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Agenda item 3

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AIR POLLUTION AND ENERGY EFFICIENCY

Study of emission control and energy efficiency measures for ships in the port area

Note by the Secretariat

SUMMARY

Executive summary:	This document provides at annex the report of a Study of emission control and energy efficiency measures for ships in the port area, undertaken to investigate existing control measures to reduce emissions from ships in ports and identify possible future innovative measures to address such emissions
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	No related provisions
Action to be taken:	Paragraph 3
Related documents:	None

Introduction

1 The Concept of a Sustainable Maritime Transportation System put forward by the Secretary-General of IMO includes the following goal relating to energy efficiency and the ship-port interface:

> A Sustainable Maritime Transportation System needs efficient port facilities to keep the operational efficiency of ships at the highest level (e.g. hull cleaning and propeller polishing facilities, specialized fuel and power supply services). The logistics infrastructure should allow ships to sail at optimal speeds for their charted trajectories (e.g. cargo logistics and port planning, just-in-time berthing, weather routeing). All these elements would form part of a "holistic" energy efficiency concept for the whole system. Innovation and best practices for efficient ship operation and ship-to-shore interfacing should be rigorously pursued.

2 In support of the goal relating to energy efficiency and the ship-port interface, a Study has been undertaken to investigate existing control measures to reduce emissions from ships in ports and identify possible future innovative measures to address such emissions, using funds provided to the Secretariat by Transport Canada for analytical studies and other activities pertaining to the control of air related emissions from ships. The report of the Study is set out in the annex.

Action requested of the Committee

3 The Committee is invited to note the information provided.

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STUDY OF EMISSION CONTROL AND ENERGY EFFICIENCY MEASURES FOR SHIPS IN THE PORT AREA

February 2015

Prepared by:

STARCREST CONSULTING GROUP, LLC
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Study of Emission Control and Energy Efficiency Measures for Ships in the Port Area

February 2015

Prepared by:

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Civic Exchange

Preface

This study of emission control and energy efficiency measures for ships in the port area was prepared by an international consortium led by Starcrest Consulting Group, LLC and the work was carried out by a consortium with the organizations and individuals working in partnership, listed below.

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The views and conclusions expressed in this report are those of the authors.

The recommended citation for this work is:

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Acknowledgements

This study was carried out using funds provided to the International Maritime Organization (IMO) by Transport Canada for analytical studies and other activities pertaining to the control of air related emissions from ships.

The consortium would like to thank the participating companies and organizations that assisted with providing contextual, technical, and operational information used to support the work described in this report, or by facilitating the process to obtain this information. This endeavor would not have been possible without their assistance and support. We truly appreciate their time, effort, expertise, and cooperation. The supporting companies and organizations are grouped by stakeholder group and listed alphabetically.

Port Authorities/Terminal Operators
Hamburg Port Authority
Panama Canal Authority
Port Authority of New York and New Jersey
Port Authority of Thailand
Port Metro Vancouver
Port of Amsterdam
Port of Gothenburg
Port of Long Beach
Port of Los Angeles
Port of Rotterdam
Shekou Container Terminals
Taiwan International Ports Corporation
Yantian Container Terminals

Ship Owners/Associations
BP Tankers
Carnival Cruise Lines
DFDS Seaways
Hong Kong Liner Shipping Association
Hong Kong Shipowners Association
Maersk Line
Spliethoff
Stena Lines
Tai Chong Cheang Steamship Company
TOTE Ocean Carriers
Wagenborg
Wallenius Wilhlemsen Logistics

Vendors/Manufacturers/Associations
Alfa Laval
Exhaust Gas Cleaning Systems Association (EGCSA)
Hamworthy
International Association of Catalytic Control of Ship Emissions to Air (IACCSEA)
Kongsberg Maritime
MAN Diesel and Turbo
Wärtsilä

Governmental/Regulatory/NGO
Clean Shipping Coalition
Environment Canada
European Sea Ports Organization
Hong Kong Environmental Protection Department
International Association of Ports and Harbors (IAPH), World Ports Climate Initiative (WPCI)
Panama Maritime Authority
Shanghai Environmental Monitoring Center
South Coast Air Quality Management District
United States Environmental Protection Agency
Vietnam Maritime Administration

Table of Contents

List of Figures

List of Tables

List of abbreviations and acronyms

AIS	automatic identification system
BC	black carbon
CAAP	Clean Air Action Plan
CAPEX	capital expenses
CARB	California Air Resources Board
cbc	case by case
CEF	Connecting Europe Facility
CO	carbon monoxide
CO_2	carbon dioxide
CSI	Clean Shipping Index
CSR	corporate social responsibility
CVI	Clean Vessel Incentive
dB(A)	decibel
DERA	Diesel Emission Reduction Act
DPM	diesel particulate matter
ECA	emission control area
ECEEMs	emission control and energy efficiency measures
EEDI	Energy Efficiency Design Index
EGS	exhaust gas scrubbers
ESI	Environmental Ship Index
EU	European Union
EUR	euro
FWC	Fair Winds Charter
g/kWh	gram per kilowatt-hour
GHGs	greenhouse gases
HC	hydrocarbons
IAPH	International Association of Ports and Harbors
IARC	International Agency for Research on Cancer
IMO	International Maritime Organization
ktonne	kilotonne
kW	kilowatt
LNG	liquefied natural gas
LSF	low sulfur fuel
MARPOL	International Convention for the Prevention of Pollution from Ships
mbm	market based measures
MDO	marine diesel oil
MGO	marine gas oil
MPA	The Maritime and Port Authority of Singapore
NAAQS	National Ambient Air Quality Standards
NECA	nitrogen emission control area
NGOs	non-government organizations
nm	nautical mile
NOK	Norwegian krone
NO_X	oxides of nitrogen
OPEX	operating expenses

OPS	onshore power supply
PANYNJ	Port Authority of New York & New Jersey
PM	particulate matter
$PM_{2.5}$	particulate matter with diameter of 2.5 micrometer or less
PM_{10}	particulate matter with diameter of 10 micrometer or less
POLA	Port of Los Angeles
POLB	Port of Long Beach
POO	Port of Oakland
POSD	Port of San Diego
PRC	People's Republic of China
PRD	Pearl River Delta
RoRo	roll-on roll-off
SAR	Special Administrative Region
SCR	selective catalytic reduction
SECA	sulfur emission control area
SO_2	sulfur dioxide
SO_3	sulfur trioxide
SO_4	sulfate
SoCAB	South Coast Air Basin
SO_X	sulfur oxides
TAP	Technology Advancement Program
tbd	to be determined
teu	twenty-foot equivalent unit
TIGER	Transportation Investment Generating Economic Recovery
ug/m^3	microgram per cubic meter
UNECE	United Nations Economic Commission for Europe
UNCITRAL	United Nations Conference on International Trade Law
UNCTAD	United Nations Conference on Trade and Development
US	United States
USA	United States of America
US EPA	United States Environmental Protection Agency
VOC	volatile organic compounds
VSR	vessel speed reduction
WCO	World Customs Organization
WPCI	World Port Climate Initiative
WTO	World Trade Organization

Executive Summary

Concept of a sustainable maritime transportation system

The International Maritime Organization (IMO) Secretariat's "Concept of a Sustainable Maritime Transportation System" highlights the importance of maritime transportation in the United Nation's broader efforts to achieve sustainability. The Concept discusses ten "imperatives" within the sector that should be investigated in more depth, with member nations developing policies that bolster the central pillars of sustainable development – social and environmental needs, including the health and safety of seafarers, and the economy of the shipping industry, and with IMO providing vision and guidance towards these goals as a "coordinator of policies".

With this broad and long term vision, the IMO Secretariat commissioned this study to initiate and enhance national discussions related to the third imperative, "Energy Efficiency and Ship-Port Interface", outlined in the Concept. It states that:

> "…ships do not operate independently from shore-based entities in the Maritime Transportation System, efficiency must extend beyond the ships themselves to shore-based entities. These include ports, which must deliver an efficient service and provide the essential maritime infrastructure, as well as other entities in the logistics chain pertaining to cargo handling, vessel traffic management and routing protocols… [and] commercial aspects of ship management and chartering..."

Two goals are identified under this imperative, namely (a) operational streamlining and (b) technology and facility improvements. To support these goals and related issues stemming from the ship-port association, this study examines strategies and measures that could be deployed to increase efficiency, decrease impacts on human and environmental health, and provide for the long-term sustainability of this facet of the maritime transportation system.

Objectives of the study

The primary objective of this study is to support IMO's goal of encouraging and guiding local and national-level discussions on how to improve the sustainability of the maritime transportation system at the ship-port interface. This study identifies measures and best practices that stakeholders can consider to reduce air emissions and improve overall efficiency in the port area. Both existing and emerging control measures are analyzed for their potential to reduce emissions and/or improve efficiency.

To this end, the study consists of three major tasks:

1. Identify existing and effective control measures and instruments (technological, operational, and market-based) to reduce emissions at the ship-port interface, as well as abatement potential and abatement costs for control measure as available;

2. Identify barriers (technological, operational, and commercial) to the uptake of measures to reduce emissions when ships are in port and provide recommendations to address these barriers; and

3. Identify and evaluate possible innovative measures and instruments, including incentive schemes, and best practices, which could be further developed for reducing emissions and optimizing operational efficiencies of ships when in port.

Target audience

The study is intended to be a resource for stakeholders involved in national and international conversations aimed at developing policies that enhance sustainability at the ship-port interface. The study contains an overview of the state of the art of a broad range of measures of a technical (e.g. onshore power supply (OPS)) or operational (e.g., speed reduction) nature, or associated with a fuel switch (e.g., to use low sulfur distillates or liquefied natural gas (LNG)). As a reference, it should be relevant to a broad range of entities including ports, ship owners and operators, and other relevant stakeholders.

To support policies and measures that emerge from stakeholder discussions, this study further provides an overview of the actions, regulatory frameworks, incentive schemes, and other relevant mechanisms that stakeholders can utilize for measure implementation.

Methodology

This work is largely based on the consortium members' extensive experience working on a variety of air quality projects associated with port-related emission sources in various port areas in North America, Europe, Asia, and Central America. The authors also included elements from a broad range of related published reports and resources associated with emission control and energy efficiency measures (ECEEMs).

In addition to the above, the consortium surveyed stakeholders to gain and incorporate broader input from a limited number of entities representing the four stakeholder groups associated with ship emissions in the port area. They are (a) ship owners and operators, (b) port authorities and terminal operators (public and private), (c) regulators, maritime trade associations, and non-government organizations (NGOs), and (d) technology manufacturers, vendors, and technology-related trade associations. Over 40 stakeholder surveys were conducted that covered a wide geographical spread.

It is important to state that the results of these surveys do not and are not intended to represent the worldwide collective opinion of the types of organizations that were interviewed. Input from the surveys are used to primarily support the project team's experience and to offer insight into various stakeholders' understanding of current environmental challenges, drivers to address these challenges, barriers to overcoming these challenges, and implementation of measures to address these challenges.

ECEEMs

Based on information gathered from both stakeholder surveys and research, a wide range of existing and future ECEEMs are being identified in Section 2 of the report for discussion. For each measure, as far as applicable, discussion has focused on its applicability to emission sources, retrofitability, effectiveness on different operational modes, emissions and energy efficiency, maturity of the measure, limitations, and implementation.

Existing ECEEMs

Existing ECEEMs fall mainly under three categories: (a) equipment, (b) energy, and (c) operational measures.

The equipment category refers to physical changes in machinery onboard a ship, particularly focused on the three primary emission sources for ships, that is, main/propulsion engines, auxiliary engines, and boilers. Equipment measures are sub-divided further into engine technologies, boiler technologies, and after-treatment technologies.

The energy category refers to ECEEMs related to energy sources used by a ship, whether they are ship-based or land-based. Energy measures may include fuels and alternative power supply.

The operational category refers to measures that primarily affect and focus on the operation of the ship, terminal, or port such that the absolute emissions of ships in the port area are reduced. This can take the form of operational efficiency improvement onboard, at the terminal, and/or at the port. Operational measures may include ship operational efficiencies, port/terminal operational efficiencies, volatile organic compound (VOC) working losses.

Cost considerations

Advanced technologies being applied to complex systems of ship and port operations makes it almost impossible to predict overall application costs of individual ECEEMs. The report attempts to only provide an insight into the most significant expenses that are embodied by ECEEM projects.

In general terms, costs associated with an ECEEM technology can be broken down into capital expenses (CAPEX) and operating expenses (OPEX), or costs incurred before and after an ECEEM is commissioned and placed in service. These two general categories embody a range of other cost categories that can change based on the technology, the specific application, and the parties involved.

In principle, costs associated with implementing an ECEEM are strongly tied to its level of development and market maturity. Once a technology has achieved a level of market penetration sufficient for costs to be more normalized, CAPEX and OPEX expenses can be more easily determined.

The next key consideration for costs is whether (in the case of a ship-based ECEEM technology) the ECEEM is being retrofit to an existing ship or installed during the process of building a new ship. In general, installing ECEEMs on a new ship is more straightforward and less costly because dependent systems can be integrated during the overall design process and adequate space can be allocated for the system footprint and peripheral components.

On top of that, different stakeholders, such as ship owner, terminal operator, and port authority, will also take into consideration the incremental costs of adopting an ECEEM before any decision is made. Beyond project costs, other abatement costs and societal benefits should also be thoroughly assessed.

Future ECEEMs

Future ECEEMs that have the potential to play a significant role in reducing emissions from ships in the port area are identified and appraised. These measures include innovative and/or emerging possible emissions reduction and energy efficiency measures, programs and strategies that optimize the energy efficiency and reduce ship emissions when in the port area. Unlike existing ECEEMs, which are readily deployable measures, future ECEEMs are specific measures that are still being developed or existing measures that have potential for substantial growth if certain barriers are overcome.

Drivers, barriers and implementation

Environmental challenges

According to the survey results, air quality is the most challenging environmental issue within the ship-port interface today, to be followed by greenhouse gas (GHG) emissions and noise pollution. The contribution of ships and port activities to local and regional air quality has become a major issue for several large ports due to air quality standards non-compliance. Improved science for better understanding the impact of air pollution on human health has also raised people's awareness and concern.

Drivers

While survey results indicate that the four primary environmental improvement drivers at the ship-port interface are (a) community and public pressure, (b) local and regional regulation, (c) national and supranational legislation, and (d) corporate social responsibility (CSR) , each key stakeholder group may take a different view on different drivers, due to their different roles at the ship-port interface.

For example, ship owners and operators are mainly driven by local, national and international regulations. The survey revealed that ship owners experience little pressure from clients to implement measures to reduce air pollutants. This finding is further supported by literature that describes the limited interest of shippers in the environmental performance improvement of carriers that move their goods, especially in cases where environmental improvement measures would require a rate increase.

In the Asian context where local regulation is lacking, the influence of internal CSR policies, peer pressure and public pressure become more important. CSR is also an important driver for port authorities and terminal operators.

Regulation, however, is the most effective driver as it creates a "level playing field" and drives the market to develop and ensures broad scale adoption of technologies and measures to reduce emissions and improve energy efficiency.

Barriers

Similarly, different stakeholder groups are facing different barriers. For instance, ship owners and operators are very concerned about whether there is a sound business case to adopting an ECEEM. Other barriers include the lack of drivers, uncertainty about future regulation, the financing of emission reduction measures, and the lack of infrastructure. These barriers will in turn have a direct impact on the demand for equipment, affecting the equipment manufacturers.

For some environmental NGOs, the lack of awareness about air pollution issues in ports is also a major barrier, as the public fails to put enough pressure on the authorities to implement regulations related to the reduction of ship and port emissions.

Port authorities have limited room to improve industry's business case, without differentiating stronger on the basis of a ship's emissions. Measures that would effectively reduce emissions cannot be easily financed by ship owners solely on the basis of discounts offered on port dues or similar port-based incentives. To increase the effectiveness of their instruments, ports could partner with regional ports and other stakeholders to harmonize requirements for ships and create a more regional level playing field. This concept of a level playing field is not only relevant for the introduction of financial instruments in ports, but also for the introduction of local regulation.

Implementation methods
According to the survey, all stakeholders indicated that regulation and standards (such as IMO regulations, European Union (EU) Directives, and state-level requirements) are the most important instruments for implementation, but a combination of regulation/standards, market based instruments (such as financial incentives) and voluntary agreements would be the best solution.

Voluntary incentive programs are an important driver for the introduction of new technologies within fleets. Surveys indicate that several of such voluntary instruments have contributed to the uptake of gas engines, selective catalytic reductions (SCR) catalysts, sulphur oxides (SO_X) scrubbers and other technologies, resulting in an increase of experience with these technologies in the industry. Experience is an important driver for further development and regulation at different government levels. The discounted port dues and other voluntary incentives for ships in areas such as Hong Kong and the California are examples of how voluntary measures can encourage early adoption of emission reduction measures in advance of regulations and create both industry and government experience that improves the effectiveness of future regulations for all stakeholders involved.

Overall, around ten different extra-legal incentive schemes are implemented by ports all over the world to improve air quality. The Environmental Ship Index (ESI) is the most widely implemented and is still growing from its current participation involving over 3,000 ships and 30 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 world-wide level. To increase the effectiveness of their instruments, ports could partner with other regional stakeholders by harmonizing the requirements for ships, which maintains the regional level playing field.

Key findings
Key findings from the study are summarized as follows:

1. Air pollution in the port area is recognized by all four stakeholder groups as a major challenge and they all anticipate that the pressure to reduce emissions from ships in ports will only increase with time.
2. Regulations, such as IMO, EU and California Air Resources Board (CARB) regulations, that specifically relate to the port area and most directly affect ships are typically the strongest drivers for implementation of emission reduction measures in port areas.
3. Numerous ECEEMs 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 ECEEM is quite extensive including engine and boiler technologies, after treatment technologies, fuel options, alternative power systems, operational efficiencies, and cargo vapor recovery.
4. There are no "silver bullets" when it comes to ECEEMs 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 bespoke nature of ECEEMs, each measure needs to be analyzed on a case-by-case basis in advance of implementation.
5. Several emerging and innovative technologies and strategies 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 strategies, with the ultimate goal of bringing them to the market in an expedited fashion.

6. Specific cost elements relating to ECEEMs and the distribution of cost over various stakeholders differ by measure. While ports and terminals are primarily looking at land-side or infrastructure costs including design and construction; incentive program costs; and administrative costs, ship owners are dealing with analysis, design, and installation costs, operational impacts during installation, staff training; reclassification, project management costs and operational costs.
7. Published cost data on ECEEMs is typically opaque as to which cost elements are included. In addition, differences in an order's size/number, a company's market share, etc. can have a significant impact on unit prices. The cost/benefit ratio of each measure depends on a number of variables that need to be considered, including capital and operational expenses, technology maturity, and ship operation, which typically leads to case-by-case analysis.
8. Ship owners and operators are very concerned about whether there is a sound business case to adopting an ECEEM. Other barriers include the lack of drivers, uncertainty about future regulation, the financing of emission reduction measures and the lack of infrastructure. These barriers will in turn have a direct impact on the demand for equipment, affecting the equipment manufacturers, and implementation of measures.
9. Overall, around ten different incentive schemes are implemented by ports all over the world to improve air quality. The ESI is the most widely implemented and is still growing from its current participation involving over 3,000 ships and 30 ports.
10. In general, the incentive schemes implemented are subsidy schemes that do not come close to fully offsetting costs associated with the incentivised measures. This yet limits the potential environmental benefits of incentive schemes. Stronger differentiation within the incentive schemes on the basis a ship's emissions may contribute to an improved business case.
11. 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.
12. There are ship owners implementing voluntary ECEEMs and participating in voluntary and incentive-based programs set up mainly by port authorities. CSR and sustainability ethos have played a role for some ship owners to go beyond regulation.
13. While implementation of air quality improving instruments at the ship-port interface has mostly taken place in North America and Northern Europe, Asia is becoming active in the issue, and as drivers arise in other parts of the world to reduce ship-related emissions in the port area.

1 Introduction

At the United Nation's Conference on Sustainable Development (Rio+20) meeting in 2012, IMO Secretary General Mr. Koji Sekimizu presented a vision for sustainable maritime transportation system development and committed the IMO to working informally with internal partners to promote this vision. These efforts culminated on World Maritime Day 2013 when IMO revealed a blueprint for sustainable development for the sector. IMO's "Concept of a Sustainable Maritime Transportation System"[1] highlights the importance of maritime transportation in the United Nation's broader efforts to achieve sustainability and discusses ten "imperatives" or overall goals within the sector that should be investigated in more depth. These goals would be deliberated at the national level by member nations to develop policies that bolster the central pillars of sustainable development: social and environmental needs, including the health and safety of seafarers, and the economy of the shipping industry. IMO would provide vision and guidance pertaining to these goals and act as a "coordinator of policies."

This study was commissioned by IMO to support their effort to initiate and enhance national discussions related to the third imperative outlined in the Concept: "Energy Efficiency and Ship-Port Interface." The Concept notes that:

> "…ships do not operate independently from shore-based entities in the Maritime Transportation System, efficiency must extend beyond the ships themselves to shore-based entities. These include ports, which must deliver an efficient service and provide the essential maritime infrastructure, as well as other entities in the logistics chain pertaining to cargo handling, vessel traffic management and routing protocols… [and] commercial aspects of ship management and chartering..."

The two goals for this section described in the Concept are:

> **Goal 1: Operational streamlining**
> "Inherent in a Sustainable Maritime Transportation System should be efficiency beyond the ship, addressing the ship-shore interface through streamlining and standardization of the documentation for both the delivery and the reception of cargo, improving coordination and promoting the use of electronic systems for clearance of ships, cargoes, crews and passengers."
>
> **Goal 2: Technology and facility improvements**
> "A Sustainable Maritime Transportation System needs efficient port facilities to keep the operational efficiency of ships at the highest level (e.g. hull cleaning and propeller polishing facilities, specialized fuel and power supply services). The logistics infrastructure should allow ships to sail at optimal speeds for their charted trajectories (e.g. cargo logistics and port planning, just-in-time berthing, weather routing). All these elements would form part of a "holistic" energy efficiency concept for the whole system. Innovation and best practices for efficient ship operation and ship-to-shore interfacing should be rigorously pursued."

[1]www.imo.org/About/Events/WorldMaritimeDay/WMD2013/Documents/CONCEPT%20OF%20%20SUSTAINABLE%20MARITIME%20TRANSPORT%20SYSTEM.pdf

In direct support of these goals and related issues stemming from the ship-port association, this report examines strategies and measures that could be deployed to increase efficiency, decrease impacts on human and environmental health, and provide for the long-term sustainability of this facet of the maritime transportation system.

1.1 Study

The primary objective of this study is to support IMO's goal of encouraging and guiding local and national-level discussions on how to improve the sustainability of the maritime transportation system at the ship-port interface. This work identifies measures and best practices that stakeholders can consider to reduce air emissions and improve overall efficiency in the port area. Both existing and emerging control measures are analyzed for their potential to reduce emissions and/or improve efficiency.

The study consists of three major tasks:

1. Identify existing and effective control measures (technological, operational, and market-based) to reduce emissions during the ship-port interface, as well as abatement potential and abatement costs for each control measure. For example, incentive schemes, such as port fees reduction, for voluntarily using fuel oil with lower sulfur content.

2. Identify barriers (technological, operational, and commercial) to the uptake of measures to control emissions when ships are in port and provide recommendations to address these barriers.

3. Identify and evaluate possible innovative measures, including incentive schemes, and best practices, which could be further developed for optimizing the energy efficiency of ships when in port.

This work is not intended to be an exhaustive account of all the elements, complexities, nor considerations associated with effectively implementing ECEEMs. The study is intended to be a resource for stakeholders involved in national and international conversations aimed at developing policies that enhance sustainability at the ship-port interface. The study contains an overview of the state of the art of a broad range of measures of a technical (e.g., OPS), or an operational (e.g., speed reduction) nature, or associated with a fuel switch (e.g., to use low sulfur distillates or LNG). As a reference, it should be relevant to a broad range of entities including ports, ship owners and operators, and other relevant stakeholders. To support policies and measures that emerge from stakeholder discussions, this report further provides an overview of the actions, regulatory frameworks, incentive schemes, and other relevant mechanisms that stakeholders can utilize for measure implementation.

This work is based on the consortium members' extensive experience working on a variety of air quality projects associated with port-related emission sources in various port areas, some of which have been engaged in this field since 1997 in North America, Europe, Asia, and Central America. In addition to this experience, the consortium surveyed stakeholders to gain and incorporate broader input from a limited number of entities representing the four stakeholder groups associated with ship emissions in the port area (defined in Section 1.2.6). Finally, the authors reviewed and included elements from a broad range of related published reports and resources associated with ECEEMs.

1.2 Report framework

This report identifies ECEEMS that can be utilized at the “ship-port interface” as described in IMO’s Concept, which broadly refers to the behavior of vessels and the sustainability of their activities in the context of “shore-based entities” on which ships depend. For the sake of this report, which seeks to identify and discuss more specific actions that can enhance the sustainability of these activities, further boundaries and definitions are needed.

The following definitions and concepts are described to provide the framework that this report uses to bind the discussions in subsequent sections and help to refine IMO’s objectives on this topic.

1.2.1 Key concepts

“Port” vs “port”

The capitalized “Port” typically refers to the administrative entity associated with a port, while “port” typically refers to the physical and geographic elements of a port.

The “port area”

The focus of this study is to look at ECEEMs for ships engaged in the ship-port interface. This necessitates delineation of a specific area in proximity to the shore that can be defined as a “port area.” The challenge is developing a universal definition that can be applied to all ports and private terminals where ships call. Since there are a vast array of diverse geographical layouts and features of ports around the world, it is not practicable to use geographical delineation or administrative boundaries to define the port areas of the world. Compounding this issue, a ship may begin preparing for its arrival at port long before entry to an official administrative boundary, creating the need to define the port area such that it extends well beyond the berths. This is emphasized in Figures 1.1 through 1.5**,** which illustrate examples of major ports with very different configurations and transits.

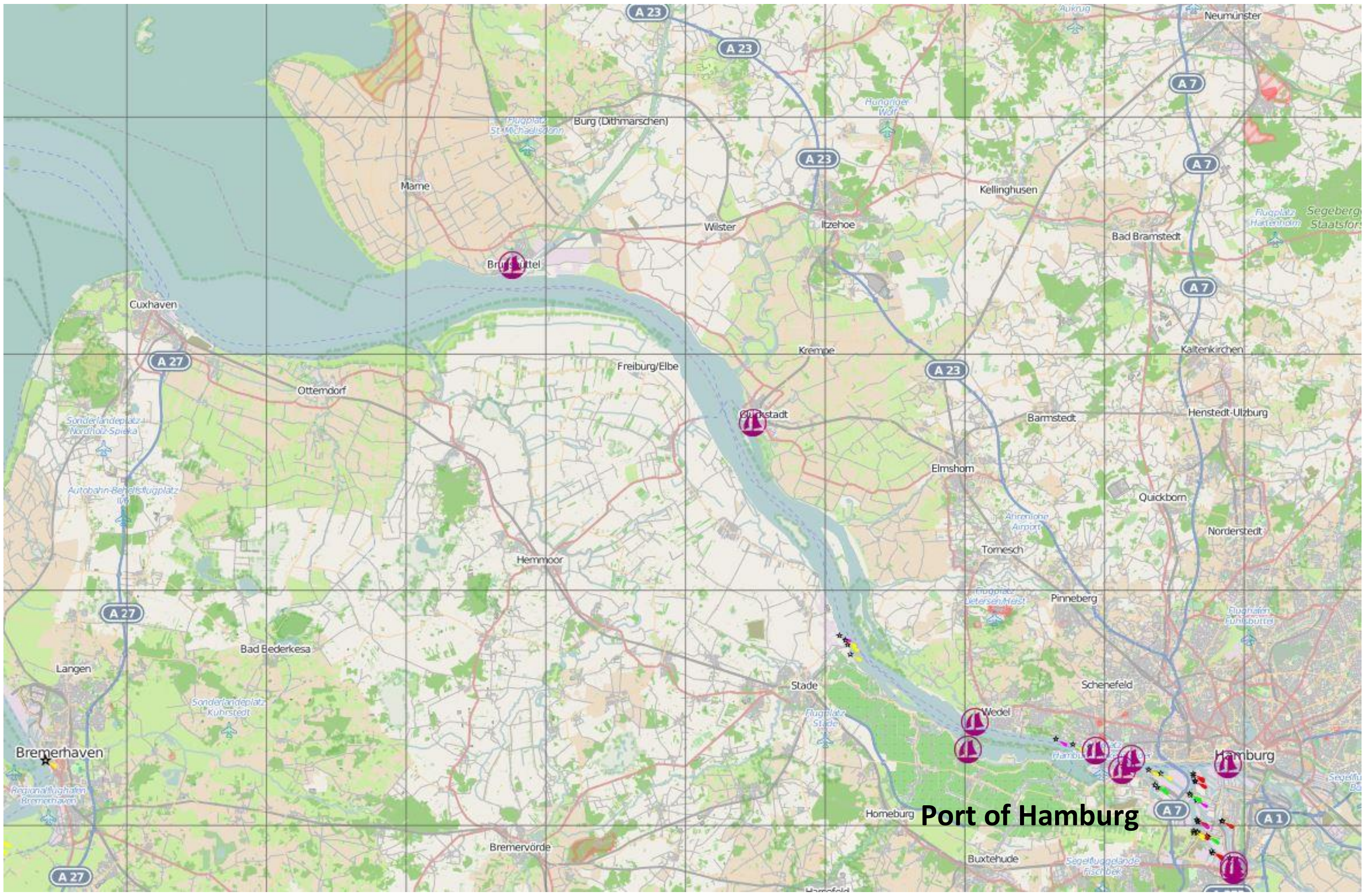
The Port of Tianjin, China, is an example of the simplest type of Port from a ship transit perspective. A ship arriving from the Pacific Ocean passes through the Yellow Sea, to the Bohai Bay at cruising speed, only to slow down at certain distance from the port. Compared to many ports, the route from open water to port is very direct, as presented in Figure 1.1.

Figure 1.1: Port of Tianjin, China[2]

[2] www.chinafreight.com.au/

The Port of Hamburg, Germany, is located at the end of a long river transit, in the vicinity of a densely populated city. A calling vessel will end its open water transit phase well before the mouth of the River Elbe where it will continue at a slower speed before it makes final maneuvers around the port complex, as presented in Figure 1.2.

Figure 1.2: Port of Hamburg, Germany[3]



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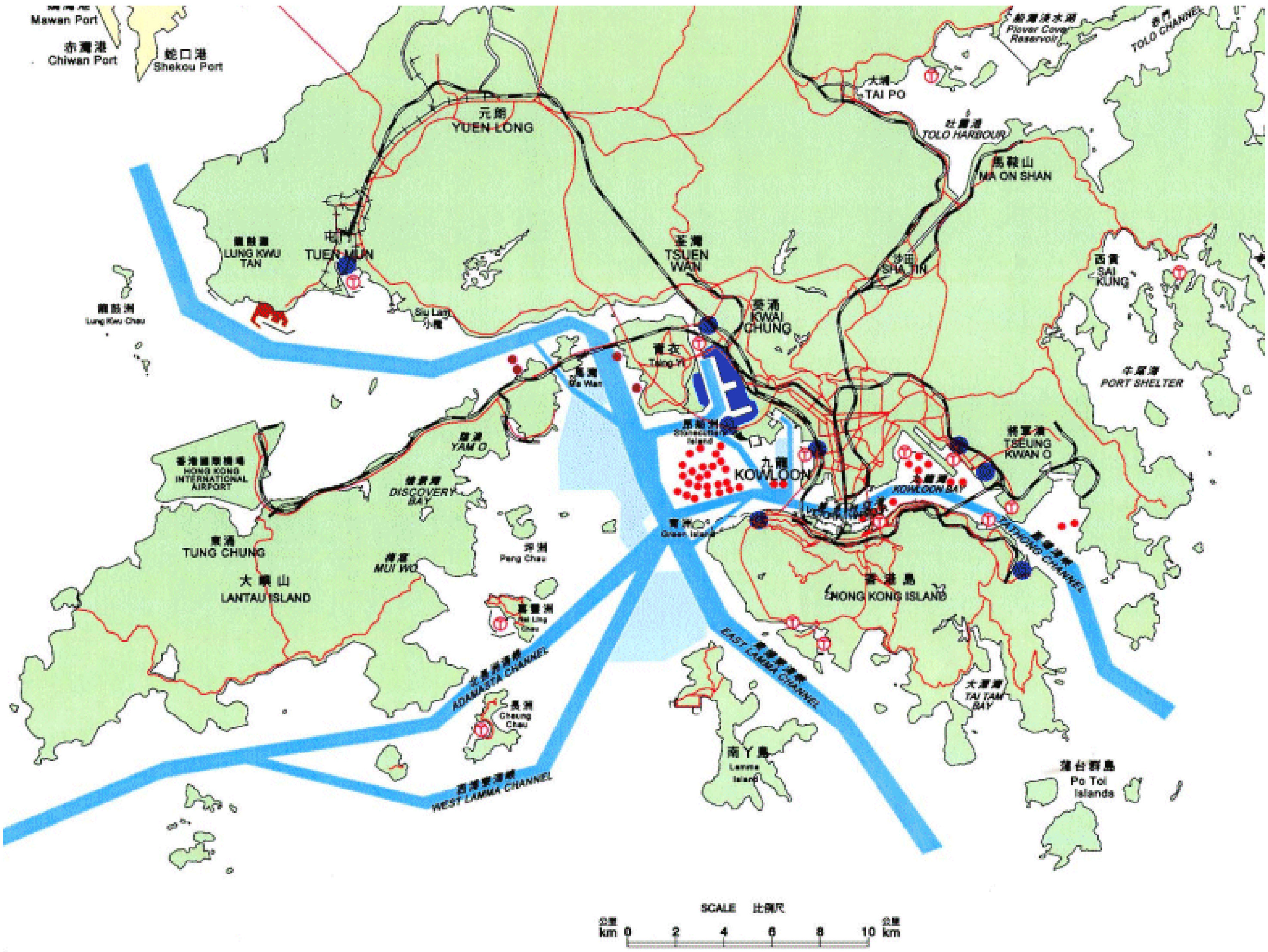
[3] Map created from www.marinetraffic.com/ais/

The Hong Kong port area has no river transit, but requires ships to navigate among several large islands and past some of the most densely populated areas in the world, as presented in Figure 1.3.

