IMO.

**Dr Zabi Bazari, EnEmSol, January 2016**

# CONTENTS

<b>1</b>	<b>INTRODUCTION TO PORTS AND PORT-AREA EMISSIONS</b>	<b>7</b>
1.1	PORT ROLE AND FUNCTIONS	7
1.2	COMPLEXITY OF PORT OPERATION	8
1.3	PORTS AND AIR EMISSIONS	9
1.4	METHOD OF REDUCTION OF PORT AREA EMISSIONS	10
1.5	PORT NON-SHIP RELATED EMISSIONS REDUCTION	11
1.5.1	<i>Port-land based side</i>	11
1.5.2	<i>Port harbour crafts</i>	11
1.6	PORT SHIP-RELATED EMISSION SOURCES	12
1.7	HOW TO DEAL WITH SHIP-PORT INTERFACE	15
1.8	REFERENCES AND FURTHER READING	16
<b>2</b>	<b>SHIP TIME IN PORT AND JUST IN TIME OPERATION</b>	<b>17</b>
2.1	INTRODUCTION	17
2.2	ACTIVITIES IN PORT OPERATIONS	17
2.3	IMPACT OF SHIP'S PORT TIME ON EFFICIENT SHIP OPERATION	18
2.3.1	<i>Ship's (voyage) time: time at sea and time in port</i>	18
2.3.2	<i>Time in port</i>	19
2.4	JUST-IN-TIME ARRIVAL/DEPARTURE AND IMPROVED CARGO HANDLING	21
2.5	PORT OPERATION MANAGEMENT	22
2.6	MEASURES FOR AVOIDING SHIP'S WAITING TIME IN PORT	26
2.6.1	<i>Virtual Arrival</i>	26
2.6.2	<i>Improved cargo handling</i>	26
2.7	IMPLICATION OF JUST IN TIME	27
2.8	REFERENCES AND FURTHER READING	28
<b>3</b>	<b>TECHNOLOGIES FOR PORT AIR QUALITY AND GHG EMISSIONS REDUCTION</b>	<b>30</b>
3.1	INTRODUCTION	30
3.2	ICCT STUDY ON PORT AIR QUALITY	30
3.3	IMO SHIP-PORT INTERFACE STUDY	31
3.3.1	<i>Measures categories</i>	32
3.3.2	<i>Symbols used</i>	32
3.3.3	<i>Study outcomes on existing technology measures</i>	33
3.3.4	<i>Future innovative technologies, fuels and operation processes</i>	36
3.3.5	<i>Study key findings</i>	37
3.4	REFERENCES AND FURTHER READING	38
<b>4</b>	<b>SHIP IN-PORT OPERATIONAL ENERGY EFFICIENCY MEASURES</b>	<b>39</b>
4.1	INTRODUCTION	39
4.2	OPERATION OF AUXILIARY MACHINERY	39
4.3	USE OF AUXILIARY ENGINES	40
4.4	OPERATION OF BOILERS IN PORT	40
4.5	SHIP OPERATIONAL EFFICIENCY MEASURES	41
4.6	REFERENCES AND FURTHER READING	41

<b>5</b>	<b>ONSHORE POWER SUPPLY (OPS)</b> .....	<b>43</b>
5.1	INTRODUCTION .....	43
5.2	THE CASE FOR OPS .....	44
5.3	INFRASTRUCTURE REQUIREMENTS.....	45
5.3.1	<i>Shore-side requirements</i> .....	45
5.3.2	<i>Ship-side requirements</i> .....	46
5.4	STANDARDIZATION .....	46
5.5	PORT RELATED INITIATIVES .....	47
5.6	IMO REGULATIONS.....	48
5.7	OPS EFFECTIVENESS .....	49
5.8	OPS AND ENERGY EFFICIENCY .....	50
5.8.1	<i>Energy efficiency</i> .....	51
5.8.2	<i>Energy cost</i> .....	51
5.9	REFERENCES AND FURTHER READING .....	51
<b>6</b>	<b>GREEN PORT INITIATIVES AND PORT ENVIRONMENTAL PROGRAMS</b> .....	<b>53</b>
6.1	INTRODUCTION .....	53
6.2	PORT RELATED VOC MANAGEMENT.....	53
6.3	DIFFERENTIATED PORT DUES.....	55
6.4	DIFFERENTIATED SHIP REGISTRATION FEES .....	55
6.5	ENVIRONMENTAL SHIP INDEX (ESI) .....	56
6.6	PORT CLEAN AIR PROGRAM .....	57
6.7	NORWAY NOX TAX AND NOX FUND .....	57
6.8	GENERAL DISCUSSION .....	57
6.9	REFERENCES AND FURTHER READING .....	58

## LIST OF FIGURES

Figure 1.1 – A simplified schematic of a logistic chain [Voorde & Elsander] .....	7
Figure 1.2 – The main activities of a marine port [Voorde & Elsander] .....	7
Figure 1.3 – Principal port activities [Voorde & Elsander] .....	8
Figure 1.4 – Schematic of major players in port-related activities [Meersman, Van de Voorde and Vanelslander] .....	9
<b>Figure 1.5 - Energy demand example: Trans Pacific transit from Shanghai to Los Angeles [Starcrest Consulting Group] .....</b>	<b>14</b>
Figure 2.1 - Schematic diagram of a container terminal operations .....	18
Figure 2.2 - Composition of ship's voyage time in container shipping line .....	19
Figure 2.3 - Breakdown of ship's time in port.....	20
Figure 2.4 - Schematic diagram of container terminal operations with activities.....	22
Figure 2.5 - Application of berthing request in a typical port management system .....	23
Figure 2.6 - MPOS and port services coordination .....	23
Figure 2.7 - Ship's times in passage, port and manoeuvring .....	28
Figure 3.1 – Port air emissions reduction measures according to ICCT December 2012 report.....	31
Figure 3.2 – Summary of engine technologies [MEPC 68 INF.16] .....	34
Figure 3.3 – Summary of engine exhaust gas scrubbing systems [MEPC 68 INF.16].....	35
Figure 3.4 – Summary of alternative fuel options [MEPC 68 INF.16] .....	35
Figure 3.5 – Summary of alternative power systems [MEPC 68 INF.16] .....	36
Figure 3.6 – Summary of innovative and emerging technologies [MEPC 68 INF.16] .....	37
Figure 4.1 – Summary of ship operational measures [MEPC 68/INF.16] .....	41
Figure 5.1 – Typical OPS arrangement [Wikipedia] .....	44
Figure 5.2 – Typical shore-side requirements.....	46
Figure 6.1 – Schematic of an oil tanker's VOC emissions control system.....	54

## LIST OF TABLES

Table 2.1 – Estimated ship fuel consumption and emissions reductions .....	28
Table 5.1 – Ports with OPS at 9 October 2012 [IMO MEPC.1/Circ.794] .....	48
Table 6.1 – Designated ports with VOC emissions control .....	54
Table 6.2 – NOx reduction incentives in port of Gothenburg.....	55

# 1 Introduction to Ports and Port-area Emissions

## 1.1 Port role and functions

Ports are part of a wider international and national network of transport and logistics. They significantly contribute to the cargo logistic network. The success of ports in the logistics chain depends on their strengths as well as the strength of other players in that chain including shipping. A similar reasoning applies to the other maritime transport players including ship owners, port operators and the land-based transport service providers. Accordingly, the function of a port like other major maritime stakeholders (e.g. ship owner) does not depend exclusively on its own facilities and management processes but also affected by a variety of other stakeholders. **Figure 1.1** shows a simple view of the basics of a logistic chain.

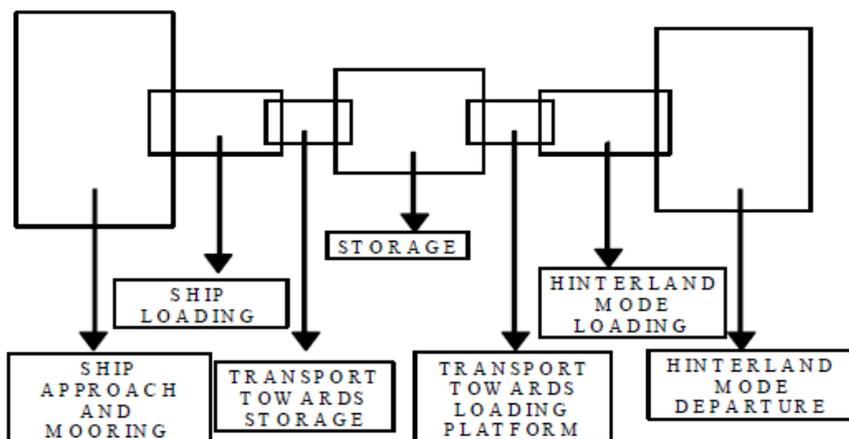


**Figure 1.1 – A simplified schematic of a logistic chain [Voorde & Elsander]**

As **Figure 1.1** indicates, the maritime logistics chain consists of three large sections:

- The purely maritime aspects (at the centre above) that mainly relates to ship operation;
- The cargo handling and storage in the port; and
- The land-based (hinterland) transport services.

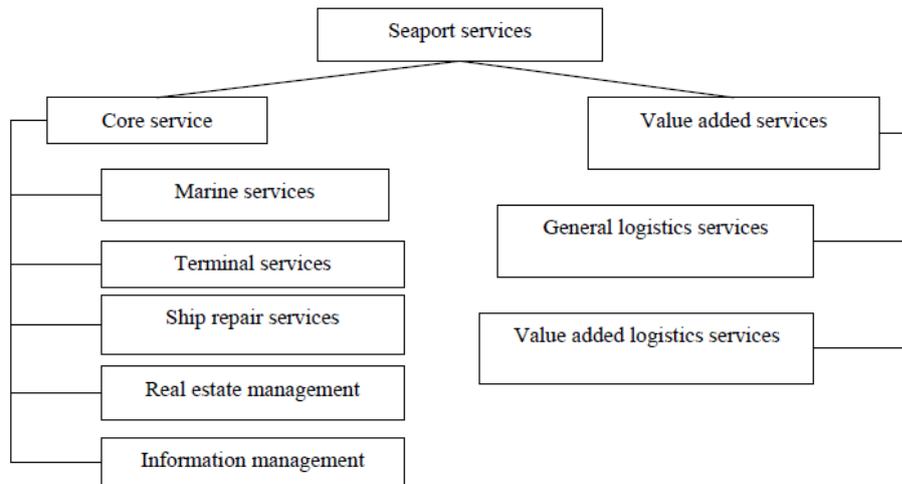
Depending on the cargo category concerned and the type of chain management applied, this structure may become more complex and possibly involve different players as well as other ports of call. Considering only the port-related activities in the above overview, one of the core and most important function of ports relate to the ships’ cargo loading and unloading. Specifically focussing on ports, **Figure 1.2** shows the main activities of a marine port in a schematic form.



**Figure 1.2 – The main activities of a marine port [Voorde & Elsander]**

Over the time, ports have engaged in a large number of so-called value-added services in addition to cargo loading and unloading plus other core services. These could include a variety of marine

services such as bunkering, to repair and real estate activities in ports as shown in **Figure 1.3**. This evolution of port activities is indicative of the increasingly complex nature of ports of modern times.



**Figure 1.3 – Principal port activities** [Voorde & Elsander]

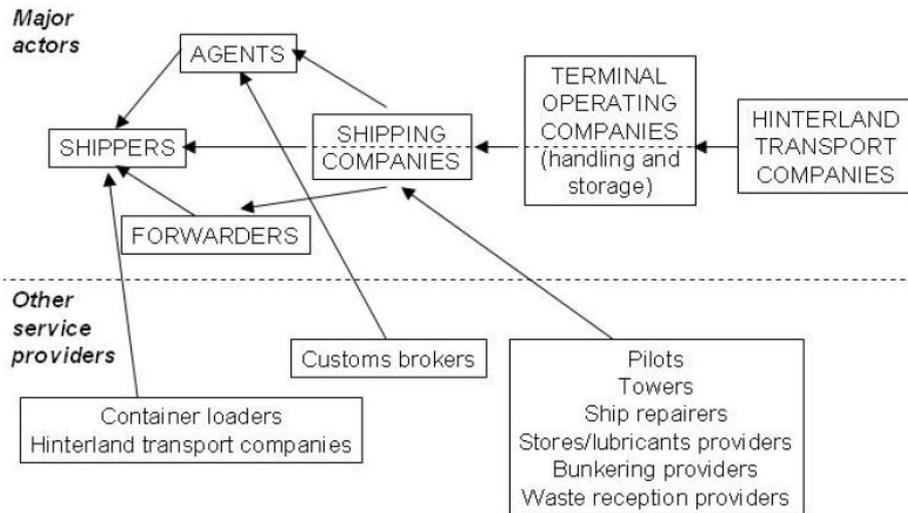
## 1.2 Complexity of port operation

A port encompasses more than the port authority as the top governing body but also other players such as shipping companies as its principal customer and terminal operating companies as the main suppliers of services. There are numerous other, often smaller players to take into account and typical examples of such players are fuel trading and dredging. The former plays a big role in ship operations, whereas the latter has its role in the construction of shipping and port facilities. The availability of efficient fuel provision can convince a shipping company to call at the port and even make a longer stay, in both cases resulting in more cargo loading and unloading capacity. Dredging activities are an important element of capacity creation and maintenance.

From a different perspective, port management is a complex process as this is normally made up of a variety of links. Often different part of the chain are controlled or managed by different players, but some activities are also integrated across links. So, ports could have a relatively complex management and decision making structure.

No two ports are physically and economically the same. Therefore, their operations will depend on the port as a physical entity, taking into account the various activities such as facilitating the loading/unloading of vessels, freight handling and storage and access to land-based transportation. Clearly these are quite diverse activities, which combine to make port services quite diverse and complex.

Port operations involve a great many players, both at management level and at operational level. The management of ports also varies from one country to the other. The port as a physical entity is managed by a port authority in which the public authorities may or may not be a stakeholder. In addition, depending on the size of the port, any number of enterprises may be located within its perimeter. **Figure 1.4** offers an overview of the various market players within a port, indicating who provides services to whom. The diagram confirms that shipping companies rely on services provided by third parties (e.g. pilots, towage services, ship repairers, provisioning, waste reception facilities, and bunkering companies) that are somehow but not fully associated with a port.



**Figure 1.4 – Schematic of major players in port-related activities [Meersman, Van de Voorde and Vanelslander]**

The large number of parties involved in port activities, each of which pursues its own objectives, gives rise to a considerable degree of diversity, both within the port and between ports. Hence, a generalised comparison between ports may not be fully possible. Moreover, the situation is further complicated by the fact that different ports often work under different economic, legal, social and tax regimes just because they are regarded as part of national entities in each country. Thus ports are to a large extent different from international shipping that is mostly regulated by IMO rather than by national-specific regulations that applies to ports [Hilde Meersman, et al].

The issues of governance, control and ownership are critical to any discussion of environmental management in ports. The vast majority of harbours are characterized by privately owned dock facilities and in these instances, control of property and operations lie with each private property owner.

### 1.3 Ports and air emissions

On the environmental side, one of the main issues that ports are facing is local air quality. This is caused due to air pollutants; rather the CO<sub>2</sub> emission that is the main topic of this training course. As most of activities relating to reduction of air pollutants have impacts on CO<sub>2</sub> emissions, in this module, the emphasis will be on all air emissions rather than simply CO<sub>2</sub>.

In port areas, air emissions and energy consumptions are primarily due to ships. However, there are other equipment and facilities that use energy or contribute to air emissions to port areas. These are for example:

- Cargo loading and unloading devices.
- Trucks and other land-based transportation units such as locomotives.
- Buildings and energy needed for these building.
- Harbour crafts that provide additional services to port and shipping companies.

Emissions in port areas are mainly those due to diesel engines and boilers. These air emissions include:

- Nitrogen Oxides (NOx): The main sources of NOx are diesel engines both for ships and other land-based trucks.
- Particulate Matters (PM): Again diesel engines are the main source of such emissions.

- Sulphur Oxides (SOx): These are due to burning of sulphur content of fuel.
- Some carbon monoxide and unburned hydrocarbons could also be emitted from ship engines if they are not properly tuned.

The amount and level of such emissions will depend on not only technologies used but also operational aspects of ships, the time they stay in port and other energy using machinery and facilities in port itself.

Emission reductions in the port area are typically focused on PM, SOx and NOx due to air quality health impacts. Controlling NOx, PM and SOx is the central focus for most national and regional regulatory agencies and therefore the same applies for ports as does to the shipping industry. GHGs emissions have recently been seriously addressed by regulatory agencies such as IMO, although in the port area, health effects and thus pollutants typically take the priority over GHG emissions.

In a discussion paper by International Transport Forum [Olaf Merk], it is claimed that shipping emissions in ports are substantial, accounting for 18 million tonnes of CO<sub>2</sub> emissions (this is equivalent to burning of about 6 million tonnes of fuel oil), 0.4 million tonnes of NOx, 0.2 million tonnes of SOx and 0.03 million tonnes of PM<sub>10</sub> (PM with size of less than 10 microns) in 2011. Around 85% of emissions come from containerships and tankers. Containerships have short port stays, but high emissions during these stays.

The same paper states that most of CO<sub>2</sub> emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). European ports have much less emissions of SOx (5%) and PM (7%) than their share of port calls (22%), which can be explained by the EU regulation to use low sulphur fuels at berth. Future forecasts indicate that most of shipping emissions in ports are estimated to grow fourfold up to 2050. This would bring CO<sub>2</sub>-emissions from ships in ports to approximately 70 million tonnes in 2050 and NOx-emissions up to 1.3 million tonnes. Asia and Africa will see the sharpest increases in emissions, due to strong port traffic growth and limited mitigation measures.

The above indicates that various initiatives are needed to combat air pollution in ports. These will be discussed in this module with specific reference on CO<sub>2</sub> emissions. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. These instruments would need wider application in order for ship emissions in ports to be significantly reduced.