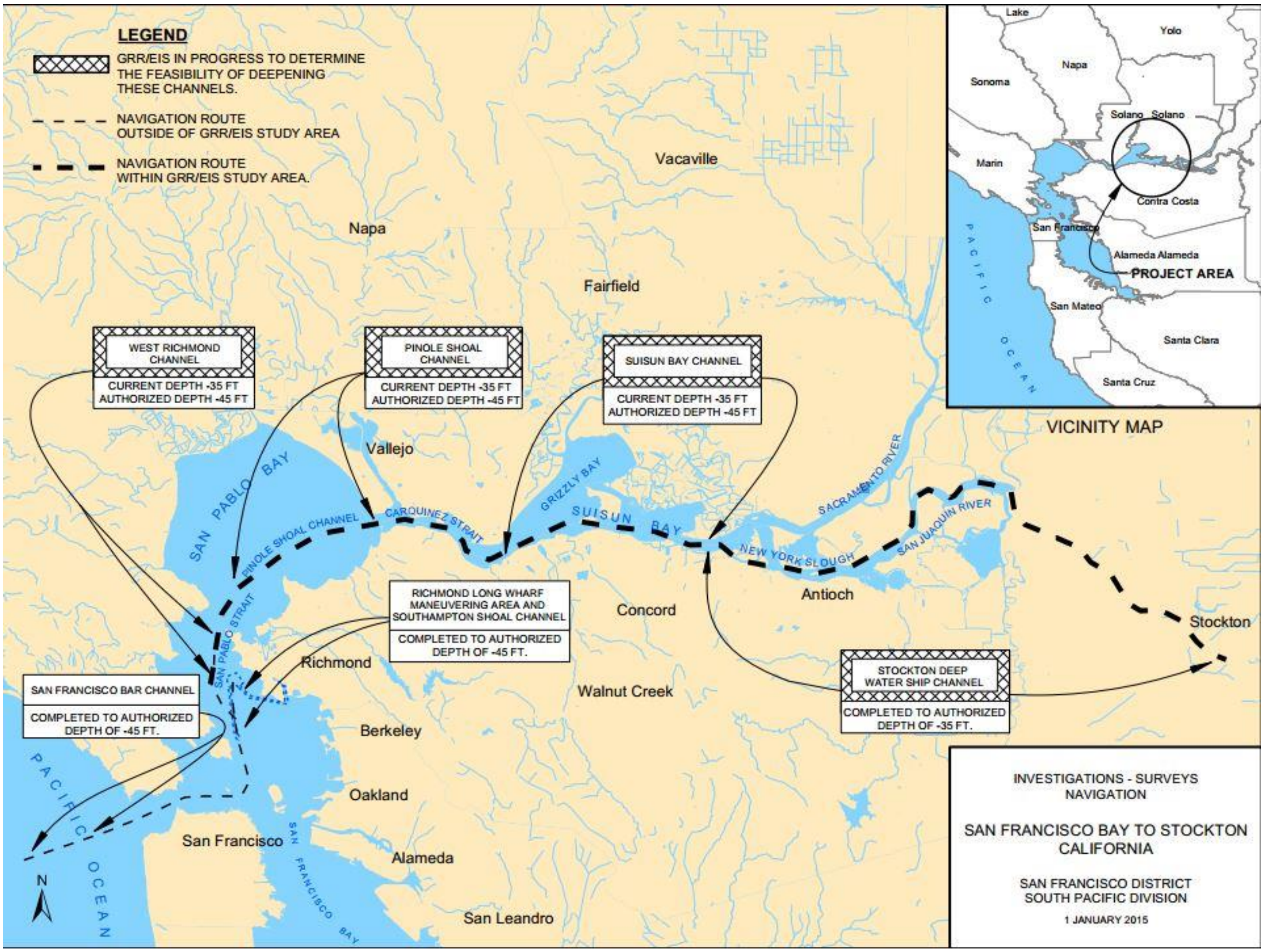
Figure 1.3: Hong Kong SAR port area, People's Republic of China[4]



[4] Map adapted from www.pdc.gov.hk/chs/facilities/enlarge.htm

The Port of Stockton, United States of America (USA), a major port for produce being shipped out of California, has not only a long river transit past numerous populated areas, but an additional transit through the San Francisco Bay past a major United States (US) city, as presented in Figure 1.4.

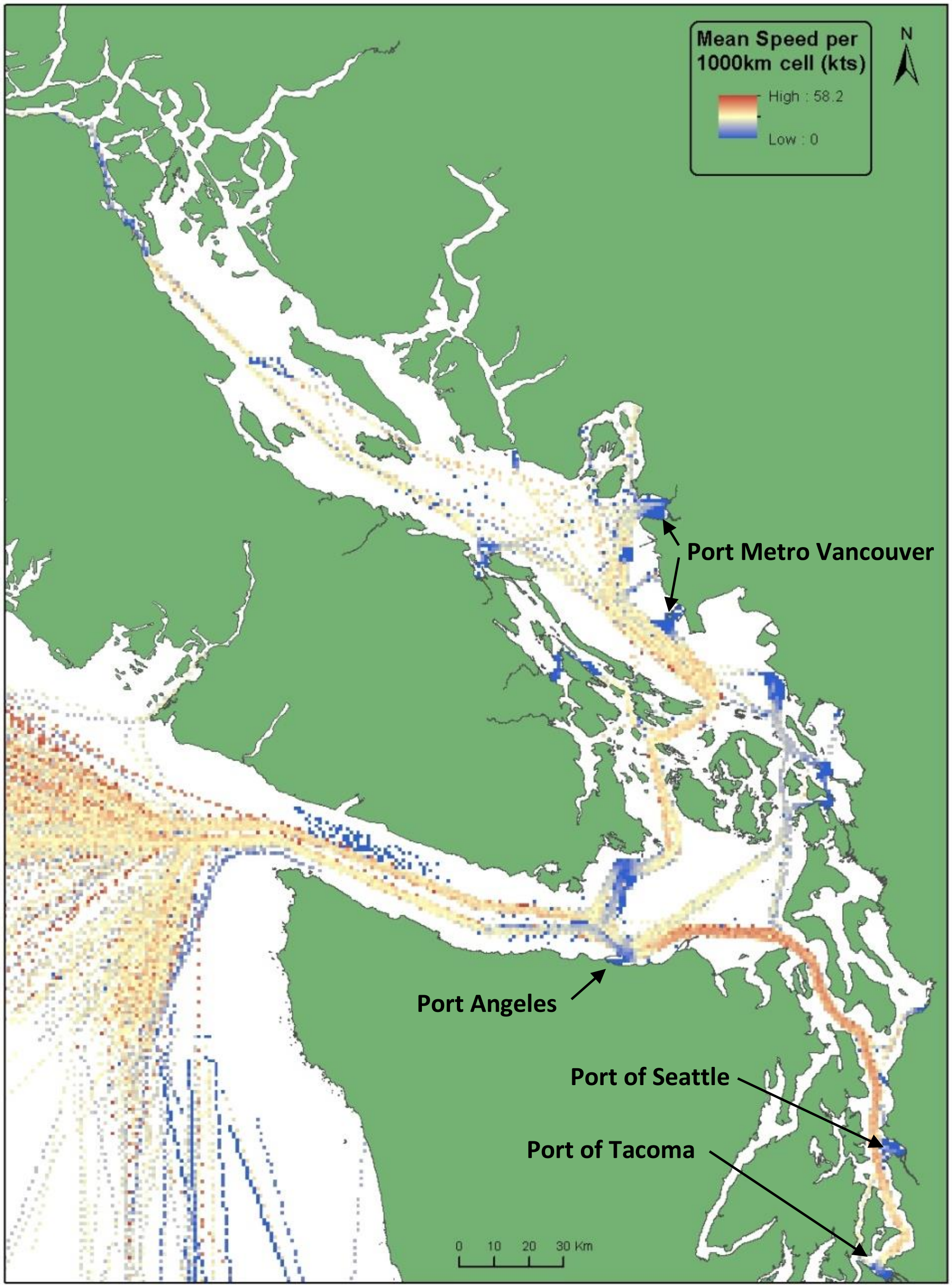
Figure 1.4: Approach to Port of Stockton, USA[5]



[5] Map adapted from www.spn.usace.army.mil/Missions/ProjectsandPrograms/ProjectsbyCategory/ProjectsforNavigableWaterways/SanFranciscoBaytoStockton(JFB).aspx

The greater Georgia Basin system includes several Canadian and US ports that are located throughout the system. These ports are inland from the west coast; however, there are significant areas in which the ships move through the systems at open water transit mode, as presented in Figure 1.5.

Figure 1.5: Greater Georgia Basin Vessel Transit[6]



[6] Image from: whalesandships.wordpress.com/2011/02/17/ship-noise-impacts-on-sr-killer-whales/

The diverse configurations of port areas and ship movements near the populated areas around the world, and other key factors such as the varying geographical extent from which emissions from ships impact populated areas, require a non-geographically limited definition of "port area." For this reason, a "port area" in this study is defined by a ship's operational modes that are associated with activities in the port area. These modes are broken down into the following categories:

- the end of the open-water transit portion of the ship's voyage where a ship first adjusts speed or direction in anticipation of entering the transition phase
- transition phase between open water transit and the start of deliberate maneuvering or piloted transit
- maneuvering in confined waters up to the point of berthing, anchorage, or other end-point activities
- at-berth at a port or terminal facility or engaged in other shore-entity administered activity where the ship is directly tied to shore-side structures (berth, lay-berth, etc.)
- at-anchorage away from shore-side structures, typically in protected waters, and may include cargo exchange (cargo loading/discharge to feeder vessels, lightering ships, pipelines, etc.)

The time that a vessel spends in each of these modes is dependent on numerous factors including: the geographical extent, approach, and layout of the port that is being called; the type of vessel; the service type the vessel is operating in; the efficiency of the port and terminal being called, etc. For example, container ships serving in liner services typically spend very little time at anchorage, whereas bulk ships serving on spot or tramp services may spend extended time at anchorage while waiting for their next assignment.

In some cases, national and regional air quality regulators may define the geographical extent for a port area with regards to inland or over water boundaries, from an air quality perspective. For example, the regulators may, through research, establish the geographical area that has the most impact on an area's air quality and regulate the sources within this area in order to meet the applicable air quality standards.

Ship-related emission sources

The emission sources associated with ship-related operations include: propulsion engines, auxiliary engines, auxiliary boilers (boilers), VOC working losses associated with bulk liquid cargos, and refrigerants. Propulsion engines provide power directly (direct drive or gear drive) or indirectly (diesel-electric) based on the ship's configuration. Auxiliary engines provide electric power to house loads, pumps, loading/unloading equipment, etc. Auxiliary boilers provide steam power for pumps, inert gas for volatile organic bulk liquid operations, crew needs, etc. Propulsion and auxiliary engines are typically diesel cycle engines, although there is more recent growth in natural gas engines running either as gas only or dual fuel configurations.

Working losses or fugitive emissions associated with the loading and unloading of volatile organic bulk liquid cargoes include emissions of VOC from hatches, pressure relief valves, flanges, etc. as cargos are moved to and from shore-side facilities. Refrigerants are typically ozone-reactive substances that also have global warming potentials that are a concern when leaked or vented from refrigeration systems. Refrigerants are not addressed in this report.

From an air pollutant perspective, vessels can produce significant amounts of nitrogen oxides (NOx) and particulate matter (PM) from burning of 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 calling, these three sources can have the same magnitude in emissions, or one or two can be dominant over the others. This differentiates the port area from open water transit where the propulsion engines are typically the dominant ship-related emission source.

Most emissions from ports and ships are the result of engines burning some type of fuel oil in a diesel combustion process. Diesel engines' energy efficiency, reliability, longevity, and power have made them the most common choice for use in maritime operations both on ships and in terminal equipment. In the port area in particular, marine engines are typically the last major engine group to be regulated and their standards at this time include only NOx and fuel standards. Compared to land-based mobile sources, these sources are still relatively newly regulated and do not have as stringent standards or the range of pollutants regulated compared to their land-based counterparts. National and regional regulatory agencies have limited control over international engine standards and can typically only set standards for their respective countries' flagged vessels. Reducing emissions from diesel engines on ships is therefore one of the most 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 operate through the various modes associated with the port area. The following text and graphics, adapted from the International Association of Ports and Harbors (IAPH) carbon footprinting guide,[7] illustrate the variety of configurations and activities of a ship's emission sources during each of its activities within the port area. 1.6 through 1.8 provide a graphical representation of how the three power systems (propulsion system, auxiliary power system, and boilers) change in activity by operating mode on a typical ship. In the illustrations, green denotes an operating engine, blue indicates equipment that is turned off, while purple identifies generators of electricity.

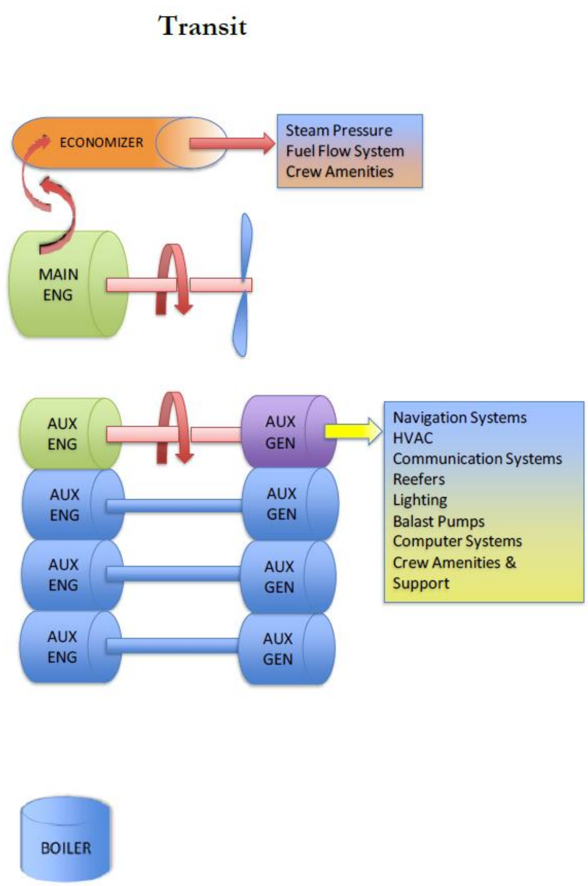
[7] Starcrest Consulting Group, LLC et. al. 2010, "Carbon Footprinting for Ports, Guidance Document" can be found at:
wpci.iaphworldports.org/data/docs/carbonfootprinting/PV_DRAFT_WPCI_Carbon_Footprinting_Guidance_Doc-June-30-2010_scg.pdf

Transit - During this mode, a ship is sailing in the open ocean/unrestricted waters. Typically,

- the ship is traveling at its sea-speed or cruising speed
- propulsion engines are operating at their highest loads
- auxiliary engine loads required by the ship are at their lowest loads
- auxiliary boilers are off and economizers are on because of the high propulsion engine exhaust temperatures
- vessel fuel consumption is at its highest level due to the propulsion system's power requirements, and auxiliary fuel consumption is low

Vessel systems in operation during transit mode are presented in Figure 1.6.

Figure 1.6: Illustration of vessel systems in operation during transit mode[8]



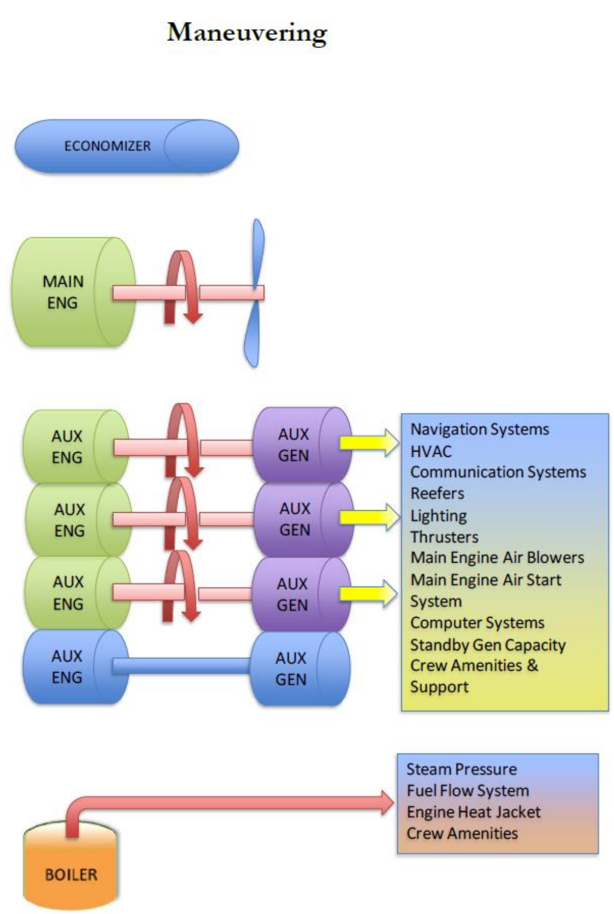
[8] Starcrest Consulting Group, LLC et. al. 2010, "Carbon Footprinting for Ports, Guidance Document" wpci.iaphworldports.org/data/docs/carbonfootprinting/PV_DRAFT_WPCI_Carbon_Footprinting_Guidance_Doc-June-30-2010_scg.pdf [IAPH 2010]

Transitioning and maneuvering - During this mode, a ship is typically operating within confined channels and within the harbor approaching or departing its assigned berth. The distance associated with this mode is unique for each port depending on geographical configuration of the port. Typically,

- the ship is transiting at its slowest speeds
- propulsion engines are operating at low loads
- auxiliary engine loads are at their highest load of any mode, as additional on-board equipment such as thrusters, air scavengers/blowers, and additional generators are online in case an auxiliary engine/generator fails
- auxiliary boilers are on because the economizers are not functioning due to low propulsion engine loads and resulting lower exhaust temperatures; this generally does not apply to large diesel-electric powered vessels, which produce sufficient exhaust heat to power economizers at maneuvering speeds
- vessel fuel consumption is very low for the propulsion system, is highest for the auxiliary engines, and low for the auxiliary boilers

An illustration of the vessel systems operating in maneuvering mode are presented in Figure 1.7.

Figure 1.7: Illustration of vessel systems in operation during maneuvering mode [IAPH 2010]

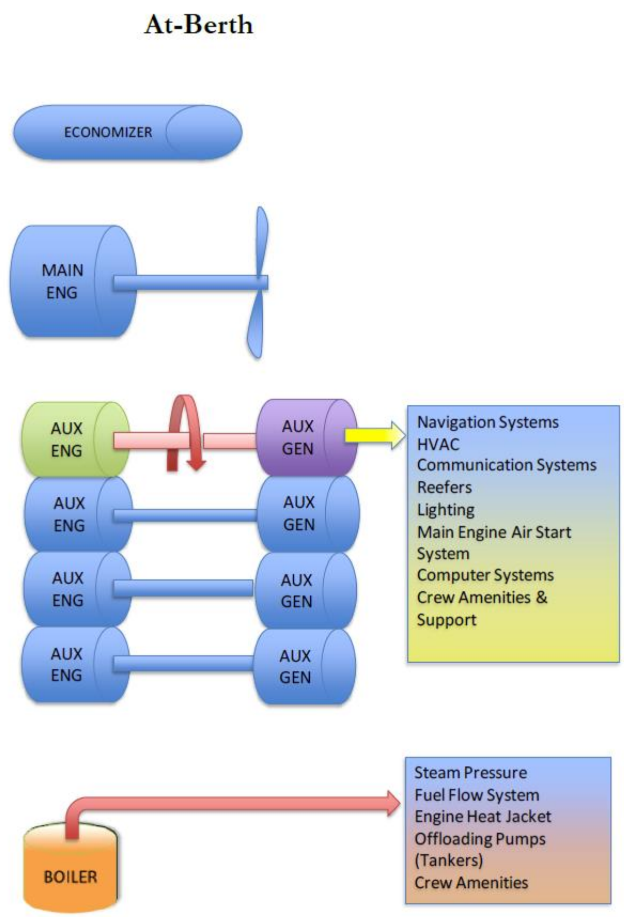


At berth or anchored - During this mode, a ship is secured and not moving. Typically,

- 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)
- 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, for crew amenities, and, for certain types of tankers, for offloading cargo through the use of steam-powered pumps
- vessel fuel consumption can be medium to high for auxiliary engines and can be medium to very high for boilers

An illustration of the vessel systems operating in at-berth mode are presented in Figure 1.8.

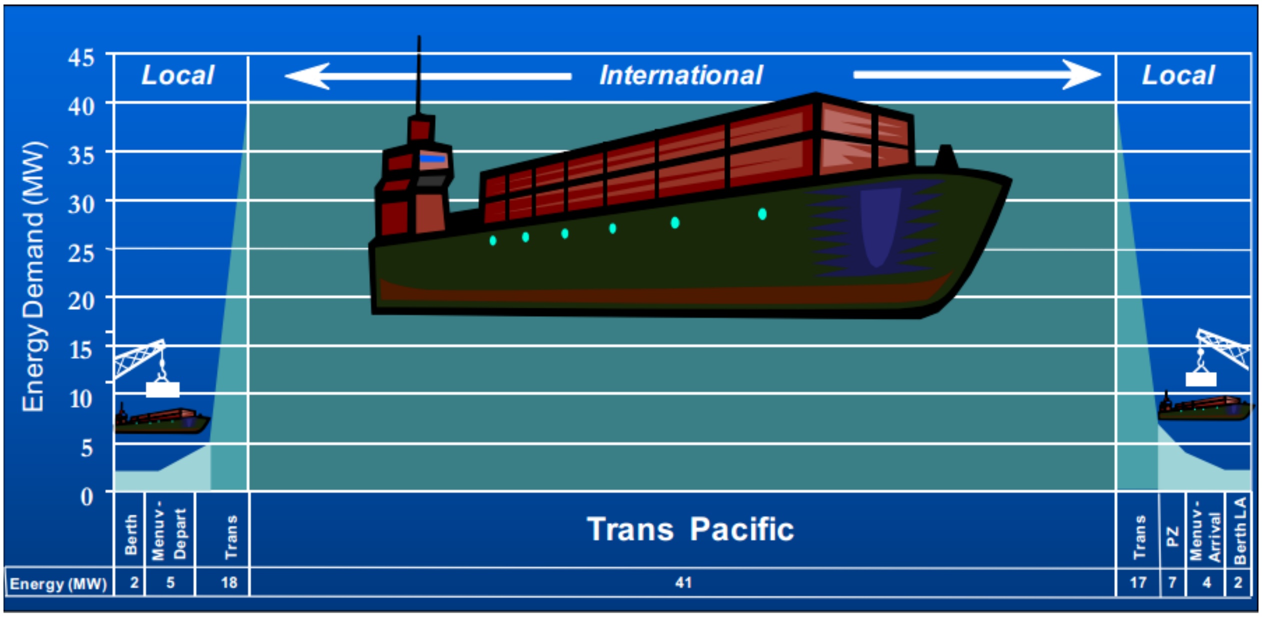
Figure 1.8: Illustration of vessel systems in operation during at-berth mode [IAPH 2010]



Where is a typical ship's energy consumed?
The majority of ship owners, operators, and engine manufacturers focus their efforts in reducing NOx and increasing efficiency for 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 is at sea. Ship emissions estimation studies show total ship carbon dioxide (CO_2) emissions in the port area range from 2% at the Port of Los Angles[9] as compared to the entire voyage of the ship to 6% at the Port of Rotterdam[10] as compared to greater North Sea area. Figure 1.9 emphasizes this point by illustrating the magnitude of time and energy spent at sea versus time and energy spent during the modes that define the port area for this study.

Figure 1.9: Relative energy demand during modes of operation for a single port-to-port ship transit[9]



Shore-based entities

IMO's overall "Concept of a Sustainable Maritime Transportation System" concept identifies interaction between ships and "shore-based entities." Ships interact with a broad range of external entities in the course of their operations. Many of these are based on shore or other fixed locations, but not all of these entities are related to the port area.

The shore-based entities relevant to this report, such as terminal operators and port authorities, are those based on or near shore that may interact with a ship for the purpose of influencing that ship's activities in the vicinity of the same shore area. Examples of entities not considered include those involved in emergency activities, routine coastwise transit that does not focus on a particular shore-related activity, and any type of non-commercial activity.

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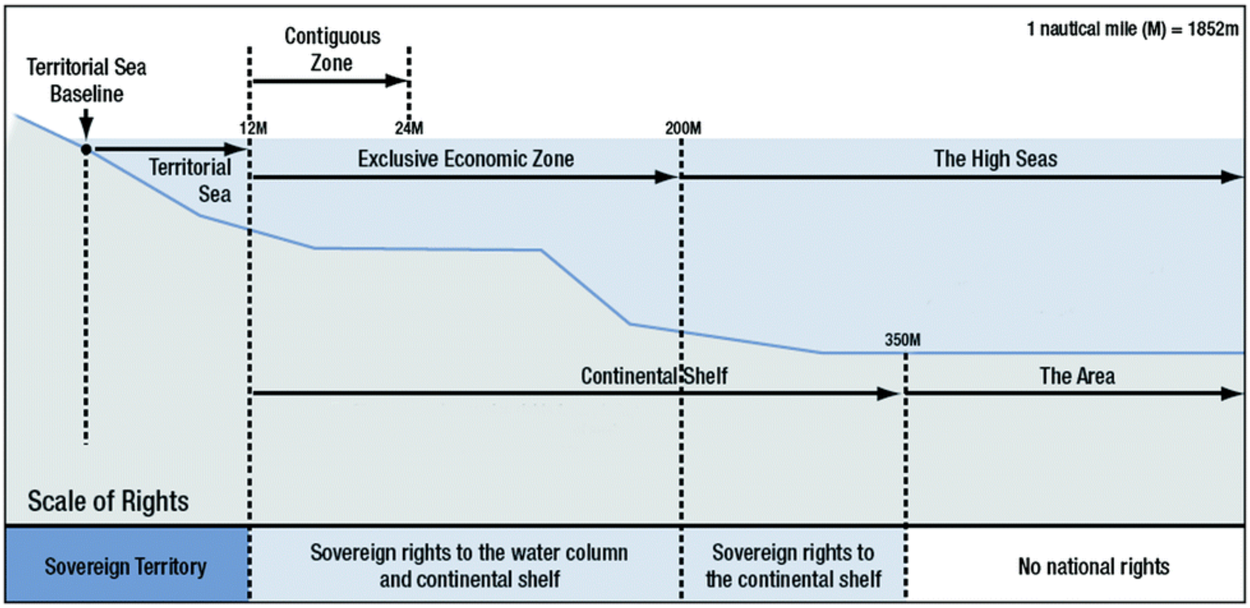
[9] www.portoflosangeles.org/DOC/REPORT_GHG_Inventory_2010.pdf

[10] Emissions 2008: Netherland Continental Shelf, Port Areas an OSPAR REGION II; Report # 23502.620 B12

Regulatory zones associated with the port area

The maritime industry is subject to a wide range of regulations and treaties that come into force based on where the ship is in relation to the land. Due to international, supranational, national, regional, and local regulations and treaties, the distance to a given land mass can result in various regulatory frameworks under which a ship's operations are affected, as illustrated[11] in Figure 1.10.

Figure 1.10: Maritime air quality regulatory zones illustration



From an air quality perspective, as a ship moves into the port area it may encounter several overlapping "regulatory zones" where international, supranational, national, regional, local regulations (which includes port specific air quality regulations) are in force. These regulatory zones are based on various distances to a given land mass and their applicability can change from port to port. Figure 1.11 conceptually illustrates this progression in relation to air quality regulatory zones.

Figure 1.11: Maritime air quality regulatory zones illustration

An example of the above applicable zones for a ship traveling to a Californian port would include: IMO/national regulations associated with the supranational North American Emission Control Area (ECA) affecting both fuel sulfur and NOx engine tier requirements; regional/local regulations from CARB associated with fuel sulfur requirements and shore powering at specific port; local requirements such as opacity limits and lease requirements from selected ports.

[11] Maritime Boundaries in the UNCLOS. Source: Tromsø, Norway: 2009, Arctic Council, "Arctic Marine Shipping Assessment 2009 Report", p.52

1.2.2 Considerations

Ship propulsion emissions by mode

As illustrated above, the port area as defined for this report includes the following modes: end of the open water transit, transition (not shown above), maneuvering, at-berth, and at-anchorage. NOx, PM, and VOCs emissions change in units of grams per kilowatt-hour (g/kWh) across the engine load range, while SOx and CO_2 remain the same, in terms of g/kWh, across the entire engine load range. 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 transition and maneuvering modes, the propulsion engine is operating with variable loads and is even turned off/on depending on the specific area the ship is maneuvering through. Recently, as part of an evaluation of MAN Diesel & Turbo valve configurations at low loads by the POLA and POLB,[12] testing was conducted over the E3 duty cycle and at 10% and 15% load to determine the g/kWh effects that low loads and fuel valves had on emissions.

While NOx increases at lower loads, it does so less substantially than previously thought. For PM, low load operations have little effect on the relative emissions. Note that these tests were conducted on a new 2-stroke engine during the certification testing at the engine manufacturer's facility. In addition to the complexity added by needing to adjust emission factors across the engines load ranges for specific modes, these low-load operational modes create unique technical challenges for many control measures discussed in this report because:

- ship engines are operating with lower and varying loads
- propulsion engines are below their optimal performance loads
- temperatures and exhaust volumes are dynamically changing

Key pollutants in the port area

The main emissions from the diesel engines discussed above that are targeted for control are NOx, PM, SOx, which is also a precursor to PM, VOC, and to a lesser extent carbon monoxide (CO) and CO_2. NOx and VOC are precursors of ozone, which is a common air pollutant of concern around port areas. Ozone is not directly emitted from combustion sources but rather formed from NOx and VOC mixing in the atmosphere and with the addition of sunlight. Typically, NOx is the primary pollutant emitted by fuel-oil-powered sources that is controlled in relation to ozone. PM and its precursor SOx are linked to health risk and some locations consider diesel particulate matter (DPM) a toxic air contaminant. Controlling NOx, PM, and SOx is the central focus for most national and regional regulatory agencies and therefore the same for ports and maritime organizations throughout the world. GHGs, including CO_2, are starting to be seriously addressed by regulatory agencies, although in the port area, health effects typically take the priority over GHGs. Not all CO_2 reducing strategies also result in reductions in NOx and PM and therefore in the port area consideration of control strategy effects need to be aligned with the air quality regulatory agency's goals.

Oxides of nitrogen

NOx is a colorless and odorless gas that is formed when fuel is burned at high temperatures, as in an internal combustion engine. NOx is a precursor to the development of ground level ozone. Environmental impacts from NOx also include acid rain, nutrient overload in water bodies, and visibility impairment when combined with atmospheric particles.

[12] Starcrest, MAN, Mitsui, *MAN Slide Valve Low-Load Emissions Test, Final Report*, June 2013, prepared for POLB and POLA, www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2571

Health Effects: NOx does not have substantial direct human health impact. Instead, through a complex series of chemical reactions in the atmosphere, NOx combines with VOC to create ground level ozone, a very potent human respiratory irritant and short-term climate forcing gas. Ozone causes inflammation in the respiratory system that leads to coughing, choking, and reduced lung capacity over long periods of exposure. Increased hospital visits for respiratory problems such as asthma especially among children are common in urban areas with high ozone pollution. The effects of ground level ozone are more frequent during the warmer summer months. Children, elderly people, and people who work or exercise outdoors are especially vulnerable to the impacts of ground level ozone.

Particulate matter

Unlike other pollutants that have a specific chemical definition, PM is a general term used to describe aerosols that can have a wide range of physical and chemical properties. PM consists of mixtures of solid particles and liquid droplets found in the air. Regulatory and control purposes define PM primarily by size. There are two forms of particle pollution that are regulated due to their potential impact to human health; inhalable coarse particles with diameter larger than 2.5 micrometers and smaller than 10 micrometers (PM_{10}), and fine particles that are 2.5 micrometers and smaller in diameter ($PM_{2.5}$).

Health Effects: The effect of PM on public health is very direct, causing acute respiratory stress and contributing to a range of chronic illnesses from long-term exposure. PM contains microscopic solids or liquid droplets that are so small that they penetrate deep into human lungs causing inflammation and restricting the passage of oxygen to the blood. Particle size is a key determinant of how severe PM's effect of human health can be. As measurement techniques and epidemiologic studies have improved in recent decades, increasing attention is being given to the effects of particles even smaller than $PM_{2.5}$. Several health authorities including the World Health Organization's International Agency for Research on Cancer (IARC) have listed PM that specifically comes from diesel engines (i.e., DPM) as a "toxic air contaminant" indicating it has specific and demonstrated carcinogenic effects.[13]

Sulfur oxides

SOx describes the family of sulfur oxide gases that primarily includes sulfur dioxide (SO_2) but also sulfur trioxide (SO_3) and sulfate (SO_4). Sulfur is found in raw materials such as crude oil, coal, and ore that contain common metals (aluminum, copper, zinc, lead, and iron). Fuel containing sulfur, such as coal and oil, when burned can lead to the production of SOx gases. SOx gases in an exhaust stream serve as an accumulation point for a range of toxic organic chemicals and other substances in the exhaust stream creating additional PM. Despite regulations that have helped to decrease sulfur concentrations in fuel around the world, SOx emissions from ships and land-based equipment remain a significant concern.

Health Effects: SOx emissions have long been understood to negatively impact public health and the environment. While SOx gas can itself be harmful in high concentrations, exposure to the PM it produces in the combustion exhaust stream is the primary health concern for this study. PM created from SOx is harmful both as a physical lung irritant and for its chemical characteristics, making it particularly harmful to sensitive groups. These groups include people who have

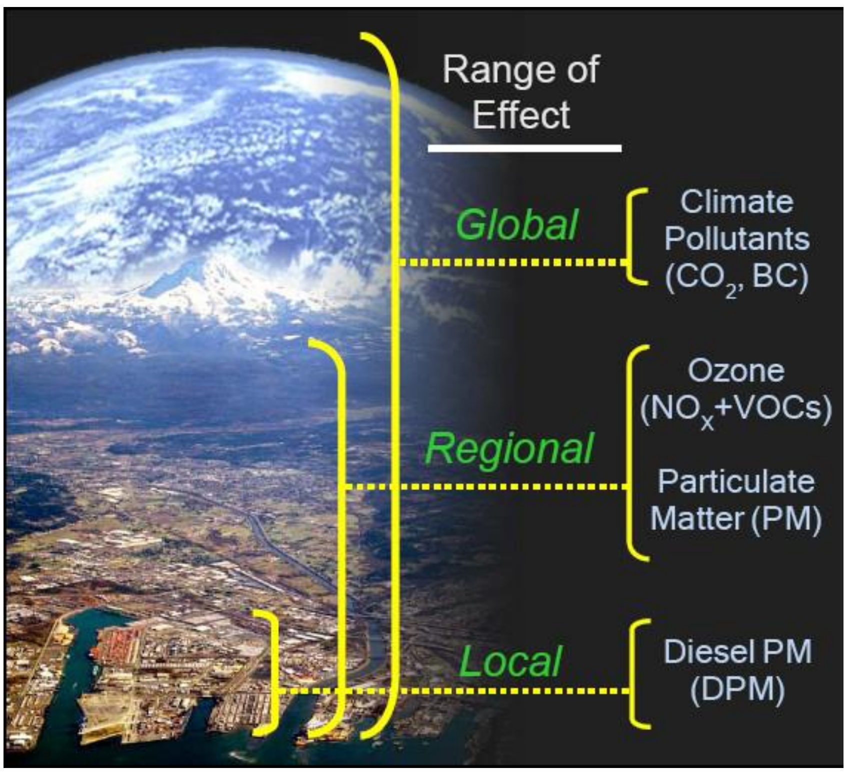
[13] www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf

respiratory ailments such as asthma and chronic obstructive pulmonary disease. They also include people with developing, decreasing, or hyperactive lung function such as children, elderly people, and active adults, respectively. In addition to health effects, SOx in the atmosphere can create significant aerosols that impair visibility and can contribute to the formation of acid rain.

Port area air pollutants in context

Using broad terms like "air emissions" or "air pollutants" is a simple way to package a range of substances that individually are much less simple when it comes to their effects, the mechanisms of release and transport, and potential measures for mitigation. Understanding more about the chemical and physical properties of individual pollutants is ultimately critical to understanding what pollutants are most important to address in the port area. One of the most important of these distinctions is that not all ship emissions have the same effect at the same ranges from the emissions sources. As illustrated in Figure 1.12, the actual range of impacts that cause concern for pollutants varies from nearby to worldwide.

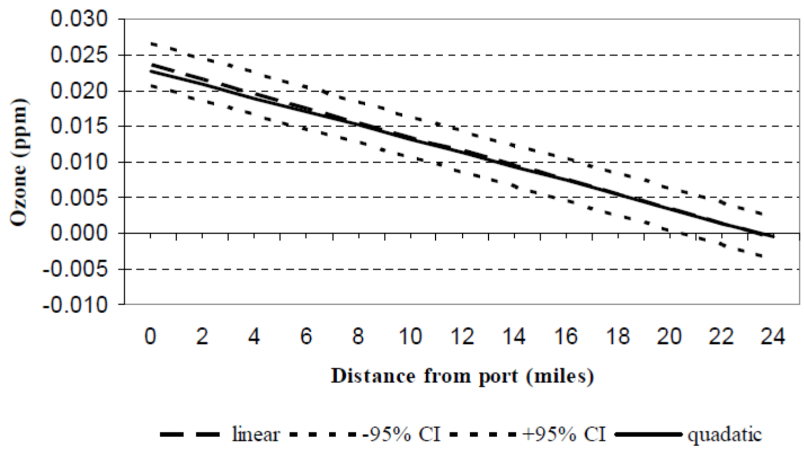
Figure 1.12: Range of impacts for various pollutants related to the ship-port interface



In most cases, port area stakeholders will be most concerned with pollutants that have more near-term and localized impacts. Even though effects of climate change such as sea level rise and extreme weather events are a general concern for many ports over the long term, climate-related pollutants such as CO_2 and black carbon (BC) do not have the same level of local and near-term impacts as pollutants that cause health concerns. On a regional level NOx (associated with ozone), PM, and SOx (which contributes to PM) are the most critical pollutants affecting air quality around port areas. Ozone and PM are the two most common drivers of air quality initiatives worldwide and will be central to any port area efforts to reduce emissions.

Past studies have shown that, depending on geographic and meteorological conditions, emissions generated hundreds of miles out at sea can reach shore-based populations. This implies a very large region of potential impact. This type of research forms the large body of literature supporting IMO's International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI amendments to control sulfur emissions. However, pollutants emitted near shore in the port area, as described above, have an even higher potential for negative effects. Figure 1.13 shows how emissions from operations at Southern California ports directly affect ozone levels at various distances from the Port[14].

Figure 1.13: 2009 Incremental ozone levels attributable to port activity near California's San Pedro Bay ports



The Port of Los Angeles (POLA)[15] and the Port of Long Beach (POLB)[16] annual emissions inventories showed that between 2005 and 2013 ship-related emissions in the port area associated with the two ports have:

- decreased by 81% for PM
- decreased by 55% for NOx
- decreased by 89% for SOx

However, the contributions of ship-related emissions towards the total emissions in the South Coast Air Basin or SoCAB (the greater inland and overwater area that makes up the greater regional air quality domain) have:

- decreased from 11% to 5% for PM
- remained the same for NOx (4%)
- decreased from 51% to 14% for SOx

The emissions trends between 2005 and 2013 illustrated above show that despite significant reduction in ship-related emissions at the two ports, which is due to the implementation of several emission

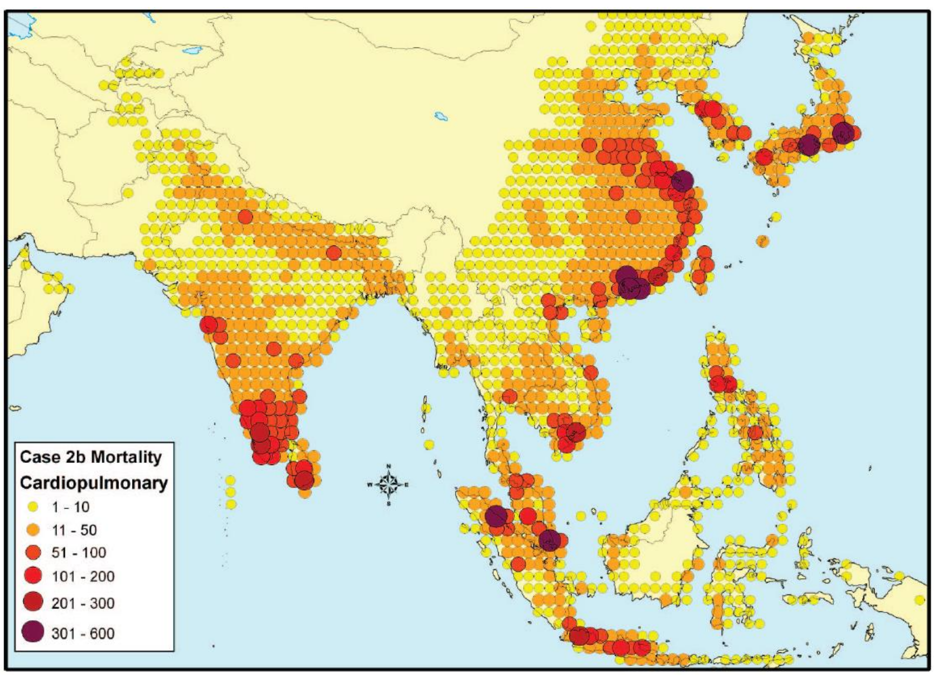
[14] Moretti, E. & Neidell, M. (2011) "Pollution, Health and Avoidance Behavior: Evidence from the Ports of Los Angeles" Journal of Human Resources 46(1), 154-175
[15] Starcrest 2005-2013, www.portoflosangeles.org/environment/studies_reports.asp
[16] Starcrest 2005-2013, www.polb.com/environment/air/emissions.asp

control measures since 2005 as part of the Clean Air Action Plan (CAAP),[17] the relative contributions of ship-related emissions to the greater SoCAB total emissions (from all sources) have decreased to a lesser extent for PM and SOx, and remained the same for NOx. The reason NOx did not change is that emission reductions associated with all the other sources in the area decreased at the same rate due to national and regional regulations. This example shows that in areas with advanced regulations, reducing ship-related emissions by their "fair share" with other emissions sources in the greater region can be challenging.

In recent years, growing concern over ship and port induced air pollution across Asia has led to proliferation of new research studies that seek to add similar context. The majority of these studies focused primarily on the compilation of ship and port emission inventories and the contribution of the maritime sector relative to other air pollution sources in the local context. Only a handful of studies have taken a regional perspective, which was driven either by the need to take a high-level view of ship-port emissions and its impact on human health, or the prospect of regional control strategy that would bring more effective results. This is an honest reflection of the current state of play in Asia, where regulatory control over ship-port emissions is lagging behind North America and Europe, and several port cities that are leading the pack in Asia are playing catch up both in the development of research capacity and in emission control strategy.

In 2007, Corbett *et.al.*[18] modeled ambient PM concentrations due to ocean-going vessels, and estimated annual global and regional cardiopulmonary and lung cancer mortalities as a result of the increase in PM concentrations attributable to ships. Some of the greatest regional burden of mortality were found along coastlines in East Asia and South Asia, which coincides with the extremely high level of ship and port activities in these Asian regions, as presented in Figure 1.14.

Figure 1.14: Annual cardiopulmonary mortality due to ship $PM_{2.5}$ emissions in Asia

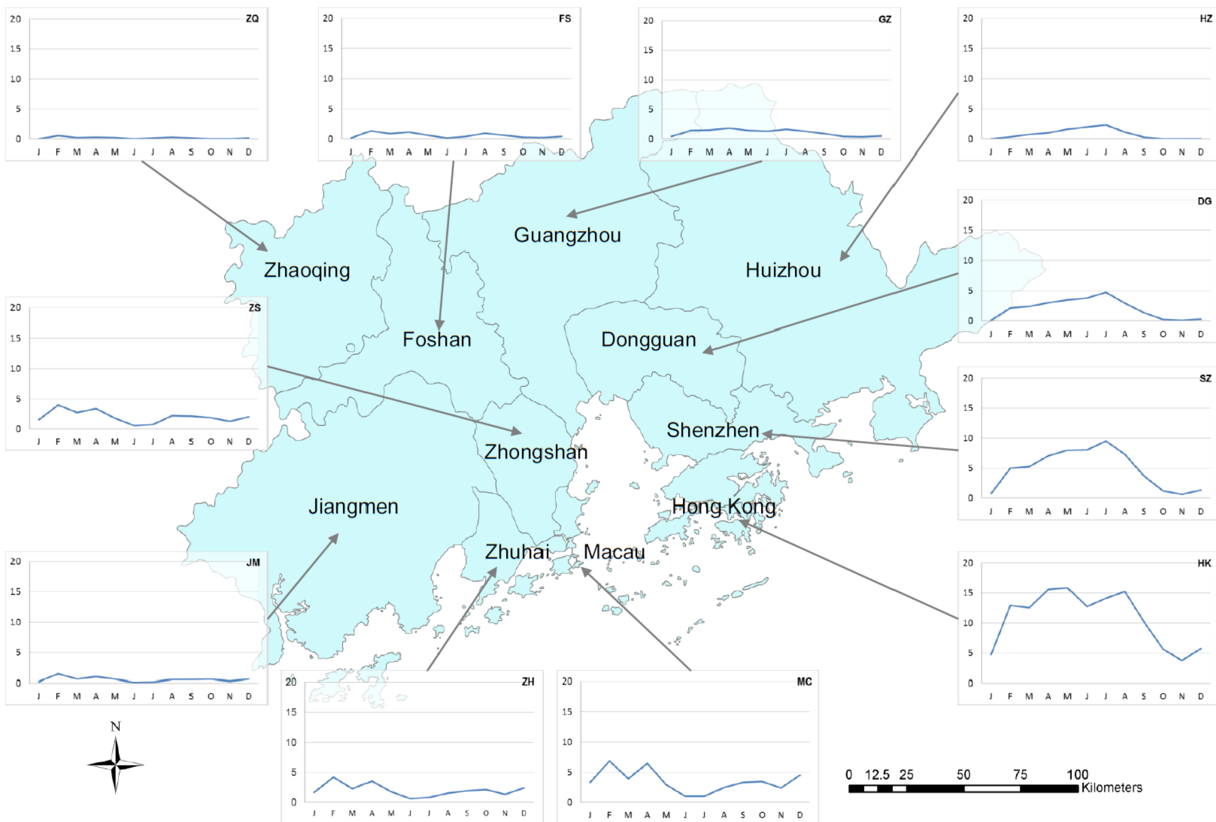


[17] www.cleanairactionplan.org

[18] Corbett, et al (2007) "Mortality from ship emissions: a global assessment", *Environ. Sci. Technol.*, 2007, 41, p.8516

In arguably the first attempt in Asia to study ship induced air pollution and to model its impact on regional air quality, Ng et.al. (2012)[19] compiled an ocean-going vessel emissions inventory for the Pearl River Delta (PRD) in southern China, covering a sea area up to 100 nautical mile (nm) from Hong Kong, China. The PRD covers three of the top ten container ports in the world, including Hong Kong, Shenzhen and Guangzhou. After completion of the emissions inventory, emission estimates were fed into an air dispersion model to distinguish the impact of ship emissions on regional ambient air quality. Using SO_2 as an example, Figure 1.15 shows that Hong Kong, being closest to open sea and surrounded by major fairways, is most affected by ship emissions, ranging from 5 ug/m^3 in winter (with north and north-easterly wind) to as high as 15 ug/m^3 in summer (wind coming from the sea). Shenzhen, which is slightly inland, found a contribution of 1 to 10 ug/m^3 from ships. For locations further inland, the contribution of ship emissions to ambient SO_2 concentrations becomes negligible.

Figure 1.15: Monthly average SO_2 concentrations (ug/m^3) in the PRD region attributable to ships, 2008



19 Ng, et.al. (2012) *Marine Vessel Smoke Emissions in Hong Kong and the Pearl River Delta*, Final Report, Atmospheric Research Center, HKUST Fok Ying Tung Graduate School, the Hong Kong University of Science and Technology.

1.2.3 Stakeholders

IMO's "Concept of a Sustainable Maritime Transportation System" envisions a process that will include consultation and discussion among a broad range of maritime industry stakeholders at the local, national, and international levels. The group of stakeholders that IMO envisioned includes the "industry at large, both at sea and ashore," consisting of the following groups:

- The maritime technologies cluster
  - classification societies
  - ship managers
  - cargo owners
  - flag and port State authorities
- Governments (represented by different administrative authorities with competences in ports)
  - port and other maritime authorities
  - customs, immigration and police
  - health, food, and agricultural authorities
  - environmental regulatory agencies responsible to ensure public health under their jurisdiction is protected
  - environmental groups that generally act as independent entities to ensure public health is being protected to the maximum level possible
- Businesses
  - private sector port operators
  - shippers
  - cargo interests
  - ship agents
  - trade organizations
  - ship owners and ship managers
  - technology manufactures
- International organizations
  - World Customs Organization (WCO)
  - World Trade Organization (WTO)
  - United Nations Conference on International Trade Law (UNCITRAL)
  - United Nations Conference on Trade and Development (UNCTAD)

In addition to the groups listed above, public engagement and the role of the affected communities have always played a substantial role in the development and deployment of strategies related to emission reductions at ports. Many port authorities refer to a "license to operate" that is granted to them by the nearby public. While not a formal process, this license is more an indication of public sentiment with regard to how port activities and future plans are perceived. Because public opinion can play a strong role in a port's ability to conduct and expand their operations, many ports have become adept at outreach and maintain regular dialogs with local community interests.

Of the stakeholders identified above by IMO, not all play a role in reducing emissions in the port area. For the most part, the activity of a ship calling a port is purely transactional; it fulfills the business needs of the trade being conducted, the ongoing operational needs of the vessel, and any compliance requirements related to the port state control authority. Unless governed by a specific port state requirement or other voluntary agreement, an individual vessel will not need to engage with port area stakeholders on air quality or energy efficiency issues. Engagement on these issues is done separately on behalf of the vessels by either their trade organization or the management of the company they are a part of.

The process of consultation that leads to new local air quality and energy efficiency goals therefore occurs independently of operational activities and may involve a subset of stakeholders than those ensuring the viability of operations. It requires groups that can speak for business interests and those that can make the case for the public. The stakeholders consulted for this report cover four distinct categories of entities that speak to those two general needs in the consultation process. These categories, listed below, are mainly established to provide consistent sets of questions that are relevant to each entity within the group.

1. Ship owners and operators
2. Port authorities and terminal operators (public and private)
3. Regulators, maritime trade associations, and NGOs
4. Technology manufacturers, vendors, and technology-related trade associations

1.2.4 Stakeholder surveys

To ensure broad coverage of experiences and opinions within the maritime sector, surveys were conducted via bilateral interviews with a broad range of stakeholders. The results of these surveys inform this study and complement the project team's experience and research. Overall, over 40 surveys were conducted that covered wide geographical spread. For the survey, organizations representing the four key groups discussed in Section 1.2.6 were approached, covering the primary stakeholders involved with reducing emissions at the ship-port interface:

- 12 port authorities/terminal owners
- 12 ship owners
- 8 manufacturers and equipment suppliers
- 10 governmental/regulatory/NGOs

It is important to note that the results of these surveys do not and are not intended to represent the worldwide collective opinion of the types of organizations that were interviewed. Interviewed organizations were chosen partially because they were available and willing and partially because they were considered likely to have experience and information that could usefully inform this report. For example, 10 active ship owners were interviewed, all of which have been involved in sustainability discussions over the years. These companies were selected because they have experience with implementing sustainability measures but do not represent the larger majority of ship owners in the world that either are not participating actively or do not have much experience with these measures. The ship owners interviewed also have relatively large fleets in operation, compared to the average. By far the largest number of companies around the world own less than 4 ships. It is clear that the sample of ship owners interviewed for this report cannot be considered to represent the opinions or experience of entire group of ship owners.

In order to ensure complete candor during the interviews, the project team committed to keep the questionnaire results anonymous. The survey questions were grouped as follows:

- environmental challenges
- drivers

- barriers
- implemented measures

A sample questionnaire for each stakeholder group is provided in Annex 1. Format included both multiple choice and open questions. As applicable, the following scale was used:

- (1) not perceived at all
- (2) slightly perceived
- (3) moderately perceived
- (4) perceived
- (5) very much perceived

Input from the surveys are included throughout this study, primarily supporting the project team experience and offering insight into various stakeholders' understanding of current environmental challenges, drivers to address these challenges, barriers to overcoming these challenges and implementation of measures to address these challenges.

1.3 Document structure

Section 2: ECEEMs
This section builds on information gathered from both stakeholder surveys and research to compile a list of emissions control and ECEEMs that are being used in the port area today or are readily available for deployment. Each measure is highlighted with information that should allow industry stakeholders to consider the applicability of a given measure for their needs. Elements of individual ECEEMs that may affect incremental implementation or operational costs are discussed to provide context for the case-by-case nature of overall ECEEM project costs on ships. Many ECEEMs are being developed in the context of increased industry interest in energy savings and greater public interest in air quality. These new technologies and strategies may not be readily available or thoroughly tested, but they can give an indication the direction where stakeholders are moving into.

Section 3: Drivers, Barriers, and Implementation

The ECEEMs described in Section 2 are more generally discussed in the context of the drivers that favor their implementation, the barriers that may impede them, and implementation methods. A broad range of economic, technical, and regulatory considerations are reviewed with the goal of providing information that may indicate strategic pathways for easier deployment of programs that involve ECEEMs.

Section 4: Summary and Findings

This section compiles the key findings identified during the study and provides the authors perspective on the current trends and status of how the industry is moving towards a sustainable maritime transportation system.

2 Emission Control and Energy Efficiency Measures

This section identifies a broad range of existing and future innovative ECEEMs that ship owners and operators, ports, and other stakeholders can consider and evaluate for reducing emissions in the port area. Existing ECEEMs are readily deployable measures that are currently being implemented to reduce emissions from various operational modes of ships associated with the port area. Existing ECEEMs are detailed in Section 2.1. A discussion of cost considerations associated with ECEEMs is provided in Section 2.2.

Future ECEEMs include innovative technologies or strategies 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 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 land-side or in other applications from which it can be re-envisioned or otherwise utilized for the maritime sector

Future ECEEMs are summarized in Section 2.3.

2.1 Existing ECEEMs

Existing ECEEMs are grouped into three major categories: equipment, energy, and operational measures.

The equipment category refers to physical changes in machinery on board a ship, particularly focused on the three primary emission sources for ships: main/propulsion engines, auxiliary engines, and boilers. Equipment measures consist of the following groups:

- engine technologies
- boiler technologies
- after-treatment technologies

The energy category refers to ECEEMs related 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:

- fuels
- alternative power supply

The operational category refers to measures that primarily affect and focus on the operation of the ship, terminal, or port such that the absolute emissions of ships in the port area are reduced. 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

For each measure, there is a brief description that provides relevant summary information about the measure, followed by discussion on how these considerations relate directly to the port area:

- 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)
    - working VOC cargo tanks (Tank)
- Retrofitable – denotes if the measure is retrofitable on existing ships (Yes – Y) or limited to only new builds (No – N), and not applicable (na).
- Terminal/vessel – for port/terminal operational efficiencies only
    - terminal (T)
    - vessel (V)
- Applicable operational modes – port area-related operational mode in which the measure is effective. This includes:
    - open water or sea conditions (S)
    - transition (T)
    - maneuvering (M)
    - at-berth (B)
    - at-anchorage (A)
    - all modes (all)
- Emissions and energy efficiency– lists the pollutant specific emission changes anticipated by the measure and provides a relative potential reduction. Emission reduction impacts are based on public data and published values, which do not necessarily represent verification by appropriate authority. If information is available, the following indicators are used:
    - ↑ for increases
    - ↓ for decreases
    - ↕ 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, they are denoted as “to be determined” (tbd). 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.

The following are considered in the study:

- NOx – oxides of nitrogen
- PM – particulate matter
- SOx – sulfur oxides
- HC - hydrocarbons
- VOC – volatile organic compounds (relating to VOC cargo working losses)
- energy consumption as a surrogate for energy efficiency

For each category, a summary table is presented for the measures in the group that includes the measure title, applicability, retrofit, applicable modes, and emission reduction indicators for NOx, PM, and SOx as applicable. More detailed descriptions, illustrations, and related information for each of the specific ECEEMs presented in the summary tables is provided in Annex 2. In addition to the above, the detailed descriptions in Annex 2 include the following elements for each measure:

- Maturity – denotes the status of ECEEM maturity (e.g., is it established and being applied, is it undergoing testing or is it in the development process, etc.).
- Limitations – known limitations associated with the ECEEM (e.g., temperature, mode, engine load, etc.)
- Implementation – identifies implementation methods that have been used with the specific ECEEM that resulted in the deployment of the measure and provides limited examples and includes:
    - business case – implementation is driven by a compelling business savings or advantage
    - market based measures (mbm) – implementation recognized in mbm such as incentive schemes
    - grants – implementation included grant funding
    - mitigation – implementation is driven by project mitigation requirements
    - voluntary – implementation is on a voluntary basis
    - regulation – implementation is driven by regulation

It should be noted that several of the emission control measures can potentially be used in combination; however, analysis is needed to determine the degree to which the potential emission reductions may (or may not) be additive. In addition, NOx and PM changes are typically inversely related due to their formation as a function of engine temperature and fuel to air ratio. An efficient or lean burn engine is typically hotter and creates more NOx and less PM and an inefficient engine or rich fuel/air mixture, which is typically cooler, reduces NOx but increases PM.

2.1.1 Equipment

The equipment category includes engine, boiler, and after-treatment technologies.

Engine technologies

Engine technologies reduce emissions or improve efficiencies associated with propulsion engines and auxiliary engines onboard a ship. It is important to note that near the port area it is common for auxiliary engines to contribute total mass emissions roughly equal to, or more than, the propulsion engines. This is due to the fact that propulsion emissions associated with arrivals, shifts, and departures are limited in time and power applied, whereas auxiliary engines are operating the entire duration at constant loads. Therefore, ECEEMs focused on propulsion may not have as significant an impact as initially presumed. A screening analysis should be performed to determine the potential impacts of any of the ECEEMs prior to implementation in order to ensure results will meet expectations. Table 2.1 provides a summary of the engine technologies highlighted in this study with further details provided below. For more detailed description and information relating to ECEEMs presented Table 2.1, see Annex 2.

Table 2.1: Summary of Engine Technologies

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Engine Technologies								
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%↓	–

Boiler technologies
Boiler technologies reduce emissions or improve efficiencies associated with steam plants and auxiliary boilers on board a ship. Table 2.2 provides a summary of the boiler technologies highlighted in this study with further details for each provided below.

Table 2.2: Summary of Boiler Technologies

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Boiler Technologies								
High Efficiency Boilers	B	Y	All	↓ tbc	tbd	–	–	↓ tbc
Auxiliary Engine Wast Heat Recovery	B	Y	All	↓ tbc	↓ tbc	↓ tbc	↓ tbc	↓ tbc

There are efficiency improvements related to boiler systems such as propulsion engine heat recovery that can reduce CO_2 up to 12%; however, as stated in Section 1, CO_2 generation from most ships' boilers is typically a fraction of the total ship CO_2 emissions during the life of the ship. Since the propulsion engine will be transitioning to variable low loads and ultimately off while at-berth and at-anchorage for all non-diesel-electric configured ships, advanced heat waste recovery units could have minimal impact in the port area, depending on the geographical parameters of the port area modes.

For more detailed description and information relating to ECEEMs presented in Table 2.2, see Annex 2.

After-Treatment Technologies

After-treatment technologies reduce exhaust emissions from propulsion and auxiliary engines as well as boilers/steam plants by treating the exhaust emissions of these sources. After-treatment technologies are not integral to the workings of the engine or boilers they are treating. Most after-treatment technologies have their origins in reducing emissions associated with land-based stationary sources, which have been adapted to land-based mobile sources and later "marinized" for use on board ships. Currently there are two primary after-treatment technologies being deployed on ships: selective catalytic reduction (SCR) and exhaust gas scrubbers (EGS). SCR significantly reduces NOx while scrubbers significantly reduce SOx and PM. Table 2.3 provides a summary of the scrubber technologies highlighted in this study with further details for each provided below.

Table 2.3: Summary of After-Treatment Technologies

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

For more detailed description and information relating to ECEEMs presented in Table 2.3, see Annex 2.

2.1.2 Energy

The energy category includes fuels and alternative power systems.

Fuels

Fuels have been in the "spotlight" due to a number of requirements including IMO fuel sulfur limitations, upcoming IMO ECA and sulfur emission control area (SECA) requirements, EU at-berth requirements, CARB marine fuel requirements, and various mbm that incentivize the use of cleaner fuels. Table 2.4 provides a summary of the different types of fuels based measures highlighted in this study with further details for each provided below.

Table 2.4: Summary of Fuels

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

For more detailed description and information relating to ECEEMs presented in Table 2.4, see Annex 2.

Alternative power systems
Alternative power systems utilize power sources other than onboard auxiliary engines to meet onboard power requirements. Current projects range from OPS to alternative power generation while at berth such as solar and LNG. The important aspect of the use of alternative power systems is that they reduce the generation of emissions by ships with diesel powered engines while at berth near the populated area, using alternative power systems such as solar, LNG and power plants which are lower in emissions compared to diesel powered engines on board the ship. For each type, the following information is provided: overview description of the system, whether the system is applicable to new builds and/or existing ships, the applicable operation modes where the system is effective, whether the system is applicable to propulsion and/or auxiliary engines, what pollutants are reduced, whether there are CO_2 benefits (i.e., fuel consumption improvements), potential limitations of the system, and other pertinent information. Table 2.5 provides a summary of the scrubber technologies highlighted in this study with further details for each provided below.

Table 2.5: Summary of Alternative Power Systems

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Alternative Power Systems								
On-Shore Power Supply	A	Y	B	≤95%↓	≤95%↓	≤95%↓	≤95%↓	≤95%↓
Barge Power Supply	A	Y	B	↕ tbc	↓ tbc	↓ tbc	↑ tbc	↕ tbc
Solar Power	A	Y	B	↓ tbc	↓ tbc	↓ tbc	↓ tbc	↓ tbc

For more detailed description and information relating to ECEEMs presented in Table 2.5, see Annex 2.

2.1.3 Operational

The operational category includes operational ship operational efficiencies, port and terminal operational efficiencies, and VOC working losses from bulk liquid ships.

Ship operational efficiencies

Ship operational efficiencies are improvements that reduce fuel consumption in the port area. Depending on the port configuration, optimization of a ship's movement through water may or may not have a significant impact. This is dependent on the distance and speed a ship is moving in a particular port area. Port areas that have extended open-water transit can materially benefit from emission reductions associated with ship movement efficiency improvements. Typically, in the port area auxiliary engines have a much higher contribution to emissions than during the open-water transit mode, however this is dependent on the distance and characteristics associated with the area's open water transit mode.

For this group, the assessment of "retrofitable" is replaced with "applicability" for new and/or existing vessels, because "retrofitable" is not an applicable concept.

Table 2.6 provides a summary of ship operational efficiencies highlighted in this study with further details for each provided below.

Table 2.6: Summary of Ship Operational Efficiencies

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

For more detailed description and information relating to ECEEMs presented in Table 2.6, see Annex 2.

Port and terminal operational efficiencies
Port and terminal operational efficiencies can bring co-benefits to operational bottom lines through reduced fuel consumption, fees, taxes, as well as emission reductions in the port area. For each approach, the following information is provided: overview description of the approach, if the approach is applicable to new builds and/or existing ships, the applicable operation modes where the approach is effective, if the approach is applicable to propulsion and/or auxiliary engines, what pollutants are reduced, if there are CO_2 benefits (i.e., fuel consumption improvements), potential limitations of the approach, and other pertinent information.

For this group, the assessment of “retrofitable” is replaced with “applicability” for terminals or vessels, because “retrofitable” is not an applicable concept. Table 2.7 provides a summary of the port and terminal operational efficiencies highlighted in this study with further details for each provided below.

Table 2.7: Summary of Port and Terminal Operational Efficiencies

	Applicable Emission Source	Terminal/Vessel	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Port/Terminal Operational Effiicencies								
Automated Mooring Systems	AB	T	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimization of Terminals & Ports to Reduce At-Berth Time	AB	T	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Electric Shore Side Pumps for Bulk Liquids	B	T	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Off-Terminal Transloading	All	V	A	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

For more detailed description and information relating to ECEEMs presented in Table 2.7, see Annex 2.

VOC working losses

Working losses from tankers due to fugitive emissions from valves, flanges, fittings, and pressure relief valves are not included because the most significant fugitive VOC emission source in the port area occurs during the ship loading operation. Vapor recovery of VOC has been a strategy utilized by several countries, requiring emissions from tanks being filled to be controlled to reduced health and environmental impacts. Table 2.8 provides a summary of the VOC working losses measure highlighted in this study with further details for each provided below.

Table 2.8: Summary of VOC Working Losses

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	VOC	Energy Consumption
VOC Working Loses								
Vapor Recovery for Volatile Bulk Liquids	Tank	Y	B	–	–	–	↓	–

For more detailed description and information relating to ECEEMs presented in Table 2.8, see Annex 2.

2.2 Existing ECEEM cost considerations

Almost no application of the ECEEMs in Section 2.1 is technically or economically simple. These complex, advanced technologies for emissions control or efficiency improvement are being applied to even more complex systems that provide auxiliary or propulsion power to ships. This implies a multitude of specialized design considerations for specifying and installing the ECEEM, as well as future operation and maintenance activities that need to be tailored for every application. Each of the steps that ensure the proper fit and function of an ECEEM comes with an associated cost. The compounded complexity of the technologies and peripheral considerations makes it impossible to predict overall costs accurately without substantial understanding of the specific application.

While portions of this report discuss specific costs associated with certain technologies in order to provide a sense of scale, such generalized cost values can be misleading when trying to estimate total costs for a specific application. Actual overall application costs of ECEEMs are a compilation of individual costs that begin with the cost of a specific technology but may expand by an order of magnitude as other expenses are added. Numerous studies have explored the range and complexity of these cost considerations. They begin with major technical costs[20] and range from topics such as the accessibility of capital and other hidden costs at inception[21] to costs associated with transactions where multiple stakeholders are involved[22]. This section seeks to provide insight into the most significant expenses that embodied by ECEEM projects and how over-simplified values are often reported as the project cost.