#### **1.4 Method of reduction of port area emissions**

Numerous and diverse measures and strategies are available to effectively reduce emissions and improve energy efficiency for ships in the port area. Experience with addressing ship emissions and implementing measures in the port area dates back to the late 1990's and is becoming more prevalent over the past decade. There are initiatives underway by various stakeholders to evaluate and demonstrate emerging and innovative measures that could be effective both at-sea and in the port area.

Although the direct control of ports/terminals on ships' emissions is limited, they can have an impact on the reduction of ship emissions in the port area in a number of ways [MEPC 68/INF.16]:

- Ports/terminals can facilitate the just in time ship operations in ports that substantially reduces the ship's port time, thus emissions.
- Ports/terminals can directly or indirectly provide incentives for the ship owners to implement emission abatement measures on-board.

- Ports/terminals can facilitate port area ship emissions reductions by providing certain infrastructure themselves, like OPS facilities.

To deal with the above, one could deal with port related emissions for ship sources and non-ship sources.

## 1.5 Port non-ship related emissions reduction

### 1.5.1 Port-land based side

If the land-based side of marine transport operations is taken into account, it would include cargo handling equipment, stationary power sources, locomotives and heavy-duty trucks operating within the port area. These are non-vessel related emissions from ports. To reduce emissions in such cases, the following may be considered [Corson et al]:

- Clean Fuel: Change to advanced clean diesel fuel, such as low or ultra low sulphur diesel (LSD) (ULSD), emulsified diesel, bio-diesel, compressed natural gas, liquefied natural gas, liquefied petroleum gas (propane, which requires a dedicated engine) and so on. All of these will provide direct benefit to port air quality and at the same time some reduction in GHG emissions.
- Technology Retrofit: Installation of “after treatment” devices on existing diesel engines such as diesel particulate filters, oxidation catalysts, closed crankcase ventilation, selective catalytic reduction, lean NOx catalyst, exhaust gas recirculation and so on. Trucks could be retrofitted with some of these technologies.
- New technologies: Use of hybrid-electric technologies as replacements for pure diesel engine vehicles and equipment.
- Operation management: This could include a large number of measures that helps to reduce fuel consumption and emissions including:
  - Implementation of policies that would reduce the idle operation of vehicles such as reduction of port congestion and start-stop technologies.
  - Include incentives for emissions reduction in leases and contracts with tenants, contractors and transportation service providers;
  - Expand operating hours to reduce truck queuing, idling and traffic congestion;
  - Promote other aspects that would reduce port area traffic congestion and emissions.

The above include a summary of the important pollution reducing measures. For reduction of energy consumptions, port need to follow energy management system and develop energy management plan that could be applied to all aspects of port operation. ISO 50001 (see **Module 6**) can be used for this purpose and energy review and audit will form a part of energy planning for the port.

### 1.5.2 Port harbour crafts

Apart from ships calling a port, there are a significant number of harbour crafts that provide support services to ships and port. Although not directly related to international shipping emissions, such crafts contribute to port air quality as they are mostly powered by diesel engines.

For harbour crafts and in order to save fuel and reduce pollutants to port, similar general measures as larger ships are applicable. Measures that can be applied to address emissions from harbour crafts are often adapted from those developed for on-road and non-road equipment. These measures include. Some of the measures that may apply for harbour crafts are:

- **Engine Replacement:** Replacement of a harbour craft engine is not an easy option as it normally will require all sort of different auxiliary machinery, space and fuel requirements. However, retrofit of engine can be an important consideration for harbour crafts in view of changing technologies, move to hybrid electric options as well alternative fuels. Replacing main-propulsion engines with cleaner engines will provide great emission benefits that compound over the remaining life of the equipment. For harbour craft, this can be significant because the total operating life can be up to 30-40 years. Cleaner engines are, however, costly and capital costs may be a major barrier [ICCT June 2012].
- **Clean Fuels:** The second option that may require less capital cost but will have implications on operating costs is the use of cleaner alternative fuels. The most obvious one is the use of low sulphur fuel in a similar fashion as road transport that uses ultra-low sulphur fuels these days. Additionally, other options could include emulsified diesel fuels and biodiesel. The more promising alternative fuel is natural gas in the form of LNG as LNG fuelling infrastructure is being developed. Move to LNG will require capital investments but the longer term the return could be via cheaper fuels, and a reduction of all types of air emissions. Use of biofuels, CNG or LNG would benefit the climate change as they would reduce overall discharge of CO<sub>2</sub> to atmosphere.
- **Technology upgrade:** This option relates to retaining the engines but opting for more advanced available engine controls, fuel additives and after-treatment emission control technologies such as diesel oxidation catalyst, diesel particulate filter and selective catalytic reduction (SCR).
- **Hybrid electric systems:** The harbour crafts are good candidates for use of more advanced technologies such as hybrid technologies to include batteries and electric motor / generators in the same way that land-based vehicles are moving into hybrids domain. Also, these vessels can be connected to onshore power when at berth for on-board electrical generation for hoteling functions. Hybridization is best for harbour crafts when they are away from the berth and have fluctuating energy demands. Hybridizing for harbour crafts has become much more feasible in the past several years as several demonstration projects have illustrated the feasibility and benefits of the technology. In Long Beach, Foss tugboats retrofitted an existing tug with lithium ion batteries and advanced drives for a total project cost of \$2.1 million [ICCT June 2012].

The above discussion about port-side emissions including those from cargo handling equipment, buildings, ground transportation services, etc. plus those coming from harbour craft will not be further discussed in the following sections. Instead the full attention will be on ship-port interface and ship-related emissions from now on.

## 1.6 Port ship-related emission sources

The emission sources directly associated with ship operations in port include those due to propulsion engines, auxiliary engines and auxiliary boilers plus Volatile Organic Compound (VOC) that is associated with bulk liquid cargos and various Ozone Depleting Substances (ODS) due to

refrigeration system. From an air pollutant perspective, vessels can produce significant amount of NO<sub>x</sub>, SO<sub>x</sub> and PM from burning fuel in the propulsion engines, auxiliary engines and auxiliary boilers/steam plants. Depending on the geographical configuration of the port area and type of vessels, these three combustion systems can have varied level of emissions. It is important to know for the vessel in question, which of these plays a more important role in ports when it comes to emissions and energy efficiency reduction measures [MEPC 68/INF.16].

Most emissions from ships in ports are the result of diesel engines burning heavy fuel oil. Compared to land-based transport, the marine engines are not as strictly regulated as their land-based counterparts. National and regional regulatory authorities have limited control over international ships other than on their own flagged ships and to some extent ships visiting their ports. Reducing emissions from ship-board diesel engines is therefore one of the significant challenges and opportunities related to improving air quality in port areas.

The unique challenge associated with the port area, with regard to reducing ship emissions, is how the emission sources listed above associated with various modes of ship operation in the port area. Generally a ship in port area has two general modes of operation [MEPC 68/INF.16]:

**Transit and manoeuvring:** During this mode, a ship is typically operating within confined channels and within the harbour approaching or departing its assigned berth. The distance associated with this mode is unique for each port and varies depending on geographical configuration of the port. During this mode of operation:

- The ship is moving at its lowest speeds, thus propulsion engines are operating at low loads.
- Auxiliary engine loads are normally at their highest compared to other modes because of the need for running additional machinery on-board, such as thrusters (for manoeuvring), air scavengers/blowers (due to low main engine load), etc.
- An additional auxiliary engine (diesel generator) is online for safety reasons in case one auxiliary engine's trip/failure does not lead to dangerous situations or blackouts.
- Auxiliary boilers are on because the economizers are not producing enough steam due to low propulsion engine loads and resultant lower engines' exhaust temperatures (this does not apply to large diesel-electric ships with central electric power generation).

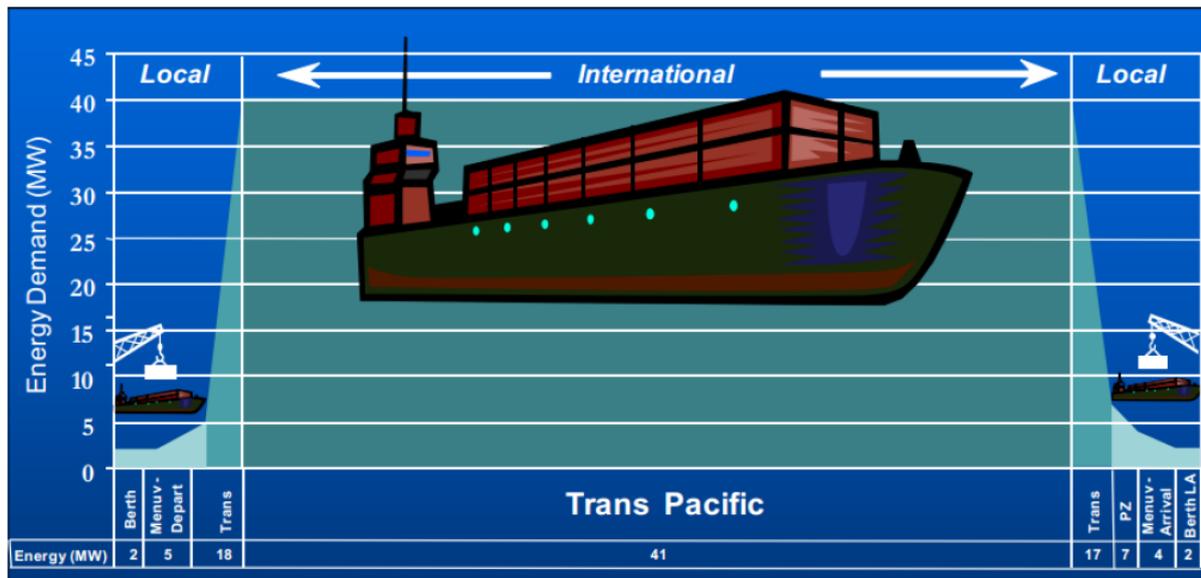
In such a mode, still most of fuel consumption will happen in main propulsion engines but boilers and auxiliary engines will consume fuel more than the normal sea going levels. The other aspect is that all the above combustion systems are working off-design at part loads. This is not good as such systems tend to be less efficient and more polluting under such low-load operating conditions.

**At berth or anchored:** During this mode, a ship is secured and not moving. Typically under this condition:

- Propulsion engines are off.
- Auxiliary engine loads can be high if the ship is self-discharging its cargo, as with general cargo vessels, auto carriers and roll-on roll-off (RoRo) vessels and oil tankers.
- Auxiliary boilers are operated to keep the propulsion engine and fuel systems warm in case the ship is ordered to leave port on short notice and also for other purposes. In some tankers, steam is used for discharge of cargo through the use of steam turbine driven pumps.

Vessel fuel consumption can be low, medium or high for auxiliary engines and can be low, medium to very high for boilers (for example for tankers when discharging), depending on ship types and if it uses energy for cargo operations. Again, both auxiliary engines and boilers will be operating at part load with low efficiency and high specific levels of emissions.

The majority of ship owners, operators and engine manufacturers as well as the regulators to some extent focus their efforts in reducing emissions and increasing energy efficiency for normal at-sea conditions as opposed to the port area. Typically, most ships move from one port area to another and for these ships, a majority of the ship's energy consumption over the life of the ship occurs at sea. Ship emissions estimation studies show total ship carbon dioxide (CO<sub>2</sub>) emissions in the port area range from 2% at the Port of Los Angeles [Starcrest Consulting] as compared to the entire voyage of the ship, to 6% at the Port of Rotterdam [MEPC 68/INF.16] as compared to greater North Sea area. **Figure 1.5** emphasizes this point by illustrating the magnitude of time and energy spent at sea versus time and energy spent during the modes that.



**Figure 1.5 - Energy demand example: Trans Pacific transit from Shanghai to Los Angeles** [Starcrest Consulting Group]

It is not uncommon for most vessels to be operating at propulsion loads below 50% in the port area and even at loads below 25% for significant portions of the time in the port area. In the transit and manoeuvring modes, the propulsion engine is operating with variable loads and is even turned off/on depending on the specific area the ship is manoeuvring through. The emission factors<sup>1</sup> of an engine will vary according to engine load and generally becomes worse (higher) at lower loads as both pollutants and CO<sub>2</sub> emissions factors will increase at lower loads per unit of power production. Thus in port and harbour areas, it can be stated that:

- Ship engines are operating with lower and varying loads.
- Propulsion and auxiliary engines are operating below their optimal performance loads.
- Auxiliary boilers are also for most of the time below their normal operating loads
- Various emissions factors for engines and boilers are higher than design values due to low load factor.

The main question is that whether one could avoid the above situations via use of alternative technologies, fuels and operational processes. These questions will be answered in various sections of this module.

<sup>1</sup> Emissions factor refers to emission produced per unit of energy produced or fuel used and for engines it is specified as g/kWh or g per kg of fuel.

## 1.7 How to deal with ship-port interface

Based on discussion about the ship-related and non-ship related emissions in port, it is clear that the emissions in port areas can be dealt with by measures to be implemented at ship level and port level via analysis of the following:

- Non-ship related air emissions
- Ship-related air emissions.

The “none-ship related air emissions from port’s infrastructure, facilities, its land-based transport, and harbour crafts” and main aspects of dealing with them was introduced and summarily covered in **Section 1.5**. As this is not the main focus area of this course, no further discussion will be provided. The readers could refer to list of references for further information on this subject in particular the ICCT reports.

The ship-related emissions to port as indicated above can be divided to those related to ship manoeuvring and transit in port area plus those when ship is at berth. To reduce them, a number of main measures could be followed:

- **Reducing the time of ship stay / operation in port:** No matter how low or high a ship emits, the absolute total amount of exhaust emissions to the port area will be a function of total time of ship manoeuvring and stay in port area. Thus staying in ports for an extra 50% of the time is expected to increase the ship emissions to port area by approximately an extra 50%. For this reason, reducing a ship’s time in port could be regarded as one major strategy for improving air quality in ports. This at the same time would help the ship save fuel significantly by running slower due to extra time in passage. This strategy can be achieved via a policy of operating just in time in port. This is covered in **Section 2** in more detail.
- **Use of alternative ship technologies and fuels:** As discussed, current diesel engines burn heavy fuel oil that is not a clean and low carbon fuel. Additionally, the conventional diesel engines technology on-board ships can be improved to more efficient engines with lower fuel consumption and pollutants. There are options to move away from these technologies and fuels to more energy efficient and clean technologies and fuels. This strategy, in particular new and alternative technologies, may be more applicable to new ships rather than existing ships. Further debates on such technologies and alternatives are given in **Section 3**.
- **Ship in-port technical operation management:** When a ship in port at berth or at anchor, various engines, boilers and machinery still need to be operating and thereby will use energy. Off course, the way these operations take place would impact a ship’s in-port fuel consumption and exhaust emissions. In **Section 4**, this topic is discussed and best practice is introduced to save with energy use and reduction of emissions.
- **Switching off the engines in port via shore connection:** The next strategy could be to switch off the ship-board engines when in port. This is subject to availability and supply of power from port to ship. This is an important development and requires investment both by port and ship and may result in some extra operational complexities. This policy is achieved via on-shore power supply system (cold ironing). This topic is covered in detail in **Section 5**.
- **Ship loading with due consideration for ship energy efficiency:** The subjects of ship loading, trim optimisation, ballast optimisation were covered in previous modules. Some of these will

not be achieved unless the cargo handling aspects of the ship are done properly. Although this may not have impact on port area fuel consumption and emissions, but is an important measure for a ship's energy efficiency that is impacted by its port operations.

- **Environmental oriented incentives:** To encourage ship-owners and operators to do their best to reduce emissions, regulations and market incentives could be used to encourage use of the above measures. IMO and regional initiatives have already regulated ships to some extent; for example with switch over to low sulphur fuel in certain areas and ports. There are financial incentives from certain ports to encourage use of environmentally friendly ships and so on. **Section 6** on green port initiatives and port environmental program cover some of these aspects.

Overall, there are significant opportunities for ship-port interface improvements to reduce air emissions from ships to port area and enhance overall energy efficiency of shipping. Although ports' core attention is on air quality and pollutions, nevertheless, there is a strong link between air pollutants and GHG emissions and this will be the subject of detailed discussion throughout this module.

### 1.8 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. "IMO train the trainer course material", developed by WMU, 2013.
2. Eddy VAN DE Voorde and Thierry Van Elsander "Market Power and Vertical and Horizontal Integration in the Maritime Shipping and Port Industry", Discussion Paper No. 2009-2, December 2008, University of Antwerp, Belgium.
3. Hilde Meersman, Siri Pettersen Strandenes, and Eddy Van de Voorde "Port Pricing: Principles, Structure and Models", a discussion paper, Institutt for Samfunnsøkonomi, Department Of Economics, April 2014.
4. Starcrest Consulting Group "The Port of Los Angeles 2010 Expanded Greenhouse Gas Inventory", Report published December 2011.
5. Lynn A. Corson, and A. Fisher "Manual of Best Management Practices For Port Operations And Model Environmental Management System", a report of study by the American Great Lakes Ports Association and the Purdue University.
6. ICCT December 2012, "Workshop brief: Technologies and operational strategies for best practices in port clean air programs" A report prepared for the International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, December, 2012.
7. ICCT June 2012, "Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor's Air Quality Toolbox", June 2012
8. MEPC 68/INF.16, "Study of emission control and energy efficiency measures for ships in the port area", MEPC 68/INF.16, 4 March 2015, report prepared by Starcrest Consulting Group, LLC CE Delft and Civic Exchange.
9. Olaf Merk "Shipping Emissions in Ports", Discussion Paper No. 2014-20, International Transport Forum, December 2014.