2.2.1 General cost considerations for ECEEMs

In general terms, costs associated with an ECEEM technology can be broken down into CAPEX and OPEX, or costs incurred before and after an ECEEM is commissioned and placed in service. These two general categories embody a range of other cost categories that can change based on the technology, the specific application, and the parties involved.

Fundamentally, costs associated with implementing an ECEEM are strongly tied to its level of development and market maturity. The newest available technologies will often require more bespoke design work and extended testing before commissioning. A technology that has a large number of prior installations is more likely to have design, fitting, and testing processes streamlined for new applications. For this reason, it is during the initial phases of a technology's market emergence that independent incentives and funding can be critical. The additional support needed to move an ECEEM to a more mature phase of market penetration often relies on the ability of the technology provider to raise investment funding. Alternatively, an increasing number of governments and other authorities that want new technology deployment at a faster pace are finding ways to bridge this gap. Such innovative incentive programs can reduce the time it takes for a technology to achieve a sufficient level of market penetration to reduce overall costs. This will be further discussed in Section 3.

[20] Faber, J. and others (2011a), Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures. MEPC 62/INF. 7. CE Delft, Delft, Netherlands

[21] Sorell, S. et al. (2004), The economics of energy efficiency: barriers to cost-effective investment, Edward Elgar Pub, UK

[22] Kesicki, F. and N. Strachan (2011), Marginal abatement cost (MAC) curves: confronting theory and practice. Environmental Science & Policy, 14, 1195-1204.

Once a technology has achieved a level of market penetration sufficient for costs to be more normalized, CAPEX and OPEX expenses can be more easily determined. The next key consideration for costs is whether (in the case of a ship-based ECEEM technology) the ECEEM is being retrofit to an existing ship or installed during the process of building a new ship (as illustrated in Figure 2.1). In general, installing ECEEMs on a new ship is more straightforward and less costly because dependent systems can be integrated during the overall design process and adequate space can be allocated for the system footprint and peripheral components.

Figure 2.1: Installation of first dual-fuel slow speed engine MAN 8L70ME-C8.2GI, TOTE

Retrofitting ECEEMs to an existing vessel will almost invariably be more complicated and costly. Beyond finding the space for key system components, piping, wiring, and other elements, accessing the areas to place these systems can require cutting through major sections of the vessel (as illustrated in Figure 2.2). This in turn requires time in an appropriately equipped shipyard. This modification effort results in time that the vessel is not generating revenue. All of these factors result in additional costs that may or may not be accounted for in a CAPEX value, but are certainly crucial to calculating whether an ECEEM may be viable for a specific application.

Figure 2.2: Preparations for installation of scrubber system, DFDS

2.2.2 Incremental cost considerations from the perspectives of key stakeholders

The broad cost components that are discussed in the previous section only begin to describe the many individual elements that make up the overall CAPEX and OPEX costs associated with ECEEMs. This section presents important considerations when determining incremental costs from the perspectives of three different stakeholders: ship owner, terminal operator and port authority. Many other stakeholders may participate, but those presented here are the primary parties involved throughout the ECEEM decision and implementation process relevant to the ship-port interface.

Some of the individual considerations on the list are elements of a business case that would be compiled to assist in the decision making process. In most cases, the decision to adopt an ECEEM relies on the business case showing a net positive return to justify the range of costs being outlaid. This standard investment consideration is true for many efficiency technologies that reduce fuel consumption over time and may be true for emission reduction technologies when they are compared to other options. ECEEMs that do not indicate a positive return on investment once all individual considerations are appraised will require some form of regulation or incentive to be viable.

From the ship owner's perspective, considerations that have direct cost implications when implementing of an ECEEM may include:

- Which ECEEM(s) is/are being considered?
- Actual hardware and software costs associated with the control measure.
- Installation costs of hardware and software on a new or existing vessel.
- Footprint of the control technology and associated equipment.

- Costs for existing ship survey to determine if there is adequate room for the equipment; options for installing associated equipment on the ship, etc.
- Technical design of integrating the system into an existing or new build ship.
- Lead times for ordering equipment and fabrication.
- Will installation have to be completed while at dry dock or can the installation be completed while the vessel continues to operate.
- Which ship yards are qualified and available for installation of the control technology?
- Cost and duration of installation/retrofit for existing ships and build schedule impacts for new ships.
- Fleet operational impacts and costs while existing vessels are being retrofitted, or extended build schedules for new ships.
- Operational consumables for the control technology relating to availability, ordering, supplying, onboard storage, etc.
- Operational waste streams from the control technology relating to treatment, storage, availability of shore-side disposal, etc.
- Class Society commissioning
- Project management costs
- Project financing through self-financing, financial institutions, or third party financing
- Project financing costs
- Crew training costs
- Recordkeeping requirements
- Is the technology verified by regulating authority/classification society or not
- Will it work at all ports the ship visits

From a terminal operator's perspective, the business case will still be a fundamental driver, but national and regional regulations can also be a significant driver. Concerns from the local community, from which the local management and workforce will be drawn, can also be relatively strong drivers for implementing ECEEMs or encouraging customers to do so. From the terminal operators' perspective, considerations that have direct cost implications when considering the implementation of an ECEEM include:

- Which ECEEM(s) is/are being considered?
- Actual hardware and software costs associated with the control measure.
- Installation costs of hardware and software on terminal.
- Footprint of the control technology and associated equipment.
- Costs for terminal survey to determine if there is adequate room for the equipment and evaluation of terminal infrastructure to determine if upgrades are required, etc.
- Technical design of integrating the system into existing terminal infrastructure.
- Lead times for ordering equipment and fabrication.
- Will installation affect terminal operations?
- Cost and duration of installation
- Operational consumables for the control technology relating to ordering, supplying, etc.
- Operational waste streams from the control technology relating to treatment, storage, disposal, etc.
- Infrastructure improvement analysis costs for consumables or energy supply, as applicable for the ECEEM.

- Infrastructure improvement costs associated with consumables and/or energy supply, as applicable for the ECEEM.
- Engineering, electrical, and environmental permitting requirements relating to installation and operation of the ECEEM.
- Project management costs
- Project financing through self-financing, financial institutions, or third party financing and related costs
- Terminal staff training costs
- Recordkeeping requirements

From a port authority's perspective, national, regional, and local regulatory compliance is a primary driver, with community concerns weighing heavily into the equation. Even though port authorities are usually required by their charters to operate a cost-effective business, a unique part of the business equation for ports involves what they refer to as the "license to operate" that is granted by the local community. This "license" is not a formal contract, but rather an unspoken agreement that the port will seek to provide the maximum value for the community it operates in. In most cases this value is in the form of jobs and as an economic hub, but in many cases a port's license extends to environmental stewardship.

These additional considerations may strongly affect a port's decision making, but otherwise a port will have similar cost considerations as a terminal operator, especially if the port also operates its own terminals. If a port authority operates solely as a landlord, then their direct cost implications when considering the implementation of an ECEEM include:

- Which ECEEM(s) is/are being considered?
- What is the implementation method to be used with the ECEEM being considered (direct Port incentive funding, tariff requirements, lease requirements, project mitigation requirements, etc.)?
- Analysis of ECEEM implementation scenarios costs.
- Port Administration CAPEX costs associated with development of any administrative systems needed for the implementation of the measure.
- Incentive payout costs, if applicable.
- Outreach associated with the implementation of the measure costs.
- Project management costs.
- Verification and auditing costs.
- Project financing through self-financing, financial institutions, public bonds, or third party financing and related costs
- Record keeping and reporting costs.

2.2.3 Beyond project costs: assessing abatement costs and effectiveness from the public standpoint

Even if a project can be shown to be cost effective from the standpoint of the key stakeholders, it is also crucial to be able to demonstrate that measures being implemented achieve goals that align with the public policies that created drivers for their implementation. With respect to ECEEMs in the ship-port interface, cost effectiveness for the public will be mainly related to how much ECEEMs reduce air emissions for a given level of investment and how these reductions translate to improved air quality in the port area.

A common approach in the US is to establish the cost effectiveness of ECEEMs is to compare measures on an "annualized cost per ton NOx reduced" or "annualized cost per ton NOx + PM reduced" basis[23]. This approach may appear simple in that it allows cost effectiveness to be determined simply by knowing the quantity of emissions that are reduced and the costs associated with those reductions. The complexity of this approach is that it also requires a well-developed understanding of local air quality concerns and emission sources. In Houston, because of the intense air quality issues and difficulty of reducing emissions, stationary source projects that reduce NOx can cost upwards of US$100,000/ton NOx, while in other areas, the cost effectiveness could be an order of magnitude lower or less.

Of critical importance is developing a link between publically-created drivers leading to ECEEM implementation and results in the form of improved air quality and public health. This understanding begins with a well-conceived and executed emission inventory to understand the basic emission sources that are leading to ambient air quality concerns. A more complete understanding would combine emission inventory results with meteorological modeling and health impact analysis in order to create clear connections that can relate calculated cost-effectiveness of individual projects with actual benefits to the public. Development of emissions inventory and conducting health impact analysis could be an additional cost element for a port if they do not regularly update their emissions inventory and do not have access to health impact analysis.

The difficulty in tying the abatement potential of ECEEMs described in this report to specific abatement costs that are relevant to the public as discussed above is evident from studies that have already attempted to do this. The European Commission's Joint Research Centre's report on emission abatement in 2008[24] shows the level of detail and investigation necessary to generate these types of details. Similar efforts related to all of the measures outlined in this report were not feasible within the project scope and timeframe, but may be a useful exercise for public agencies considering a limited number of specific measures.

2.2.4 Examples of reported costs associated with ECEEM projects with references

As a complement to the cost considerations discussed above, this section provides examples of a variety of ECEEM-related projects for which total project costs have been published. The total project costs will be some compilation of incremental costs but exactly which incremental costs are included in that final value will vary subjectively based on who is calculating the overall cost.

Each project below provides both the total published cost and a link to the study or announcement from which the cost was cited. These are intended to be used as a tool to enrich the understanding of project costs at high level when viewed in the context of the discussions in preceding sections.

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[23] www.arb.ca.gov/msprog/moyer/guidelines/2011gl/2011cmp_appc_07_11_14.pdf

[24] V. Andreoni et al. "Cost effectiveness Analysis of the Emission Abatement in the Shipping Sector Emissions" JRC publication EUR 23715 EN, 2008

Engine Technologies

Repower

- TOTE — 2014 – 2 ro-ro ship conversions to LNG-only main engine, auxiliary, storage, and gas handling systems $84 million[25]
- NOx Fund[26] — 2011 – *Bit Viking* bulk liquid ship LNG retrofit €7.2 million
  2011 – *Boknafjor* ferry new build LNG gas only engines €4.63 million
  2012 – *Høydal* PSV new build LNG gas only propulsion upgrade €3.6 million
  2012 – *Normand Arctic* PSV new build LNG dual fuel upgrade €6.3 million
  2012 – *Viking Prince* PSV new build LNG dual fuel upgrade €5.75 million
  2013 – 2 Fjordline ferries new builds LNG gas only engines €22 million (granted)
- Stena Line — 2013 – 25 ferries to be adapted to methanol if *Stena Germanica* is successful[27]
  2014 – *Stena Germanica* ro-pax ferry conversion to methanol €22 million[28]
  2013 – 25 ferries to be adapted to methanol if *Stena Germanica* is successful[29]
- PANYNJ — 2004 – 2009 – 25 tugs repowered for US$4 million
- Carl Moyer — 1999-2006 – 448 various domestic vessel engine repowers for US$25.8 million[30]

After-Treatment Technologies

Scrubbers:

- Carnival Corp. — 2013 – 32 cruise ships to be retrofitted with scrubbers for US$180 million[31]
  2014 – 38 cruise ships to be retrofitted with scrubbers for US$220 million[32]
  Total of 70 ships for US$400 million, includes design, build, and installation of the systems. Includes Carnival Cruise Lines (22), Holland America Line (9), Princess Cruise (7), Cunard (3), AIDA Cruises (10), Costa Cruises (6). Remaining schedule and numbers by line to be forthcoming.
- Brittany Ferries — 2014 – 3 ferries to be retrofitted with scrubbers for €70-80 million[33]
- Grimaldi Group — 2014 – 10 ro-ro ships to be retrofitted with scrubbers, no costs identified[34]
- DFDS — 2009 – *Ficaria Seaways* ro-ro ship retrofitted with scrubber ~€5 million[35]
  2013 – *Magnolia Seaways*, *Petunia Seaways*, and *Selandia Seaways* ro-ro ships retrofitted with scrubbers ~€14 million[36]
  2013 – 8 more ro-ro ships to be retrofitted with scrubbers for €40 million[37]
  2014 – 6 more ro-ro ships to be retrofitted by 2015 for €4 to 7 million each[38]

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[25] toteinc.com/totem-ocean-chooses-wartsila-technology-for-largest-lng-ship-conversion-in-north-america/; www.fleetsandfuels.com/fuels/lng/2012/08/tote-converting-two-to-lng/
[26] www.ndptl.org/c/document_library/get_file?folderId=19620andname=DLFE-1547.pdf
[27] www.portofgothenburg.com/News-desk/News-articles/Stena-Line-invests-in-methanol/
[28] www.ship-technology.com/news/newsstena-line-to-convert-passenger-ferry-to-methanol-propulsion-4445836; www.ihsmaritime360.com/article/15535/stena-announces-methanol-fuel-conversion-for-ferries
[29] www.portofgothenburg.com/News-desk/News-articles/Stena-Line-invests-in-methanol/
[30] www.arb.ca.gov/msprog/moyer/status/2006status_report.pdf
[31] phx.corporate-ir.net/phoenix.zhtml?c=200767andp=irol-newsArticleandID=1852354
[32] phx.corporate-ir.net/phoenix.zhtml?c=200767andp=irol-newsArticleandID=1933369
[33] www.motorship.com/news101/industry-news/ferry-company-puts-lng-plans-on-hold
[34] www.finnlines.com/company/news_press/press_releases/finnlines_invests_in_environmental_technology
[35] www.dfdsconnects.com/big-investment-in-sulphur-cleaning/
[36] www.dfdsconnects.com/full-speed-ahead-with-scrubbers/
[37] www.dfdsconnects.com/40-million-euro-extra-scrubbers/
[38] www.dfdsconnects.com/creating-the-world-largest-scrubber-fleet/

- Alfa Laval Cost scenarios – 800 twenty-foot equivalent unit (teu) container feeder ship, Aframax tanker, ro-ro ferry[39]

Selective Catalytic Reduction systems:

- IACCSEA 2013 – Marine SCR cost benefit analysis[40]
  2013 – SCR cost benefit analysis tool[41]
- MAN D&T 2014 - *Petrofac JDS 6000* deepwater derrick-lay vessel new build, cost not indicated[42]
- DFDS 2014 - *Petunia Seaways* ro-ro ship retrofitted with SCR, cost not indicated

Alternative Fuels

LNG

- Totem Ocean 2012 – 2 LNG gas only 3,100 teu container ships for +US$350 million[43]
- NOx Fund[44] 2011 – *Boknafjor* ferry new build LNG gas only engines €4.63 million
  2012 – *Høydal* PSV new build LNG gas only propulsion upgrade €3.6 million
  2012 – *Normand Arctic* PSV new build LNG dual fuel upgrade €6.3 million
  2012 – *Viking Prince* PSV new build LNG dual fuel upgrade €5.75 million
  2013 – 2 Fjordline ferries new builds LNG gas only engines €22 million (granted)

Methanol

- Stena Line 2013 – Investment in shore-side infrastructure at Port of Gothenburg

Alternative Supplement Power Systems

- WPCI OPS 2014 – associated costs details and cost calculator[45]
- POLA 25 container and 3 cruise berths US$180 million
- POLB 12 container berths US$185 million
- POO 11 container berths US$70 million
- POSD 1 cruise berth – US$4.25 million
- PANYNJ 2012 – cruise berth with maximum of 14 mw capacity US$19.3 million[46]
- vessel side US$500,000 to $1.1 million per installation

[39] www.alfalaval.com/industries/marine/oil-treatment/Documents/PureSOx%20product%20brochure.pdf
[40] www.iaccsea.com/fileadmin/user_upload/pdf/SCR_cost_calculation_model2_v1.pdf
[41] www.iaccsea.com/scr-cost-model/
[42] www.dfdsconnects.com/dfds-awarded-for-catalyser/
[43] toteinc.com/worlds-first-lng-powered-container-ships-to-serve-puerto-rico-for-toteinc/
[44] www.ndptl.org/c/document_library/get_file?folderId=19620andname=DLFE-1547.pdf
[45] www.ops.wpci.nl/costs/
[46] www.bloomberg.com/article/2012-06-28/azzfA4oosmfc.html

2.3 Future ECEEMs

The goal of this section is to identify and appraise possible innovative or emerging emissions reduction and energy efficiency measures, programs and strategies that optimize the energy efficiency and reduce ship emissions when in the port area. Unlike Section 2.1, which focuses on readily deployable measures, this section discusses specific measures that are still being developed. It also discusses measures that are market ready with substantial potential for growth if certain barriers such as cost can be overcome in the future. While some of the measures may be the same as measures described in Section 2.1, this section focuses specifically on the future potential of these measures. In cases where the future potentials are similar and details of individual measures have been already given, measures are aggregated into a more general category.

Because the terms "innovative" and "emerging" can imply a variety of meanings, for this study we define these terms as limited to any of the following:

- A distinctly novel technology or strategy with 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.
- A technology or strategy that is available and ready to deployed and is in limited or niche use, but with a substantial potential for expansion if certain key barriers like cost can be overcome.
- A technology or strategy that is being used on land-side or in others application from which it can be re-envisioned or otherwise utilized for the maritime sector.

The measures described in this section are intended to be restricted to measures that have substantial potential to affect emissions or efficiency of ships in the port area. As such, measures that are relevant primarily to the ocean transit portion of a ship's voyage are not addressed here. The following are examples of technologies that may be innovative or emerging according to the above definitions, but not likely to be most effective when a ship is within the port area:

- Hull technologies, including advanced coatings and air lubrication
- Vessel hydrodynamic, aerodynamic, and other major alterations to reduce friction while under way. These include propeller changes, bow adjustments, and other major alterations.
- Engine modifications that are mainly active or effective at higher loads, including waste heat recovery and engine de-rating.
- Alternative or augmentative propulsion technologies such as kites, fixed sails, and Flettner rotors

For each measure, a brief description provides relevant summary information about the measure as well as discussion about what "emerging" means in this specific case. For measures that have been discussed in the previous section, detailed descriptions are assumed to already have been covered and the text focuses more on the future potential. Similar to the "existing measures" section, summary information follows the narrative for each measure but will cover slightly different information including:

- System Applicability – describes which emission sources can be affected by the measure. These include:
    - propulsion engines (P)

  - auxiliary engines (A)
  - auxiliary boilers (B)
  - electrical (E)
  - other or operational measures (O)
- Retrofitable – denotes if the measure is retrofitable on existing ships (Yes – Y) or limited to only new builds (No – N).
- Market maturity – denotes the status of maturity for the ECEEM (e.g., is it in the development stage, undergoing validation testing or being applied to a new application, etc.). Each measure is designated with one or more of the following:
  - market ready (M)
  - emerging (E)
  - limited production (L)
  - theoretical (T)
- Emissions and energy efficiency – for each measure the anticipated change in NOx, PM and efficiency improvements are indicated as follows:
  - ↑ for increases
  - ↓ for decreases
  - ↕ for either increase or decrease depending on various factors

  As stated above, each measure and application must be evaluated on a case-by-case basis.

- Cost – an indication as to whether a measure is likely to be one of the following
  - ↓ - cost negative, implying that it will likely reduce cost over the long term even with all costs associated with the measure taken into account. This will mainly be for measures that have energy efficiency as a central benefit.
  - ↕ - cost neutral, implying that the financial costs and savings associated with the measure are likely to be near even or slightly higher or lower depending on the specific application of the measure.
  - ↑ - cost positive, implying that a measure will not pay for itself and will likely need regulatory or other incentive to overcome net additional costs associated with the measure.

More detailed descriptions, illustrations, and related information for each future ECEEM are provided in Annex 2. In addition to the above elements, the detailed descriptions in Annex 2 include the following additional items for each measure:

- limitations – known or anticipated limitations associated with a measure
- key challenges to deployment – known or anticipated critical challenges relating to the measure's deployment
- potential fleet penetration – theoretical potential of a measure's fleet penetration
- theoretical reductions – theoretical maximum potential reduction based on published literature or survey data

The summary table below indicates two general sets of measures: those that are presented previously as existing measures, and those that are new to this section. For each measure, the summary includes the measure title, applicability, retrofitability, likely market readiness, and indicators for their effectiveness for NOx, PM, and energy efficiency, as applicable. For measures that are reiterated from the previous section, all of the summary denotations and associated information may not be precisely the same. This is a result looking at these measures in the context of how they will most likely exist in the future as opposed to how they exist now.

Table 2.9: Summary of innovative and emerging measures and attributes

	System Applicability	Retrofitable	Market Maturity	NOx	PM	Efficiency Improvement	Cost
Measures from Existing List							
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	↓	↓	↑	↓
"New" Measures							
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	↓	↕	↕	↑
Eletrical 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	↓	↓	↑	↓

3 Drivers, Barriers and Implementation

The summary of existing and future measures in Section 2 encompasses a wide range of technologies and approaches being implemented or considered at ports throughout the world to reduce emissions or improve energy efficiency, and sometimes both. When considering the implementation of such measures, an understanding of the implementation drivers, barriers associated with measure adoption, and associated implementation schemes is critically important. Section 3 provides this important linkage from the perspective of each identified port area stakeholder category: port authorities and terminals, ship owners and operators, equipment manufacturers as well as governmental and regulatory authorities. However, before discussing measure implementation, it is important to place the environmental challenges faced by maritime stakeholders into context.

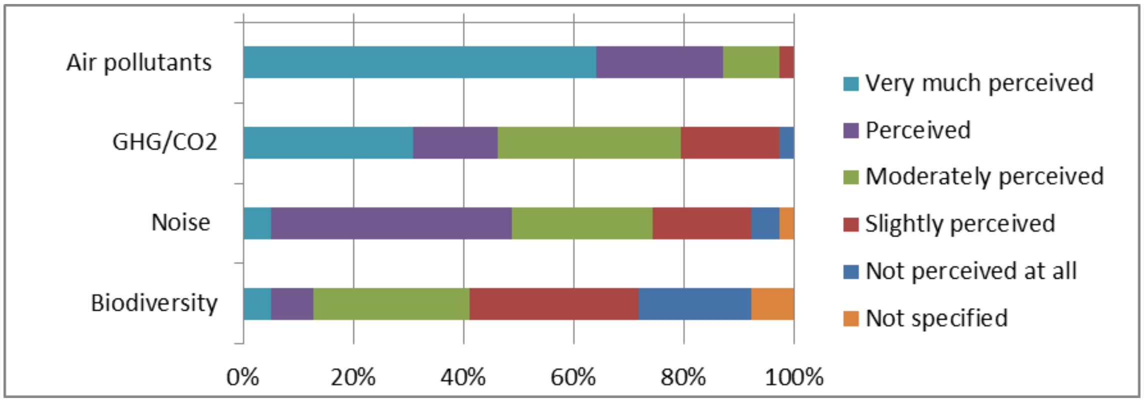
3.1 Environmental challenges

Air quality is the most challenging environmental issue within the ship-port interface today. A significant majority of interviewees indicated air quality as a very much-perceived challenge, as illustrated in Figure 3.1. Port authorities gave the highest average score, illustrating the impact air quality challenges have on their daily operation and future expansion plans. Regulators and NGO associations also indicate they perceive air quality as a significant challenge. GHG and noise follow air pollutants in importance according to the survey results.

The contribution of ships and port activities to regional air quality became a major issue for several large ports starting in the 1990's as the combination of increasing landside emissions and growing ports led to exceedances of the air quality standards set. These same issues gradually affected more ports into the next decade as science on PM, ozone, and other major air pollutants clarified their impacts to human health. In the middle of the last decades the IMO worked to pass Annex VI to MARPOL to reduce NOx and SOx emissions from the world maritime fleet.

In Europe (in the context of Directive 2012/33/EU and its predecessors) and North America, government authorities and ports implemented their own fuel sulfur programs and have begun to devise strategies to further reduce NOx and PM from port-related sources. Currently, as GHGs and BC are becoming more pressing concerns around the world, ports are engaged in a renewed effort to address air emissions.

Figure 3.1: Environmental Challenges Perceived by Ports



An interesting survey result is that noise exposure for the port community (workers, neighbors) is also perceived as an environmental challenge, although to a somewhat lesser extent. The stringency of noise exposure legislation that applies in some countries may play a role in this result. As an example, a ship that meets the 70 dB(A) IMO external noise limit can have a diesel generator exhaust sound level of 107 dB(A), with a listening post at 20 m. distance from the auxiliary exhaust (Danish EPA, 2014[47]). Further, in some EU countries (Denmark, the Netherlands) the applicable noise limit for city residential areas is 40-50 dB(A), with a night time limit of 40 dB(A). At these low limits, a single ship can easily exceed the 40 dB(A) limit within a kilometer. In the US and Asia noise exposure limits are not that stringent. Despite having no specified legal limits associated with nuisance-level noise, the United States Environmental Protection Agency (US EPA) issued guidance in April, 1974 indicating that routine 24-hour exposure to environmental noise will lead to hearing loss and levels of 55dB outdoors and 45 dB indoors would constitute annoyance thresholds that interfere with routine daily activities.

Although not specifically raised during the interviews, biodiversity has been a challenge in some cases. Potential impacts of ports on biodiversity cover a wide range – from degradation, fragmentation or loss of ecosystems or species till the intrusion of invasive species, for which ports are one of the main entry points. Invasive species are currently under discussion at the IMO as part of the provisions for ballast water control. There are examples of ports areas where protected species have been found while developing new terminals, such as with the development of Maasvlakte 2 at the port of Rotterdam.

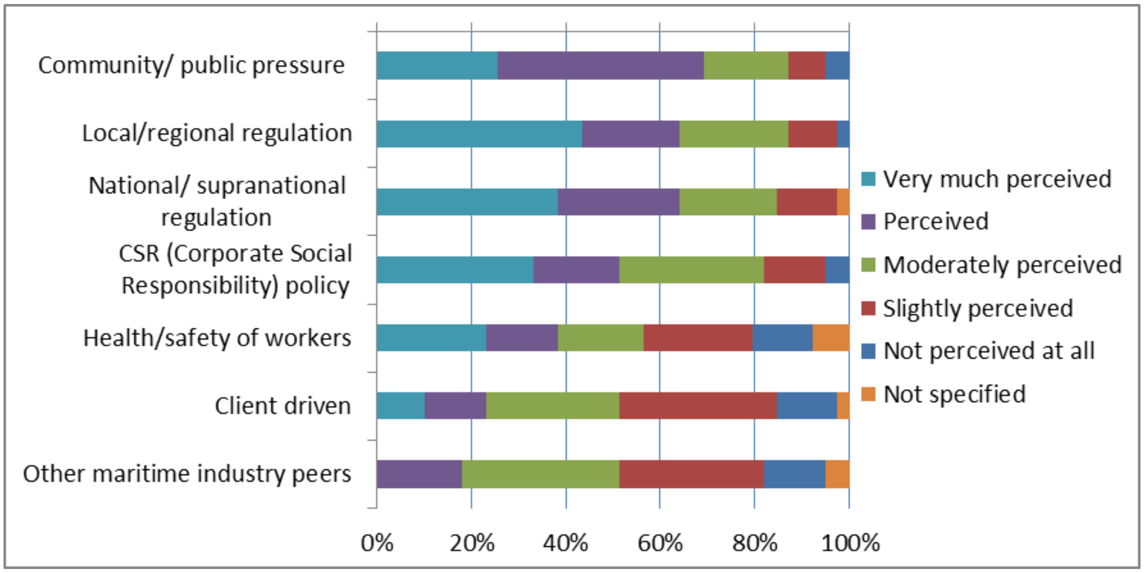
Environmental challenges are not static. While air quality is the greatest challenge now, ports originally began with management of water resources and water quality, coinciding with the first MARPOL in the 1980s. Protecting these aquatic environments and resources continues to be an environmental issue, but many ports in the world have managed to improve the water quality.

[47] Noise from ships in ports Possibilities for noise reduction, Lloyd's Register ODS, Environmental Project No. 1330 2010 Miljøprojekt

3.2 Drivers

A wide variety of drivers play a role in reducing emissions at the ship-port interface, ranging from government regulation to developing private initiatives, because stakeholders feel responsible to do so. The survey results for the most relevant drivers relating to reducing the environmental impacts in the ship-port interface are depicted in Figure 3.2.

Figure 3.2: Relative Importance of Drivers



The survey results indicate that there are four primary environmental improvement drivers at the ship-port interface:

- community and public pressure
- local and regional regulation
- national and supranational legislation
- corporate social responsibility (CSR)

The other environmental drivers, such as the health and safety of workers and pressure of cargo owners and other maritime industry peers, are less important for the uptake of emission reduction measures, according to the survey responses. It is interesting to note that while worker health and safety was indicated as a strong driver by ship owners, technology suppliers evaluated this as having nearly no importance.

The stakeholders evaluated the ship-port interface as having the same relevance as other available sources of emissions, like local industry, logistic operations and sailing ships. Human health was mentioned as the most important reason for implementing measures at the ship-port interface, closely followed by two other arguments for implementation of measures: the care for the local and global environment and the license to operate honored by the local public were indicated as reasons for implementing measures at the ship-port interface. Nearly all stakeholders believe that the pressure to implement additional measures will increase over time.

Below is a detailed discussion regarding the drivers for each identified stakeholder category associated with the ship-port interface: ship owners and operators, port authorities and terminal operators, equipment manufacturers, and regulatory agencies and NGOs. The drivers for each stakeholder group vary based on their role in the port area.

3.2.1 Ship owners and operators

Ship owners and operators are directly affected by many of the regulations developed for reduction of the emissions at the ship-port interface which include (for further examples, see Section 3.4.2):

- IMO MARPOL Annex-VI regulations focusing at reduction of NOx and SOx
- EU fuel sulfur directive
- CARB at-berth regulation
- CARB low fuel sulfur requirements

Ship owners and operators that participated in the survey confirmed that the primary driver of ECEEMs is regulation at the local, regional, national, supranational and international levels. In addition to the impacts of the IMO MARPOL regulations, the impact of local/regional and supranational regulations for ship owners can be explained by requirements from EU and CARB regulation. The regulations oblige ship owners to use up to three different fuels: fuels for use at the high seas, fuels for use in the ECA and fuels for use at berth or in the 24 nm zone in California waters. In addition, the local CARB at-berth requirements oblige applicable ship owners to make significant investments in onboard shore-power equipment for ships that are anticipated to call at California ports, starting from 2014. These ship specific investments could impact the business case evaluations and decisions on when to "shift" ships in and out of strings calling applicable California ports. For more information, see the onshore power case study in Annex 3.

Interestingly, all stakeholders, including ship owners, indicated that there is only limited pressure from their clients and industry peer groups, and this pressure is not expected to influence future investment patterns of ship owners. One respondent indicated that due to the economic crises the interest of clients in emission reduction reduced. Accordingly, only in a few cases, multinational cargo owners are experienced as a driver for emission reduction by ship owners and operators. The few cargo owners that were reported to push for emission control measures, sell their products at the business-to-consumer market, reflecting the public pressure they experience to green their logistic chains.

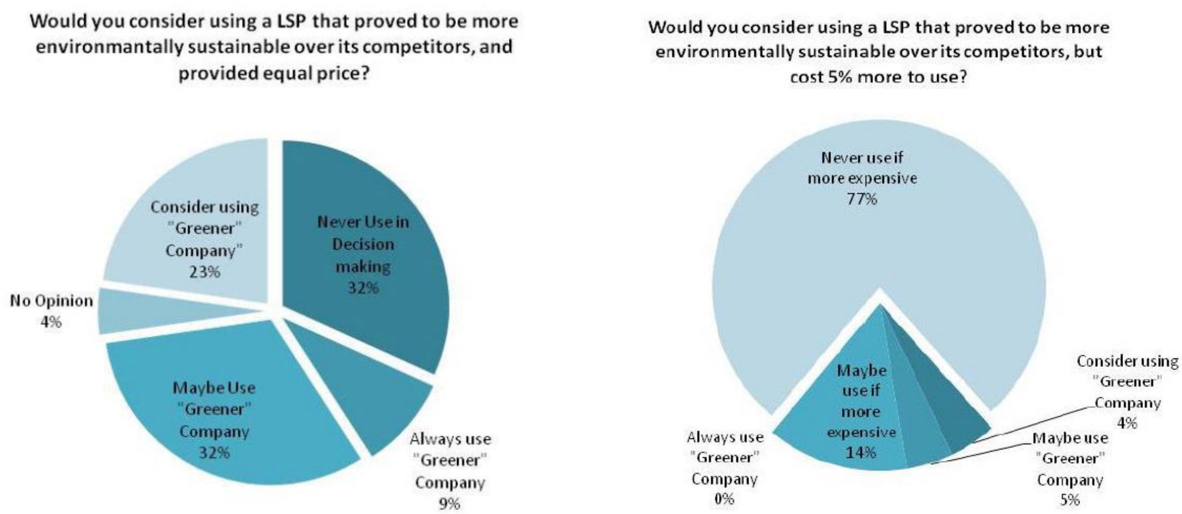
Although ship owners hardly experience any pressure from clients to implement measures, some cargo owners do express their CSR policies, for example, the development of the Clean Shipping Index (CSI).[48] Out of the group of 12 surveyed ship owners, 4 indicated to join, and 5 ship owners join the ESI, (see Section 3.4.3), initiated by ports. This implies that a 30-40% share of the ship owners in the sample joins these voluntary schemes. It should be noted, however, that our stakeholder sample may be biased towards relatively large ship owners that joined the sample as indicated in Section 1.2.7.