## 2 Ship Time in Port and Just in Time Operation

### 2.1 Introduction

International shipping is the most energy efficient mode of cargo transport in world trade but unfortunately is also a major producer of NO<sub>x</sub>, SO<sub>x</sub> and CO<sub>2</sub> emissions. The level of such emissions were explained and quantified in **Module 1**. The IMO regulations on ship energy efficiency were extensively discussed in **Module 2**; the existing measures being EEDI (Energy Efficiency Design Index) for new ships and SEEMP (Ship Energy Efficiency Management Plan) for all ships. With the current debates on further measures and fuel consumption measurement and reporting, new regulations in this area are forthcoming.

When it comes to ports, there have been limited studies on port operation / management and its contribution to ship energy efficiency. The main reason for this may be the lack of IMO's regulatory authorities on ports because the IMO's main focus is on ships and international shipping rather than ports that are mainly regarded as national entities. Despite this lack of regulatory focus, marine ports are important for shipping energy efficiency and in particular they play a major role in delivering an energy efficient ship operation. Thus, their roles and responsibilities and what they could do need to be understood.

As discussed before, there are few effective ways of reducing a ship's fuel consumption. Two main examples are:

- Operating the ship at a reduced speed during passage via Just-in-Time operation (**Module 4**). It was shown that speed reduction can bring about significant energy savings.
- Trim optimisation and ballast water management can contribute to significant energy saving as discussed before in **Module 4**.

Port operation has impacts on both of the above cases. For example, when it comes to the energy efficient ship operations, reduced ship speed at sea is closely related to the minimisation of a ship's time in port. A ship's time in port will be referred to here as ship's "port time". Reduction in port time through the high quality port operations allows shipping lines to improve the operational efficiency via reduced ship speed and thus fuel consumption. This calls for examination of all aspects of port operation in order to find practical ways to cut down on ship port time.

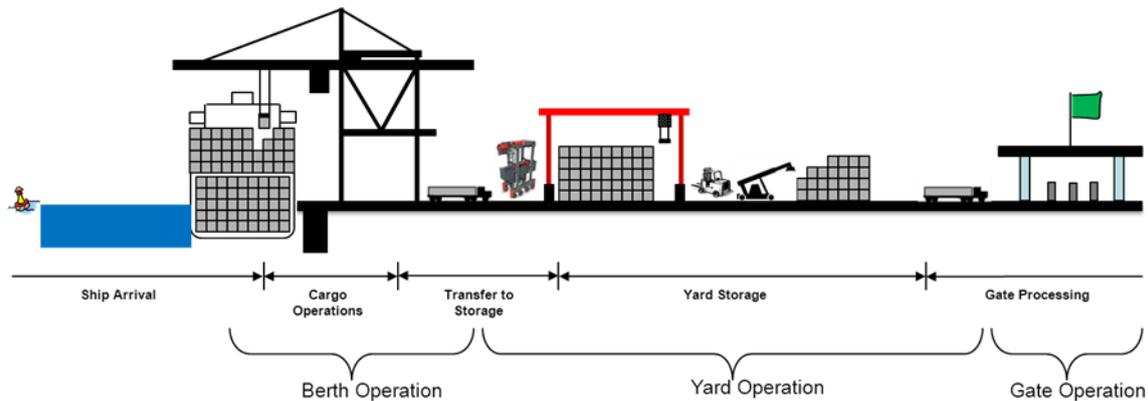
One possible way is to make a ship to operate Just-in-Time that involves getting rid of the waiting times in port. This will not only help shipping lines to get the maximum notice of berth availability, but also facilitate the use of optimum ship speed at sea. Further, reduction of berth time by improved cargo handling could be another way to reduce ship time in port. Few studies, however, have been done to identify the relationship between ship time in port and efficient ship operation at sea.

The main goal of this section is to investigate the operational issues on how time in port affects the efficient ship operation in terms of operating costs, GHG emissions and other externalities and methodologies for reducing not only the ship-in-port time but also improve other aspects of ship handling that could reduce a ship's fuel consumption.

### 2.2 Activities in port operations

As shown in **Figure 2.1**, activities in port operations are largely divided into 2 parts: ship related activities and cargo related ones. In the case of import cargoes, the latter consists of activities that are cargo handling in the apron area, transfer to storage, yard storage and gate processing. This

diagram is representative of a container ship terminal; however, similar diagrams could be constructed for other ship types to define the activities in port operations.



**Figure 2.1 - Schematic diagram of a container terminal operations**

When a ship arrives at the entrance buoy of a port, the pilot comes aboard the ship to help the master in maneuvers to the designated place. If no berth is available on arrival, the ship is assigned an anchorage area. If the berth is available, the ship is berthed with the help of tug(s), depending on ship size and port's rules and regulations. At this point, line handling services are provided at the berth. In particular, the time when a first line is connected to the pier (or dock) is very important since it is the starting point of the so-called 'berthing time'. The berthing time stops when the last line from the ship let's go of the bollard as it leaves the berth.

When berthed, the Custom, Immigration and Quarantine (CIQ) authorities may board the ship. Usually cargo handling is not made until the authorities have completed their inspections, with the exception of the container shipping business.

In dedicated container terminals, container boxes<sup>2</sup> are unloaded and loaded usually using a gantry crane<sup>3</sup> at the apron where containers are moved to or from storage by In-terminal Movement Vehicles (IMV). Once the container cargoes are unloaded, they are transferred to an assigned slot; this is a space in the yard where storage operations occur. The containers are stored until they are inspected and claimed by the consignee (importers). The containers, then, are moved from the yard onto trucks (or railcars) for their final destinations through the gate operation.

Gate processing includes weighing the container, reviewing paperwork, and conducting a security check. All the above are shown in **Figure 2.1**.

## 2.3 Impact of ship's port time on efficient ship operation

### 2.3.1 Ship's (voyage) time: time at sea and time in port

Tough competition in the last couple of decades has caused container shipping, in particular, to be able to achieve profit only through economies of scale<sup>4</sup>. This has led to larger ships and ever shorter

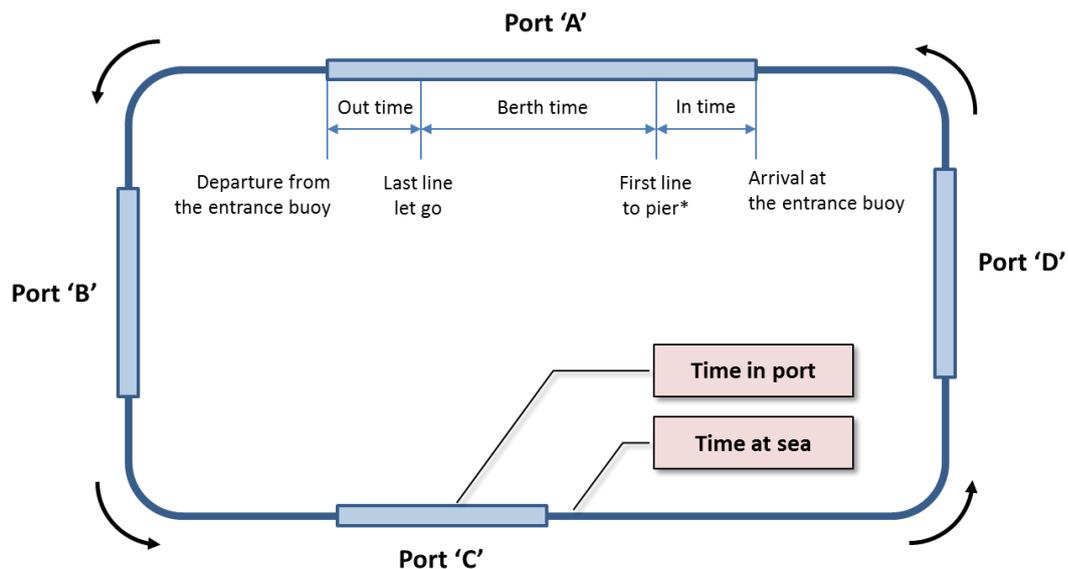
<sup>2</sup> Container size is measured in terms of 20-foot equivalent unit (TEU). A typical container is one TEU (20 footer) or 1 FEU (40 footer) that is two TEUs.

<sup>3</sup> Some ships, referred to as "geared" vessels, have their own cranes, but these are not as productive as gantry cranes.

<sup>4</sup> It is well-known that cost of production depends on the number of products being produced; normally cost per unit produced reducing with size of production. Thus economies of scale (larger production units) is one effective way to reduce unit cost due to size, output, or scale of operation, with cost per unit of output generally decreasing with increasing scale as fixed costs are spread out over more units of

cargo handling times and demurrage<sup>5</sup>. Today, new potential for economization can only be achieved by reducing operating and fuel costs. Two ways out of this predicament are either to use "slow steaming", meaning a ship's speed is reduced to save fuel, or to deploy even bigger ships, allowing the higher fuel costs to be spread over the additional tonnage. However, increasingly strict environmental requirements in harbors and en-routes limit the engine size and thus the size of the ships.

When it comes to the operation of container shipping lines, the timetables of the routes are normally fixed. If the ships are delayed in port at some points, they are forced to make up for the lost time by increasing their speeds at sea. As illustrated in **Figure 2.2**, a ship's (voyage) time is composed of 'time at sea' and 'time in port'.



**Figure 2.2 - Composition of ship's voyage time in container shipping line**

### 2.3.2 Time in port<sup>6</sup>

Ports are essentially providers of service activities, in particular for vessels, cargo and inland transport as discussed in **Section 1**. The degree of satisfaction that is obtained on the basis of pre-set standards will indicate the level of port performance achieved. It is obvious that port performance levels will be different depending on the ships, cargoes or inland transport vehicles that are used or served. Port performance cannot be assessed on the basis of a single value or measure. In fact, a meaningful evaluation of a port's performance will require sets of measures; one of which will be the ships' time in port.<sup>7</sup>

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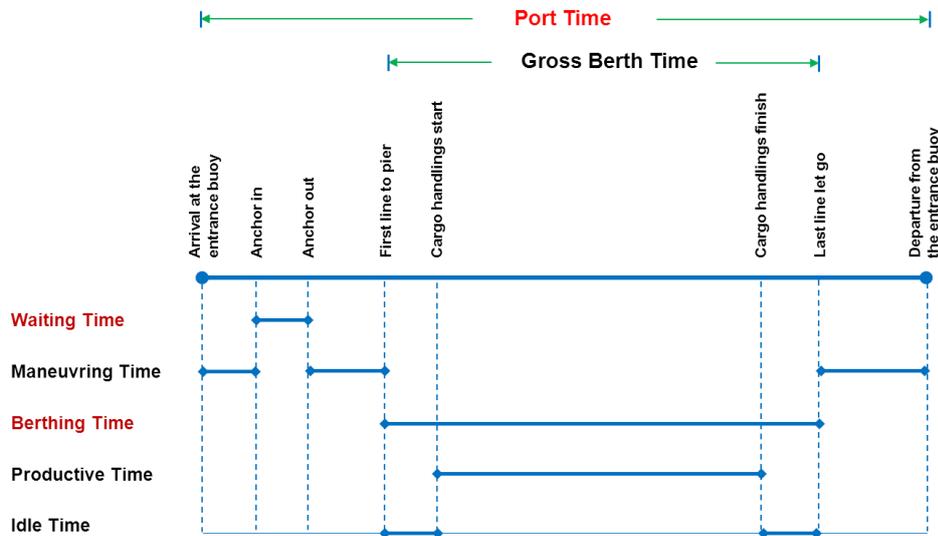
output. This principle applies to shipping as well and with larger ships and more ships under management control; the cost of transportation per unit cargo is reduced. This is one main reason why shipping has moved to larger and larger ships.

<sup>5</sup> Demurrage, by definition, refers to 1) the delay of a ship at mooring beyond the time stipulated for unloading or other purposes and 2) the charge levied for such delays.

<sup>6</sup> Otherwise called as 'port time' or 'ship turnaround time (in port)'

<sup>7</sup> G. De Monie (1987). Measuring and evaluating port performance and productivity. UNCTAD Monographs on Port Management. A series of monographs prepared for UNCTAD in collaboration with the International Association of Ports and Harbours (IAPH).

**Figure 2.3** shows the times at which each step of ship's port operation starts and stops as documented in the port, allowing for the calculation of a variety of parameters (or indicators) that the shipping industry uses to calculate performance.



**Figure 2.3 - Breakdown of ship's time in port**

The ship's time in port of a given vessel on a given call is an important concern in an efficient ship operation for shipping lines. The shorter it is, the better it is economically<sup>8</sup>. Port time (or a ship's time in port or ship turnaround time) is the time duration between a ship's arrival at the entrance buoy and ship's departure from the same buoy (see **Figure 2.3**). It can be categorised as the following times:

- **Waiting time:** The period the ship waits for berth availability.
- **Manoeuvring time:** periods of manoeuvring in port either to reach anchorage or to reach berth or too leave the port.
- **Berthing time:** Actual time at birth. Berthing time normally consists of two parts: productive time and idle times (preparation time and arrangement time). The preparation time is the time before starting cargo handling after the ship is berthed, while the arrangement time is the time after finishing cargo handling until the ship is un-berthed. To increase the productivity at the berth<sup>9</sup>, these non-production times must be minimized. Further, to make productive time more efficient, there should be no stoppage time that is related to breakdown, maintenance, etc.
- **Productive time:** Actual time from start of cargo handling operation to end of cargo handling operation.
- **Idle time:** Times in berth where there is no cargo handling operations.

<sup>8</sup> From the viewpoint of transport economics, this is true. Whatever the transport mode, e.g. ship, airplane, train, taxi, etc, the vehicle must move to make operating profits; when standing still no income is generated!

<sup>9</sup> Shipping lines calculate the so-called gross berth productivity (GBP) that is "the number of container moves or tons of cargo (for break-bulk and bulk cargoes) divided by the vessel's total time at berth measured from first line to last line".

A reduction of any of “these times” will improve the overall productivity of the ship in port. Among these times, in particular ‘waiting time’ and ‘berthing time’ must be emphasised since they are crucial criteria in ports facing latent or acute port congestion.

In a nutshell, measures of the duration of a ‘ship’s stay in port’ are key indicators of the service quality that is offered by ports to shipping lines.

#### 2.4 Just-in-time arrival/departure and improved cargo handling

The search for efficiency across the entire transport chain takes responsibility beyond what can be delivered by the owner/operator alone. A list of all the possible stakeholders in the efficiency of a single voyage is long; obvious parties are designers, shipyards and engine manufacturers for the characteristics of the ship, and operators, charterers, ports and vessel traffic management services, etc., for the specific voyage. All the involved parties should consider the inclusion of efficiency measures in their operations both individually and collectively.

When it comes to efficient port operations that aim to reduce ship’s time in port, as discussed and shown in **Figure 2.3**, ‘waiting time’ and ‘berthing time’ are two key components to consider in more detail.

If the ship involved gets a berth on-arrival, there will be no waiting time. In this regard, just-in-time arrival and departure is very important for shipping lines to operate their fleet efficiently. According to “2012 Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP)”<sup>10</sup>, good early communication with the next port of call should be an aim in order to give maximum notice of berth availability and facilitate the use of optimum speed where port operational procedures support this approach. Optimised port operation could involve a change in procedures that are engaged in different handling arrangements in ports. Port authorities should be encouraged to maximise efficiency and minimise delay.

Regarding the just-in-time arrival/departure of ships, from the viewpoint of ship operators, the reliability of the berthing window is another issue to be looked at. In another words, on-arrival services for ships have to be guaranteed between port authorities and shipping lines. Otherwise, even though ships are already in port, they might have to wait until the berths are available. This will definitely make the time at sea shorter than anticipated, thus increased ship speed in passage will be used to counter act the lost time. This will be counterproductive in terms of efficiency of total voyage time or fuel consumption.

In this sense, the relationships between ship operators and ports must be kept close and their operations harmonised in order to enhance reliability for securing on-arrival services in port. Having a contract for a dedicated (exclusive) terminal with shipping companies on a long-term basis is an exemplary case of resolving this kind of reliability issue.

#### Just-in-time arrival and departure

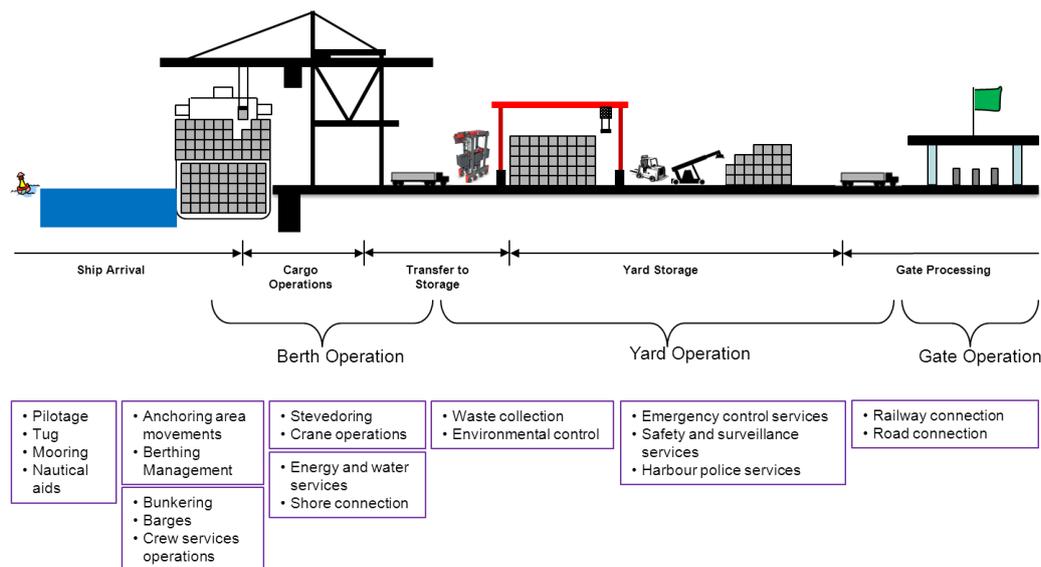
**Figure 3.4** shows that the main activities of the whole container terminal operation can be divided into three operations:

- Berth operation,
- Yard operation
- Gate operation.

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<sup>10</sup> IMO MEPC 63/23, ANNEX 9, Resolution MEPC.213(63), Adopted on 2 March 2012.

This diagram lists specific operations/activities that take place in each phase.



**Figure 2.4 - Schematic diagram of container terminal operations with activities**

The berth operation mainly concerns the schedules of arriving vessels and the allocation of berth space and quay crane resources to serve the vessels. The key concern of the berthing operation is the turn-around time of vessels. It also involves the unloading and loading of containers on-board the vessel that is handled by gantry cranes. To achieve high crane rates (number of containers moved per hour), the planner has to optimise the crane working sequence (a detailed list of crane moves).

The yard operation is perhaps the busiest of all the activities in the terminal. The operation involves the unloading of containers from the ships, the loading of containers onto vessels, the shuffling of containers that are out of sequence in the yard block, the redistribution of containers to other blocks (yard shifting) for more efficient loading onto the second vessels and the inter-terminal haulage where containers are moved to other yards in another terminal.<sup>11</sup>

The gate operation deals with external freight forwarders. Two activities are involved, namely export delivery where the freight forwarders bring in export containers to the yard or wharf to be loaded onto the vessels, and import receiving, where the freight forwarders receive containers from the yard or wharf to bring into the country.

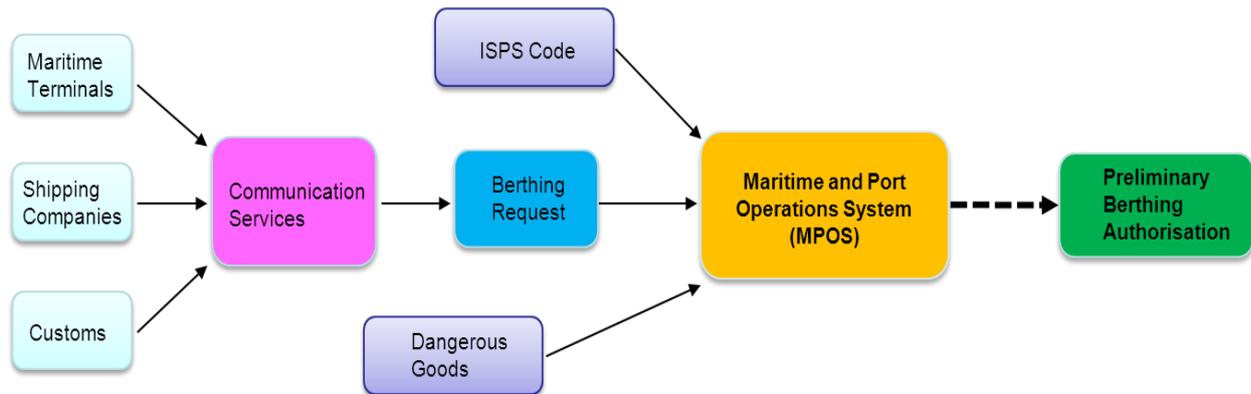
## 2.5 Port operation management

Each port (or terminal) has its own port management system for the efficient and effective operation of port, which will be referred to as Maritime and Port Operation System (MPOS) as an example to be explained here. This is a customized management tool that focuses and optimizes the work of “agents”, “entities” and “port services on ships” by coordinating the actions, controlling them and allowing them to analyze how best to reduce the cost/time.

All the parties concerned, including the ships, must participate in the MPOS from prior to the ship’s arrival in the port to the ship’s departure from the port. Whenever the ship wishes to enter a port,

<sup>11</sup> Iris F.A. Vis and Ren\_E De Koster (2003) “Transshipment of Containers at a Container Terminal: An Overview”, European Journal of Operational Research. 147. 1–16.

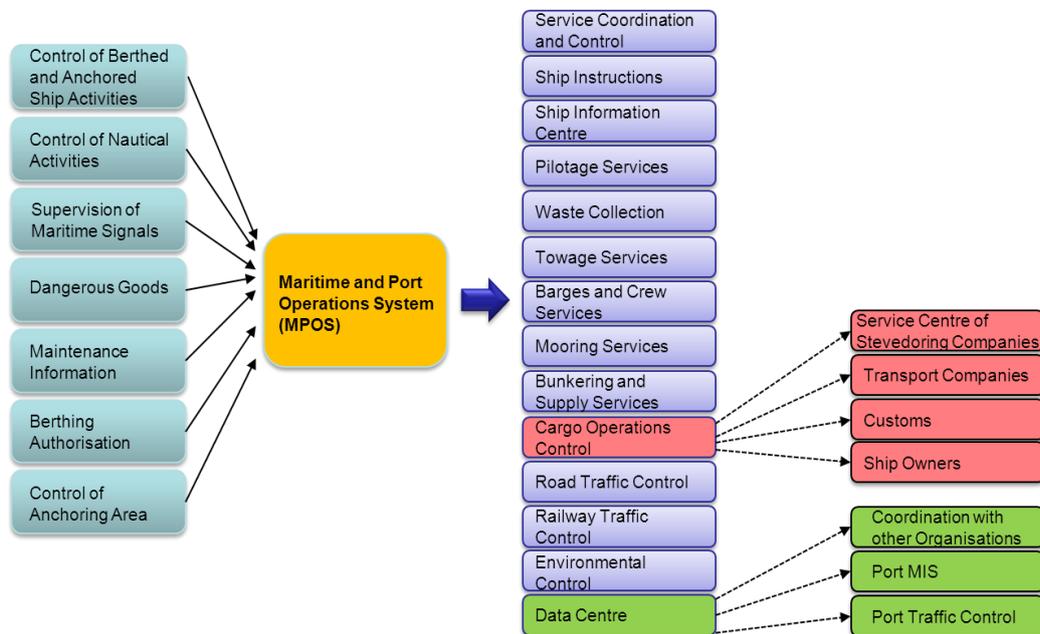
'the Request for Berth' is made through Communication Services (normally internet) well before arrival and is confirmed by the MPOS, against the ISPS (International Ship and Port Facility Security) and Dangerous Goods Codes, before issuing the Preliminary Authorization to Berthing. (See **Figure 2.5**)



**Figure 2.5 - Application of berthing request in a typical port management system**

After issuing the Preliminary Berthing Authorization, the MPOS compares it with information from the anchoring area and with activities of any anchored or berthed ships, nautical activities inside the harbor, status of maritime signals, maintenance status of berths, and informs the berthing operation to the ship and to the pilot service. It supervises at all times compliance with the Operating Procedures.

The MPOS informs and coordinates all Port Services regarding berthing maneuvers, informing also the other agents. Furthermore, throughout this phase, the MPOS is capable of performing the control actions and coordination tasks with other agents as shown in **Figure 2.6**.



**Figure 2.6 - MPOS and port services coordination**

Generally, the MPOS controls port activities relating to maritime safety and the protection of the marine environment. Typically, the MPOS is part of the port authority organisation and is responsible for ensuring the efficient flow of traffic through port and coastal waters (including allocation of vessels to berths) and—on behalf of the government or port authority—for coordinating all marine services.

Major port services that are related to MPOS can be as follows:

- **Pilotage services:** These are services given by maritime pilots that provide an essential and unique service to the shipping industry. Their principal role is to provide critical independent local knowledge and navigational information to vessels and to bring the highest level of ship-handling skills to manoeuvre vessels within their port. The prime obligation of pilots is to provide a critical public safety service by ensuring the careful management and free flow of all traffic within their pilotage area, thus protecting the environment.<sup>12</sup>
- **Towage services:** These are services provided by a small, strongly built powerful tugboat that is used to guide large ships into and out of port and to tow barges, dredging and salvage equipment, and disabled vessels. Tugboat operations are typically carried out by private firms. If the volume of vessel traffic is not sufficient to support a tugboat service on a commercial basis, a port authority may be obliged to provide such a service itself.
- **Line handling services by line boats:** These are the services given by line boats that help the ship to be berthed. When berthing, once the lines from the ship are given to line boats, they approach a berth and try to throw a line to someone on land who ties off the lines at the dock.
- **Mooring services:** These are the services that secure a ship to the designated place, i.e. a berth or a dock or a buoy, or anchoring with two anchors. Mooring services in smaller ports can be provided by the local stevedore. In larger ports, a mooring service is usually performed by a specialised private firm. Especially in a complicated nautical situation (for example, single point mooring buoys, specialised piers for chemicals or gases, or ports with large tidal differences), mooring activities require expert skills and equipment. A port authority may choose to regulate this activity when only one specialised firm exists.<sup>13</sup>
- **Vessel traffic services (VTS) and aids to navigation:** This is a marine traffic monitoring system established by port authorities. VTS is a service designed to improve vessel traffic safety and efficiency and to protect the environment; it offers the potential to respond appropriately to traffic situations emerging in an area. VTS is usually part of a port or a maritime authority. Such services are provided in port areas and in densely used maritime straits or along a national coastline. VTS should be regulated by the competent authority. Responsibility for aids to navigation usually rests with the national maritime authority in port approaches and in coastal areas, and with the port authority in port areas. Often, provision and maintenance of buoys and beacons are contracted out. Because aids to navigation are generally part of an integrated maritime infrastructure, the costs of providing these services are included in the general port dues.

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<sup>12</sup> <http://www.impahq.org>

<sup>13</sup> World Bank (2008). *Port Reform Tool Kit, 2nd Edition*, Washington D.C., United States, p.127.

- **The control of dangerous goods:** This is usually performed by a specialised branch of the port authority. The same goes for the handling of dangerous goods in port terminals. The oversight and regulation of the land transport of dangerous goods is normally the responsibility of government.<sup>14</sup>
- **Waste management services:** These are privatised under the strict control of a port authority or another competent body. Proper waste management can be expensive for shipping lines. With high costs, ship masters might be tempted to dump waste into the sea or into port waters. The control of such dumping practices is extremely difficult, especially for chemical cargoes. To spread waste management costs, ports can include all or part of the waste management costs in the general port dues. The transport of waste from the ship to a reception facility also poses a challenge, especially in larger port areas. Port authorities should directly provide or organize the provision of transport barges or trucks for this purpose. The entire waste management system, including personnel and facilities, should be closely controlled by the competent authority. When private firms are engaged in waste handling, the authority should employ experts from its organisation to ensure compliance with all relevant laws, rules, and regulations.<sup>15</sup>
- **Emergency response services:** These are carried out by a variety of public organisations such as the port authority, fire brigade, health services, and police. Some ports have sophisticated tools available to aid in crisis management, such as prediction models for gas clouds. Such tools are often integrated in a traffic centre of the local vessel traffic management system (VTMS). Private firms (for example, tugboat companies) may play a subsidiary role in crisis management in the event that they are equipped with fire-fighting equipment. Larger ports use patrol vessels and vehicles for a variety of public control functions. In some ports, such patrol vessels also have fire-fighting equipment on board. When a port does not have patrol vessels available, a contract with a tugboat company should be arranged to guarantee the availability of floating fire-fighting capability.<sup>16</sup>
- **Control of dredging operations:** These are normally given by a port authority. Often, the port authority or the competent maritime administration does not have enough expertise to exercise sufficient control over both maintenance and capital dredging. Port authorities with large water areas under their control should employ sufficient competent personnel to prepare dredging contracts and oversee dredging operations. Sounding is an activity that should preferably be carried out (or contracted out) by the port authority itself. Dredging is usually carried out by private firms. It might be cost effective for some ports to use their own dredgers, especially when continuous and important maintenance dredging is required<sup>17</sup>.

As the above list of services, ships may need to use the above services in addition to cargo handling service. This then may have impacts on port time of the ships.

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<sup>14</sup> World Bank (2008). *Port Reform Tool Kit, 2nd Edition*, Washington D.C., United States, p.128.

<sup>15</sup> World Bank (2008). *Port Reform Tool Kit, 2nd Edition*, Washington D.C., United States, p.128.

<sup>16</sup> World Bank (2008). *Port Reform Tool Kit, 2nd Edition*, Washington D.C., United States, p.128.

<sup>17</sup> World Bank (2008). *Port Reform Tool Kit, 2nd Edition*, Washington D.C., United States, p.129.

## 2.6 Measures for avoiding ship's waiting time in port

### 2.6.1 Virtual Arrival

Virtual Arrival is a concept for a ship's just in time operation. The main focus is to avoid early arrival and resultant waiting. This topic has been fully covered in **Module 3**.

### 2.6.2 Improved cargo handling

Cargo handling is, in most cases, under the control of the port and the optimum solutions matched to the ship and port requirements should be explored. Whatever solutions that might be thought of, they should contribute to increasing the gross berth productivity, meaning faster cargo handling that can lead to reduce the berthing time.

When it comes to container terminal optimization, for example, the integrated planning and scheduling of all the activities of a terminal could be suggested to increase moves per hour and reduce costs<sup>18</sup>. To improve cargo handling, the following planning needs to be improved:

- Berth planning
- Quay crane scheduling
- Prime mover scheduling
- RTG (Robber Tyre Gantry) /RMG (Rail Mounted Gantry) cranes scheduling
- Operational planning, typically day(s) ahead

These activities are closely connected to cargo handling in port where efficient operations can bring about the reduction of ship's time in port as well as giving environmental benefits.

Efficient cargo handling in port can definitely be helpful for the environment<sup>19</sup>. A well-planned cargo operation, both in port and on board can reduce the level of emissions from the ship's machinery that leads to reduced energy consumption per transported unit. Ways to improve cargo handling resulting in environmental benefits include:

- The use of an internal movement vehicle that has less fuel consumption per cargo unit
- The introduction of high capacity loading and unloading operations with lower emissions to reduce the ship's time in port
- Safer and easier cargo operations and monitoring
- The application of new technology with advanced software tools
- The use of eco-friendly and user-friendly cargo handling products
- Well trained shore-staff and ship- staff who are keen on safety and environment matters

Quick ship turnaround time in port will ensure slow steaming at sea and this will again contribute to reduce emissions.

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<sup>18</sup> QUINTIQ (2012) "Advanced Planning, Scheduling and Supply Chain Optimisation Solutions for the Container Shipping Industry".

<sup>19</sup> <http://www.marineinsight.com/marine/environment/how-efficient-cargo-handling-can-be-helpful-for-the-marine-environment/>

## 2.7 Implication of just in time

It is not difficult to make an economic analysis of just in time in relation to various ship costs including fuel costs as well as ship air emissions during passage and in port. Numerous analyses including the one carried out by INTERTANKO and OCIMF on virtual arrival shows the benefits. Based on this study [INTERTANKO and OCIMF (2010)] for a typical ship, Virtual Arrival gives a 43% reduction in the ship's voyage fuel consumption. Of course this number will depend on ship type, size, voyage characteristics and current port times. Nevertheless all indications are that if just in time is realized, the saving levels will be in double digit numbers.

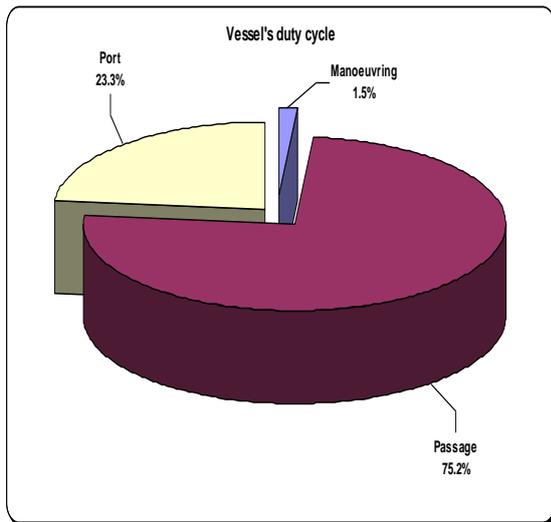
Firstly, the fuel consumption and the amount of CO<sub>2</sub> emissions are sensitive to the changes of port time. As port time decreases, the fuel consumption and the amount of CO<sub>2</sub> emissions are sharply reduced (assuming total voyage time is fixed). This result means that port time has a big impact on efficient ship operations. The reduction of port time, or minimization of waiting time through just-in-time arrival and departure, improvement of berth productivity and simplification of the administration process, lead not only to the reduction of the operating cost but also to the improvement of the environmental performance of the shipping industry. In particular, this result tells us why port selection (or choice) is important to shipping lines. In other words, when a shipping line establishes and/or improves their service loop based on the calling ports that have high productivity and efficiency, they can improve their ship operational efficiency by minimizing their operating cost and the amount of CO<sub>2</sub> emissions.

Secondly, as vessel size increases, the impacts of the changes of port time on the operating cost and the amount of CO<sub>2</sub> emissions also increase. This result implies why port time is more important to a shipping line that operates larger vessels. Moreover, this result tells us why shipping lines have been focusing on the development of their own container terminals on the major routes. Namely, the larger vessel is more sensitive to unstable port operations and non-production times in port, and this leads to an increase in operating costs and acceleration in the amount of CO<sub>2</sub> emissions.

In summary, terminal operators have to improve their operational efficiency. This is because the improvement of operational efficiency leads not only to strengthen their own competitiveness but also to contribute to the reduction of costs and the amount of CO<sub>2</sub> emissions in the liner shipping industry. A simple exercise is provided in the next section to demonstrate the benefits of port operation improvements.

### **A simple estimated level of fuel saving and CO<sub>2</sub> reductions**

**Figure 2.7** show the actual operation times for a specific ship, denoting that 23.3% of her time is spent in ports (combined berth and anchorage).



**Figure 2.7 - Ship's times in passage, port and manoeuvring**

The same ship was analysed for number of port calls and just-in-time operations and the required time for just in time operation was estimated. If operated according to port just-in-time, the ship time in port will reduce from 23.3% to 16% (a reduction of about 30% of port time). For calculation purposes, it is assume that the ship would in practice get partial just-in-time operations and thus port time could be reduced from 23.3% to 20.3% in a real feasible scenario.