Available literature supports this survey's finding that shippers attach limited value to environmental performance, especially when it increases costs. Other logistic and performance criteria are more important.

[48] www.cleanshippingindex.com/

Lieb and Lieb (2010)[49] asked whether shippers would consider an operator with a better sustainability performance under equal price and quality conditions. Second, they asked for situations with an increase of freight rates by 5%. As shown in Figure 3.3, one tenth of the shippers would always use this operator, and over half of the shippers would maybe do so. However, when asking the same question with the exception that the more sustainable operator would cost 5% more, priorities change significantly. Not one of the shippers would definitely use the greener company and only 23% would still consider choosing for this company. However, the majority of the shippers (77%) would not consider a more sustainable operator at all if it were 5% more expensive than its competitors. This indicates that the willingness to pay for sustainability is limited. Consequently, ship operators that have improved their environmental performance will generally not be able to ask a premium price in return.

Figure 3.3: Shippers' Willingness to Pay for Sustainability



Note: LSP stands for logistics service provider

The difficult position of ship owners voluntarily implementing advanced technologies was illustrated by a ship owner that invested in a technology to reduce air pollutant emissions, as part of a contract. After contract termination, the ship was laid up, since the improved air emission performance resulted in slightly higher fuel operating costs and clients preferred ships with higher pollutant emissions against lower operating costs.

Notably, a few ship owners, mainly active in EU and US waters, that have invested in advanced technologies such as LNG and SCR catalysts indicated that investment decisions were not made upon client pressure. Decisions were rather based on their own CSR policy and company ethics, they argued.

[49] Lieb, K. & Lieb, R., 2010. Environmental sustainability in the third-party logistics (PL) Industry. International Journal of Physical Distribution & Logistic Management, Volume 40, pp. 524-533.

Internal CSR policies of large operators may play an even greater role in the Asian context, by absence of any local regulation to control emissions at the ship-port interface in this region. Several voluntary incentives, mainly to reduce the fuel sulfur content at berth, have been implemented in Asian ports recently (see section 3.4.3). Peer pressure and voluntary initiatives-championed by big companies-puts pressure on ports and regulators to join the initiatives.

3.2.2 Ports authorities and terminal operators

Regulations are an important driver to reduce emissions at the ship-port interface, the survey confirmed. However, ports and terminals are in many cases not the stakeholder directly affected by the regulation and responsible for implementation of the technical measures. IMO regulation on the reduction of NOx and SOx is targeted rather on ship operators than on ports and terminals, and the same is true for the EU's legislation on the use of low sulfur fuel (LSF) for ships at berth. There are, however, some examples of regulation that (in)directly affect ports and terminals:

- The EU air quality legislation (Directive 2008/50) that requires EU countries to meet certain air quality standards. The relevance for ports is that, depending on the local situation, they can only develop expansion projects if the local air quality limits are met, and mitigation measures to compensate for a project's additional emissions are implemented.
- California ports are significantly affected by CARB rules and regulations[50] that affect port tenants at the ship-port interface. Ports must facilitate the ability of their tenants and customers to comply with CARB rules and regulations in the areas of infrastructure support and facilitation, monitoring, reporting, etc.

An important driver for ports to implement environmental policies is CSR, the ports indicated. Ports and terminals see CSR policies as the most important driver, while other stakeholders see a more limited role for CSR (see Figure 3.2). This may be explained by the limited direct impact of regulations on ports.

Many ports publish a CSR report every year, in which they present and illustrate their environmental management policies and achievements. CSR has an economic (image), social (license to operate) and political (regulatory pressure) dimension, according to the World Bank.[51] CSR policies are driven by public pressure, the pressure of NGOs, and are also linked to political and regulatory pressure. As awareness and regulatory pressure differs between the various world regions, CSR policies may differ as well.

As part of their corporate responsibility programs, some ports have started to cooperate in the World Port Climate initiative (WPCI) in recent years. This resulted in the development and implementation of ESI, to encourage cleaner vessels and improve air quality in their ports. Annex 3 further elaborates on the details of and use of the ESI by ports. In addition, many ports outside California (where CARB requires significant reduction of at berth emissions) voluntarily invested in OPS facilities.[52]

[50] www.arb.ca.gov/ports/marinevess/marinevess.htm
[51] Corporate social responsibility, is a common CSR framework possible?, Piotr Mazurkiewicz, World Bank
[52] www.onshorepowersupply.org for more information

Survey respondents generally acknowledged that public pressure and awareness is the most important driver for the implementation of measures at the ship-port interface. Some of the survey respondents said to observe a difference in awareness between Northern and Southern Europe, illustrated by the relatively high number of incentive schemes implemented in ports in Northern Europe.

The impact of public pressure on ports can be indicated by the role of NGOs. As part of the Maasvlakte 2 expansion by the Port of Rotterdam Authority, for example, NGO Friends of the Earth played an important role in the reduction of environmental impacts of the ports' expansion. In the context of the development of Maasvlakte 2, the Port Authority and the NGO cooperatively developed of a set of measures to reduce emissions of Maasvlakte 2 by 10% in exchange for termination of the legal procedures to retard the development of the new port expansion project.

The Ports of Los Angeles and Long Beach's CAAP is also an example of how public pressure can affect meaningful improvements at a port, and how closely public pressure and the "license to operate" for ports are linked. The CAAP was developed in response to what was originally local neighborhood and community groups working together with local city officials to pressure the ports to reduce emissions. Over time, the public pressure, combined with the threat of lawsuits led to what became a coordinated, pro-active effort to develop the CAAP. See Annex 3 for a case study on the CAAP.

Further, in California, there are a number of environmental NGOs that work solely toward air quality improvement. When coordinated and working together with local community groups, these organizations push for regulatory and voluntary programs that result in emissions reductions. In Hong Kong, the independent think tank Civic Exchange worked with the shipping industry to rolling out an industry-led voluntary at-berth fuel switching initiative called the Fair Winds Charter (FWC) in 2011 (see Annex 3), which will become mandatory in mid-2015.

3.2.3 Equipment manufacturers

The most obvious driver for equipment manufactures is meeting market demands of ship owners needing to meet international, national, regional, local regulations, and the market demand to improve efficiencies of ships.

Equipment manufacturers can implement measures to result in emissions reduction by themselves only very limitedly. They are strongly dependent upon action and demand of other stakeholders, being the regulators or ship owners. However, the role of ship owners is also limited, especially if investment in measures does not provide economic gains for them.

Equipment manufactures see regulation as the most important driver for emission reduction. They also strongly expressed their favor for stricter regulations during the interviews, as they generally consider regulation as the most important driver for market development and implementation of measures at the ship-port interface.

For reasons of the development of a larger market for clean technologies, equipment manufacturers also suggested a stronger focus on the existing fleet.

One of the large equipment manufacturers indicated that for every single technology that company offers, corresponding IMO regulation exists, illustrating the relevance of legislation for the development of market demand. The only business arguments they see, not being legislation, are fuel economy arguments and health of workers.

3.2.4 Regulatory agencies and NGOs

The vast majority of the survey respondents indicate that the pressure to implement measures at the ship-port interface has increased over time, mainly driven by the various regulations implemented at different government levels (see section 3.4.2). The main reason for focus and attention shifting to the ship-port interface is that land based emissions sources have been addressed more effectively from an air quality regulation standpoint than shipping related emissions in earlier decade(s).

Health and environmental arguments have become more important in developing policies and regulations over the last decade(s), in the various world regions. In the EU, socio economic cost benefit analysis is generally applied when evaluating further tightening of emission standards or other air quality regulations. By doing so, economic and health arguments are being treated in a balanced way. In the US, Clean Air Act regulations require regulators to set standards that are independent of cost consideration so that safeguarding human health remains the top priority. Local state and regional governments are then responsible for working with their local public and business communities to find ways to meet national standards that have the least economic impact to the community.

In addition, there is a growing exchange of expertise and experience between Asia and the rest of the world in ship and port emission control. Hong Kong, for example, has taken onboard the regulatory and technological best practices in North America and Europe in its journey to address the issues.[53] Also in Asia, the US Environmental Protection Agency has been running a partnership program since 2008 with the Environmental Protection Administration of the Taiwan Province of China to reducing air and GHG from ocean-going vessels that operate between the US and Taiwan ports. Workshops and technical meetings were organized to foster collaboration, which led to the development of emission inventory for four major Taiwan ports and an emission reduction strategy.[54]

Local and national/supranational regulations were evaluated by the group of stakeholders as the largest drivers for emission reduction. 65% of all respondents see legislation on the different levels as important (4) or very important (5). Consequently, the SECA and nitrogen emission control area (NECA) deadlines were reported as the substantial drivers for implementation of measures to reduce emissions of NOx and SOx that also will provide benefits at the ship-port interface, as well as the EU fuel sulfur directive. Specifically for the Californian basin, the local at-berth emissions control regulation and the fuel sulfur regulation are being seen as of major importance in the control of emissions at the shore/ship interface. The standards oblige other stakeholders (e.g. ship owners and ports/terminals) to implement measures to meet the requirements.

One of the respondents mentioned that putting legislation into force takes a lot of time, since it is difficult to find the right instruments and to find agreement with all relevant stakeholders. This can be explained by the IMO consensus-action decision-making process that may take years to negotiate and additional years to enter into force, according to Corbett (2010)[55]. But, once implemented, legislation is the most effective according to our respondents.

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[53] Gall, C and M Van Rafelghem (2006) *Marine Emission Reduction Options for Hong Kong and the Pearl River Delta Region*, Civic Exchange, March 2006; and Van Rafelghem, M and R Modini (2007) *Lessons for Hong Kong: Air Quality Management in London and Los Angeles*, Civic Exchange, August 2007.

[54] Bruce, R, Loh, C and V. Booth (2011) *Green Ships and Ports: Navigating the Waters Ahead*, CLSA U®, Hong Kong, p.32.

[55] The Role of International Policy in Mitigating Global Shipping Emissions, James J. Corbett James J. Winebrake, University of Delaware, Rochester Institute of Technology, 2010, Brown Journal of World Affairs, Spring/Summer, volume xvi, issue ii

Some of the interviewed regulators and NGOs acknowledged that implementation of measures for existing ships would be a time consuming issue, but indicated that extension of the current NOx regulations to existing ships would provide significant benefits in terms of reducing emissions, because of the long service lifetime of ships. However, the technical feasibility to install exhaust gas cleaning systems on existing ships may be a challenge, and the cost-effectiveness for old ships may be limited, respondents indicated.

Compliance monitoring and enforcement were mentioned as important prerequisites for effective policies. Respondents especially focused on the European situation, where there is concern about the effectiveness of the SECA as a result of limited control. Stakeholders indicate that enforcement policies differ considerably between EU countries, so far and that sulfur related inspections are generally rare. In California, there are a number of CARB rules and regulations that affect the ship-port interface (see Section 3.4.2). In order to ensure maximum compliance, each regulation includes initial and annual reporting, field inspections such as vessel boarding (includes, but is not limited to records review, equipment inspections, fuel sampling, etc.) and mechanisms to issue fines and penalties for non-compliance.

Pressure from the local community and the general public as a driver for measures has been evaluated highest by the interviewed regulators and NGOs. Together with knowledge about the adverse impact on nature and human health, it influences the development of regulations.

Voluntary programs sometimes find their way into regulation. In California, CARB often implements regulation based on the success of voluntary programs. In fact, CARB is currently assessing the efficacy of a statewide vessel speed reduction (VSR) regulation, based on the success that has occurred to date where VSR is being implemented on a voluntary basis. In Hong Kong, as described in Section 3.2.2, the FWC will become mandatory in 2015.

The implementation of the Clean Air Act regulations has also led to an evolution in the relationship between regulators and the port and maritime community, to a collaborative partnership. For Southern California ports this has progressed to a point that they are finding way to envision, promote and deploy technologies that are not even available yet in the hopes that air emissions can be driven even lower.

The upcoming pressure in Asia can be illustrated by a series of plans in the People's Republic of China (PRC). In 2013, the State Council of the PRC issued the Action Plan on Prevention and Control of Air Pollution with 10 different measures. Specific air quality targets for 2017 were set for the three major regions, including the Beijing-Tianjin-Hebei Province, the Yangtze River Delta, and the PRD.[56] In order to achieve the targets set out by the State Council, provincial and local governments are putting together respective air quality action plan to address air pollution problems. Some of the local action plans, such as the Shenzhen Air Quality Enhancement Plan and the Shanghai Clean Air Action Plan, recommend measures to reduce ship and port emissions, including fuel switching and the use of onshore power.

[56] See Ministry of Environmental Protection, the People's Republic of China, "The State Council issues Action Plan on Prevention and Control of Air Pollution introducing ten measures to improve air quality", english.mep.gov.cn/News_service/infocus/201309/t20130924_260707.htm

3.2.5 World regional differences of drivers

Environmental challenges are perceived most in the US and Europe, for at least the past 10 years. Some of the stakeholders indicate the American West Coast and Northern Europe in particular as the regions with most awareness. In Asia (Hong Kong, China/ Singapore/Japan/ the People's Republic of China), public concern and awareness has increased over the past 3 to 5 years, but challenges regarding GHGs and noise are valued lower. In Asia, the current focus is on reducing SOx emissions, something that is well underway in Europe and North America. In Africa and South America, the level of awareness appears to be the lowest, according to the globally active stakeholders interviewed.

The higher awareness in the US and Europe can primarily be attributed to legislation that is implemented in these countries. On the basis of national requests, SECAs and NECAs have been implemented in Europe and the US, but not elsewhere. Furthermore, European and California legislation require the reduction of ship emissions while at berth, but also, different types of (financial) incentives are used most frequently within these continents. Out of the 24 ports that participate in the ESI, only three are from outside Europe or the US.

3.3 Barriers

Several barriers that prevent further reduction of ship emissions in port areas exist. Based on the expertise of the project team and the survey results, these barriers are discussed below. The barriers are discussed by stakeholder group to account for the difference of the barriers between them.

3.3.1 Ship owners and operators

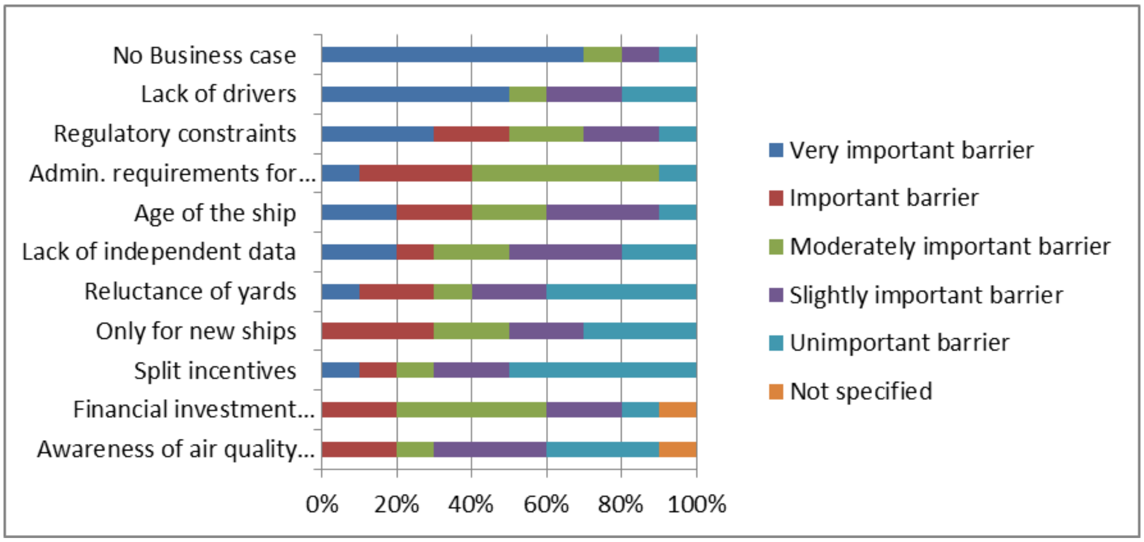
If a CO_2 abatement measure is implemented on board a ship, the fuel efficiency of the ship will consequently improve and the fuel bill will, *ceteris paribus*, decline. A comparable direct financial benefit does not accrue from the implementation of on-board air pollution reduction measures. If there are no drivers in place that turn the implementation of an air pollution reduction measure into a beneficial business case (e.g. subsidies) or if there are no legal obligations to reduce air pollutants, then many ship owners will therefore probably not be able to implement a port area ship emissions abatement measure.

If there are financial incentive schemes in place, these have to provide sufficient resources to turn the investment into a beneficial business case and the administrative burden associated with (voluntary) incentive scheme should not be prohibitively high.

In the survey ship owners were asked to what extent they perceive specific factors as a barrier to the implementation of port area ship emissions reduction measures on their vessels. 50% or more of the responding ship owners stated that the fact that the adoption is not a beneficial business case, the lack of drivers, as well as regulatory constraints are very important or important barriers (see Figure 3.4). The following constraints were mentioned:

- The recent discussion within IMO on the allocation and requirements of future NECAs has a major impact on the ship owners and equipment manufacturers.
- The uncertainty about the 2020 global sulfur cap influences the cost/benefit ratio of current investment decisions.
- The uncertainty amongst ship owners operating in EU waters about the allowance of open-loop scrubbers in EU waters, including port areas. There may be a potential conflict with the Water Framework Directive.

Figure 3.4: Importance of specific implementation barriers according to responding ship owners



From the literature on the barriers to the implementation of on-board CO_2 abatement measures, such as CE Delft et al. (2012)[57], Maddox (2012)[58], Eide et al. (2011)[59], and IMarEST (2010)[60], we know that split incentives between ship owners and ship operators, the lack of independent data regarding the efficacy of the abatement measures and the access to capital play crucial roles. These conclusions are not supported by the survey carried out in the study at hand. This can probably be explained by the fact that in order for a split incentive to play a role, a direct financial benefit has to accrue, that the efficacy

[57] CE Delft, Marena Ltd., David S. Lee, The Fuel Efficiency of Maritime Transport - Potential for improvement and analysis of barriers, Delft, 2012

[58] Analysis of market barriers to cost effective GHG emission reductions in the maritime transport sector, Maddox consulting, 20th September 2012, Reference: CLIMA.B.3/SER/2011/0014

[59] Magnus S. Eide, Tore Longva, Peter Hoffmann, Øyvind Endresen, Stig B. DalsØren, Future cost scenarios for reduction of ship CO_2 emissions, In: Maritime Policy & Management: The flagship journal of international shipping and port research, 1464-5254, Vol. 38, Issue 1 (2011); p. 11–37

[60] Institute of Marine Engineering, Science and Technology (IMarEST)
Reduction of GHG emissions from ships: Marginal abatement costs and cost-effectiveness of energy-efficiency measures (MEPC 61/INF. 18) London: IMO, 2010

of a measure that reduces air pollutants is easier to measure than the efficacy of a measure that reduces CO_2 emissions, and that the sample of ship owners is not representative in the sense that relatively big ship owners are overrepresented and that big ship owners in general have easier access to capital than smaller ship owners.

Therefore, an overlooked potential barrier for some ship owners may be related to costs and financing emission reduction measures. Typically there are three options available for ship owners to finance such projects: self-finance, institutional lenders, and third parties. Larger fleet owners may have more options compared to smaller fleet owners.

There is an emerging barrier that may affect vessels in the port area related to meeting different compliance schemes. In the US, US EPA and CARB have exclusive authority to verify emission control technologies that are retrofitted onto existing marine engines. As such, entities complying with the North America ECA using (retrofit) technologies that are not yet verified by EPA and CARB will not get credit at the regional and national planning level for emissions reductions under the national and regional regulations. Currently, the EPA and CARB verification protocols are not setup with international ships in mind. The barrier to the ship owner that results from this issue arises when they apply to receive any additional credit for reductions made beyond regulation (all applicable) to meet compliance needs elsewhere.

The majority of the responding ship owners also stated that the awareness of air quality issues in or near ports and the fact, that some measures may only be applicable to new ships do play only an unimportant or slightly important role as barrier.

3.3.2 Ports authorities and terminal operators

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 two ways. On the one hand, ports/terminals can directly or indirectly provide incentives for the ship owners to implement emission abatement measures on-board. On the other hand, ports/terminals can facilitate port area ship emissions reductions by providing certain infrastructure themselves, like OPS facilities.

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. If ports impose environmental requirements on their tenants, they indirectly, via terminals give an incentive for the reduction of ship emissions in the port.

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, as further indicated in Section 3.5.3. Ports have limited options to incentivize ship owners in that case; or
- the 'polluter pays principle' can be applied, 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 emission mark-ups are introduced, the port runs the risk of losing business to competing ports, which have not introduced a comparable incentive scheme. The fear of losing customers to other ports is also a barrier that makes ports reluctant to impose environmental requirements on their terminals. 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.

In general, port authorities collect funds through a variety of methods including leases with terminals (for land-lord ports) and various fees/dues (such as dockage, wharfage, harbor, anchorage, wharf demurrage, wharf storage, fairway, pilotage, etc.). Fee structures are typically unique to each port. This can be a barrier for a port authority if it wants to implement an incentive program and does not collect any port fees associated with vessels. As an example, The Port Authority of New York & New Jersey (PANYNJ) does not have any fees/dues associated with vessels calls; instead it collects its money only through the leases with the terminals. Therefore, the PANYNJ had to develop an innovative approach to implement their LSF Incentive Program and their current Clean Vessel Incentive (CVI) program, as highlighted in the case study attached in Annex 3.

Barriers can also arise with the design of publically funded incentive programs from governmental agencies if they are found to violate the legal concept of "gift of public funds." An example was the redesign of the Port of Seattle's At-Berth Clean Fuel (ABC) Incentive program. The original program was found to violate gift of public funds[61] and the program had to be structured in the current version of the program.

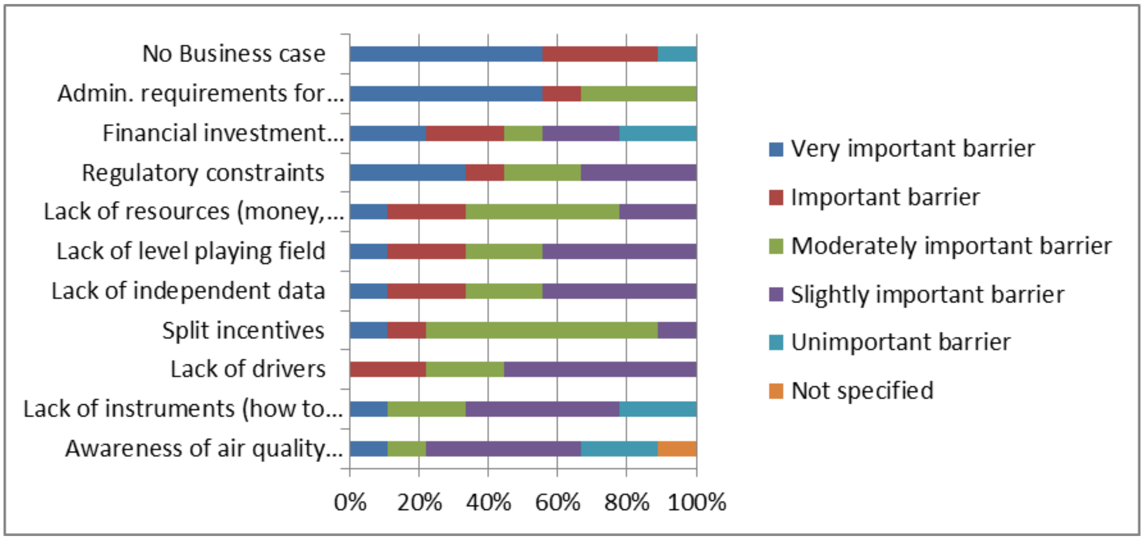
Ports/terminals could also facilitate ship emissions reductions in the port area by providing certain infrastructure, for example OPS facilities or LNG infrastructure. Two kinds of barriers to this facilitation can be identified.:

- First, a typical chicken and egg problem is on hand if supply and demand are not coordinated. It will, for example, only be invested in land-based LNG or OPS infrastructure if there is sufficient demand for LNG or onshore power, but it will also only be invested in LNG-fuelled ships and on-board OPS equipment if sufficient land-based infrastructure becomes available; and
- Second, there has to be sufficient demand for the infrastructure to be profitable. If OPS electricity prices turn out to be relatively high, even if demand is high, then there is no business case for the land-based OPS facilities and ports/terminals have no incentive to provide the infrastructure. The uncertainty regarding the future LNG price acts as a barrier too.

[61] www.portseattle.org/About/Commission/Meetings/2012/2012_12_04_SCM_Minutes_LINKED.pdf

In the survey ports/terminals were asked to what extent they perceive specific factors as a barrier to the implementation of port area ship emissions reduction measures at their ports. In Figure 3.5, the various barriers experienced by ports and terminals are illustrated.

Figure 3.5: Importance of specific implementation barriers according to responding ports/terminals



The majority of the responding ports/terminals, just as the responding ship owners, think that the adoption of the measures is not a beneficial business case. In addition, the access to capital for financing the measures as well as the lack of resources (in terms of money and staff) are perceived as very (important) barriers by the ports/terminals. In addition, ports see the administrative requirements related to the introduction of incentives as a barrier. One of the reasons for WPCI to introduce ESI as a voluntary system with self-assessment was related to keeping the administrative requirements simple.

The recent support of the Ports of Rotterdam and Antwerp for the timely introduction of the IMO Tier 3 standards on the North Sea is an illustration of the lack of drivers for emission reduction these ports perceive. They indicate that the allocation of the North Sea as an NECA is consistent with their sustainability objectives and want to maintain clarity for the market.

As only unimportant/slightly important barriers, the majority of the responding ports/terminals perceive:

- the awareness of air quality issues in or near ports
- regulatory constraints
- lack of independent data
- lack of instruments that could incentivize the implementation

3.3.3 Regulatory agencies and NGOs

A common misconception about regulatory authorities in the port area is that local port authorities have regulatory power. In fact, even when they are governmental or quasi-governmental organizations, ports only have the power to administer their assets within the constraints of their contractual obligations. In spite of this, both the public and industry look to port authorities to provide guidance with complicated issues like air quality. This role as an intermediary or convener is common for port authorities and is crucial for addressing major environmental concerns such as air quality.

While the role of national regulators is to create rules and regulations in line with national laws that apply uniformly throughout the country, local regulators are responsible for enacting regulations that address problems that are distinct to their jurisdictions. This may involve placing more stringent limits on sources that are already regulated or enacting novel regulations that address a specific source or region-specific air quality issues. With regard to ports, local regulators that are not bound by more specific mandates will often seek to meet long-term goals through voluntary measures and incentive programs. If there is sufficient time to address air quality issues, these voluntarily programs are broadly preferred to regulatory mandates because they allow industry more flexibility to address air quality problems.

On the levels of regulations, different barriers apply, that are not easy to solve. Local authorities might be reluctant to implement regulation on a local/regional level for not disturbing the level playing field between ports and local/regional authorities may also have only limited budget to provide funds to stimulate the uptake of the reduction measures. Under the circumstances, some port cities may opt for tighter control in response to public aspiration, but their neighboring ports may not be ready to follow. It may take years to get to a point where consistent regional standards on ship-port emission control can be agreed. Depending on the position of the national ports, even national regulation could potentially disturb the level playing fields of the ports, whereas international regulation may take very long to be developed, the stakeholders indicated.

Interestingly, the US has completed its roll-out of new engine standards affecting small and medium-sized vessels that operate domestically and Canada is finalizing similar rules that will harmonize with the US. This example shows how ship emissions have been reduced, while the level playing field has not been affected.

According to the environmental NGOs that have responded to the survey, and this is in contrast to the assessment of the other three stakeholder groups, a lack of awareness does play a major role here. Due to the lack of awareness of the air pollution issues in ports, the public would not put enough pressure on public authorities to implement regulation. In addition, the awareness would differ too much to come to an international solution. The mentality of the ship owners and the indifference and opposition from the industry would also work against an implementation.

3.3.4 Equipment manufacturers

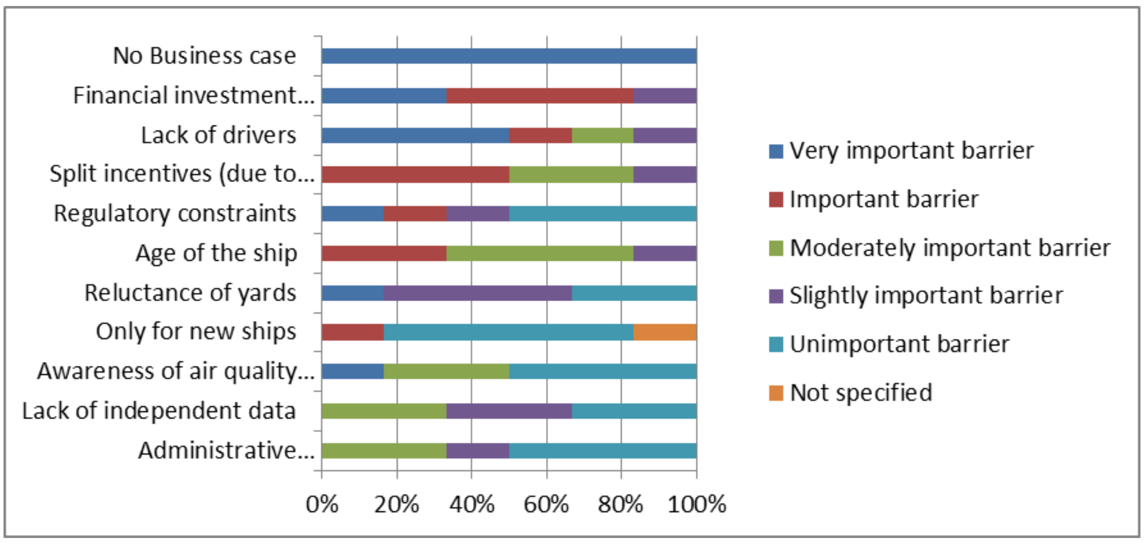
Barriers that prevent ship owners and ports/terminals from implementing emission control measures at the ship-port interface have a direct impact on the demand for equipment. A factor that in addition works as a barrier to the development of measures that reduce ship emissions in the port area is the uncertainty about future regulation in terms of time consistency and stringency. As discussed earlier, this is also a barrier for ship owners.

In the survey equipment manufacturers were asked to what extent they perceive specific factors as a barrier to the implementation of port area ship emissions reduction measures in the context of the ship-port interface. As illustrated in Figure 3.6, a clear-cut picture evolves here in the sense that the responding manufacturers/suppliers find the following four barriers (very) important:

- no business case
- access to capital to finance measures
- lack of drivers
- split incentives between ship owners and manufacturers

Equipment manufacturers indicated that they perceive almost all the other potential barriers (with the exception of 'Age of the ship') only slightly or not at all.

Figure 3.6: Importance of specific implementation barriers according to responding equipment manufacturers/suppliers



A barrier not raised during the interviews is the lack of a universally accepted verification system for emissions control measures as part of local regulation or incentive programs. Equipment manufacturers may have to participate in different verification programs to prove the efficacy of their technologies,[62] raising the equipment costs. Rather, a commonly recognized credit system may need to be developed in reaction to the increasing number local of incentives from regulators and ports. This was also discussed as a barrier for ship owners.

[62] As an example: CARB does not automatically allow alternatives to LSF, while scrubbers have been agreed by IMO as an alternative option to reduce SOx emissions.

3.4 Implementation methods

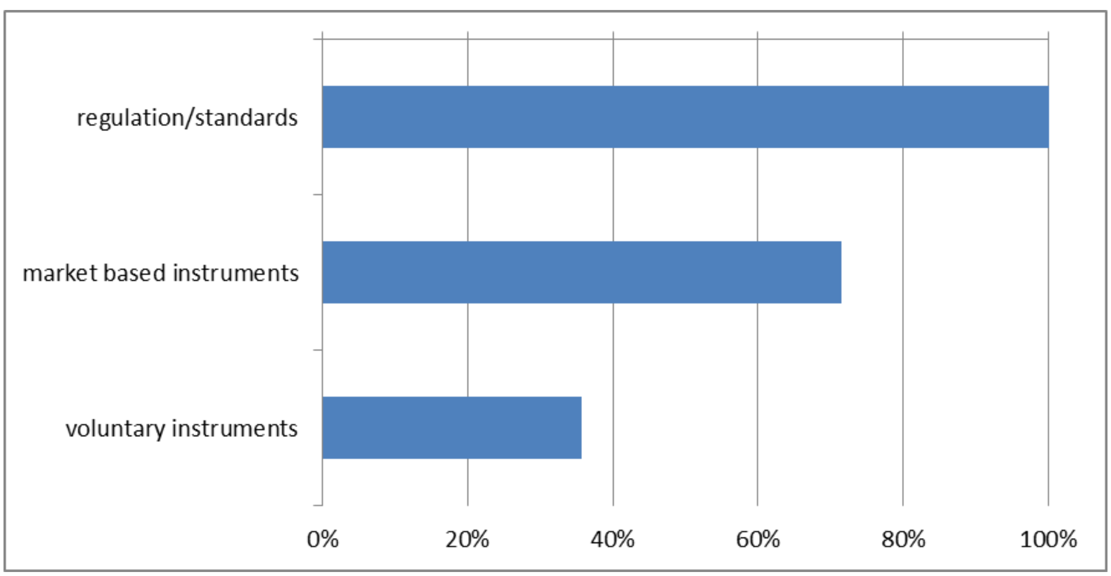
Generally, the financial benefits of reducing air pollutant emission for ship owners or operators at the ship-port interface are limited, while the technology requires investments by ship owners. This implies that instruments are needed to drive implementation. A wide range of measures is in use at the moment to address these barriers. For the purpose of this study, we classify the instruments into three groups:

- regulation/standards
- market based instruments (financial incentives)
- voluntary agreements

In response to the question "what the best instrument would be to reduce emissions in the ship-port interface," all stakeholders replied that regulation and standards are of major importance. A majority of the respondents indicated that a combination of all three instruments indicated in Figure 3.7 would be the best solution. The stakeholders indicated that international policies should focus on regulation and technical standards, while local policies should encompass market based instruments and voluntary agreements.