It is further assumed that the extra time gained from better port operation will be used in passage, thus increasing the in-passage periods from 75.2% to 78.2%. This extra time will then be used to proportionally reduce the in-passage ship speed, assuming that the total annual number of port calls will remain the same. The reduced ship speed is then converted to fuel consumption reduction using the well-known cubic relationship between ship speed and required propulsion power. CO<sub>2</sub> Emissions reduction is estimated using fuel consumption reduction and relevant emissions factors.

**Table 2.1** shows the result of this simple calculation in terms of ship fuel consumption reduction; denoting a reduction of more than 1,000 tonnes of fuel consumption per year. This exercise shows how effective the port times could be on overall energy efficiency of a ship and how large gains could be achieved via better port related operations.

Passage operation time in passage, current	75.2% of annual
Passage operation time with less port time (see above)	78.2% of annual
Fuel consumption reduction for same distance (estimated)	7.5%
<b>Fuel consumption and emissions reduction</b>	
Main engine fuel consumption reduction	1,065 MT/year
Boilers and auxiliary engines fuel consumption reduction	Assumed negligible
Net fuel consumption reduction	1,065 MT/year
Net CO <sub>2</sub> reduction	3,400 MT/year

**Table 2.1 – Estimated ship fuel consumption and emissions reductions**

## 2.8 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. "IMO train the trainer course material", developed by WMU, 2013.

2. De Monie, G. (1987). Measuring and evaluating port performance and productivity. UNCTAD Monographs on Port Management. A series of monographs prepared for UNCTAD in collaboration with the International Association of Ports and Harbours (IAPH).
3. INTERTANKO and OCIMF (2010). Virtual Arrival: Optimising Voyage Management and Reducing Vessel Emissions – an Emissions Management Framework. Oil Companies International Marine Forum, Bermuda.
4. IMO (2012). 2012 Guidelines for the development of a ship energy efficiency management plan (SEEMP), Resolution MEPC.213(63), Adopted on 2 March 2012.
5. IMO (2009). Guidelines for voluntary use of the ship energy efficiency operational indicator (EEOI), MEPC.1/Circ.684, 17 August 2009.
6. IMO (2011). Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating thereto (Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI), RESOLUTION MEPC.203(62), Adopted on 15 July 2011.
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11. Vis, Iris F.A. and Koster, Ren\_E De (2003). Invited Review. Trans-shipment of Containers at a Container Terminal: An Overview. European Journal of Operational Research. 147. 1–16.
12. Dan Johnson, “Alternative RMG applications in container ports”, Port Technology International, [http://www.porttechnology.org/images/uploads/technical\\_papers/PT35-17.pdf](http://www.porttechnology.org/images/uploads/technical_papers/PT35-17.pdf), cited August 2015

## 3 Technologies for Port Air Quality and GHG Emissions Reduction

### 3.1 Introduction

Port operations involves not only ship operation but a lot of other activities such as cargo loading and unloading, ground-level port related transportations and activities of harbour crafts for provision of various services to ports or ships (e.g. dredging, tugs, bunkering, etc.). The main prime mover for most of these vessels, vehicles, cargo handling equipment are diesel engines although move to electrification and use of other technologies are underway. In this section, technological solutions for port area emissions reduction and GHG emissions reductions are discussed. A number of studies has been carried out in the past, the most prominent ones are those by ICCT<sup>20</sup> and the IMO. These studies are used as the basis of material in this section and the main outcomes of these studies are highlighted.

### 3.2 ICCT study on port air quality

Most of the studies performed on port related emissions concentrate on port air quality and not energy efficiency. One of these is reported by ICCT in December 2012. In this report, the ICCT highlights the technologies that could be used in diesel engines as the prime mover for ships and port-side trucks. The main focus is on pollutants including PM (Particulate Matters), carbon monoxide, SO<sub>x</sub>, NO<sub>x</sub> and VOC. The types of technologies identified for reduction of emissions are<sup>21</sup>:

- Diesel oxidation catalysts: This is a device installed at the back of the engine on the exhaust gases path to oxidize such pollutants as CO, PM and HC.
- Diesel particulate filter: This is the device used at the back of diesel engines on the exhaust gases path to trap the particulates and prevent them from leaving the engines.
- SCR (Selective Catalytic Reduction): This is a very well know technology for significant reduction of NO<sub>x</sub> emissions. As the name implies, it work via use of agents at the presence of a catalyst to covert NO<sub>x</sub> beck to N<sub>2</sub> and O<sub>2</sub>.
- Exhaust Gas Scrubbers: Again this is a very well-known technology for the back of engines on the exhaust gases path to capture the SO<sub>x</sub> and prevent them from leaving the engine exhaust.
- Exhaust Gas Recirculation (EGR): This is a well-known technology that aims to reduce the engine's combustion temperature and thus reduce NO<sub>x</sub> via circulating part of the exhaust gas back into cylinder.
- Shore power: This refers to ship connection to port electricity so that the ship-board engines could be completely switched off. Full description in given in **Section 5**.
- Clean fuels: These include a variety of options such as ultra-low sulphur fuel, LNG, CNG, water-emulsified fuels, biofuels and so on. Most of these options not only reduce SO<sub>x</sub> but also NO<sub>x</sub> as well.

**Figure 3.1** summarizes various options, itemises potential applications for use at ports, provides estimates for the reduction potential for various pollutants and provides basic cost estimations of

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<sup>20</sup> International Council for Clean Transportation

<sup>21</sup> Description of these technologies is beyond the scope of this training course. The reader could refer to the internet for general information for each of these technologies.

each option. This shows a significant potential for alleviating air quality issues from ports but they mostly are considered as options for CO<sub>2</sub> reduction directly. In fact, most of these options may lead to a small increase in overall fuel consumption as for example NO<sub>x</sub> control methods most of the time makes engines less efficient. The description of these technologies is beyond the scope of this course but general information on each can easily be found on the internet.

Type	Technology Name	Application	Potential Emissions Reduction	Cost (US\$)
General Emissions Control Technologies	Diesel Oxidative Catalysts (DOC)		PM 20-30% HC 50-90% CO 70-90%	\$1,000-2,000 (Truck, CHE) \$3,000-4,000 (Marine) Variable Cost (Locomotive)
	Closed Crankcase Ventilation (CCV)		PM 15-20%	\$700 (\$48-50 filter replacement)
	Diesel Particulate Filters (DPF)		PM up to 90% HC, CO 60-90%	\$6-18K (Truck) up to \$40K (Marine, Locomotive)
	Selective Catalytic Reduction (SCR)		NO <sub>x</sub> 70-90%	\$36K (Truck & CHE) \$60K-120K (Marine)
	Lean NO <sub>x</sub> Catalyst (LNC)		Moderate NO <sub>x</sub> Reductions	\$14K (On-road) \$40K (Off-road (limited))
	Exhaust Gas Scrubbers		SO <sub>x</sub> 90-99% PM 60-80%	\$5M (Marine)
	Shore Power		Net emissions reductions	\$1-15M
On-Engine Modification	Exhaust Gas Recirculation (EGR)		NO <sub>x</sub> 40-50% PM 70% (with DPF)	\$12K (Truck) \$10M (Marine)
	Engine Replacement, Repower, Rebuild, Refuel		NO <sub>x</sub> up to 90% PM up to 90%	\$0.5-1.5M
	Slide Valves		PM 10-50% NO <sub>x</sub> 10-25%	\$1.5-16K (Marine)
Alternative Fuels	Ultra Low Sulphur Diesel (ULSD)		PM 5-15% SO <sub>x</sub> 99%	Surcharge: \$0.05-0.15/gal
	Biodiesel Fuel (BXX)		PM 15-70% HC 10-40% CO 10-50%	Surcharge \$0.25-0.40/gal
	Emulsified Diesel Fuel (EDF)		NO <sub>x</sub> 10-20% PM 15-60%	Surcharge \$0.25-0.40/gal
Operational Strategies	Vessel Speed Reduction (VSR)		Net reductions in NO <sub>x</sub> , PM, and other air pollutants	Net negative cost over time (balance fuel savings and travel time increase)
	Landside Operational Improvements		Net emissions reductions	Multi-million/billion dollar improvements

Notes: = Trucks, = Cargo Handling Equipment, = Marine, and = Locomotive. 1 icon = Low or uncertain deployment, 2 icons = Emerging, 3 icons = More Widespread. The technology and operational emission reduction options are diverse, and the per cent emission reduction estimates represent the potential reduction from best practices in each area. The associated cost ranges are illustrative, based on the most common such alternatives; "K" = 1,000 USD, "M" = 1,000,000 USD. Cost estimates are based on Starcrest (2012) estimates from the *Developing Port Clean Air Programs*.

Figure 3.1 – Port air emissions reduction measures according to ICCT December 2012 report

### 3.3 IMO ship-port interface study

The MEPC 68/INF.16 document presents the results of an IMO commissioned study that deals with a broad range of topics on ship-port interface including a large number of existing and future innovative technologies that ship owners and operators, ports, and other stakeholders can consider

and evaluate for reducing emissions in the port area. A number of technology classification has been done in this study including for example “existing technologies” that are considered to be readily implement-able to reduce emissions from various operational modes of ships associated with the port area. This IMO commissioned study’s focus is ship-port interface thus is not dealing with port-side measures.

### 3.3.1 Measures categories

Existing measures<sup>22</sup> are grouped into three major categories:

- Equipment measures
- Energy measures
- Operational measures

**Equipment measures:** Equipment measures consist of the following groups that are applicable mainly to diesel engines and boilers:

- Engine technologies
- Boiler technologies
- After-treatment technologies

**Energy measures:** The “energy” measures relate to energy sources used by a ship, whether they are physically located on board or on land (e.g., shore power). Energy measures include the following groups:

- Alternative fuels
- Alternative power supply

**Operational measures:** The operational measures refer to those that primarily affect and focus on the operation of the ship, terminal, or port and can be implemented for reduction of emissions of ships in the port area. This can take the form of operational efficiency improvement on board, at the terminal, and/or at the port. Operational measures include the following groups:

- Ship operational efficiencies
- Port/terminal operational efficiencies
- VOC working losses

### 3.3.2 Symbols used

The IMO commissioned report then provides a brief description of each measure including summary information about the measure, followed by discussion on how these considerations relate directly to the port area. The report then, in systematic way, summaries the findings using the following symbols as shown in brackets below:

- Applicable emission sources – describes which emission sources can be affected by the “measure” and include:
  - Propulsion engines (P)
  - Auxiliary engines (A)
  - Auxiliary boilers (B)
  - Applicable to propulsion engines, auxiliary engines, and auxiliary boilers (all)

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<sup>22</sup> In the original report, the term ECEEM (Emission Control and Energy Efficiency Measures) is used. In this course notes, the term “measure” has mostly replaces the ECEEM to simplify the text.

- Working VOC cargo tanks (Tank).
- Retrofit-able: This provides information if the measure can be retrofitted on existing ships with three options; (Yes – Y) or limited to only new builds (No – N), and not applicable (na).
- Terminal/vessel: The port/terminal operational efficiencies measures are sub-categorised as below:
  - Terminal (T)
  - Vessel (V)
- Applicable operational modes: This specifies the ship operational mode category in which the measure is effective. This operational modes are sub-categorised as:
  - Open water or sea conditions (S)
  - Transition (T)
  - Manoeuvring (M)
  - At-berth (B)
  - At-anchorage (A)
  - All modes (all)
- Emissions and energy efficiency: This lists the pollutant specific emission changes anticipated by the measure and provides a relative potential reduction. The IMO commissioned report highlights that emission reduction impacts are based on public data and published values, which do not necessarily represent verification by appropriate authority. For case where information have been available, the following symbols on impact of measure on emissions are used:
  - ↑ for increases in emissions
  - ↓ for decreases in emissions
  - ⇕ for either increase or decrease depending on various factors

If a percentage value is provided it represents the potential maximum value. If published levels or limited data are such that the reductions cannot be quantified at this time, then the symbol “to be determined” (tbd) denotes this case.

It should be noted that emission reduction levels are dependent on applicable modes, engine loads, ship power configuration, fuels, operational parameters, equipment parameters, and other factors. Typically, each application of a measure needs to be evaluated on a case-by-case (cbc) basis such that specific parameters and conditions are considered to determine the most appropriate reduction level. Energy consumption is included as an indicator for energy efficiency.

### 3.3.3 Study outcomes on existing technology measures

For each category, the IMO commissioned study presents a summary table within which the list of measures (first column) is given together with the applicability, retrofit-ability, applicable modes, and emission reduction potential for NO<sub>x</sub>, PM, SO<sub>x</sub> and HC and last but not least the “energy consumption” that denotes energy efficiency of some form. IN the following, a brief description of findings on various categories and measures are given.

#### Engine technologies

**Figure 3.2** shows the engine related technologies that are to a large extent comparable to items covered under ICCT report (**Section Figure 3.1**).

	Applicable Emission Source	Retrofittable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
<b>Engine Technologies</b>								
Repower	P/A	Y	All	≤80%↓	↓ cbc	–	–	↕ cbc
Remanufacture Kits	P/A	Y	All	↕ cbc	↓ cbc	–	↕ cbc	↕ cbc
Propulsion Engine Derating	P	Y	STM	↑ cbc	↕ cbc	–	tbd	↕ cbc
Common Rail	P/A	Y	All	≤25%↓	↓ cbc	–	–	≤5%
Exhaust Gas Recirculation	P/A	Y	All	≤60%↓	tbd	–	tbd	tbd
Rotating Fuel Injector Controls	P	N	STM	≤25%↓	≤40%↓	cbc	cbc	cbc
Electronically Controlled Lubrication Systems	P	Y	STM	–	≤30%↓	–	≤30%↓	–
Automated Engine Monitoring/Control Systems	P/A	N	ALL	≤20%↓	tbd	≤3%↓	–	≤5%↓
Valve, Nozzle, & Engine Timing NOx Optimization	P	Y	STM	↓ cbc	↕ cbc	–	↓ cbc	↑ cbc
Slide Valves	P	Y	STM	↓ cbc	↓ cbc	–	↓ cbc	↕ cbc
Continuous Water Injection	P/A	Y	All	≤30%↓	≤18%↓	–	–	–
Direct Water Injection	P/A	Y	All	≤60%↓	↕ cbc	–	↕ cbc	–
Scavenging Air Moistening/Humid Air Motor	P/A	Y	All	≤65%↓	↑ cbc	↑ cbc	–	↑ cbc
High Efficiency Turbochargers	P/A	Y	All	↓ cbc	↓ cbc	–	↕ cbc	↓ cbc
Two Stage Turbochargers	P/A	Y	All	≤40%↓	tbd	–	–	↓ cbc
Turbocharger Cut Off	P	Y	STM	≤40%↓	tbd	–	tbd	↓ cbc
Crank Case VOC Leakage	P	Y	STM	–	tbd	–	≤100%↓	–

**Figure 3.2 – Summary of engine technologies** [MEPC 68 INF.16]

As can be seen, many technologies are judged to be retrofit-able, they apply mostly to both propulsion and auxiliary engines, and their impacts on energy consumption and GHG emissions could not be quantified. Some of the measures could have negative impacts on energy efficiency.

### After-treatment technologies

**Figure 3.3** shows the after-treatment technologies that are mainly related to diesel engines exhaust gas after treatment systems. These technologies include scrubbers, SRC, etc. and the main aim for their use is to reduce exhaust pollutants rather than CO<sub>2</sub> emissions.

	Applicable Emission Source	Retrofittable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
<b>After-Treatment Technologies</b>								
Selective Catalytic Reduction (SCR)	All	Y	All	≤95%↓	–	–	–	↑ cbc
Exhaust Gas Scrubbers - Wet	All	Y	All	≤5%↓	≤80%↓	≤98%↓	–	↑ cbc
Exhaust Gas Scrubbers - Dry	All	Y	All	≤5%↓	≤80%↓	≤98%↓	–	↑ cbc
Barge-Based Systems	AB	na	B	≤95%↓	≤95%↓	≤95%↓	tbd	↑ cbc

**Figure 3.3 – Summary of engine exhaust gas scrubbing systems [MEPC 68 INF.16]**

As can be seen, many technologies are judged to be retrofit-able and they could significantly reduce ship exhaust pollutants. Unfortunately, these technologies will generally increase the ship’s energy consumption, thus the level of GHG emissions. The level of increase of energy consumption could not be quantified and will also depend on case by case.

### Alternative fuels options

**Figure 3.4** shows the alternative fuels that includes a large list of options such as natural gas, low sulphur fuel, bio fuels, methanol and so on.

	Applicable Emission Source	Retrofittable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
<b>Fuels</b>								
Low Sulfur Fuels	All	NA	All	↓ cbc	↓ cbc	↓ cbc	–	↓ cbc
Liquefied Natural Gas - gas only	All	N	All	≤88%↓	≤98%↓	100%↓	↑ cbc	↓ cbc
Liquefied Natural Gas - dual-fuel	All	Y	All	↓ cbc	≤78%↓	97%↓	↓ cbc	↓ cbc
Water in Fuel	All	Y	All	≤30%↓	–	–	–	–
Methanol	All	Y	All	↓ tbd	tbd	100%↓	tbd	↓ cbc
Biofuels	All	Y	All	↑	tbd	↓ cbc	tbd	tbd

**Figure 3.4 – Summary of alternative fuel options [MEPC 68 INF.16]**

As can be seen, many of alternative fuels are judged to be useable with current technologies (retrofit-able). Some demonstrates significantly reduction potential for exhaust gas pollutants. They may lead to reduced energy use or GHG emissions depending on a case by case analysis. The case for alternative fuel is well known to industry, regulations on ECA (Emissions Control Area) forces industry to use low sulphur fuel or other relevant alternatives in designated areas and the move to natural gas in the form of LNG is underway in some parts of the world.

### Alternative power system technologies

Figure 3.5 shows the alternative power technology options where on-shore power, barge power supply and solar power systems are highlighted.

	Applicable Emission Source	Retrofittable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
<b>Alternative Power Systems</b>								
On-Shore Power Supply	A	Y	B	≤95%↓	≤95%↓	≤95%↓	≤95%↓	≤95%↓
Barge Power Supply	A	Y	B	↕ cbc	↓ cbc	↓ cbc	↑ cbc	↕ cbc
Solar Power	A	Y	B	↓ cbc				

Figure 3.5 – Summary of alternative power systems [MEPC 68 INF.16]

As can be seen, the on-shore power system is the most effective system for reducing ship air pollutants. On other technologies, the level of reductions is not clear and will be case by case dependent. Also, on energy consumption and GHG emissions, the impact is not clear cut and the number for on-shore power only refers to ship-board fuel consumption reduction since same amount of energy will be used but this time in the form of electricity from onshore.

### 3.3.4 Future innovative technologies, fuels and operation processes

The measures included are those innovative technologies, fuels and operation methods that:

- Possess a clear theoretical potential for emission reductions or efficiency improvements that is either not yet tested in real-world application or exists primarily in a prototype phase of development.
- Are available and ready to be deployed and is in limited or niche use, but with a substantial potential for expansion if certain key barriers like cost can be overcome.
- Are being used at land-side facilities or in other applications from which it can be adapted and re-engineered for application in the maritime sector.

Figure 3.6 shows a large number of alternatives in this area, some relating to existing technologies but some are purely new measures.

	System Applicability	Retrofitable	Market Maturity	NOx	PM	Efficiency Improvement	Cost
<b>Measures from Existing List</b>							
Engine Optimization Technologies	P	Y	M/E	↓	↓	↑	↕
Engine Automation and Data Collection	P/A	Y	M/E	↓	↓	↑	↓
Turbocharger technologies	P	Y	M/E	↓	↕	↑	↕
Combustion Water Technologies	P	Y	M/E	↓	↕	↕	↑
Shore-based exhaust treatment systems	P/A	Y	L/E	↓	↓	↕	↑
Automated Berthing	O	Y	M	↓	↓	↑	↓
Alternative Fuels	P/A	Y	M/E	↕	↕	↕	↕
Solar Power	E	Y	M	↓	↓	↑	↓
<b>"New" Measures</b>							
Variable camshaft timing	P	Y	L/E	↓	↓	↕	↓
Selective non-catalytic reduction (SnCR)	P	Y	L/E	↓	↕	↕	↑
Low-Temperature SCR	P	Y	L/E	↓	↕	↕	↑
Low NOx Burners	B	Y	L/E	↓	↕	↕	↑
Electrical System Improvements	E	Y	M	↓	↓	↑	↓
Low energy lighting	E	Y	M	↓	↓	↑	↓
Multi-mode propulsion	P	N	M/E	↓	↓	↑	↕
Battery Hybrids	P/E	Y	L/E	↓	↓	↑	↓
Fuel Cells	P/E	N	L/E	↓	↓	↑	↓
Vessel size increase	O	N	M	↓	↓	↑	↓
Megaboxes	O	N	T	↓	↓	↑	↓
Alternative cargo Loading	O	N	T	↓	↓	↑	↓
Mid-stream operations	O	Y	L/T	↓	↓	↑	↓
Virtual Arrival and Alternative Berth Policies	O	Y	M/E	↓	↓	↑	↓

**Figure 3.6 – Summary of innovative and emerging technologies** [MEPC 68 INF.16]

As can be seen, many of these measures are judged to reduce not only air pollutants (NOx and PM) but also improve (increase) the energy efficiency of the ship and reduce costs.

### 3.3.5 Study key findings

From the above technical and operational measures identified and studies, the following key findings relevant to this section are reported by the MEPC 68/INF16 report:

- Numerous technical measures are available to effectively reduce emissions and increase energy efficiency, and experience with some of the measures implemented in the port area goes back over ten years and is growing. The range of available technical measures is quite

extensive including engine and boiler technologies, after treatment technologies, fuel options, alternative power systems, operational efficiencies, and cargo vapour recovery.

- There are no “one size fit all” technical measure solution for ships and ports. Due to numerous variables such as pollutant(s) targeted, port configuration, cargos handled, drivers, barriers, vessels servicing the port area, vessel configurations, operational conditions and the nature of technical measures, each measure needs to be analysed on a case-by-case basis in advance of implementation.
- Several emerging and innovative technologies and measures potentially could provide additional options to reduce emissions from ships in the port area. There are initiatives underway from various stakeholders that are focused on the demonstration of emerging technologies and measures, with the ultimate goal of bringing them to the market in an expedited fashion.

### **3.4 References and further reading**

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. MEPC 68/INF.16, “Study of emission control and energy efficiency measures for ships in the port area”, MEPC 68/INF.16, 4 March 2015, report prepared by Starcrest Consulting Group, LLC CE Delft and Civic Exchange.
2. ICCT December 2012, “Workshop brief: Technologies and operational strategies for best practices in port clean air programs” A report prepared for the International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, December, 2012.
3. ICCT June 2012, “Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor’s Air Quality Toolbox”, June 2012

## 4 Ship in-port operational energy efficiency measures

### 4.1 Introduction

When the ship arrives at a port, there are some limited scope for the ship to reduce its fuel consumption while at anchor or at berth. Despite the fact that such reduction in fuel consumption may not have significant impact on a ship's overall annual fuel consumption; the impact on port air quality could be significant. Therefore the question "if ship-board staff could do anything to support a more efficient ship-in-port operation" is main topic of this section.

A number of measures could be identified that if implemented would reduce fuel consumption for the benefit of ship's energy efficiency and port air quality. These measures are analysed by assuming that ship will not be connected to shore power or a major switch in terms of fuel type will not take place as these changes may make some of the arguments put forward herein redundant.

The aspects covered in this section are simple day to day ship-board operational measures that can be undertaken by all ships. In fact, some of them could be implemented also by harbour and port support vessels.

The main ship-board systems working when ship is at anchor or at berth include:

- Auxiliary machinery and equipment
- Diesel generators,
- Boilers

Additionally and on some ships, cargo handling equipment may be in operation that would provide extra opportunities and further measures for energy saving. However, in this section, the above three items are only investigated.

### 4.2 Operation of auxiliary machinery

The ship's diesel generators operate in port in order to produce electricity for operation of a large number of machinery and systems in engine room, deck and accommodation areas. Amongst them are the engine room auxiliary machinery like fans, pumps and other devices. On the accommodation side, the need for lighting, HVAC and galleys exists in port. In order to save energy and reduce emissions, auxiliary machinery utilisation in port should be minimised with consideration for safety.

There are practical evidences showing that such machinery are normally over-utilised in ports. Ship staff may follow the same processes as sea-going condition and keep the machinery running in the same way as during sea going conditions. This could also be considered as a way of avoiding additional processes, remain ready to leave the port without the need to re-start some of the machinery and for simple reasons that the company may not have plans and procedures on how the port operations with regard to machinery utilisation need to be handled.

This should not be the case and it can be changed via specific planning for the engine room machinery operations for at-berth/at-anchor operation to ensure energy efficiency while safety is taken into account. The main aim of the plan will be to save energy via switching off the unnecessary machinery. As examples, the following may be undertaken:

- Minimising the number of running auxiliary machinery based on port operation requirements. There are a large number of pumps on board such as sea water cooling pumps, steering pumps, engine water circulating pumps, engine lubricating oil pumps, etc. All these need to be investigated and a plan for their port-operation should be devised based on port requirements.

- Minimising the number of A/C units operated or switch them off when conditions permit.
- The number of engine ventilation fans should be reduced in port or brought to slower speed. Since main engine(s) is not working in ports, there is no need to run all the engine room ventilation fans.
- The fuel treatment machinery need to be reviewed if they all needed to run in the same way as sea-going condition in view of the significant reduction of ship fuel consumption because of main engine being switched off.
- Minimisation of use of compressed air and its use where required. Compressed air is an expensive commodity and for example should not be used for ventilation purposes.

As indicated, these measures will provide less demand for electric generation and thus will lead to reduced fuel consumption. Additionally, the machinery run hours will reduce and this will be beneficial from maintenance point of view.

There are opportunities for reduction of energy needed in the accommodation area when in port. Although these measures are applicable to sea going conditions as well, it will be more effective under port condition. Some aspects include:

- Lighting system: The lights in spaces when not in use can be switched off and deck lighting during day hours can be avoided.
- Galleys: The galley area also provides some opportunities. For example lighting and electric equipment can be switched off after use.
- Deck lighting: No need for lighting during day time.

These measures also help to reduce demand for electric power.

### 4.3 Use of auxiliary engines

In ports, many ship staff run two auxiliary engines (diesel generators) in parallel to safeguard security of electric power supply. This is not needed for most of normal berth activities or when at anchor. When two engines operate in parallel, each run at very low loads thus give higher pollutant levels, consume more energy (they operate less efficiently) and the operation mode not good for engine components and maintenance.

Therefore, it is best practice if unnecessary cases of operation of two diesel generators can be minimised. In **Module 4**, this topic was covered in detail with an example showing how reducing this aspect could lead to energy saving. This would equally reduce air pollutants to port as well.

To do this safely, the communication between deck department and engine department is crucial. If such communications are effective, then the engine room control engineers could pre-plan diesel generator operations in ports.

### 4.4 Operation of boilers in port

Boilers form a major part of ship-board energy consumption in ports in particular for certain types of ships such as oil tankers. Although boilers emit less harmful emissions than diesel engines (e.g. less NO<sub>x</sub>), nevertheless the control of their energy use will be beneficial for the port area emissions. This is the case as the ship auxiliary boilers mostly operate at low loads while in port. At low loads, the energy efficiency reduces and emissions factors increase that is not helpful.

The following ship board measures could potentially reduce the usage of boilers in ports:

- Use of parallel operation of two boilers should be avoided. This not only improves the efficiency of the working boiler but also gets rid of electrical requirements for the second auxiliary boiler.
- Planning and optimisation of cargo discharge operation is another area if it relies on steam driven cargo pumps (e.g. larger oil tankers). In some of the ships, there may be provisions for a mix of electric and steam driven pumps. Proper planning could be done to avoid excessive use of boilers.
- Plan and optimise ballast operation if it relies on steam driven ballast pumps. In many ships, the ballast pumps are now electric driven or a mix of steam and electric drives are used for this purpose.
- All aspects covered in relation to steam system maintenance in Module 4 on reducing the ship-board steam demand will also help the port operation. In other words, steam users need to be investigated and their operations decided based on port requirements.

In some ships such as oil tankers, auxiliary boilers may be used for inert gas generation (IGG). The whole process of generating inert gas and its use can be part of optimisation; as for inner gas generation, the boiler would normally run at very low load (normally a dedicated IGG system is used to avoid use of large boilers).

#### 4.5 Ship operational efficiency measures

The IMO commissioned study on ship-port interface [MEPC 68/INF.16] was discussed in detail in Section 3 of this module, also provide a list of operational measures as shown in Figure 4.1.

	Applicable Emission Source	Retrofittable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
<b>Ship Operational Efficiencies</b>								
Vessel Speed Reduction/Slow Steaming	All	Y	STM	↓ cbc				
Optimization of Ship Reefer Systems	All	Y	All	↓ cbc				
Optimization of Ship Systems	A	Y	All	↓ cbc				
Optimization of Fleet Sizing to Maximize Vessel Efficiency	All	Y	All	↓ cbc				

Figure 4.1 – Summary of ship operational measures [MEPC 68/INF.16]

Of the measures listed above, the optimisation of ship reefer system and other cargo conditioning systems need to be also considered as a case by case basis.

#### 4.6 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. “IMO train the trainer course material”, developed by WMU, 2013.

2. MEPC 68/INF.16, "Study of emission control and energy efficiency measures for ships in the port area", MEPC 68/INF.16, 4 March 2015, report prepared by Starcrest Consulting Group, LLC CE Delft and Civic Exchange.
3. ICCT December 2012, "Workshop brief: Technologies and operational strategies for best practices in port clean air programs" A report prepared for the International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, December, 2012.

## 5 Onshore Power Supply (OPS)

### 5.1 Introduction

During the ship's port operations and at berth, auxiliary engines are run in order to generate electricity for supply to ship-board systems as well as to the cargo loading or loading/unloading machinery, where applicable. Today, this power is generally provided by auxiliary engines that emit carbon dioxide (CO<sub>2</sub>) and air pollutants, affecting local air quality and ultimately the health of both port workers and nearby residents.

As an alternative to on-board power generation, vessels can be hooked up to an onshore power supply, i.e. connected to the local electricity grid. In this way ships' operations can proceed uninterrupted, while eliminating negative side-effects. The amount of power generated and fuel consumed is dependent on type of ships and could be anything from a few hundred kW to several MW of electric power. The operation of auxiliary engines is a major source of SO<sub>x</sub>, NO<sub>x</sub> and Particulate Matters (PM) emissions to ports. The amount of emissions is generally proportional to the amount of fuel used. The longer the ship stays at berth or at anchor, the higher the ship fuel consumption will be and thereby the more the exhaust pollutants emitted to the port.

Concern over air quality in ports has led to growing pressure on port operators to reduce exhaust emissions; in particular pollutants of SO<sub>x</sub>, NO<sub>x</sub> and PM. The supply of power from onshore (port) to ship is one system that has been advocated for this purpose. Use of this system allows ships to turn off their auxiliary engines when in port and plug into a shore-side electricity supply. As a result, not only air emissions to port are reduced but also it helps positively with other aspects of the ship and port operations. It is claimed that this system, in addition to the environmental and social benefits, could provide economical savings to all stakeholders. However, this last point has yet to be validated.

Onshore Power Supply (OPS), as defined above, has been known for a long time in particular for naval ships, where the ship normally stays at berth for a long period of time. Under such conditions, it is cost effective to run the vessel via a supply of electricity from shore. This was used by the US Navy originally and the term "cold ironing" originates from this naval application. Over the years, other terms have also been used for OPS; some of which are listed below:

- Alternative Maritime Power (AMP)
- Shore side electricity
- Shore power

In this section, the term Onshore Power Supply (OPS) will be used throughout. **Figure 5.1** shows a typical OPS system.

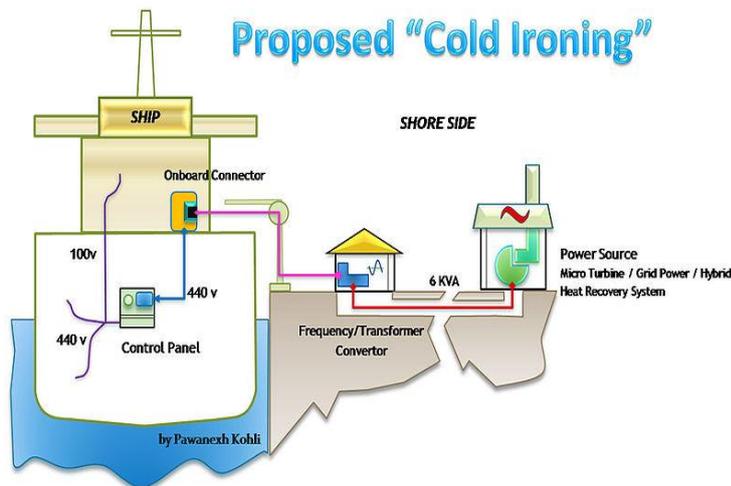


Figure 5.1 – Typical OPS arrangement [Wikipedia]

## 5.2 The case for OPS

Ships normally use some base-load electricity levels for essential services all the time, including while at berth. For a case of a typical mid-size tanker, this could be about 400 kW (excluding the electricity needed for cargo operations and ballast operations). For such a tanker staying at port for 30 hours, it would require 12 MWh of electricity; the longer the vessel stays at berth, the larger this figure will be. For an average cruise ship, the electrical requirement could be about 8 MW. For such a cruise vessel, staying at berth for 12 hours will require 96 MWh of electric power. Generating this power on-board generates NO<sub>x</sub>, SO<sub>x</sub>, PM and CO<sub>2</sub> emissions that could be significant if the number of ships at berth, and/or their duration of stay, or number of calls increase.

The environmental profile of electricity generated by power plants on land versus ships' diesel electric generators running on bunker fuels, is one of the main advantages of OPS technology. In land-based power plants, electricity can be generated at high energy efficiency in large efficient power plants with the use of either clean fuel or exhaust gas cleaning systems. Also, electricity is generally generated in remote areas beyond population centres with minimal air quality impact on population centres. On the contrary, ship-board generation is not as energy efficient as land-based plants and also any exhaust emissions from engines directly pollutes the port and surrounding areas. The reason that ship board generation is less efficient is due to smaller engines<sup>23</sup> used (with an MCR of up to 2,000 kW) as well as part-load operation (engine load factors<sup>24</sup> at berth barely go beyond 50% for most of the time).

OPS will substantially but not completely reduce SOX emissions as the steam generated by the on-board boiler is still needed for some ship's operation at berth. Nevertheless, OPS have been widely used as a viable way to reduce ship-based local polluting emissions. The California Air Resource Board, for example, requires a fleet operator to reduce at-berth emissions from its vessels' auxiliary engines at each California port by approximately 80 percent by 2020 either through connecting the vessel to shore power or through alternative control technique(s) that achieve equivalent emission reductions. Major ports in Europe, such as Antwerp and Gothenburg, are also engaged in provision

<sup>23</sup> As a general rule, the smaller the engine, the lower its energy efficiency is. Thus larger power plants and engines are generally more energy efficient.

<sup>24</sup> Engine load factor is the ratio of actual load to MCR in percentage.

of shore power to ships. Shore power is also being developed in some ports in China, such as Shanghai and Lianyungang. It is expected that lowered cost resulting from the economy of scale and standardization will make the OPS more attractive in the future [ICCT December 2012].