Several stakeholders indicated voluntary measures for technology development at the local level could add value.

Figure 3.7: Stakeholders' preference for instruments aimed at measures to reduce emissions in the ship-port interface



3.4.1 Uptake of instruments by the various stakeholders

The options for stimulating the uptake of emission reducing measures at the ship-port interface differ per stakeholder. Regulators apply the widest range of options, as they have implemented legislation, but also grants and incentive schemes. Ports and terminals have also implement grants and incentive programs, aiming at a reduction of ship emissions at the ship-port interface.

Ship owners and equipment manufacturers generally face economic difficulties when implementing measures, the barrier analysis showed. The room for applying clean technologies in the business environment for them is limited without incentives from regulators and ports/terminals. Ship owners rather act upon implementation of incentives by regulators and ports.

Table 3.1 provides an overview of the type of instruments applied by the various stakeholders and its examples.

Table 3.1: Stakeholder group instrument options[63]

Stakeholder	Examples of instruments
Regulators	
Rulemaking	EU Fuel Sulfur Directive, IMO MARPOL Annex VI, CARB At-Berth (Shore Power) Regulation, CARB LSF Regulation, CARB Ship Onboard Incineration Regulation
Financial/grant incentives	Finnish investment aid, differentiation of fairway dues, TEN-T subsidies, NOx tax, US EPA –DERA funding, Incentive programs – Carl Moyer (CARB) , prop 1b goods movement funding program
Recognition	US EPA Clean Air Act Award
Ports/Terminals	
Incentive/grant programs	ESI incentives/VSR (POLA, POLB, PANYNJ CVI), POS At-Berth Clean Fuels Program; PMV Blue Circle (fuel switch, low-sulfur fuel, shore power, vapor recovery, ESI), Maritime Singapore Green Initiative, Shenzhen incentive scheme
Lease/tariff conditions	POLA, POLB
Voluntary programs	VSR- POSD
Recognition	Maritime Singapore Green Initiative, POLB Green Flag, POLB/POLA CAAP Awards
Ship owners	
Self implementation	CSR programme (business case), NOx business fund
Voluntary programs	Hong Kong FWC
Equipment Manufacturers	
Demonstration projects (team with early adopters to demonstrate technologies)	CSR (business case)

[63] All voluntary instruments and financial incentives are elaborated and explained in section 3.4.3.

The table clearly shows the limited options for ship owners and equipment manufacturers. In the following, we focus on the instruments implemented to drive uptake of clean technologies at the ship-port interface. The methods are divided into two broad categories: regulations and standards, and voluntary measures.

3.4.2 Regulation and standards

IMO Regulation (MARPOL Annex VI)[64]

The IMO has established regulations on the fuel sulfur content of ship fuels and set mandatory NOx emission limits for new-build engines. These regulations are implemented through the IMO's MARPOL. In addition to these engine and fuel requirements, certain areas have also been designated as ECAs where stricter emissions limits are enforced.

Emissions of sulfur oxides are limited through regulation of fuel sulfur content. Alternatively, ship owners can opt to use LNG as a fuel or install a scrubber to remove the SOx from the exhaust gas.

Shipping NOx emissions are regulated by mandatory limits on the emissions of new-build engines, defined according to engine speed. The limits for these different "Tiers" are shown in the table below.

The Tier 3 requirements apply to install marine diesel engines operated in NECAs.

Table 3.2: Annex VI mandatory limits for NOx emissions of new-build engines (main and aux. engines)

	Entry into force	**New diesel engines installed on ships**	**NOx limit in g/kWh**	**Relative reduction compared with Tier I**
Tier I	2005	From 1 January 2000 to 1 January 2011	9.8-17.0	-
Tier II	2011	After 1 January 2011	7.7-14.4	15-25%
Tier III	Flexible, form 2016	Flexible, but only when operating in NECAs	2.0-3.4	80%

Note: emission standards are based on the E3/D2 duty cycle, which may not be fully representative for activity in the port area.

[64] www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx

SECA

As of January 2015, the sulfur content of fuels used in the SECAs dropped significantly to a level that ships can no longer meet without switching to a distillate fuel (such as marine gas oil, MGO) or using LNG or a scrubber technology.

Table 3.3: IMO fuel quality requirements to limit SOx emissions

<table>
<tr><th>Fuel sulfur content</th><th>2008</th><th>2010</th><th>2012</th><th>2015</th><th>2020*</th></tr>
<tr><td>SECA</td><td>1.5%</td><td colspan="2">1%</td><td colspan="2">0.10%</td></tr>
<tr><td>Worldwide</td><td colspan="2">4.5%</td><td colspan="2">3.5%</td><td>0.5%</td></tr>
</table>

** or 2025, depending on a review of fuel availability to be carried out in 2018*

The requirements in SECAs, which include the Baltic Sea, North Sea and North American East and West coasts, are more stringent than the general requirements that apply to other waters (see Table 3.4).

Table 3.4: MARPOL Annex VI: ECAs

	Emissions	In effect from
Baltic Sea	SOx	19 May 2006
North Sea	SOx	22 November 2007
North American	SOx, NOx	1 August 2012
United States Caribbean Sea ECA	SOx, NOx	1 January 2014

NECA

Waters within 200 nm of North American coasts and within 50 nm of the coasts of Puerto Rico and the US Virgin Islands have been designated under MARPOL Annex VI as a SECA and a NECA. The North Sea and Baltic Sea are designated as a SECA only. Neighboring countries are investigating the option of making this a NECA as well.

Recently, IMO adopted amendments to MARPOL Annex VI on NOx emissions concerning the date for implementing Tier 3 standards within ECAs, laying down that ships built on or after January 1, 2016, must comply with NOx Tier 3 standards when operating in the North American ECA or the US Caribbean Sea ECA.

The NOx Tier 3 regulation will apply to ships constructed on or after the date of adoption by the Marine Environment Protection Committee of any new NECA, or a later date as may be specified in the amendment designating the NOx Tier 3 ECA.

EU Fuel Sulfur Directive (2012/33/EU)

The EU has implemented the updated IMO Annex VI fuel sulfur requirements adopted in 2008 and incorporated into European Community legislation. The Directive also sets maximum sulfur content of 0.1% for fuels used at berth in EU ports. Ships at berth less than two hours and ships using an OPS are exempted. Because this part of the Directive only applies to vessels at berth, only the auxiliary engines need to switch to low-sulfur fuel, which already needs to be on board when arriving in port. Since January 2015, the IMO fuel sulfur requirements for SECAs suit with the EU's fuel sulfur requirements for ships in ports.

Directive on the Deployment of Alternative Fuel Infrastructures (2014/94/EU)

Article 4 of this Directive that stimulates the development of alternative energy infrastructure, adopted late 2014, states: "Member States shall ensure that the need for shore-side electricity supply for inland waterway vessels and sea-going ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply shall be installed as a priority in ports of the TEN-T Core Network, and in other ports, by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits."

EU Air Quality Directive (2008/50/EU)

The EU air quality Directive set standards for the ambient concentration of air pollutants, including NO, SOx and PM. Depending on the local circumstances, the Directive may limit the freedom of ports and terminals to expand their activities. Depending on the transposition of this Directive into national legislation, there may be difference between EU countries. The most critical annual average thresholds to be met are:

- 40 ųg/m^3 for NOx (2010)
- 40 ųg/m^3 for PM_{10} (2010)
- 25 ųg/m^3 for $PM_{2.5}$ (2015)
- indicative value to be reviewed: 20 ųg/m^3 for $PM_{2.5}$ (2020)

US National Ambient Air Quality Standards[65]

The US EPA set National Ambient Air Quality Standards (NAAQS) for several pollutants that are considered harmful to public health and the environment. Based upon the status of science, these standards are periodically reviewed and adjusted. State, local and tribal agencies are responsible to develop emission reduction strategies, plans and programs to assure they attain and maintain the NAAQS. Since ports operations emit pollutants in the region which have NAAQS, state and local agencies develop regulation to reduce emissions from ports sources including ocean going vessels or put pressure on ports to reduce at least their fair share of emissions in the region. The list of current ambient air quality standards for pollutants related to ports operations are shown below:

- 1-hour 100 ppb and annual 53 ppb for NOx
- 24-hour 150 ųg/m^3 for PM_{10}
- 24-hour 35 ųg/m^3 for $PM_{2.5}$
- 1-hour 75 ppb for SOx
- 8-hour 0.075 ppb for ozone

[65] www.epa.gov/ttn/naaqs/

California Low-Sulfur Fuel Requirements[66]

The State of California in the US adopted the Ocean Going Vessels Fuel Rule that requires LSF to be used in main, auxiliary and boiler engines on vessels operating within 24 nm of the California coastline and leeward islands. The regulation is being implemented in two phases: first phase required the use of MGO with sulfur content of less than 1.5% by weight or marine diesel oil (MDO) with sulfur content equal to or less than 0.5% by weight. The second phase, implemented as of January 2014 requires use of MGO or MDO with sulfur content equal or less than 0.1% by weight.

Californian At-Berth Emission Control Requirements[67]

The At-Berth (Shore Power) Regulation requires vessels to plug into shore power or use alternative controls to meet emission reduction requirements. The purpose of this regulation is to reduce emissions from diesel auxiliary engines on container ships, passenger ships and refrigerated-cargo ships while berthing at six California ports: Los Angeles, Long Beach, Oakland, San Diego, San Francisco and Hueneme. The At-Berth Regulation provides vessel fleet operators visiting these ports two options to reduce at-berth emissions from auxiliary engines:

- turn off auxiliary engines and connect the vessel to some other source of power, most likely grid-based shore power; or
- use alternative control technique(s) that achieve equivalent emission reductions.

Beginning 1 January 2014, at least 50% of a fleet's visits to a port must plug into onshore power and total on-board auxiliary engine power generation must be reduced by at least 50%, measured against the fleets' baseline power generation. The requirement will increase to 70% in 2018 and 80% in 2020.

3.4.3 Financial incentive schemes and voluntary instruments

While regulation is mainly used at the global level, except for the two examples discussed above, market based instruments are implemented on a national or local scale, specifically designed for meeting local objectives. Several examples will be discussed, that came up amongst others during interviews with stakeholders, including:

1. Differentiation of fairway dues*
2. Vessel speed reduction*
3. NOx business Fund (Norway)*
4. CAAP*
5. Finnish investment aid*
6. Hong Kong FWC*
7. Shenzhen Incentive Scheme*
8. Maritime Singapore Green Initiative*
9. Environmental Ship Index*
10. Funding for Infrastructure [Connecting Europe Facility (CEF)/TEN-T]
11. DERA Moyer and Transportation Investment Generating Economic Recover (Tiger) grants
12. CAAP Technology Advancement Program (TAP)*

[66] www.arb.ca.gov/ports/shorepower/shorepower.htm

For the instruments indicted with an asterisk (*), we include a case study in Annex 3, providing an elaborated overview. All instruments are designed to address the specific local or regional challenges perceived. Most of the instrument include a financial incentive, and mostly as a discount. Below, the key features of the instruments used are presented.

Differentiation of Fairway Dues (Sweden)

Recognizing the need for abatement measures, the Swedish Maritime Administration, the Swedish Port and Stevedores Association and the Swedish Ship owners Association in 1996 arrived at a Tripartite Agreement to use differentiated fairway and port dues to reduce emissions of NOx and SOx by 75% by the end of the first decade of the new millennium. The objective was to reduce pollution in the Baltic Sea. By January 2015, the system will be limited to reducing NOx emissions, due to the introduction of 0.1% fuel sulfur SECA requirements. Ships with NOx emissions below 6 g/kWh receive a 30% discount on the gross tonnage component of the due, increasing to 95% in case of emissions below 0.5 g/kWh. Several dozens of ships receive the discounts, based on certified emissions reduction technologies.

Vessel Speed Reduction (various US ports)

VSR is one of the emission control measures implemented by the ports of Los Angeles, Long Beach, San Diego, New York and New Jersey. An advantage of VSR is that it can be implemented in short time frame with no capital expenditure. The Ports have overcome the delays in reaching the berth by moving work assignment from dockside to VSR zone boundary. Another advantage of this program is reduction in GHG and fuel consumption.

Except the Port of San Diego (POSD), all ports provide financial discounts. The ports typically spend 1.5 to 2 million USD per year for providing benefits. Ships slow down their speed from open sea transit speed to VSR speed, which ranges between 15 knots to 10 knots. Speeds are monitored by use of automatic identification system (AIS) data. The share of ships meeting the speed requirement in the 20 nm zone is close to 100% in the ports where financial discounts are provided. In the POSD, where no discounts are provided, 59% of the ships comply with the VSR speed requirements.

NOx Business Fund (Norway)

In Norway, a NOx tax was introduced 1st of January 2007 of 1.9 € (15 NOK) per kg NOx, to meet the objectives of the Gothenburg protocol (national emission cap). The Gothenburg protocol is a United Nations Economic Commission for Europe (UNECE) initiative that requires countries to reduce its emissions, below a certain agreed level.

The NOx business fund was set up by 15 co-operating business organizations and the Ministry of Environment. Affiliated companies pay € 0.5 per kg NOx to the NOx Fund, instead of paying the NOx tax. Undertakings that join the Environmental Agreement are obliged to apply for support for measures to reduce NOx emissions in situations with a return-on-investment time shorter than three years, taking the fiscal NOx tax and the support from the fund into account. Support will be granted for investment costs (up to 80% of overall additional costs) as well as operating costs (urea). Between 2011 and 2016, the NOx fund is committed to reduce NOx emissions by 34 ktonne per annum (2012: 180 ktonne in baseline). The NOx fund has granted significant parts of the overall granted budget for LNG and SCR investment projects, mainly for seagoing ships.

Propulsion engines exceeding 750 kW –aimed at marine engines- are subject to taxation. Emissions from sources that are subject to the so-called Norwegian Environmental Agreement are exempted from the NOx tax. All technical measures that reduce the emissions of NOx. This is mainly LNG, but also SCR, etc. and the tax applies to domestic shipping only.

Finnish Investment Aid

The objective of the Finnish investment aid is to maintain the competitiveness of the Finnish maritime industry whilst aiming at sustainable maritime transport – in particular SOx emissions. 80% of foreign trade of Finland is transported by sea. The objective of the scheme is to:

- to encourage ship owners to make environmentally friendly investments
- to speed up commercial use of environmentally friendly technology
- to simplify the adaptation to new emission requirements

The aid is only eligible for vessels under the Finnish flag, and covers extra investment costs necessary for reaching a higher level of environmental protection, including operational costs and benefits. The aid intensities are between 15 and 70%, depending on:

- the size of the company (smaller companies receive higher grants)
- new build or retrofit investment (retrofits receive 50% of eligible costs)

The Finnish scheme is in line with the EU state aid framework. The maximum aid per vessel is EUR 30 million. Individual aid exceeding EUR 7.5 million shall be notified to the European Commission. The budget of the notified amendments of the scheme is EUR 100 million for the period 2013-2014.

The aid scheme was in force between March 2013 and December 2014. After this date the 0.1% SECA regulations came into play and aid was not possible anymore.

Hong Kong FWC

The regulatory regime developed in the US and in Europe have shed lights on what can be done in a major seaport like Hong Kong, especially when a big portion of the ship companies operating in Hong Kong are international carriers, who are already required to comply with tighter fuel standards and environmental practices in American and European ports.

The Hong Kong FWC is the first industry-led initiative that encourages the voluntary practice of at-berth fuel switching to LSF with sulfur content of 0.5% or less. 17 major shipping lines operating in Hong Kong signed up for the first FWC, from 2011 to 2012. These 17 carriers contribute about 5,000 calls a year.

After the launch of the FWC in 2011, the Hong Kong SAR Government also announced an incentive scheme in September 2012 to encourage ocean-going vessels to switch to LSF at berth in Hong Kong.

Driven by the success of the FWC and the request of the shipping industry, the Hong Kong government decided to regulate at-berth fuel switching, which is expected to become effective in 2015.

Shenzhen Incentive Scheme

The Shenzhen incentive scheme is an expanded version of the FWC and Hong Kong's incentive scheme, as the Shenzhen scheme also encourages operators to use shore power. The Shenzhen scheme is the first incentive scheme to reduce ship emissions in mainland China (excluding Hong Kong, China). The Scheme was announced in September 2014.

Maritime Singapore Green Initiative

The objective of the Maritime Singapore Green Initiative is to reduce the environmental impact of shipping and related activities and promote clean and green shipping in Singapore, through 3 distinct programs:

- Green Ship Program
- Green Port Program
- Green Technology Program

Under the Green Ship Program, ships will get a reduction of Initial Registration Fees (25% - 75%) and a rebate on Annual Tonnage Tax (20% - 50%) based on the level of adoption of emission reduction and energy efficiency technologies/design:

- Ships that adopt energy efficient ship designs exceeding IMO's Energy Efficiency Design Index (EEDI) will enjoy 50% reduction of Initial Registration Fees and 20% rebate on Annual Tonnage Tax.
- Ships that adopt approved SOx scrubber technology exceeding IMO's emission requirements will enjoy 25% reduction of Initial Registration Fees and 20% rebate on Annual Tonnage Tax.
- Ships that adopt both energy efficient ship designs and approved SOx scrubber technology exceeding IMO's requirements will enjoy 75% reduction of Initial Registration Fees and 50% rebate on Annual Tonnage Tax.

Under the Green Port Program, ocean-going vessels will get a reduction of port dues (15% - 25%), determined by whether type approved abatement technology or clean fuel (1%m/m or equivalent) is used only at berth or throughout entire port stay.

Under the Green Technology Program, Singapore-registered companies may receive grants capped at S$2 million per project, with an increase cap of S$3 million per project for solutions or systems developed and adopted that can achieve over 10% reduction in emission levels.

The Maritime and Port Authority of Singapore (MPA) pledged in 2011 to invest up to S$100 million over 5 years to support the Maritime Singapore Green Initiative.

As of December 2014:

- 40 companies have pledged their commitment to promote and support clean and green shipping in Singapore.
- 174 vessels participated in the Green Ship Program as of end July 2014.
- Over 2,000 vessel calls from the top five shipping lines have participating in the Green Port Program as of end July 2014.

- 18 projects approved under Green Technology Program, with 50 Singapore-registered ships participating in the Program as of end July 2014.

Environmental Ship Index
As part of its promotion of sustainable shipping, IAPH's WPCI has developed the ESI). The Objective of ESI focuses on getting as many ports and - above all - as many ships as possible to participate. The ESI evaluates the amount of NOx and SOx that is released by a ship and includes a reporting scheme on the GHG emission of the ship. The ESI is an indication of the environmental performance of ocean going vessels and will assist in identifying cleaner ships in a general way.

The formula for calculating the ESI Score is composed of a set of sub points for each of the emission groups NOx, SOx and CO_2 (PM is included in the SOx sub score. ESI NOx and ESI SOx each score a maximum of 100 sub points and ESI CO_2 scores 10 sub points.

Around the world, nearly 30 ports in the world typically provide 5-10% discounts on harbor dues or another financial incentive, using the ESI score of ships. By doing this, the ports contribute to a more positive business case for lowering ship emissions. Over 3,000 ships have been registered to qualify for port discounts and/or incentives.

Government Funding for Innovative Infrastructure[68]
The EU's CEF policy aims to realize a core transport network comprising nine major corridors, to be completed by 2030. In the period 2014-2020 the financing for transport infrastructure will triple to €26 billion. The infrastructure package stipulates a need to update the current energy infrastructure and also identifies a need to improve gas infrastructure. As part of the CEF, this package identifies priority gas corridors and projects that can be considered potential projects of public interest and likely to need funding under CEF. LNG terminals are specifically mentioned as likely projects.

Under its predecessor, the TEN-T policy, The Port of Rotterdam and Port of Gothenburg received €34 million of TEN-T funding to partly cover the construction costs of two LNG terminals. At the port of Rotterdam a new break bulk terminal and truck loading bay will be built to enable supply of both smaller ships and LNG trucks. The Gothenburg terminal will be supplied from the GATE terminal in Rotterdam and will itself supply the Scandinavian LNG market. The project is to be finalized by December 2015.

DERA and Tiger Grants
The US Environmental Protection Agency's DERA offers grant funding on an annual basis for programs that provide funding for infrastructure such as shore-side power capability.

The US Department of Transportation's TIGER discretionary grant program that invests in road, rail, transit and port projects that promise to achieve critical national objectives, including environmental sustainability.

CARB administers the Goods Movement Emission Reduction Program a California grant program funded by a state bond that voters approved in 2006 that supports, among other things, infrastructure improvements for the ship-port interface.

[68] www.lngbunkering.org/lng/bunkering/funding-lng-infrastructure/eu-funding

3.5 Discussion on the instruments' effectiveness

In this section, we discuss the effectiveness of different instruments available for reducing emissions at the ship-port interface.

3.5.1 Voluntary instruments and corporate social responsibility

The interviews provided a mixed view on the role of CSR policies and voluntary measures on reducing emissions at the ship port interface. On the one hand, ports, especially in Europe and the US, attach great value to their CSR policies. On the other hand, the role of CSR with respect to cargo owners and other maritime peers were evaluated as limited, by the interviewees. Nevertheless, we observe several examples of voluntary instruments focusing on emission reduction at the ship port interface:

- the provision of discounts for cleaner ships on the basis of ESI
- the Hong Kong FWC
- the Shenzhen Incentive Scheme
- the Green Ship Program
- VSR
- TAP

CSR policies are strongly related to ports' license to operate. The instruments highlighted above and programs like the CAAP provide ports a license to perform port operations in the vicinity of densely populated cities. In addition, several ship owners indicated that their company's responsibility policy played a role, in addition to economic considerations.

Available literature on the relevance of CSR policies for environmental management is yet limited. Lyon & Maxwell (2008)[69] argue that market drivers of CSR will likely continue to grow in importance, but complex issues, requiring expensive remedies, or that require change across multiple stakeholders—such as global warming and air quality improvement—political pressure is likely to remain a critical influence on CSR activities, the researchers conclude. Also Corbett (2010)[70] concludes that for important and critical problems a firm hand will be needed instead of a soft or invisible hand, and may be chosen if complex barriers to market integration exist.

[69] Corporate Social Responsibility and the Environment: A Theoretical Perspective, Thomas P. Lyon∗ and John W. Maxwell, Review of Environmental Economics and Policy Advance Access published July 11, 2008

[70] The Role of International Policy in Mitigating Global Shipping Emissions, James J. Corbett James J. Winebrake, University of Delaware, Rochester Institute of Technology, 2010, Brown Journal of World Affairs, Spring/Summer, volume xvi, issue ii

3.5.2 Regulations and standards

Generally, we conclude that regulation by IMO (global), the EU (regional) and CARB (local) has yielded the most significant reduction of emissions, since the technical requirements for lowering emissions have been imposed on all ships under control of the respective authorities. All ships, irrespective the flag of the ship, have to comply with the various applying standards, creating a level playing field for ship operators. Because of that reason, and because regulation can solve the barriers of the business case, the majority of the stakeholder stated their preference the use for regulation and standards.

The implemented policies for NECAs and SECAs in various regional waters show that globally agreed regulation can be designed in such a way that the difference in awareness observed in the various world regions and the extent in which land-based emissions have been reduced can be taken into account. The variety in awareness may be linked to income inequality between various world regions, some stakeholders indicated.

3.5.3 Financial incentive schemes

The overall number of ships engaged in voluntary programs is yet relatively limited. The ESI scheme is the most significant scheme with over 3,000 participating ships. The other initiatives are much smaller and of a regional character. By comparison, the overall number of seagoing ships in 2011 amounted to almost 120,000, of which 70,000 are cargo ships (IMO, 2014).[71]

The success of other voluntary or incentive-based measures strongly depends on the balance of costs and benefits, as the largest barrier to the introduction of measures reducing the emissions is the business case. Survey results indicate that the investments and operational costs need to be outweighed by grants or discounts, at least to some extent, for an incentive to be effective. Industry logically evaluates costs and benefits of the various incentives, as clearly seems form the from the VSR compliance in the various Californian ports. The VSR schemes in US ports illustrates the role of financial incentives. In the ports granting financial incentives, close to 100% of the ships meet the VSR criteria in the 20 nm zone, while in the POSD, where no financial incentives are provided, VSR compliance remains at 58%.

It should be noted, however, that CSR policies can also contribute to the implementation of voluntary instruments. The example of the Hong Kong FWC, and the other Asian instruments that followed, underpins this statement and shows that adoption of a certain technologies by industry can be a driver for government incentives and eventually followed policies. Another example of the latter is that several CAAP ship-related measures, which started out as voluntary, incentive-based, or as lease requirements were adopted by CARB, which codified and adopted fuel switch (ahead of the North American ECA) state-wide[72] and shore power which was adopted for selected ports[73].

[71] Third IMO GHG Study 2014; IMO London, UK, June 2014

[72] www.arb.ca.gov/ports/marinevess/ogv.htm

[73] www.arb.ca.gov/ports/shorepower/shorepower.htm

NO_X fund

The Norwegian NOx business fund is characterized by an 80% subsidy of the additional investment and operational costs, covered by other economic participators in the business fund. The Norwegian NOx fund significantly contributes to creating a business case for NOx reduction, illustrated by the relatively high number of ships that have been equipped with like SCR catalysts and LNG engines. The fund has granted support to over 60 ships, conversions with gas-engines and SCR have been subsidized, as well as new builds. Applications for 30 more ships were received by the end of 2013.

The Norwegian model applies to domestic shipping only. This limits the potential of the scheme, also when looking at broader application of the scheme. Application of the scheme to international shipping at a national level may have an impact on the level playing field between ports. Application in a number of countries (e.g. all EU or US ports) may solve the level playing field problem, but a tax or charge should be uniformly introduced as a stick for stakeholder to join a comparable NO_X fund. The feasibility of such a scheme is not clear.

Port dues based incentive systems

ESI and the corresponding discount schemes implemented by individual ports is an example of how an international financial incentive can be used by a large group of stakeholders. The number of participating ports and ships in ESI is notably high already and increasing, increasing the future effectiveness of the scheme as well.

It is yet, however, difficult to create a business case for investing in new advanced technologies. The potential of ports to contribute to closing the business case gap is limited, since ports can only provide financial incentives based on the port dues they collect. The level of port dues varies between ships and routes, but ships typically pay between 0.5 and 1.0 million US dollar per year (Maritime Economics 3rd edition). Taking a 10% discount on 50% of total port dues paid into account, this would result in an overall budget for implementing measures of between $US 25,000 and $US 75,000. The annual budgets required for introducing innovative techniques are generally higher.

The role of financial incentives in adoption of new technologies

Implementation of financial incentives is also an important driver for the introduction of new technologies in the fleet. Several instruments have contributed to the uptake of LNG-engines, SCR catalysts, SOx scrubbers and other technologies, resulting in an increase of experience with these techniques. The latter is an important driver for further development or (global) regulation.

3.6 Measuring and reporting effectiveness of measures and instruments

In order to be able to assess and report the effectiveness of measures and instruments, measuring and reporting is relevant. Two primary methods are used to measure and report the effectiveness of an implemented emission control measure: qualitative and quantitative, though not all measures or programs can be reported in a quantitative way. Both methods provide different perspectives on control measure effectiveness. The methods used and the level of detail needed is usually determined by a combination of drivers and implementation methods. Both approaches can be effective and are also sometimes used together to tell the broader story of how a measure is performing. However, there is a broad range of approaches used with both methods, which can make comparing similar measures in different port areas difficult.

Qualitative methods are typically used to demonstrate participation and uptake associated with a measure. The qualitative method demonstrates a measure's effectiveness at a high level, can demonstrate uptake of a measure, and be used to assess if the participation goals are being met or how they change over time. The qualitative method provides helpful information regarding emission reductions associated with a control measure, even when the reductions are not directly measured. The use of qualitative methods for measuring and reporting a control measure's effectiveness typically include participation elements, which are sometime compared to total activity in the port area or associated with a specific port authority. Participation elements include, but are not limited to, the following:

- number of participating ships and/or operators
- number of total participating calls
- number of participating calls by vessel class
- amount of incentive funds provided
- average speeds of participants
- mass of fuel switched

Examples associated with the qualitative method are provided below:

- Reporting participation
    - In California, the POLA[74], the POLB[75] and the POSD provide annual VSR participation rates in terms of percent of vessel calls that operated at or below prescribed speeds. These ports have access to electronic actual speed data such as AIS on ships entering and leaving their respective VSR zones. Therefore verification, administration and reporting of the participation of the program can mostly be automated. For more information refer to the VSR case study in Annex 3.

- Reporting amount of incentives paid
    - PANYNJ reports progress by posting the amount of incentives paid and the name of the participating shipping lines in their Clean Vessel Incentive Programs on the program's website.[76] For more information refer to PANYNJ case study in Annex 3.

- Reporting participation and incentive paid
    - TAP under CAAP serves as the catalyst for identifying, evaluating, and demonstrating new and emerging emission reduction technologies applicable to the port industry. Under this program, TAP Annual Reports are published to document progress with the Ports' efforts to support near-term emerging technology development and demonstration. These Annual Reports include details of the projects that were either selected or continued to be implemented under the TAP each year the report is published. For more information on TAP refer to case study in Annex 3.

Quantitative methods are used to provide estimates associated with actual emissions reduced from the implementation of a control measure. The quantitative approach is typically used when drivers require the implementing entity to track and disclose estimated actual emissions reductions associated with a

[74] www.portoflosangeles.org/pdf/VSR_Compliance_Data.pdf
[75] www.polb.com/environment/air/vessels/green_flag.asp
[76] www.panynj.gov/about/clean-vessel-incentive-program.html

measure. These drivers could include the measure being incorporated into an air quality regulator's voluntary emission reduction program; the reduction is being incorporated into regulator's air quality plans which includes the port area, or by the request of the implementing entity's senior management, etc. Quantitative methods are typically used in areas that are at an advanced state of air quality management. Quantitative methods can vary significantly in uncertainty depending on extent of the reliance on surrogate data and assumptions compared to the use of detailed actual data associated with the measure. Typically, the quantitative method measures or determines the baseline emissions inventories under existing conditions and then measures the actual emissions after incorporating in the control measure to determine the benefit or emissions reduction. These estimates can be conducted on a vessel call level, a fleet level, annual results etc., and typically demonstrate emissions reductions, by pollutant, by preferred time period.

Examples associated with the quantitative method are provided below:

- Reporting emissions reduced:
  - Under the CAAP update[77], POLA and POLB set the emissions reduction goals as the percent change from baseline year of 2005 so that progress of CAAP measures implemented over the years can be measured independent of the change in the ports' activity. POLA[78] and POLB[79] utilize a comprehensive emissions inventory reporting system to report the progress of various emissions control strategies listed in CAAP as well as regulations that impact ports sources**.** Since 2005, the two ports have estimated annual emissions of ship operations near port and compared each year's emissions to 2005 to document the emission reductions achieved as a result of various emissions control programs. When reporting emission reduction progress, the ports also include the change in activity in terms of growth, which is measured by vessel throughput and vessel calls by container size, in order to report on the emissions reduction programs versus changes that resulted from reduced port activity.

[77] www.cleanairactionplan.org/
[78] www.portoflosangeles.org/environment/studies_reports.asp
[79] www.polb.com/environment/air/documents.asp

4 Conclusions

There are a number of findings and recommendations from the research, data collected, interviews, and the team's experience relating to the analysis and implementation of ECEEMs for ships in the port area. This section highlights the findings, and provides recommendations for further consideration.

4.1 Discussion

Emission reductions in the port area are typically focused on PM and NOx due to air quality health impacts associated with airborne PM and the formation of ground level ozone. The following discusses several key conclusions from this study.

EECMS

Numerous and diverse ECEEMs 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 no "silver bullets" at this time nor in the foreseeable future that would provide a common, cost effective solution for reducing PM and NOx and because of the bespoke nature of ships and emissions control technologies, analysis is needed on a case-by-case basis to determine if a measure is effective (both in terms of emissions and costs).

The overall cost of implementing measures includes numerous cost elements, which vary by stakeholder group. When ship owners consider implementing a measure, some owners can leverage market forces, such as size of order, number of ships to be retrofitted, etc. to affect the ultimate price paid per unit. Identifying the total cost of implementing a measure or strategy is further complicated by not having a common reporting scheme for costs. Publically reported costs can include a range of all the cost elements (i.e., total cost) to just a limited number of cost elements. Similarly, ports and terminals do not always disclose total costs for incentive programs and voluntary programs in a common manner. Some ports report total costs, some may leave out administrative cost elements and just report incentives paid out, while others only report potential incentives per qualifying ship call.

There are initiatives underway by various stakeholders to evaluate and demonstrate emerging and innovative ECEEMs that could be effective both at-sea and in the port area. An example of this is POLB and POLA's TAP which incentives and facilitates bringing new and innovative measures into the demonstration phase and evaluates the effectiveness in collaboration with local, state, and national air quality regulators.

Drivers/challenges

A survey of relevant stakeholders at the ship-port interface indicated that air pollution is a major environmental challenge. These stakeholders, including representatives from port authorities and terminals, ship owners and operators, equipment manufacturers as well as governmental and regulatory authorities, widely recognised that the pressure to reduce emissions will increase over time. This pressure is most perceived at US and EU ports, but awareness and public concern in Asia has started to grow in recent years. This is illustrated by the recent (voluntary) measures and instruments implemented in Asian ports. Globally active stakeholders indicated that awareness is significantly lower in other parts of the world.