The use of OPS thus could be seen primarily as a green port initiative in order to improve the port air quality. For ports, the ability to supply power to ships at berth enables them to establish a more efficient overall electrical supply and also act as a utility; i.e. as an organisation that sells electricity to ships. For the port and ship staff closely linked to ships while at berth, there is an additional benefit of reduced noise and vibration in harbour areas. For ship staff, when the system is fully operational, more time will be available to deal with maintenance and other aspects of port-related activities.

OPS are best for ships that make multiple calls at a particular terminal for multiple years. The best candidates for OPS are container ships, reefer ships, and cruise ships because they tend to operate in these types of regular services and require substantial electricity while at berth.

### 5.3 Infrastructure requirements

Installing new shore power systems requires shore-side infrastructure and can be expensive, but can also result in major reductions in port emissions. The infrastructure is typically constituted of power connection to utility, power transformation, conditioning and switching equipment, and land for these facilities, cabling, synchronization equipment, and berth side infrastructure. Shipland infrastructure is also expensive, but the cost has been declining with more streamlined and standardized designs. The cost difference between the grid power, especially the high demand charges, and price of bunker are key factors in business case for OPS. Low price differential of electricity over HFO can provide a strong incentive to the use of the shore power.

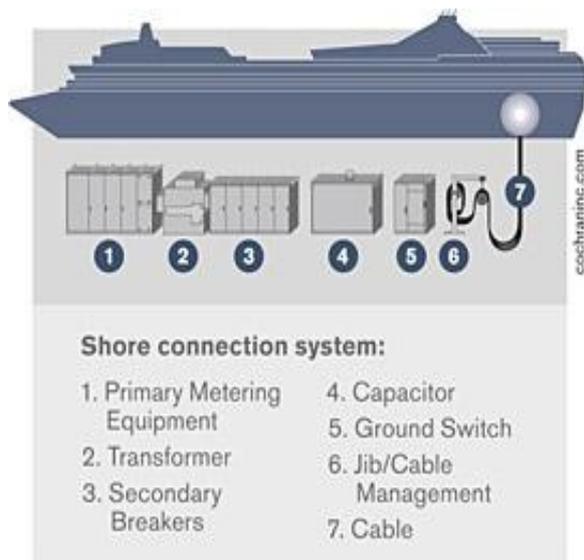
To use OPS, there will be a need for extra investment both at shore-side (port) and ship side. As the responsibility for supply of electricity to ship is with port, the capital investment of ports will be more significant. Additional investments stem from construction and installation of electricity supply conditioning/safety systems at the quay and potential needs related to strengthening the port's electricity grid.

#### 5.3.1 Shore-side requirements

Power supply in ports is typically equivalent to that of a small size factory, with electricity needed for shore-side loading and unloading infrastructure such as cranes, belts and gantries, cooling, heating, buildings as well as incidentals. Most ports have access to enough power to run these consumers.

Given that a vessel's at-berth power needs may be as much as 10 MW, depending on the type of vessel, (this high value is for cruise ships; for cargo ships it will be up to a maximum of 3 MW), the electrical infrastructure at many ports will be insufficient to handle significant shore-to-ship power connections without a major improvement to their grid. This may involve investing in a new substation or installing new incoming power lines with the associated costs for the port and power supplier.

Within ports, OPS solutions often comprise the entire chain from the incoming substation and include transformers and frequency converters to match the grid voltage and frequency to the ship's required voltage and frequency. A typical port-based system is shown in **Figure 5.2**:



**Figure 5.2 – Typical shore-side requirements**

Accordingly, the shore side system requires the following:

**Transformer for voltage reduction:** The transformer steps down the power supply from a voltage level optimized for distribution (eg, 20 kV) to one of the two voltage levels standardized for shore-ship power connections (e.g. 11 or 6.6 kV) as required by the ship.

**Switchgear for electrical safety:** Each shore-based power connection point requires some sort of medium-voltage switchgear with an automated earthing switch. In essence, the switchgear interrupts the power supply and ensures that there is absolutely no power in the cables between the ship and shore while they are being handled and connected.

**Frequency converter:** The majority of ships operate with a 60 Hz supply, whereas local power grids in many parts of the world use 50 Hz. As a result, most shore-based power connections will require a frequency conversion. Static frequency converters provide an economical solution to connect any ship to any grid independent of the required frequency.

**Automation system:** The shore side infrastructure for a shore-to-ship power connection must include an automation and communications system that allows personnel to coordinate the connection of cables and synchronize the ship's electrical load to the shore side supply.

### 5.3.2 Ship-side requirements

To use power from the shore-side electricity grid, ships must be either built or retrofitted with equipment that enables the connection to shore to synchronise the power change-over from shore to ship and connects the incoming power supply to the ship's auxiliary power system.

Ships can be safely retrofitted with such devices in a relatively short time while in operation or during dry docking, without major interruption to normal operations. Currently, the majority of ships equipped with the equipment to receive shore-side power are container vessels and to some extent cruise ships that are mainly the retrofitted equipment.

## 5.4 Standardization

In order for OPS to become widespread among various ports and ship-owners, the nature and arrangement of power connections must be standardized. Neither a port owner nor a ship-owner

can justify investment in expensive equipment to enable a shore connection system without assurance that such a system will be functional across many countries with alternative electrical characteristics in terms of voltage, frequency and other aspects.

Work on a common standard for OPS for ships at berth began early in 2005. Major players in this effort have included technology suppliers, governments, port authorities, ship-owners (particularly cruise line, tanker and container ship companies), classification societies and others. The IEC, ISO and IEEE have joined forces and developed the international standard "ISO/IEC/IEEE 80005-1:2012 ISO/IEC/IEEE 80005-1 Utility Connections in Ports - Part 1: High Voltage Shore Connection (HVSC) Systems -- General requirements". This standard revised the "IEC/PAS 60092-510:2009 Electrical installations in ships -- Special features – High Voltage Shore Connection Systems (HVSC-Systems)" and addresses the connection between ship and shore and the procedures for safe operation.

The full content list of the ISO/IEC/IEEE 80005:2012 can be seen here<sup>25</sup>.

## 5.5 Port related initiatives

The International Association of Ports and Harbours has provided information to IMO on the World Ports Climate Initiative and also established a website<sup>26</sup> to provide practical information about OPS for seagoing vessels and shore installations. The website provides information on numerous issues connected with OPS such as power generation, voltage and frequency, safety and health, costs, implementation, ports utilizing OPS, etc.

The latest list of ports with some degree of OPS capability is given in **Table 5.1**.

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<sup>25</sup> <https://www.iso.org/obp/ui/#iso:std:iso-iec-ieee:80005:-1:ed-1:v1:en>

<sup>26</sup> <http://wpci.iaphworldports.org/onshore-power-supply/environment-and-health/climate.html>

Port	Country	High Voltage	Low voltage	Frequency
Antwerp	Belgium	6.6 kV		50 Hz/60 Hz
Goteborg	Sweden	6.6 kV/10 kV	400 V	50 Hz
Helsingborg	Sweden		400 V/440 V	50 HzV
Stockholm	Sweden		400 V/690 V	50 Hz
Piteå	Sweden	6 kV		50 Hz
Kemi	Finland	6.6 kV		50 Hz
Oulu	Finland	6.6 kV		50 Hz
Kotka	Finland	6.6 kV		50 Hz
Lübeck	Germany	6.6 kV		50 Hz
Zeebrugge	Belgium	6.6kV		50 Hz
Los Angeles	U.S.A	6.6 kV/11 kV		60 Hz
Long Beach	U.S.A	6.6 kV	480 V	60 Hz
San Francisco	U.S.A	6.6 kV/11 kV		60 Hz
San Diego	U.S.A	6.6 kV/11 kV		60 Hz
Seattle	U.S.A	6.6 kV/11 kV		60 Hz
Juneau	U.S.A	6.6 kV/11 kV		60 Hz
Pittsburgh	U.S.A		440 V	60 Hz
Vancouver	Canada			
Oslo	Norway	6.6 kV		50 Hz
Rotterdam	Netherlands	6.6 kV		50 HZ

**Table 5.1 – Ports with OPS at 9 October 2012 [IMO MEPC.1/Circ.794]**

## 5.6 IMO regulations

Currently and at the time of writing this document, there is no IMO regulation on OPS. In fact, IMO has developed minimal regulations on ports development/operation other than those that may directly be required for ship operation (such as reception facilities). Thus, there have been proposals to add some new regulations to MARPOL Annex VI on introducing some ships' requirements for the future wider use of OPS. For example, it is proposed that ships should undertake an assessment of the environmental benefits as well as cost-benefit of addressing emissions from ships at berth. As part of this, it should be taken into account how the supplied electrical power is generated, and if similar environmental benefits could be achieved by other more cost-effective means.

As part of the proposed draft regulation<sup>27</sup>, submitted by Seden to MEPC 55 in 2006, it is suggested:

- Ships that can document that their on-board power production has lower total emissions than the supplied shore side electricity should, if no other local circumstances dictate otherwise, be exempted from the requirement to connect to shore-side electrical power.
- No ship should be required to connect to OPS when the planned port stay at the actual berth is less than a couple of hours (e.g. 2 hours).
- The port or terminal shall provide sufficient electrical power to sustain all normal operations during the port call, including calculated peak consumption.
- The costs for the ship to connect to shore power at berth should not exceed the average comparable costs of port services in general and the cost of supplied electricity to shore-based consumers within the vicinity of the port or terminal.

The apparent aim of the above proposals seems to be to protect ship owners from undue pressures by ports to force them to use OPS without good and reasonable business or environmental justifications.

Subsequently, IMO reviewed the situation in MEPC 64 meeting in 2012 and while considering various views including the above proposal concluded that:

“The majority was of the view that ports equipped with on-shore power supply are limited and mandatory requirements for the on-shore power supply should not be developed at this stage. The MEPC agreed to request the IMO Secretariat to disseminate the information relating to the on-shore power supply, e.g. lists of relevant standards and ports providing onshore power supply as MEPC.1/Circ.794” [IMO MEPC 64/23].

## 5.7 OPS effectiveness

There are a number of items and issues to be considered when opting for OPS as detailed in ICCT report [ICCT June 2012] from which most of the text of this section are taken. These include infrastructure development and source of electricity and cost effectiveness. In order to provide OPS infrastructure on-berth and on-board vessels, first the necessary power needed should be estimated and ensure adaptability. It is important to consider the local power company that is providing the electrical power to the port and environmental characteristics of the supplied electricity plus transmission losses. A local power company that uses a cleaner source of energy with use of emission control technologies will optimize the overall benefits of shore power.

OPS is not universally effective for all ships and ship types. OPS works best when ships operate in liner-type services that have the same vessels calling frequently over a number of years to the same terminals. Liner-type services typically include cruise ships, containership, some bulk liquid and chemical/product tanker operations, LPG tankers, LNG tankers, and some general cargo operations.

In addition to frequency of calls by the same ships to the same terminal, another key factor is the amount of energy the ship uses while at berth. Energy is the product of ship power demand while at berth and duration at berth. Cruise ships represent one extreme as they have short times at berth,

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<sup>27</sup> <http://www.sjofartsverket.se/pages/9333/55-4-13.pdf>

however their power demand at berth is high, as are their berthing frequencies. Other vessel classes have lower power demand at berth; however they are at berth for longer periods. In addition to frequent calls per year, it is important to note that these same vessels need to continue to call for several years in a row to make the OPS cost effectiveness in terms of cost versus tonnes of emissions reduced.

The most expensive part of OPS infrastructure is shore-side infrastructure. Converting an existing port to OPS capabilities can be significant and the cost varies by each port. One of the most expensive container terminal retrofit projects actually built was the China Shipping berth at Port of Los Angeles which cost ~\$7 million. Based on the range of feasibility studies done by ports in the US and Canada, a normal range of costs to provide shore power at a berth can be between about US \$1 - \$15 million. These costs vary significantly depending on the extent of terminal rebuilding, the proximity to adequate electricity supplies, and the ability to locate the shore-side infrastructure. There are also less expensive temporary approaches that use large, portable LNG generators placed on the dock near the front of the ship and connect to a ship's bow thruster electrical circuit. These systems require about \$200,000 to refit each ship and approximately \$1,000 per hour for the generator. The Port of Oakland, whose shore-side infrastructure for standard cold ironing was estimated at \$90 million, has successfully demonstrated this system and intends to make it available to all of its customers in the near future.

The ship-side OPS retrofit capital cost can range from \$400,000 to \$2 million per ship due to the wide variety of ship designs. These costs have been coming down as more retrofits have led to more streamlined and standardized designs. Many new ships currently being built are including OPS systems or implementing designs that would make future retrofits less costly.

The cost of grid power is another key factor when estimating cost effectiveness. Also, the bunker price makes a significant role in cost effectiveness. The higher the bunker price and the lower the electric grid price, the more cost effective will be the shore power investments. In USA, the shore power projects in California have been awarded grants under the Carl Moyer Grant Program. The first was to the Port of San Francisco and the second was to the Port of San Diego. These awards demonstrate that OPS can be a cost effective strategy under the right conditions. Cost effectiveness estimates vary significantly by terminal, by port, and by region. A detailed cost effectiveness analysis needs to be completed on a project-by-project basis to determine what the real cost impacts would be.

Without a full-blown analysis, it is possible to estimate the potential costs and benefits of a cold ironing system using three key pieces of information: 1) energy cost; the costs of the fuel ships use at berth and the cost of on-shore provided electricity, 2) the cost of retrofits both to ships and to port terminal facilities providing the electricity, and 3) the frequency and duration with which the system will be used. Such an analysis was performed and is documented in reference.

## **5.8 OPS and energy efficiency**

There is no doubt that OPS leads to significant reduction in air pollutants in ports and areas at their vicinity. However, the case for overall energy efficiency of the OPS in terms of power used while including all the transmissions losses and overall CO emissions to atmosphere is not clear. Although both have been advocated by OPS enthusiast as justification for OPS and reduction of ship-owners' energy cost, this topic is not certain and most likely will vary case by case.

### 5.8.1 Energy efficiency

The energy efficiency of OPS relative to ship-board generation needs to take into account all the various forms of energy transfer and transformation losses along the transfer route. In addition, the thermal efficiency of a land-based power plant versus ship-board systems needs to be taken into account.

In general, it is estimated that transmission losses from a land-based power plant to the ship will be around 10 to 25% depending on the supply transmission network (i.e. an average value of about 17.5%). This means that from the energy efficiency and CO<sub>2</sub> reduction points of view, the land-based power plant needs to be generating less CO<sub>2</sub> by at least 10 to 25% compared to ship-board generation. As indicated above, this will vary from case to case and needs specific studies for various ports.

On the other hand, the case in favour of OPS is the operating condition of auxiliary diesel engines while at berth. This should be borne in mind while at berth, since the auxiliary engines normally work at a part load of about 40 to 50%. Under this loading condition, the engine efficiency is lower than the optimum value and the emissions are higher.

There is occasionally discussion on future low-carbon electricity that could be supplied to ports (or generated by a port itself) for supply to ships. There are a number of solutions, such as the use of greener energy in ports. As an example, there have been cases where LNG-based power plants are advocated for port-side power generation. Such cases yield a significant reduction in both CO<sub>2</sub> and pollutants and get rid of transmission losses over the grid. The drawback is port self-generation that is not the core expertise of shipping ports. For ports deciding on self-generation, there is a case to help the grid when they have excess electricity and thereby impose less overall load on the grid.

### 5.8.2 Energy cost

The issue of energy cost is important for ship-owners. There is evidence that the overall cost of OPS electricity may be higher than the on-board generation for the following reasons:

- A tax on electricity will normally be applied if it comes from OPS. The tax level may change from case to case and country to country.
- The base cost of electricity as supplied to ports may be high.
- The port charges which are intended to cover the investment and running costs will be added to electricity price.

All the above require detailed studies for each port. To reduce the cost of pollutants on society and port areas, there may be a need to transfer the burden of cost to ships as they represent the main source of pollutant. However, since this may vary from port to port, it will have an impact on port business as well.

## 5.9 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. "IMO train the trainer course material", developed by WMU, 2013.
2. Wikipedia, "Cold ironing" [https://en.wikipedia.org/wiki/Cold\\_ironing](https://en.wikipedia.org/wiki/Cold_ironing), cited August 2015.
3. IMO MEPC.1/Circ.794, "On-Shore Power Supply", MEPC 63, 9 October, 2012

4. WPCI, "On-Shore Power Supply", <http://wpci.iaphworldports.org/onshore-power-supply/environment-and-health/climate.html> Cited August 2015.
5. WPCI,"World Port Climate Initiative website on on-shore power", <http://www.ops.wpci.nl/what-is-ops-/what-is-ops--1/>, Cited September 2015.
6. MEPC submission by Sweden "Standardization of On-Shore Power Supply", MEPC 55/4/13 , August 2006, <http://www.sjofartsverket.se/pages/9333/55-4-13.pdf>, Cited August 2015.
13. ICCT December 2012, "Workshop brief: Technologies and operational strategies for best practices in port clean air programs" A report prepared for the International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, December, 2012.
14. ICCT June 2012, "Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor's Air Quality Toolbox", June 2012.
15. IMO MEPC 64/23, "Report of the Marine Environment Protection Committee on its Sixty-Fourth Session", 11 October 2012.

## 6 Green Port Initiatives and Port Environmental Programs

### 6.1 Introduction

Apart from Onshore Power Supply (OPS) that could lead to improved air quality in port areas and likely reduction of GHG emissions, various ports are promoting green initiatives that aim to reduce air emissions from ships. Green port initiatives are in place in particular in USA, Europe and to some extent Asia. In the majority of cases, reduction of air pollution and improving the port area air quality are at the core of the green port initiatives.

Green port initiatives could take many forms and shapes, but the main purpose as indicated to reduce port-area emissions. Example activities could be reduced port dues for clean ships, investment in port infrastructure to improve port operations, providing OPS facilities, reducing or exemption from taxation for clean ships, etc.