Stakeholders also indicated that community and public pressure, regulation at different government levels, and corporate social responsibility are the most important drivers for reducing emissions. These drivers alone often lead to voluntary measures while regulation emerges either as an enhancement to voluntary efforts or in response to residual public pressure or needs that are not being adequately addressed through other approaches.

When regulations are implemented (from IMO, EU or CARB), those that specifically apply to the ship-port interface most directly affect ship owners and operators and are important drivers for this group. Port authorities are generally less affected by these regulations and as a consequence see their own corporate social responsibility policy as an important driver. This is closely related to public pressure and the figurative 'license to operate' that is granted to a port by maintaining a positive relationship with the surrounding community.

While public and regulatory pressure can be significant drivers, the survey revealed that ship owners experience little pressure from clients to implement measures to reduce air pollutants. This finding is further supported by literature that describes the limited interest of shippers in the environmental performance improvement of carriers that move their goods, especially in cases where environmental improvement measures would require a rate increase.

Barriers

Broadly speaking, the cost effectiveness of measures at the ship-port interface depends most significantly on either the percentage of total operational energy consumed by the ship in the port area and the potential to reduce fuel consumption or the potential for regulatory compliance at a lower cost compared to other options. The cost effectiveness of individual projects depend on numerous variables, including capital and operational expenses, technology maturity, operational compatibility, port calls, time in port, power consumption and fuel price differences. Because of this complexity, implementation of any individual measure must be analyzed on a case-by-case basis to determine viability.

The lack of a sound business case is widely reported by the stakeholders as the largest barrier to the implementation of measures. Since measures to reduce air pollutant emissions are expensive, disruptive, and will generally not result in direct financial benefit, many ship owners are reluctant to implement them. This lack of business case issue is closely related to the reason that regulation is reported in the survey as the most effective driver. Regulations generally oblige all ship owners to install emission reducing technologies on board or use LSFs, resulting in an even playing field. 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.

Closely tied to the motivations of ship owners, the equipment manufacturers are strongly dependent on the demand for emission control measures of the ship industry. They indicate that regulations are very important for signalling market development and provide confidence to spend resources to develop products in anticipation of regulatory implementation. Further, manufacturers suggest expansion of certain regulations to cover existing ships.

Regulatory uncertainty was also reported as an important barrier because it may impact business decisions. Examples of this are re-opening of the discussion on IMO NECA requirements, and the discussion about the entry into force of the global 0.5% sulfur limit. It was also observed that verification of emission control technology is challenging and lacking, but nonetheless necessary to harmonise newly emerging verification procedures.

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.

Port authorities have limited room to improve the business case. As a result, measures that would effectively reduce emissions cannot be easily financed by ship owners solely on the basis of discounts offered on port dues or similar port-based incentives. To increase the effectiveness of their instruments, ports could partner with regional ports to harmonize requirements for ships and create a more regional level playing field. This concept of a level playing field is not only relevant for the introduction of financial instruments in ports, but also for the introduction of local regulation.

Instruments

Regulation on the global, regional and local level has yielded the most significant reduction of air emissions the ship-port interface, since the technical requirements for lowering emissions have been imposed evenly. Because of this, and because regulation can help create necessary drivers for individual business cases, the majority of the stakeholders stated that they prefer the use of regulation to reduce emissions in the ship-shore interface.

In addition to increased regulation, 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 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 world-wide 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.

An example of an effective local program that is effective at enhancing the business case for measure adoption is the Norwegian NOx tax, and associated business fund, which is characterised by the high subsidy share of measure investment costs. 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, 60 ships have been equipped with technologies that significantly cut NOx emissions in Norwegian waters. This tax, introduced by the Norwegian government, acts as an incentive for ship owners to join the business fund and to implement emission-reducing technologies. This scheme only applies to domestic shipping around Norway, however, and may be difficult to translate more broadly because of varying or overlapping jurisdictional authorities.

Voluntary incentive programs are also important drivers for the introduction of new technologies. Surveys indicate that several such voluntary instruments have contributed to the uptake of gas engines, SCR catalysts, SOx scrubbers and other technologies, resulting in an increase of experience with these technologies in the industry. Experience is an important driver for further development and regulation at different government levels. The discounted port dues and other voluntary incentives for ships in areas such as Hong Kong and the California are examples of how voluntary measures can encourage early adoption of emission reduction measures in advance of regulations and create both industry and government experience that improves the effectiveness of future regulations for all stakeholders involved.

Analysis of the survey results also shows that CSR policies and community awareness are important drivers for the introduction of and gaining experience with new technologies in the ship-port interface. However, for important and critical problems requiring expensive measures, without a sound business case, regulation will be needed to ensure broad scale adoption of technologies and measures to reduce emissions and improve energy efficiency.

4.2 Key Findings

The key findings from the study of ECEEMs for ships in the port area include:

1. Air pollution in the port area is recognized by all four stakeholder groups as a major challenge and they all anticipate that the pressure to reduce emissions from ships in ports will only increase with time.
2. Regulations, such as IMO, EU and California Air Resources Board (CARB) regulations, that specifically relate to the port area and most directly affect ships are typically the strongest drivers for implementation of emission reduction measures in port areas.
3. Numerous ECEEMs 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 ECEEM is quite extensive including engine and boiler technologies, after treatment technologies, fuel options, alternative power systems, operational efficiencies, and cargo vapor recovery.
4. There are no “silver bullets” when it comes to ECEEMs 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 bespoke nature of ECEEMs, each measure needs to be analyzed on a case-by-case basis in advance of implementation.
5. Several emerging and innovative technologies and strategies 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 strategies, with the ultimate goal of bringing them to the market in an expedited fashion.
6. Specific cost elements relating to ECEEMs and the distribution of cost over various stakeholders differ by measure. While ports and terminals are primarily looking at land-side or infrastructure costs including design and construction; incentive program costs; and administrative costs, ship owners are dealing with analysis, design, and installation costs, operational impacts during installation, staff training; reclassification, project management costs and operational costs.
7. Published cost data on ECEEMs is typically opaque as to which cost elements are included. In addition, differences in an order’s size/number, a company’s market share, etc. can have a significant impact on unit prices. The cost/benefit ratio of each measure depends on a number of variables that need to be considered, including capital and operational expenses, technology maturity, and ship operation, which typically leads to case-by-case analysis.

8. Ship owners and operators are very concerned about whether there is a sound business case to adopting an ECEEM. Other barriers include the lack of drivers, uncertainty about future regulation, the financing of emission reduction measures and the lack of infrastructure. These barriers will in turn have a direct impact on the demand for equipment, affecting the equipment manufacturers, and implementation of measures.
9. Overall, around ten different incentive schemes are implemented by ports all over the world to improve air quality. The ESI is the most widely implemented and is still growing from its current participation involving over 3,000 ships and 30 ports.
10. In general, the incentive schemes implemented are subsidy schemes that do not come close to fully offsetting costs associated with the incentivised measures. This yet limits the potential environmental benefits of incentive schemes. Stronger differentiation within the incentive schemes on the basis a ship's emissions may contribute to an improved business case.
11. 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.
12. There are ship owners implementing voluntary ECEEMs and participating in voluntary and incentive-based programs set up mainly by port authorities. CSR and sustainability ethos have played a role for some ship owners to go beyond regulation.
13. While implementation of air quality improving instruments at the ship-port interface has mostly taken place in North America and Northern Europe, Asia is becoming active in the issue, and as drivers arise in other parts of the world to reduce ship-related emissions in the port area.

4.3 Recommendations

This report was prepared for the IMO in support of their "Concept of a Sustainable Maritime Transportation System." A key goal outlined in this Concept is the initiation and enhancement of national discussions related to the Concept's third imperative: "Energy Efficiency and Ship-Port Interface." The following recommendations are made by the authors:

1. The extensive list of measures and strategies, case studies, and survey results presented in this report, as well as the contextual information about ports, industry, cost elements, and regulatory concerns can provide reference materials to those who are considering implementing measures to reduce emissions from ships in the port area. -The material in the report is relevant to a wide range of important discussions currently taking place at the IMO, including "technology transfer" and "technical and operational measures for enhancing energy efficiency of international shipping."

2. Ports are the most affected among the surveyed stakeholders by air pollution in the port area. Consequently, most incentives and programs have been implemented by ports. The interviews, case studies and further analysis in this report indicate that a successful implementation of measures often comprise a number of steps, that may include:

    - identify and inventory the most important emission sources
    - analyze feasibility and cost effectiveness of potential ECEEMs and strategy(ies)
    - identify and develop/provide the necessary infrastructure associated with a measure(s) or strategy(ies) in collaboration with prospective users (as needed);
    - develop voluntary or financial incentives in agreement with relevant stakeholders (in order to maximize the uptake of the measure(s) and maintain a level playing field)
    - monitor and report effectiveness of the measures implemented
    - seek optimization of instruments by strengthening the incentive provided within the level playing field

3. The material presented in this report is current as of the date of publication. Because of the evolving nature of the technologies, drivers, barriers, costs, and regulatory environments, information in the report will most like become outdated within just a few years. As such, it is recommended that document be revisited and updated periodically such that it can continue to provide current reference materials to those engaged in the reduction of ship emissions in the port area.

ANNEX 1 – Sample Stakeholder Surveys

Port Authorities and Private Terminals
Ship Owners
Emissions Reduction Technology Manufacturers/Vendors and Related Associations
Regulators, Trade Associations, and NGOs

Questionnaire for port authorities and private terminal

Introduction

*We are conducting a survey for an IMO study investigating technologies and other strategies to reduce air emissions [and energy consumption] that occur around the **ship-port interface**. These include both conventional and greenhouse gas emissions that come both directly from ships as well as any emissions related to nearby transit, berthing, and loading & unloading operations. The study consists of three major tasks:*

The objective of the study is to:

1. *Identify existing and effective control measures (technological, operational and market based) to reduce emissions during the ship-port interface, as well as abatement potential and abatement costs for each control measure. For example, incentive schemes, such as port fees reduction, for voluntarily using fuel oil with lower sulphur content.*
2. *Identify barriers (technological, operational, commercial and institutional) to the uptake of measures to control emissions when ships are in port and provide recommendations to address these barriers.*
3. *Identify and appraise possible innovative measures, including incentive schemes, and best practices, which could be further developed for optimizing the energy efficiency of ships when in port.*

As part of the project, we are conducting interviews with ports all over the world, ship-owners and technology suppliers. Names of individual organisations will be treated confidential and only be classified into major groups, unless agreed otherwise. We will include your organisation in the list of interviewees.

The results of the questionnaire will be incorporated in a report that will be submitted to IMO MEPC 68, in early 2015. The results of the questionnaires will be anonymised where possible.

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IMO INTERNATIONAL MARITIME ORGANIZATION

Information on interviewed organisation:

Name organisation:

Contact person:

Position within organisation:

Tel:

Email:

Interviewed by:

Name:

Organisation:

General questions

Port Name	
Cargo throughput in 2013 (Million tonnes)	
Two most important cargo types	□ Dry bulk □ Liquid bulk □ Conventional cargo □ Containers □ Ferry/RoRo
Operation type:	□ Landlord □ Operator □ Mixed
Organization type:	□ National □ Subdivision of State □ Private
Number of employees:	

Environmental challenges/issues

The first questions concern environmental challenges that exist in the ship-port interface, such as air pollutants, GHG/CO2, noise and biodiversity.

1. What are the environmental challenges perceived by your port?

	(1) Not perceived at all	(2) Slightly perceived	(3) Moderately perceived	(4) Perceived	(5) Very much perceived
Air pollutants (NOx, PM, SOx, VOC)					
GHG/CO_2					
Noise					
Biodiversity					
Other					

1a. **Which of the air pollutants associated with port-ship emissions are perceived as a challenge?** How long have these challenges been in place, and why?

- ☐ NO_x
- ☐ PM
- ☐ SO_x
- ☐ VOC

Why are these air pollutants perceived as a challenge? How long have these challenges been in place?

2. On a scale of 1-5, (1 = not at all, 5 = Very): How relatively important is it to emphasize emissions and energy reductions <u>specifically focused around the ship-shore transaction in comparison to other sources (industry/sailing ships)</u>?

	(1) Not important at all	(2) Slightly important	(3) Moderately important	(4) Important	(5) Very important
Environmental health					
Human health					
Industrial viability (license to operate)					

Drivers

The next questions concern the drivers for emission reduction in the ship-port interface

3. Do you currently or have you ever experienced pressure to reduce air emissions OR improve energy efficiency at your port or terminal?

□ **Yes** □ **No**

3a. (Yes) What was the origin of this pressure? What is/was the driver?

	(1) Not a driver	(2) Somewhat a driver	(3) Moderate driver	(4) Strong driver	(5) Very strong driver
Community/public pressure					
CSR (Corporate Social Responsibility) policy					
Health/safety of workers					
Local/regional regulatory authorities					
National/ supranational regulation (EU/US EPA)					
Client driven					
Other maritime industry peers					
Other (specify)					

3b. (Yes) **How much have these pressures changed over time?** Please specify the time frame (e.g. past 3 years/ 5 years/ 10 years).

Pressure has increased/decreased (and to what extent ?) Change of pressure over time (past 3/5/10 years) Which factors have played a role in this change? (e.g. legislation, awareness, etc)

3c. **Do you expect that there will be additional pressure in the future from any of these sources?**

- □ Yes
- □ No

If yes, please specify from which sources you expect more pressure in the future

- □ Community/public pressure
- □ CSR
- □ (Corporate Social Responsibility) policy
- □ Health/safety of workers
- □ Local/regional regulatory authorities
- □ National/supranational regulation (EU/US EPA)
- □ Client driven
- □ Other maritime industry peers
- □ Other (specify)

Why?

4. Did your port formulate quantitative objectives for emission reduction or any comparable?

□ **Yes** □ **No**

Please specify and preferably send us the documents:

Measures

The next questions concern the emission and energy reduction measures in the ship-port interface

5. What are the most successful emission reduction or energy efficiency measures implemented at the ship/port interface?

(These should include direct emission reduction technologies but also may include other strategies such as better utilization of assist tugs, faster cargo loading/unloading, and performance incentives related to quantifiable energy or emission reduction)

1.
2.
3.

Please fill out the following table per successful measure

<table>
<tr><td colspan="7">Name of measure:</td></tr>
<tr><td>Description</td><td colspan="6"></td></tr>
<tr><td>Measure type</td><td colspan="2">Technical</td><td colspan="2">Operational</td><td colspan="2">Fuel type</td></tr>
<tr><td rowspan="4">Applicability</td><td colspan="3">New ships</td><td colspan="3">Existing ships</td></tr>
<tr><td colspan="2">At berth</td><td colspan="2">Manoeuvring</td><td colspan="2">Anchorage</td></tr>
<tr><td colspan="2">Main engine</td><td colspan="2">Auxiliary engine</td><td colspan="2">boilers</td></tr>
<tr><td colspan="6">Ship type/size or other constraints:</td></tr>
<tr><td rowspan="2">Please provide us links to Information about effectiveness</td><td colspan="3">Evaluation studies:</td><td colspan="3"></td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td>Funding of measures</td><td colspan="6">□ Port/terminal funds
□ Regional community (city)
□ Ship owners
□ Other</td></tr>
<tr><td>Type of implementation</td><td colspan="2">Regulatory</td><td colspan="2">Voluntary</td><td colspan="2">Market based</td></tr>
<tr><td>Limitations</td><td colspan="6"></td></tr>
<tr><td>References</td><td colspan="6"></td></tr>
</table>

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<tr><td>Limitations</td><td colspan="6"></td></tr>
<tr><td>References</td><td colspan="6"></td></tr>
</table>

6. Which measures that have been implemented were perceived as not successful and why?

7. Currently, most regulation on emission and energy reduction measures is intended for new ships. Do you consider this as effective or should regulation be extended to existing ships as well?

If yes, please specify how…

Barriers

The next questions concern the barriers to the uptake of emission reduction measures in the ship-port interface

8. What are the most important barriers for implementation of port-ship emission reduction measures at your port?

	(1) Unimportant barrier	(2) Slightly important barrier	(3) Moderately important barrier	(4) Important barrier	(5) Very important barrier
No Business case					
Lack of driver(s)					
Lack of independent data					
Split incentives (due to ownership/ contract structure)					
Financial investment possibilities					
Lack of level playing field (competition/ modal shift)					
Administrative requirements associated with funding					
Regulatory constraints					
Lack of instruments (how to incentivise)					
Lack of resources (money, staff)					
Awareness of air quality issues in or near ports					

9. **Please illustrate the most relevant barriers with examples from your experience**

10. **What lessons have you learned from successfully implementing new technologies or programs (associated with reducing port-ship interface) in your organization?** (focus especially on emissions or energy reduction measures if applicable)

11. **What specific obstacles have you encountered or would you expect to encounter when implementing new emission or energy reduction measures in the port-ship interface?**

12. **What are or would be the main sources of funding for new emission or energy reduction measures at the port-ship interface?**

13. **Would you be willing to undertake new or more extensive emission reduction measures associated with measures at the port-ship interface if external funding was available for a portion of the costs?**

    □ **Yes** □ **No**

14. **Which technological innovations do you consider as most promising for the short (2yrs) mid (2-5 yrs) to long (5-10 yrs) term?**

Other

15. Do you have internal programs for emissions reduction measures , energy efficiency goals or mechanisms to quantify the effectiveness of energy and emission reduction at the port-ship interface?

□ **Yes** □ **No**

Please specify..

15a. (Yes) Have these programs/plans/metrics been effective in helping to achieve your goals?

15b. (Yes) Have you published documents or other information related to your efforts that you can share?

□ Annual reports
□ CSR documents
□ Other

16. Do you currently participate in any port/industry-wide voluntary emission or energy reduction program in or near the port area?

□ **Yes** □ **No**

16 a) If yes, please specify

□ World Port Climate Initiative
□ Environmental Ship Index (ESI)
□ Green Award
□ Clean Shipping index
□ Any other type of external incentive program
□ ....

17. **As an organization, are you comfortable making investments towards goals that may have unclear returns in the short-term but are projected to be beneficial over many years?**

18. **Do you have staff, staff time, or consultants dedicated specifically to work on air quality or energy efficiency for your organization?**

◻ **Yes** ◻ **No**

18a. (Yes) What level of resourcing (using number of staff as a proxy) is allotted in a year?

- ◻ 1
- ◻ 2
- ◻ 3-5
- ◻ >5

18b. (Yes or no) Do you expect to need more or less resources dedicated to this in the future?

◻ **More** ◻ **Less**

Questionnaire for ship owners

Introduction

*We are conducting a survey for an IMO study investigating technologies and other strategies to reduce air emissions [and energy consumption] that occur around the **ship-port interface**. These include both conventional and greenhouse gas emissions that come both directly from ships as well as any emissions related to nearby transit, berthing, and loading & unloading operations. The study consists of three major tasks:*

The objective of the study is to:

1. *Identify existing and effective control measures (technological, operational and market based) to reduce emissions during the ship-port interface, as well as abatement potential and abatement costs for each control measure. For example, incentive schemes, such as port fees reduction, for voluntarily using fuel oil with lower sulphur content.*
2. *Identify barriers (technological, operational, commercial and institutional) to the uptake of measures to control emissions when ships are in port and provide recommendations to address these barriers.*
3. *Identify and appraise possible innovative measures, including incentive schemes, and best practices, which could be further developed for optimizing the energy efficiency of ships when in port.*

As part of the project, we are conducting interviews with ports all over the world, ship-owners and technology suppliers. Names of individual organisations will be treated confidential and only be classified into major groups, unless agreed otherwise. We will include your organisation in the list of interviewees.

The results of the questionnaire will be incorporated in a report that will be submitted to IMO MEPC 68, in early 2015. The results of the questionnaires will be anonymised where possible.

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IMO INTERNATIONAL MARITIME ORGANIZATION

Information on interviewed organisation:

Name organisation:

Contact person:

Position within organisation:

Tel:

Email:

Interviewed by:

Name:

Organisation:

General questions

Name of company:	
Fleet size (#vessels):	
Ownership structure:	% chartered: % owned:
Size of organization (#employees):	
Annual turnover:	
Vessel types:	□ Dry bulk □ Liquid bulk □ Ferry □ Containers □ Auto Carriers □ RO/RO □ Other…….
Primary routes/services:	□ Global □ Intercontinental □ Regional/continent □ National
Type of company:	□ Public □ Private □ State owned □ Other

Environmental challenges/issues

The first questions concern environmental challenges that exist in the ship-port interface, such as air pollutants, GHG/CO2, noise and biodiversity.

1. **What are the environmental challenges perceived by ports, in the context of the ship-port interface in your opinion?**

	(1) Not perceived	(2) Slightly perceived	(3) Moderately perceived	(4) Perceived	(5) Very much perceived
Air pollutants (NOx, PM, SOx, VOC)					
GHG/CO_2					
Noise					
Biodiversity					
Other					

1a. **Which of the air pollutants associated with port-ship emissions are perceived as a challenge?** How long have these challenges been in place, and why?

- □ NO_x
- □ PM
- □ SO_x
- □ VOC

Why are these air pollutants perceived as a challenge? How long have these challenges been in place?

Drivers

The next questions concern the drivers for emission reduction in the ship-port interface

2. Do you believe there are drivers/pressure on the ship owners/operators to reduce air emissions OR improve energy efficiency in ports?

□ **Yes** □ **No**

2a. (No) Why do you believe your organization has no pressure to reduce air emissions OR improve energy efficiency in ports?

2b. (Yes) What was the origin of this driver? What is the challenge/issue driver?

	(1) Not a driver	(2) Somewhat a driver	(3) Moderate driver	(4) Strong driver	(5) Very strong driver
Community/public pressure					
CSR (Corporate Social Responsibility) policy					
Health/safety of workers					
Local/regional regulatory authorities					
National/ supranational regulation (EU/US EPA)					
Client driven					
Other maritime industry peers					
Other (specify)					

2c. (Yes) **How much have these pressures changed over time?** Please specify the time frame.

Pressure has increased/decreased (and to what extent ?) Change over time (past 3/5/10 years) Which factors have played a role in this change? (e.g. legislation, awareness, etc)

2d. **Do you expect that there will be more pressure in the future from any of these sources?**

- □ Yes
- □ No

If yes, please specify from which sources you expect more pressure in the future:

- □ Internal management
- □ Ports or port communities
- □ National or international regulatory authorities
- □ Customers or other maritime industry peers
- □ Operational competitiveness
- □ Other sources (specify)

2e. Please specify the most relevant drivers from your point of view at the port-ship interface.

Measures

The next questions are about the measures that can be implemented for emission and energy reduction in the port-ship interface.

3. What emission reduction or energy efficiency measures have you implemented on your vessels, <u>especially focussing</u> on the ship-port interface?[1]

- ☐ Optimising hoteling functions (optimizing auxiliary engine/boiler loads, time at berth)
- ☐ Onshore power supply / cold ironing
- ☐ LNG
- ☐ Scrubbers
- ☐ SCR catalysts
- ☐ Low sulphur fuels (lower than required by legislation)
- ☐ Cleaner (newer Tier) Vessels
- ☐ Vessel speed reduction (in the port area)
- ☐ Cleaner fuels
- ☐ LED lighting
- ☐ Other:……

4. Do you expect to implement new or additional emission or energy reduction measures in the future that will be employed in the port-ship interface?

☐ **Yes** ☐ **No**

4a. (Yes) **What specific measures are you considering?**

5. What lessons have you learned about successfully implementing new technologies or programs in your operations?

6. What specific challenges/issue have you encountered or would you expect to encounter when implementing new emission or energy reduction technologies or other measures that would operate in the port-ship interface?

[1] (These should include direct emission reduction technologies but also may include other strategies such as more efficient near-port transit and berthing, faster cargo loading/unloading, and performance incentives related to quantifiable energy or emission reduction).

7. **What are or would be your main sources of funding for new emission or energy reduction measures that would operate in the port-ship interface?**

8. **Would you be willing to undertake new or more extensive emission reduction measures that could operate in the port-ship interface if external funding was available to cover a portion of the costs or public recognition was provided for those ship owners/operators utilizing emission reduction/energy efficiency measures?**

   □ **Yes** □ **No**

9. **Do you have internal programs to quantify the effectiveness of efforts to reduce energy use or emissions, especially near or in the port?**

   □ **Yes** □ **No**

   9a. (Yes) Have these programs or metrics been effective in helping to achieve your goals?

   9b. (Yes) Do you have published documents or other information related to your efforts that you can share?

Barriers

The next questions concern the barriers to the uptake of energy and emission reduction measures in the ship-port interface

10. What are the most important barriers for implementation of measures to reduce port-ship interface emissions on your vessels?

	(1) Unimportant barrier	(2) Slightly important barrier	(3) Moderately important barrier	(4) Important barrier	(5) Very important barrier
No Business case					
Lack of driver(s)					
Lack of independent data					
Split incentives (due to ownership/ contract structure)					
Financial investment possibilities					
Reluctance of yards					
Administrative requirements associated with funding					
Regulatory constraints					
Age of the ship					
Only for new ships					
Awareness of air quality issues in or near ports					

11. Please list and illustrate the most relevant barriers with examples form your experience

12. **A frequently mentioned barrier for the implementation of existing and emerging emissions and energy reduction technologies is the lack of proof on the effectiveness of the technology. What degree of testing and verification should be required before a technology can be certified as achieving the levels of reductions advertised?**

Other

13. **Do you currently participate in any port/industry-wide voluntary emission or energy reduction program in or near the port area?**

    □ **Yes** □ **No**

    If yes, please specify:

□ World Port Climate Initiative
□ Environmental Ship Index (ESI)
□ Green Award
□ Clean Shipping index
□ Any other type of external incentive program
□ ….

12a. (Yes) Do you feel that these programs are effective for achieving their purported goals

12b. (No) What kind of motivation or incentive would you need to participate in such a program?

Questionnaire for emissions reduction technology manufacturers/vendors and related associations

Introduction

We are conducting a survey for an IMO study investigating technologies and other strategies to reduce air emissions [and energy consumption] that occur around the ***ship-port interface****.*
These include both conventional and greenhouse gas emissions that come both directly from ships as well as any emissions related to nearby transit, berthing, and loading & unloading operations.
The study consists of three major tasks:

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The results of the questionnaire will be incorporated in a report that will be submitted to IMO MEPC 68, in early 2015. The results of the questionnaires will be anonymised where possible.

Information on interviewed organisation:

Name organisation:

Contact person:

Position within organisation:

Tel:

Email:

Interviewed by:

Name:

Organisation:

Environmental challenges

The first questions concern environmental challenges that exist in the ship-port interface, such as air pollutants, GHG/CO2, noise and biodiversity.

1. What are the environmental challenges perceived by ports, in the context of the ship-port interface in your opinion?

	(1) Not perceived at all	(2) Slightly perceived	(3) Moderately perceived	(4) Perceived	(5) Very much perceived
Air pollutants (NOx, PM, SOx, VOC)					
GHG/CO_2					
Noise					
Biodiversity					
Other					

1a. Which of the air pollutants associated with port-ship emissions are perceived as a challenge? How long have these challenges been in place, and why?

- ◻ NO_x
- ◻ PM
- ◻ SO_x
- ◻ VOC

Why are these air pollutants perceived as a challenge? How long have these challenges been in place?

Drivers

The next questions concern the drivers for emission reduction in the ship-port interface

2. Do you believe that there is a pressure to reduce air emissions OR improve energy efficiency at port or terminals?

□ **Yes** □ **No**

(Yes) Why is it a challenge? What is the challenge driver?

	(1) Not a driver	(2) Somewhat a driver	(3) Moderate driver	(4) Strong driver	(5) Very strong driver
Community/public pressure					
CSR (Corporate Social Responsibility) policy					
Health/safety of workers					
Local/regional regulatory authorities					
National/ supranational regulation (EU/US EPA)					
Client driven					
Other maritime industry peers					
Other (specify)					

3. Do the drivers sufficiently create a market for cleaner technologies? Please list and illustrate what is needed for wider product deployment

4. Which instruments are most preferred by your organisation for implementing new emission reduction measures at the port-ship interface?

□ Regulation (such as IMO tier I, II, III)
□ Voluntary (such as technologies implemented on ships)
□ Market based(such as port fee reduction)
□ ..

5. Do the drivers differ in various regions of the world?

Technologies

The next questions are about the technologies that can be applied for emission and energy reduction in the port-ship interface.

6. What emission and energy reduction technologies/products does your organization offer or promote and what are the primary forces driving the market for these products?

1. 2. 3.

Please fill out the following table per measure

<table>
<tr><td colspan="5">Name of measure:</td></tr>
<tr><td>Description</td><td colspan="4"></td></tr>
<tr><td>Measure type</td><td>Technical</td><td colspan="2">Operational</td><td>Fuel type</td></tr>
<tr><td rowspan="2">Reduction potentials</td><td colspan="2">Pollutant</td><td colspan="2">Abatement potential (in comparison to state-of-art) (%)</td></tr>
<tr><td colspan="2">CO_2 (fuel)
NO_x
PM
VOC
SO_x</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Applicability</td><td colspan="2">□ New ships</td><td colspan="2">□ Existing ships</td></tr>
<tr><td>□ At berth</td><td colspan="2">□ Manoeuvring</td><td>□ Anchorage</td></tr>
<tr><td>□ Main engine</td><td colspan="2">□ Auxiliary engine</td><td>□ boilers</td></tr>
<tr><td colspan="4">Ship type/size or other constraints:</td></tr>
<tr><td>Validation of effects</td><td colspan="2">Please illustrate your validation procedure:</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Please provide us links to Information about effectiveness</td><td colspan="2">Evaluation studies:</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Limitations</td><td colspan="4">(temperature/fuel quality, etc.)</td></tr>
<tr><td>References</td><td colspan="4"></td></tr>
</table>

7. What are the capital and operational unit costs and cost drivers?

Capital costs (euro/kW) Operational costs (euro/kWh): Cost drivers: (for example fuel costs)

8. Could you supply us with information (pdf or weblinks) about the technologies that you offer regarding the costs, effectiveness, application and/or case studies?

- Costs:………………
- Effectiveness:……………………..
- Application:…………………………..
- Case studies:………………………..

9. In your opinion, how does the company/industry respond to the availability of new technologies and measures for emissions or energy savings (e.g. slowly, enthusiastically, etc.) and how has this response differed from your expectations?

10. What will the next generation of emissions or energy savings equipment in your sector look like and how much further reductions are possible?

Barriers

The next questions concern the barriers to the uptake of energy and emission reduction measures in the ship-port interface

11. What are the most important barriers to be overcome for implementation of measures on vessels, in context of the ships/port interface?

	(1) Unimportant barrier	(2) Slightly important barrier	(3) Moderately important barrier	(4) Important barrier	(5) Very important barrier
No Business case					
Lack of drivers					
Lack of independent data					
Split incentives (due to ownership/ contract structure)					
Financial investment possibilities					
Reluctance of yards					
Administrative requirements associated with funding					
Regulatory constraints					
Age of the ship					
Only for new ships					
Awareness of air quality issues in or near ports					

12. Please illustrate the most relevant barriers with examples form your experience

13. **Among shipowners, a frequently mentioned barrier for the implementation of existing and emerging emissions and energy reduction technologies is the lack of proof on the effectiveness of the technology.**

    What degree of testing and verification should be required before a technology can be certified as achieving the levels of reductions advertised?

14. **a) What do you see as the main barriers for the implementation of emissions or energy savings technologies in the port-ship interface?**

    b) What is needed to overcome these limitation/ barriers?

Questionnaire for Regulators, Trade Associations and NGOs

Introduction

We are conducting a survey for an IMO study investigating technologies and other strategies to reduce air emissions [and energy consumption] that occur around the ***ship-port interface****.*
These include both conventional and greenhouse gas emissions that come both directly from ships as well as any emissions related to nearby transit, berthing, and loading & unloading operations.
The study consists of three major tasks:

The objective of the study is to:

1. *Identify existing and effective control measures (technological, operational and market based) to reduce emissions during the ship-port interface, as well as abatement potential and abatement costs for each control measure. For example, incentive schemes, such as port fees reduction, for voluntarily using fuel oil with lower sulphur content.*
2. *Identify barriers (technological, operational, commercial and institutional) to the uptake of measures to control emissions when ships are in port and provide recommendations to address these barriers.*
3. *Identify and appraise possible innovative measures, including incentive schemes, and best practices, which could be further developed for optimizing the energy efficiency of ships when in port.*

As part of the project, we are conducting interviews with ports all over the world, ship-owners and technology suppliers. Names of individual organisations will be treated confidential and only be classified into major groups, unless agreed otherwise. We will include your organisation in the list of interviewees.

The results of the questionnaire will be incorporated in a report that will be submitted to IMO MEPC 68, in early 2015. The results of the questionnaires will be anonymised where possible.

STARCREST CONSULTING GROUP, LLC ENVIRONMENTAL MANAGEMENT AIR QUALITY • CLIMATE • SUSTAINABILITY — CE Delft — 思匯 CIVIC EXCHANGE — IMO INTERNATIONAL MARITIME ORGANIZATION

Information on interviewed organisation:

Name organisation:

Contact person:

Position within organisation:

Tel:

Email:

Interviewed by:

Name:

Organisation:

Environmental challenges

1. The first questions concern environmental challenges that exist in the ship-port interface, such as air pollutants, GHG/CO2, noise and biodiversity. **What are the environmental challenges perceived by ports, in the context of the ship-port interface in your opinion?**

	(1) Not perceived	(2) Slightly perceived	(3) Moderately perceived	(4) Perceived	(5) Very much perceived
Air pollutants (NOx, PM, SOx, VOC)					
GHG/CO_2					
Noise					
Biodiversity					
Other					

1a. Which of the air pollutants associated with port-ship emissions are perceived as a challenge? How long have these challenges been in place, and why?

- ☐ NO_x
- ☐ PM
- ☐ SO_x
- ☐ VOC

Why are these air pollutants perceived as a challenge? How long have these challenges been in place?