In this section, a number of port related green activities that relate to air emissions are presented and discussed.

### 6.2 Port related VOC management

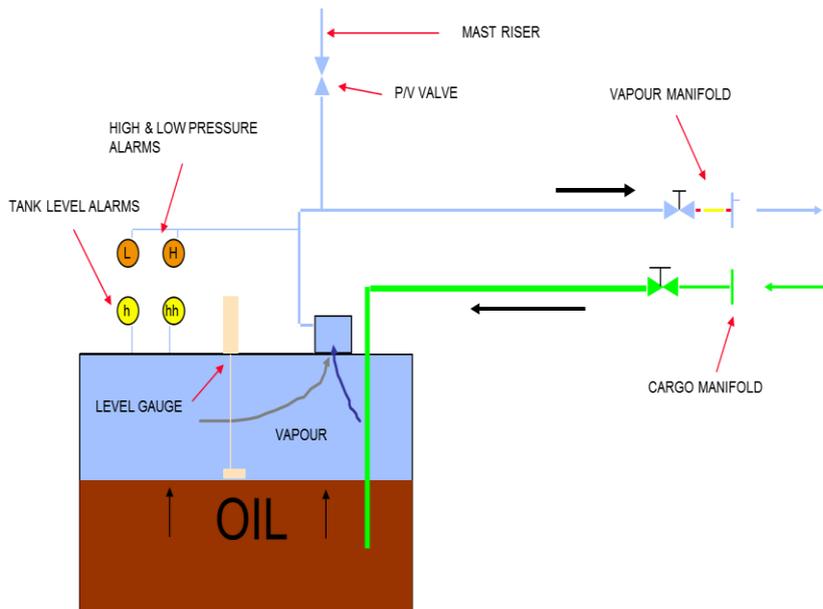
Volatile Organic Compounds (VOCs) are the lighter parts of crude oil, or their products. They normally vaporise during the ship loading process in the loading tanks. This is then normally vented to the atmosphere causing air pollution in port areas.

IMO MARPOL Annex VI regulations allow the Flag state to designate ports that intend to control and reduce VOC from tankers. This is embodied in Annex VI Regulation 15 on VOC. The regulation enables ports and terminals to implement VOC controls.

For compliance purposes, these ports should be able to receive such gases and collect and safely dispose of them. Tankers that visit such ports should also have a Vapour Emissions Control System (VECS) to be compliant with IMO MSC/Circ. 585 on Standards for VECS system. **Figure 6.1** shows a schematic of such a ship-board VECS. Further information on technical information on systems and operation to assist development of VOC management plans can be found in the relevant IMO MEPC Circular (MEPC.1/Circ.680, 27 July 2009)<sup>28</sup>.

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<sup>28</sup> MEPC.1/Circ.680, 27 July 2009 "Technical information on systems and operation to assist development of VOC management plans"



**Figure 6.1 – Schematic of an oil tanker’s VOC emissions control system**

Additionally, crude oil tankers are required to have an approved VOC manual. This should contain procedures for minimizing VOC emissions during loading, sea passage and discharge and additional VOC during washing.

Currently, a number of ports have been assigned as VOC control ports; see the list below (**Table 6.1**).

**DESIGNATED PORTS AT WHICH VOC EMISSIONS ARE REGULATED**

NAME OF PORTS, TERMINAL/FACILITY		SIZE OF TANKERS	CARGOES REQUIRING VAPOUR EMISSION CONTROL SYSTEMS	EFFECTIVE DATE
<b>The Netherlands</b>				
Amsterdam	All terminals	All sizes	Cargoes with VOC, with the exception of methane, with a vapour pressure of 1 kPa (10 mbar) or more at a temperature of 293.15 K (20°C) or such cargoes with an equal volatility of 10 mbar	9 November 2011
Rotterdam	Botlek Tank Terminal, Rubis, ETT, Argos	All sizes	Cargoes with VOC, with a vapour pressure of 1 kPa (10 mbar) or more at a temperature of 293.15 K (20°C). For Rubis only, substances under class LT2 are to be controlled	9 November 2011
Moerdijk	Afval Stoffen Terminal Moerdijk ATM, Shell Chemie Moerdijk, Den Hartoch Moerdijk bv	All sizes	Cargoes with VOC, smelling products and ADR Class 3 and 6	9 November 2011
Terneuzen	Dow Benelux BV Terneuzen, Oiltanking Terneuzen BV.	100,000 GT and less	Cargoes with VOC	9 November 2011
Groningen	VOPAK	All sizes	Cargoes with VOC, with the exception of methane, with a vapour pressure of 1 kPa (10 mbar) or more at a temperature of 293.15 K (20°C) or such cargoes with an equal volatility of 10 mbar	1 July 2012
Vlissingen	Zeeland refinery	9,000 GT and above	Cargoes with VOC	9 November 2011
<b>The Republic of Korea</b>				
Busan Incheon Pyeongtaek/Dangjin Ulsan Yeosu Kwangyang		400 GT and above	Crude oil Gasoline Naphtha	20 May 2009
Daesan		400 GT and above	Crude oil Gasoline Naphtha	20 May 2015

**Table 6.1 – Designated ports with VOC emissions control<sup>29</sup>**

<sup>29</sup> IMO MEPC.1/Circ.774, 21 December 2011 on regulated VOC emissions control ports

### 6.3 Differentiated port dues

If ports/terminals give ship owners and operators of relatively clean ships a port due advantage, they give a direct incentive for reducing ship port emissions. Thus port dues advantages for relatively clean ships can be put into practice by two options:

- Reducing port dues for relative clean ships while keeping port dues for the other ships unchanged and thus reducing a port's income.
- To apply the 'polluter pays principle', raising the port dues for those ships that have relatively high port emissions.

In the first case, where discounts are given, the funding of the incentive scheme could turn out to be a problem for a port. In the second case, where port dues are raised based on ship emission level, the port runs the risk of losing business to competing ports, which have not introduced such a penalty-based scheme. Another potential barrier in this context is the presence of privately owned quays in the port area that may hamper the introduction of the polluter pays principle, as this also may affect the level playing field within the port [MEPC 68 INF.16].

Some of the existing ports provide incentives for efficient and clean shipping via reduced port dues based on their regulated emissions levels. Examples are the Swedish ports that currently provide differentiated port dues based on environmental criteria. About 20-25 of the bigger ports in Sweden have differentiated port dues on the basis of the sulphur content of the fuel used and the NOx emissions from the engines on-board. For example, in Gothenburg, Sweden the port dues used to increase if the sulphur content of the fuel exceeded 0.2% (currently, the regulatory limits for Swedish ports are 0.1% due to the IMO Emissions Control Area regulations, thus the above is irrelevant).

For ships with a NOx emission level lower than 10 g/kWh, a discount is applied that increases progressively<sup>30</sup> as shown in below **Table 6.2**.

Emission level in grams of NOx/kWh	Reduction in SEK per unit of the ship's gross tonnage (GT)
6.0-9.9	0.05 SEK/GT
2.0-5.9	0.10 SEK/GT
0-1.9	0.20 SEK/GT

**Table 6.2 – NOx reduction incentives in port of Gothenburg**

### 6.4 Differentiated ship registration fees

The EEDI (Energy Efficiency Design Index) is part of the energy efficiency regulations under MARPOL Annex VI that aims to improve shipping CO<sub>2</sub> emissions via enforcing future targets for ship designs that will provide major reductions to EEDI (see **Module 2** for details). Some administrations have taken, or are evaluating, to use this index for differentiated registration fee or tonnage taxation. An

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<sup>30</sup> <http://cleantech.cnss.no/policies-and-instruments/voluntary-instruments/clean-shipping-index/>

example of such an initiative is the one by Singapore MPA (Maritime Port Authority) in 2011 that was undertaken under the Singapore Green Ship Programme<sup>31</sup>.

The Green Ship Programme targets Singapore-flagged ships. The MPA provides incentives to ship owners who adopt energy efficient ship designs that will reduce fuel consumption and carbon dioxide emissions. Accordingly, Singapore-flagged ships registered on or after 1 July 2011, which go beyond the requirements of the International Maritime Organization's EEDI, will enjoy a 50% reduction on the Initial Registration Fees under both the normal registration and the Block Transfer Scheme during the registration of the ship. They will also enjoy a 20% rebate on Annual Tonnage Tax payable every year for a number of years based on a scheme that uses EEDI.

Existing ships which utilise energy efficient ship designs that meet the requirements for the Green Ship Programme can also take part in this programme, but will only enjoy the 20% rebate on Annual Tonnage Tax payable every year until the ship ceases to exceed the requirements of IMO EEDI reference lines.

## 6.5 Environmental Ship Index (ESI)

A large number of the world's key ports have committed themselves to reducing the port-related GHG. This commitment is called the World Port Climate Initiative (WPCI)<sup>32</sup>. One aspect of this initiative is to give incentives to ships that visit such ports as a way of reducing port-related emissions.

One of the projects within WPCI is the development of an Environmental Ship Index (ESI). The ESI identifies seagoing ships that perform better in reducing air emissions than the levels required by the IMO MARPOL Annex VI. The ESI evaluates the amount of nitrogen oxide (NOx), sulphur oxide (SOx) that is released by a ship and includes a reporting scheme on the GHG emission of the ship.

The ESI aims to identify cleaner ships in a general way. The index is intended to be used by ports to reward ships when they participate in the scheme for promoting clean shipping. Also, WPCI encourages the shippers and ship owners to use the index as their own promotional instrument. ESI is a voluntary scheme designed to improve the environmental performance of sea going vessels. It can be applied to all types of seagoing ships. It is easy to calculate and simple in its approach.

ESI relies on various formulas for the calculation of various parts for NOx, SOx and CO<sub>2</sub>. It additionally awards a bonus for the presence of OPS. The ESI Score ranges from 0 for a ship that meets the IMO environmental regulations that is already in force and 100 for a ship that emits no SOx and no NOx and reports or monitors its energy efficiency. In other words, a ship with a score of 0 point is actually in full compliance with the applicable regulations while a ship with 100 points has zero air emissions. In reality, the best performing ships currently score at around 40 points.

For further information on ESI and current ship ranking, refer to Environmental Ship Index website<sup>33</sup>. For the ESI calculation formula, refer to ES web site<sup>34</sup>.

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<sup>31</sup> [http://www.mpa.gov.sg/sites/maritime\\_singapore/msgi/green-shipping-programme.page](http://www.mpa.gov.sg/sites/maritime_singapore/msgi/green-shipping-programme.page)

<sup>32</sup> [www.wpci.nl](http://www.wpci.nl)

<sup>33</sup> <http://www.environmentalshipindex.org/Public/Home>

<sup>34</sup> <http://www.environmentalshipindex.org/Public/Home/ESIFormulas>

## 6.6 Port clean air program

A port clean air program is a comprehensive initiative used by some ports to address air emissions from shipping and port operations. Such a program is generally established and implemented by a port authority with input from other stakeholders. Such a program normally sets specific emission reduction targets for a port and develops a roadmap to achieve those targets. To ensure success, the management would follow continuous improvement cycle and success is measured and monitored and target revised periodically based a Plan – Do – Check – Act (PDCA) process cycle [ICCT December 2012].

As any other management continuous improvement cycle, the port clean air program will be successful where the management and staff of port authorities and regulatory agencies are committed to the improvement of air quality in the region. In addition, the participation from other stakeholders and port relate organisations give the clean air team more influence and authority over the air quality improvement in the port.

A successful port clean air program is dependent on the identification, evaluation, and use of appropriate technologies and operational strategies. During the “Plan” stage, it is required to determine emission mitigation measures and coordinate with different stakeholders to implement these measures. After choosing the right measures and during other parts of the cycle, the measures need to be executed and their effectiveness monitored. Finally, the overall achievements need to be reviewed and assessed against the initial targets and objectives. So far, a number of ports have been developing and implementing the “port clean air programme” as documented in ICCT reports given in the references.

## 6.7 Norway NOx tax and NOx fund

This is a NOx tax applicable mainly to national industries including shipping. The NOx tax is collected from participating industries and is fed into a NOx fund. The participating companies could include oil and gas producers, fishing and offshore supply vessels, ferries, airlines, cargo, railways, land based industry, etc. The NOx fund then provides financial incentives for those participating organisations that want to implement NOx reduction measures including shipping industry.

This incentive system in Norway is only applicable to domestic shipping around Norway. It is an example of an effective local program that tries to create a financial scheme and business case for NOx reduction from shipping. These funds are generated by gathering revenue from companies that emit NOx emissions by making them subject to a NOx tax. On the basis of the scheme, a large number of ships have so far been equipped with NOx reduction technologies.

As for shipping, this started from 1st January 2007 and tax level is 1.9 €/per kg NOx. It is applicable to propulsions engines exceeding 750 kW. This fund has so far widely funded major Norwegian initiatives such as the move to LNG as fuel for ships operating in Norwegian water.

## 6.8 General discussion

IMO commissioned a study on ship-port interface in 2014 [MEPC 68/INF.16] that is widely looking at many aspects of ship-port interface including the green initiatives. Based on this study a survey of stakeholder was conducted. These stakeholders included representatives from port authorities and terminals, ship owners and operators, equipment manufacturers as well as governmental and regulatory authorities. This section mainly taken from this study discussed some the issues raised.

All stakeholders indicated that air pollution is a major environmental challenge. On international or regional regulations, these have specific and high impacts on ship owners and operators but not

necessarily ports. When it comes to port-ship interface green initiatives, the lack of a sound business case was widely reported by the stakeholders as the largest barrier to the implementation of various initiatives. This lack of business case issue is closely related to the reason that regulation is reported in the survey as the most effective driver.

On the other hand, voluntary and financial instruments leave room for individual decisions and evaluations regarding the use of advanced technologies or other measures, but also require a business case to be driven by factors beyond direct return on investment.

The availability of energy infrastructure, for example with LNG bunkering or connection to OPS, was also reported as a barrier, and is closely connected to the problem of having an insufficient business case. Subsidies may be needed to address this barrier, followed by fine-tuned regulation that considers local circumstances and cost effectiveness of the measures on the basis of clear criteria.

In addition to regulations, it is cited that the number of voluntary and financial incentive schemes has grown significantly in recent years. Various schemes have been implemented in Asian ports (Hong Kong, Shenzhen, Singapore), providing discounted port dues to visiting ships using low sulphur fuel. The ESI as explained is the most widely implemented and is still growing from its current participation involving over 3,000 ships and 24 ports. However, compared to the overall number of cargo ships in operation worldwide, the share of ships joining such voluntary schemes is estimated to be around 5%. As a consequence, the effectiveness of voluntary schemes is limited on the worldwide level. It can however be effective at smaller scale, such as the port level, where a smaller portion of the overall fleet can be targeted and incentives can be tailored in a way that incrementally enhances (without entirely satisfying) the business case for adoption of measures.

Maintaining a level playing field among ports when implementing financial incentives schemes or regulations is a challenge. Partnering with other regional stakeholders by harmonizing the requirements for ships may increase the effectiveness of instruments, while the regional level playing field is maintained. There are ship owners implementing voluntary measures and participating in voluntary and incentive-based programs set up mainly by port authorities.

## 6.9 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. “IMO train the trainer course material”, developed by WMU, 2013.
2. IMO, MEPC 61/INF.12, full report of the work undertaken by the Expert Group on Feasibility Study and Impact Assessment of possible Market-based Measures, 13 August 2010
3. For further information on OPS refer to: <http://wpci.iaphworldports.org/onshore-power-supply/environment-and-health/climate.html>, cited August 2015.
4. Green Ship Programme in Singapore [http://www.mpa.gov.sg/sites/maritime\\_singapore/msgi/green-shipping-programme.page](http://www.mpa.gov.sg/sites/maritime_singapore/msgi/green-shipping-programme.page), cited August 2015.
5. Lean Shipping Technology website, <http://cleantech.cnss.no/policies-and-instruments/voluntary-instruments/clean-shipping-index/>, cited August 2015.
6. “Environmental Ship Index”, <http://esi.wpci.nl/Public/Home>, cited August 2015.
7. MEPC.1/Circ.774 on “Information on designated ports at which VOC emissions are regulated”, IMO, 21 December 2011.

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9. A Guide to Good Practice on Port Marine Operations Prepared in Conjunction with the Port Marine Safety Code, July 2013, [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/79296/guide-good-practice-port-marine.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/79296/guide-good-practice-port-marine.pdf), cited August 2015.
10. Jenny Hill, MSc Thesis “Executive Summary: Unlocking the capacity for CO<sub>2</sub> abatement in ships arriving and departing from UK ports”, Centre for Environmental Policy, Imperial College London. [https://workspace.imperial.ac.uk/environmentalpolicy/Public/Executive%20Summaries%202009-2010/Global%20Environmental%20Change%20and%20Policy%20Option/Hill%20J\\_10\\_Executive\\_Summary.pdf](https://workspace.imperial.ac.uk/environmentalpolicy/Public/Executive%20Summaries%202009-2010/Global%20Environmental%20Change%20and%20Policy%20Option/Hill%20J_10_Executive_Summary.pdf), cited August 2015.
11. Port of Gothenburg, “Examining the commercial viability of cold ironing”, [http://www.ops.wpci.nl/images/downloads/original/1265119200\\_greenshippingonshorepowersupply19nov2009asawilskeportofgothenburgfinal.pdf](http://www.ops.wpci.nl/images/downloads/original/1265119200_greenshippingonshorepowersupply19nov2009asawilskeportofgothenburgfinal.pdf), cited August 2015.
12. ICCT December 2012, “Workshop brief: Technologies and operational strategies for best practices in port clean air programs” A report prepared for the International Workshop on Reducing Air Emissions from Shipping, Shanghai, China, December, 2012.
13. ICCT June 2012, “Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor’s Air Quality Toolbox”, June 2012