2. On a scale of 1-5, (1 = not at all, 5 = Very): How relatively important is it to emphasize emissions and energy reductions <u>specifically focused around the ship-shore transaction in comparison to other sources (industry/sailing ships)</u>?

	(1) Not important at all	(2) Slightly important	(3) Moderately important	(4) Important	(5) Very important
Environmental health					
Human health					
Industrial viability (license to operate)					

Drivers

The next questions concern the drivers for emission reduction in the ship-port interface

3. Do you observe that there is pressure to reduce air emissions OR improve energy efficiency in ports?

□ **Yes** □ **No**

3a. (Yes) Why is it a challenge? What is the challenge driver?

	(1) Not a driver	(2) Somewhat a driver	(3) Moderate driver	(4) Strong driver	(5) Very strong driver
Community/public pressure					
CSR (Corporate Social Responsibility) policy					
Health/safety of workers					
Local / regional regulatory authorities					
National/ supranational regulation (EU/US EPA)					
Client driven					
Other maritime industry peers					
Other (specify)					

3b. (Yes) **How much have these pressures changed over time?** Please specify the time frame (e.g. past 3 years/ 5 years/10 years).

Pressure has increased/decreased (and to what extent ?) Change over time (past 3/5/10 years) Which factors have played a role in this change? (e.g. legislation, awareness, etc)

3c. **Do you expect that there will be more pressure in the future from any of these sources?**

- □ Yes
- □ No

If yes, please specify from which sources you expect more pressure in the future:

- □ Community/public pressure
- □ CSR
- □ (Corporate Social Responsibility) policy
- □ Health/safety of workers
- □ Local/regional regulatory authorities
- □ National/supranational regulation (EU/US EPA)
- □ Client driven
- □ Other maritime industry peers
- □ Other (specify)

Why?

4. How does your organization view the potential of existing mandatory and voluntary incentive schemes to reduce ships' emissions or energy consumption in ports?

Potential of mandatory incentive schemes (such as legislation and regulation) Strong/weak………………why? Potential of voluntary incentive schemes (such as port fee reduction based on ESI) Strong/weak………………why?

5. What are the most successful incentives currently applied?

6. Which instruments are most preferred by your organisation for implementing new measures at the ship-shore interface?

- □ Regulation (such as IMO tier I, II, III)
- □ Voluntary (such as technologies implemented on ships)
- □ Market based (such as port fee reduction)

7. Reducing the emissions at the ship-shore interface could be most effectively enacted at the:

- □ International level
- □ Regional level
- □ Local level
- □ Both
- □ …

8. Currently there is a large difference in the application of measures in ports world-wide and within regions How can this be explained in your opinion?

9. Currently, most regulation on emission and energy reduction measures is intended for new ships. Do you consider this as effective or should regulation be extended to existing ships as well?

If yes, please specify how…

Barriers

The next questions concern the barriers to the uptake of emission reduction measures in the ship-port interface

10. What are the greatest barriers for the implementation of incentive schemes/legislation, etc. (why no NECA)?

11. What is needed to solve the current barriers?

12. Among shipowners, a frequently mentioned barrier for the implementation of existing and emerging emissions and energy reduction technologies is the lack of proof on the effectiveness of the technology. , What degree of testing and verification should be required before a technology can be certified as achieving the levels of reductions advertised?

Other

13. What are your organization's near (2 yrs), mid (2-5 yrs), and long term 5-10 yrs) goals for supporting and encouraging emission and energy reductions at the ship-port interface?

ANNEX 2 – ECEEM Details

Existing ECEEMs

- Equipment
  - Engine Technologies
  - Boiler Technologies
  - After-Treatment Technologies
- Energy
  - Fuels
  - Alternative Power Systems
- Operations
  - Ship Operational Efficiencies
  - Port and Terminal Operational Efficiencies
- VOC Working Losses

Future ECEEMs

Existing ECEEMs

Existing ECEEMs are grouped into three major categories: equipment, energy, and operational measures.

The equipment category refers to physical changes in machinery on board a ship, particularly focused on the three primary emission sources for ships: main/propulsion engines, auxiliary engines, and boilers. Equipment measures consist of the following groups:

- engine technologies
- boiler technologies
- after-treatment technologies

The energy category refers to ECEEMs related 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:

- fuels
- alternative power supply

The operational category refers to measures that primarily affect and focus on the operation of the ship, terminal, or port such that the absolute emissions of ships in the port area are reduced. 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

For each measure, there is a brief description that provides relevant summary information about the measure, followed by discussion on how these considerations relate directly to the port area:

- 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)
  - working VOC cargo tanks (Tank)
- Retrofitable – denotes if the measure is retrofitable on existing ships (Yes – Y) or limited to only new builds (No – N), and not applicable (na).
- Terminal/vessel – for port/terminal operational efficiencies only
  - terminal (T)
  - vessel (V)
- Applicable operational modes – port area-related operational mode in which the measure is effective. This includes:
  - open water or sea conditions (S)
  - transition (T)
  - maneuvering (M)
  - at-berth (B)
  - at-anchorage (A)
  - all modes (all)

- Emissions and energy efficiency– lists the pollutant specific emission changes anticipated by the measure and provides a relative potential reduction. Emission reduction impacts are based on public data and published values, which do not necessarily represent verification by appropriate authority. If information is available, the following indicators are used:
  - ↑ for increases
  - ↓ for decreases
  - ↕ 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, they are denoted as "to be determined" (tbd). 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. The following are considered in the study:
  - NOx – oxides of nitrogen
  - PM – particulate matter
  - SOx – sulfur oxides
  - HC - hydrocarbons
  - VOC – volatile organic compounds (relating to VOC cargo working losses)
  - energy consumption as a surrogate for energy efficiency

For each category, a summary table is presented for the measures in the group that includes the measure title, applicability, retrofit, applicable modes, and emission reduction indicators for NOx, PM, and SOx as applicable. More detailed descriptions, illustrations, and related information for each of the specific ECEEMs presented in the summary tables is provided in Annex 2. In addition to the above, the detailed descriptions in Annex 2 include the following elements for each measure:

- Maturity – denotes the status of ECEEM maturity (e.g., is it established and being applied, is it undergoing testing or is it in the development process, etc.).
- Limitations – known limitations associated with the ECEEM (e.g., temperature, mode, engine load, etc.)
- Implementation – identifies implementation methods that have been used with the specific ECEEM that resulted in the deployment of the measure and provides limited examples and includes:
  - business case – implementation is driven by a compelling business savings or advantage
  - market based measures (mbm) – implementation recognized in mbm such as incentive schemes
  - grants – implementation included grant funding
  - mitigation – implementation is driven by project mitigation requirements
  - voluntary – implementation is on a voluntary basis
  - regulation – implementation is driven by regulation

It should be noted that several of the emission control measures can potentially be used in combination; however, analysis is needed to determine the degree to which the potential emission reductions may (or may not) be additive. In addition, NOx and PM changes are typically inversely related due to their formation as a function of engine temperature and fuel to air ratio. An efficient or lean burn engine is typically hotter and creates more NOx and less PM and an inefficient engine or rich fuel/air mixture, which is typically cooler, reduces NOx but increases PM.

Equipment

The equipment category includes engine, boiler, and after-treatment technologies.

Engine technologies

Engine technologies reduce emissions or improve efficiencies associated with propulsion engines and auxiliary engines on board a ship. It is important to note that near the port area it is common for auxiliary engines to contribute total mass emissions roughly equal to, or more than, the propulsion engines. This is due to the fact that propulsion emissions associated with arrivals, shifts, and departures are limited in time and power applied, whereas auxiliary engines are operating the entire duration at relatively constant loads. Therefore, ECEEMs focused on propulsion may not have as significant an impact as initially presumed. A screening analysis should be performed to determine the potential impacts of any of the ECEEMs prior to implementation in order to ensure results will meet expectations. Table A2.1 provides a summary of the engine technologies highlighted in this study with further details provided below.

Table A2.1: Summary of Engine Technologies

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Engine Technologies								
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%↓	–

Repower

Vessel repowering means replacing an older, existing engine with a new cleaner and/or more efficient engine, for example removing a pre-2000 model year auxiliary engine (Tier 0) and replacing it with a Tier 2 or 3 engine. Repowering is a common method to reduce ship emissions in smaller domestic ships. Repowering involves operational evaluation to determine the performance of the new engine in the ship, engineering analysis of how to exchange engines and if any additional machinery elements need to be replaced, and a business case analysis to determine the recovery period of capital expenditures (CAPEX) due to operational expenditure (OPEX) savings, assuming there are fuel/oil consumption improvements and lower engine maintenance costs. For most ships, repowering would focus on auxiliary engine(s), which would be advantageous for reducing emissions in the port area. All of the auxiliary engines could be replaced, or only those needed to cover the at-berth and at-anchorage modes.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all port-related operational modes
Emissions	NOx and PM - dependent on the original and new engine selected and operating profile, case-by-case (cbc) dependent CO_2 – potential reductions and improved fuel economy, cbc
Maturity	established strategy, widely used by regulators, ports, etc.
Limitations	emission reduction and fuel consumption improvement potentials may be compromised if the new engine is of a higher power rating and the new operating profile uses more power;
Implementation	market-based-measures (*mbm)* – Commercial Marine Vessel Engine Repower Program, PANYNJ[1] *grants* – CARB Carl Moyer Program[2], Diesel Emission Reduction Act[3], NOx Fund[4], etc. *voluntary* – Houston/Galveston Ozone Nonattainment Area Tugboat and Towing Vessel Program[5] *regulation* - repowering to a higher tier concept is used in Regulation 13 of the 2008 NOx Technical Code *business case*

[1] www.northeastdiesel.org/pdf/CMVERP.pdf
[2] www.arb.ca.gov/msprog/moyer/moyer.htm
[3] www.epa.gov/cleandiesel/prgnational.htm
[4] www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/
[5] www.tceq.texas.gov/assets/public/implementation/air/sip/agreements/hga_tow_agreement.pdf

Remanufacture kits

Existing older engines can be rebuilt with approved marine remanufacture kits that bring the engine into a higher/cleaner IMO tier. The kits include installation instructions, specifications, limitations, and can contain "upgraded" engine components (piston rings, fuel injectors, etc.) that bring the existing engine into compliance with a higher tier (i.e., cleaner standard). Sometimes, kits may consist simply of engine tuning/calibration instructions to bring performance to a higher tier. It should be noted that remanufacture kits are not currently available for all commercial marine engine types; engine manufacturers can be queried on availability.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all port-related operational modes
Emissions	NOx and PM - dependent on the setting of original engine setting and engine setting with the remanufacture kit, cbc CO_2 – potential reductions and improved fuel use, cbc
Maturity	established strategy, used by regulators
Limitations	availability of approved remanufacture kits is limited
Implementation	*regulation* – IMO Regulation 13 *mitigation* – Staten Island Ferry Retrofits, PANYNJ[6] *grants* – typically from regional or national government programs such as Carl Moyer Program[7] and Diesel Emission Reduction Act[8] *business case*

[6] www.panynj.gov/press-room/press-item.cfm?headLine_id=328
[7] www.arb.ca.gov/msprog/moyer/moyer.htm
[8] www.epa.gov/cleandiesel/prgnational.htm

Propulsion engine derating

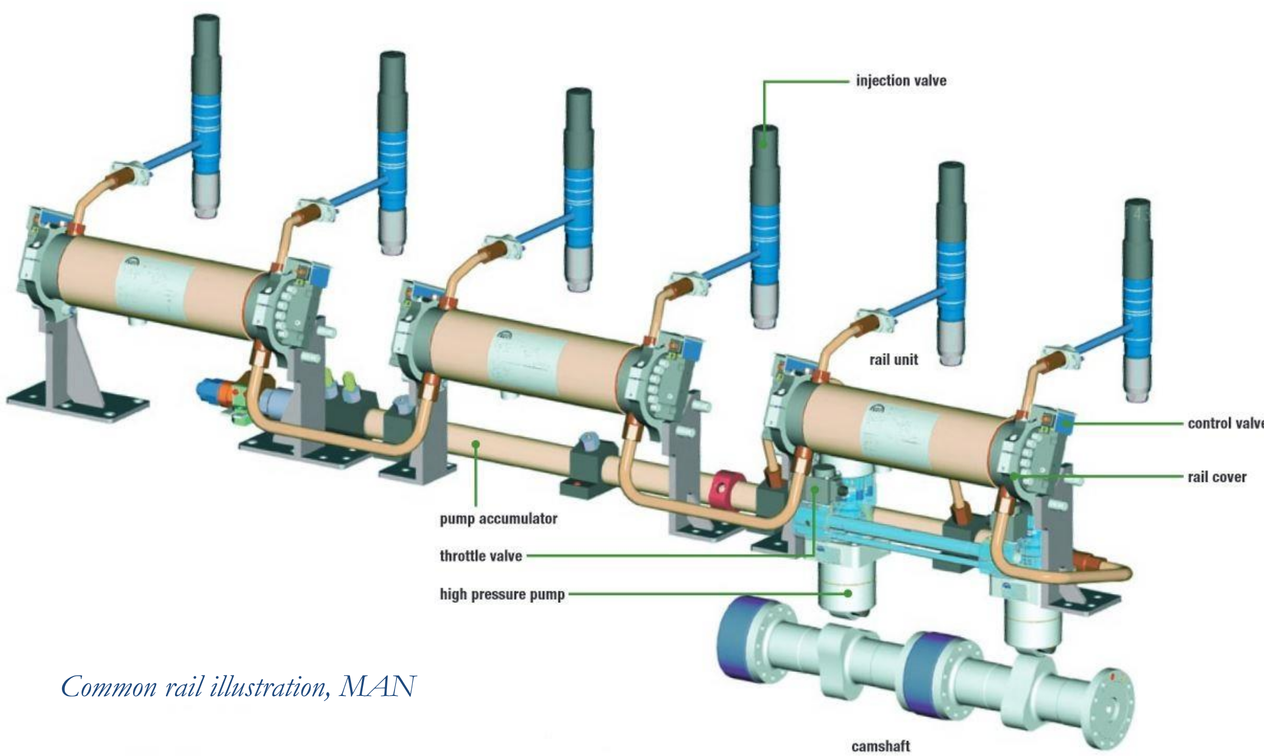
Engine derating takes advantage of the relationship between engine power and engine speed of slow speed engines such that lower fuel consumption can be achieved. NOx and SOx emissions are reduced as a co-benefit. An engine's maximum continuous rating (MCR) can be selected at any point in the power/speed layout field. One of the basic principles of the engine layout field is that the same maximum cylinder pressure is employed at all MCR points within the layout field, thus the reduced effective cylinder pressure at reduced power outputs in the field results in lower fuel consumption. The other principle of derating is that the lower MCR engine speeds allow for flexibility in selection of optimum propeller with a co-benefit of increased propulsion efficiency. While NOx on a gram/kilowatt-hour (g/kWh) basis increases, absolute NOx is reduced within the operational domain due to the greater offsetting due to decreased engine load compared to the engine's original configuration.

Applicability	propulsion engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	NOx – reduced, determined on cbc
	PM – potential reduction, dependent on cbc
	HC – to be determined (tbd)
	CO_2 – potential reductions due to improved fuel use, cbc
Maturity	established strategy, used in conjunction with slow steaming
Limitations	2-stroke engines
Implementation	*business case*

Common rail

Common rail[9] permits the continuous and load-independent control of fuel injection timing, injection pressure, and injection volume. The common rail system comprises pressurizing fuel pumps, fuel accumulators, and electronically controlled fuel injectors. The fuel pumps are driven by the camshaft and each pump and accumulator serve two cylinders. All system functions are controlled by the embedded control system on the engine. Due to the flexibility of the fuel injection process, NOx emissions, fuel consumption, and exhaust opacity can be improved by varying injection pressure when the fuel injection is started, relative to piston location in the cylinder. Thus, the system's main advantages are that the injection pressure can be kept at a sufficiently high level over the entire load range, which helps reduce NOx and smoke at low loads.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	NOx – up to 25% reduction
	PM – cbc dependent
	CO_2 – up 5% reduction
Maturity	established technology
Limitations	none identified
Implementation	*regulation* – option to meet IMO engine standards



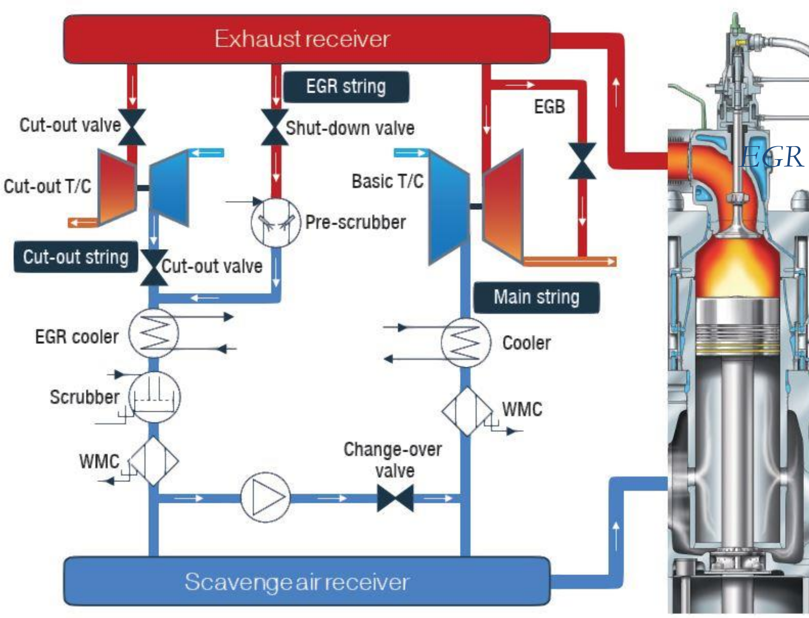
Common rail illustration, MAN

[9] marine.man.eu/docs/librariesprovider6/marine-broschures/common-rail-less-consumption.pdf?sfvrsn=2

Exhaust gas recirculation

In exhaust gas recirculation (EGR), engine exhaust gas is recirculated into the charged air after the turbocharger, thus reducing the oxygen content in the cylinder and increasing the specific heat capacity of the air. Both conditions cause lower combustion temperatures and thus reduce NOx emissions. EGR is sensitive to sulfur content of the fuel being combusted, as higher sulfur content can lead to soiling and component corrosion. Thus EGR works well with exhaust gas scrubber technologies that remove sulfur and PM from the exhaust gas. EGR systems can achieve NOx reductions typically up to 60%, although some systems are showing promise up to 80%. The focus of EGR development has been on two-stroke, slow speed engines; however, development for four-stroke medium speed engine EGR is under way. Both MAN and Wärtsilä offer retrofitable versions of EGR. The *Alexander Maersk* is one of the first large marine engines to be fitted with EGR.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	NOx – up to 60% reduction, potentially up to 80% reduction
	PM, HC, CO_2 – to be determined (tbd)
Maturity	established technology, increasingly used in ships
Limitations	none identified
Implementation	*regulation* – option to meet IMO engine standards
	business case

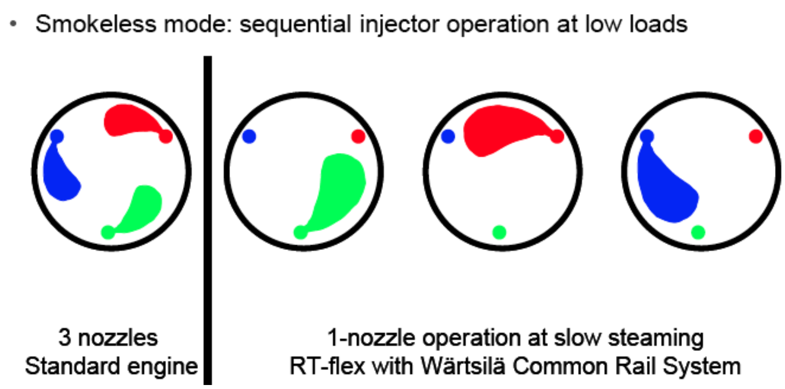


EGR illustration, MAN

Rotating fuel injector controls

Rotating fuel injector systems are found on some electronically controlled marine propulsion engines, specifically the Wärtsilä RT-Flex engine line, in conjunction with use of a common rail system. At low loads, which occur when complying with VSR, these systems reduce the fuel injection from three nozzles, as in a standard engine, to two or one nozzle(s) that are rotated one position with each firing in order to maintain even cylinder wall temperatures. The result is that reduced fuel amounts are injected into the cylinder at low loads when fuel demand decreases, which optimizes the combustion process in the cylinder. The system has been tested by Wärtsilä and shows promise for reducing both NOx and PM with the co-benefit of CO_2 and fuel consumption reductions.

Applicability	Wärtsilä RT Flex propulsion engines
Retrofitable	no
Operational modes	potential to reduce emissions during transition, and maneuvering
Emissions	NOx – up to 25% reduction PM – 20% to 40% reduction SOx, HC, and CO_2 – reduction is associated with reduced fuel consumption, cbc
Maturity	established technology, available on all RTFlex engines
Limitations	Wärtsilä RT-Flex engines only; it should be noted that Wärtsilä states that the emission reductions for the combination of common rail and rotating fuel injector systems are not additive.
Implementation	*business case*



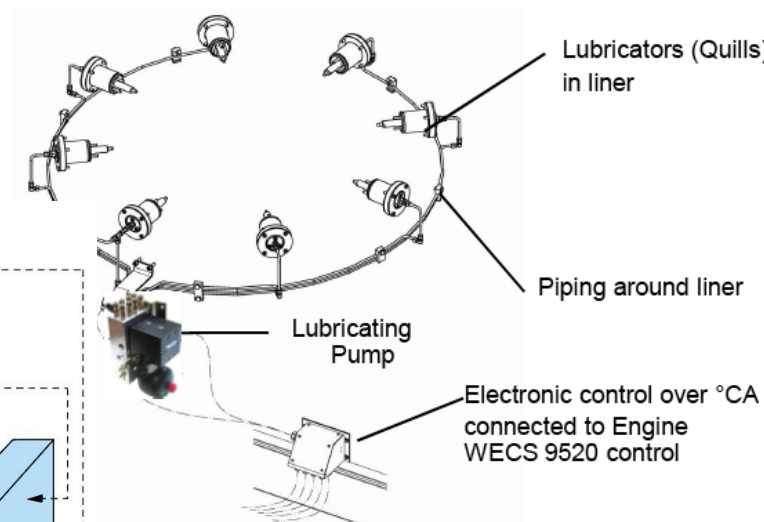
RT-Flex engine low-load nozzle cutout, Wärtsilä

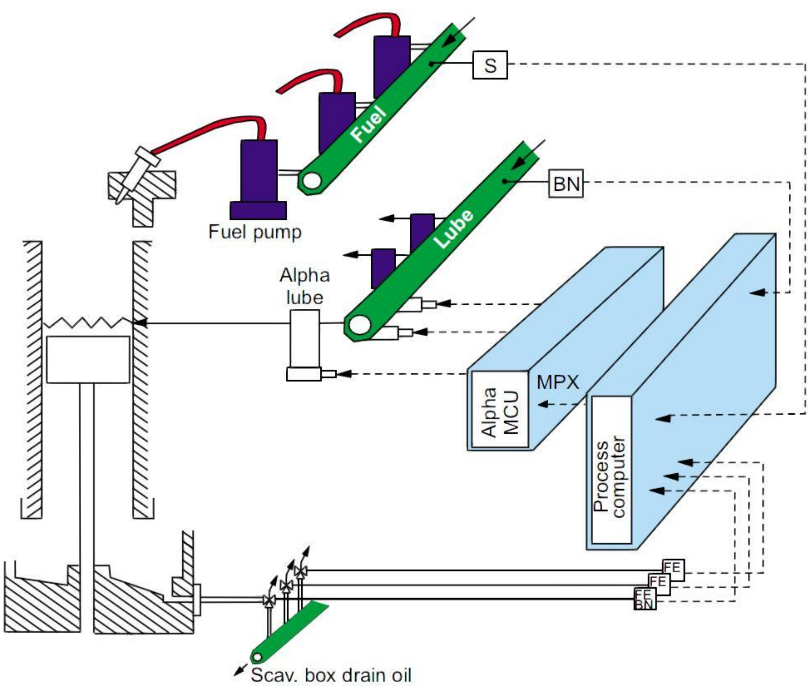
Electronically controlled lubrication systems

Electronically controlled lubrication systems developed by both MAN and Wärtsilä provide for more efficient cylinder lubrication, reducing the amount of lubrication needed and improving the combustion cycle timing of lubrication oil injection/dosing. The injection rate can be adjusted automatically or manually as load changes, during startup and stoppage, at reduced loads in VSR, based on varying fuel oil sulfur content, as cylinder liner temperature levels change, etc. The systems have electronic controls that can be accessed by the ship's on-board engineering computers. In return, emissions associated with lubrication oil are reduced with the co-benefit of reduced maintenance costs. MAN has the Alpha Lubrication System and Wärtsilä has the Pulse Lubrication System.

Applicability	propulsion engines
Retrofitable	yes
Operational modes	potential to reduce emissions during transition, and maneuvering
Emissions	PM and HC – 20% to 30% reduction
	Lube oil consumption – reduced 15% to 35%
Maturity	established technology
Limitations	none identified
Implementation	*business case*

Pulse lubrication system illustration, Wärtsilä



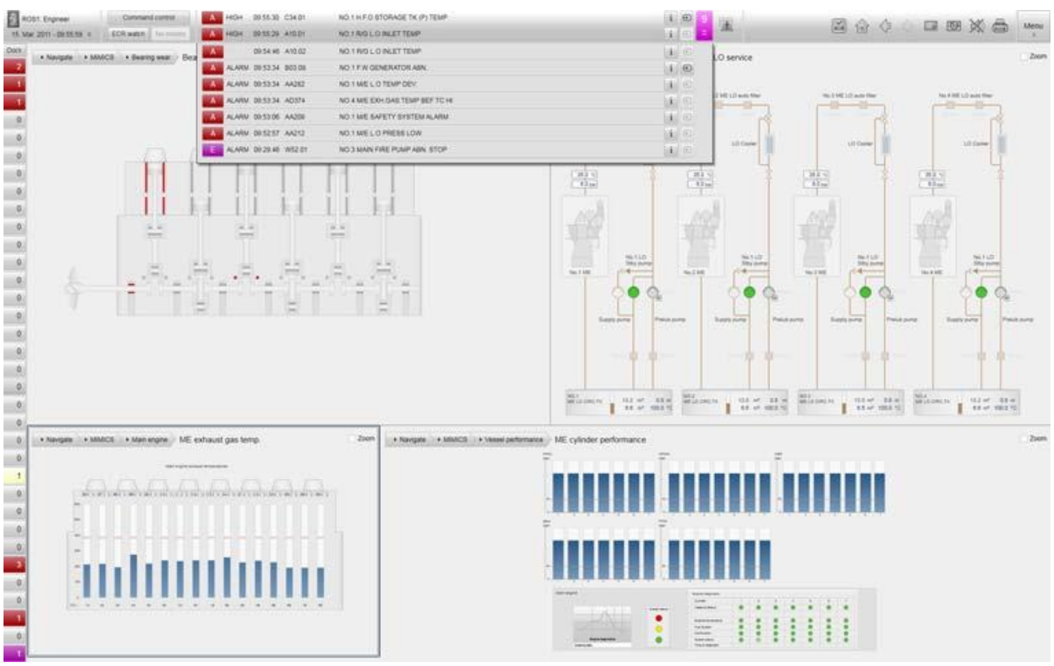


Alpha lube system illustration, MAN

Automated engine monitoring/control systems

Automated engine monitoring and control systems[10] that are typically found on electronically controlled engines provide for automatic tuning or adjustment of engine parameters during different operational conditions and engine loads. These systems can control turbocharger shutoff, fuel system equipment, engine fuel efficiency, adjust compression ratio, adjust exhaust valve timing, and adjust fuel injection timing, etc. Engines with these systems can be set to reduce peak combustion temperatures to reduce NOx (low NOx mode) and can include low load tuning packages. Dynamic tuning of the engine allows for efficient response to varying injection pressures and timing, which can be optimized for fuel and/or NOx over all engine loads.

Applicability	auxiliary and propulsion engines
Retrofitable	no
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 20% reduction PM – tbd, potential increase with lower NOx SOx – up to 3% reduction CO_2 – up to 5% reduction
Maturity	established technology, increasing use for energy management
Limitations	best with electronically controlled engines
Implementation	*business case*



Control palette example, Kongsberg Maritime

[10] www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/E1C7040DC299F88CC12570A400338307?OpenDocument

Valve, nozzle, and engine timing NOx optimization

NOx optimized valves, nozzles, and engine timing[11] adjust fuel injection with the number and size of spray holes along with the timing of the injection, which are all influencing factors on NOx formation. Low NOx valves/nozzles/timing optimization reduces NOx at the expense of PM and CO_2 emissions as well as a fuel consumption penalty. Fuel valve and nozzle optimization along with timing control to precisely time the amount of fuel injected and the time at which the fuel is injected, as the benefits are obtained in the control of the fuel injection. Indecently controlled exhaust valve timing adds to the benefit by ensuring more optimum air supply to the cylinders at any load condition.

Applicability	propulsion engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	NOx, PM, HC – reductions cbc
	CO_2 – up to 5% reduction
Maturity	established strategy
Limitations	none identified
Implementation	*business case*
	regulation – option to meet engine standards

[11] www.flamemarine.com/files/MANBW.pdf

Slide valves

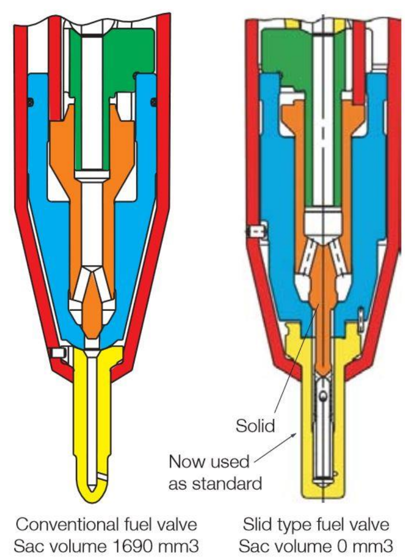
Slide valves are specific to MAN slow speed engines and are addressing a condition called "sac-hole effect" where standard valves have a void between the actual valve and the discharge point into the cylinder. Fuel that is injected into the cylinder is combusted while the fuel left in the sac-hole is burned at a suboptimal time within the combustion cycle, which is referred to as the "sac-hole effect."

Engine manufacturers including MAN and Wärtsilä have been developing alternative solutions including slide valves, optimized atomizer geometries, shielding of the orifices, and emptying of the sac-hole upon completion of injection.

MAN's solution has been the development of slide valves, which reduce the volume of the sac hole (shown in red) and are theoretically more efficient than standard designs. Slide valves, like most fuel valves, can be optimized for fuel consumption, NOx, or an operational load range. Data on the emission reduction potentials of slide valves at low loads and across the E3 duty cycle were evaluated through a joint project between Port of Los Angeles, Port of Long Beach, Mitsui Heavy Industries, and MAN Turbo and Diesel in 2012[12]. The goal of this test was to determine if slide valves reduce pollutants in main engines at low loads, simulating ships traveling within the ship speed reduction or VSR program zone.

Applicability	2-stroke MAN propulsion engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	NOx – increased over conventional valves at low loads, dependent on operational load profile PM and HC – significantly reduced, dependent on operational load profile CO_2 – dependent on operational load profile
Maturity	established technology, on all 2004 and newer MAN 2 –stroke engines
Limitations	MAN engines only
Implementation	*regulation* – option to meet IMO engine standards *business case* – improve fuel consumption

Conventional and slide valve configurations, MAN

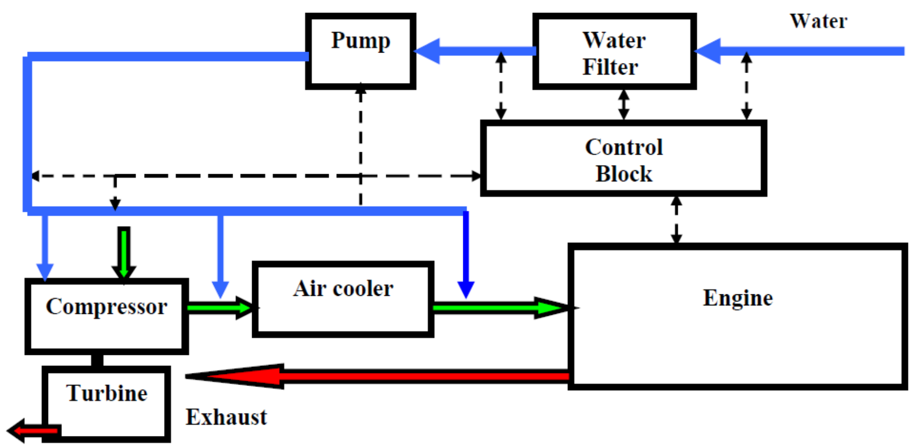


12 www.cleanairactionplan.org/civica/filebank/blobdload.asp?BlobID=2571

Continuous water injection

Continuous Water Injection (CWI)[13] involves the injection of high quality water at relatively low pressures into the hot air stream after the turbochargers. CWI can be installed in either two or four stroke engines as retrofits. CWI operates on the principle that peak combustion temperatures and reduced oxygen results in NOx reductions during the combustion cycle. The potential emission reductions with CWI are up to 30% for NOx and 5 – 18% PM. Companies such as M.A. Turbo Engine, LTD offer retrofit-able CWI.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 30% reduction PM – up to 18% reduction
Maturity	established technology, limited use onboard ships
Limitations	the need for water filtering system and maintenance on the water filters by crew.
Implementation	*regulation* – option to meet engine standards *business case*



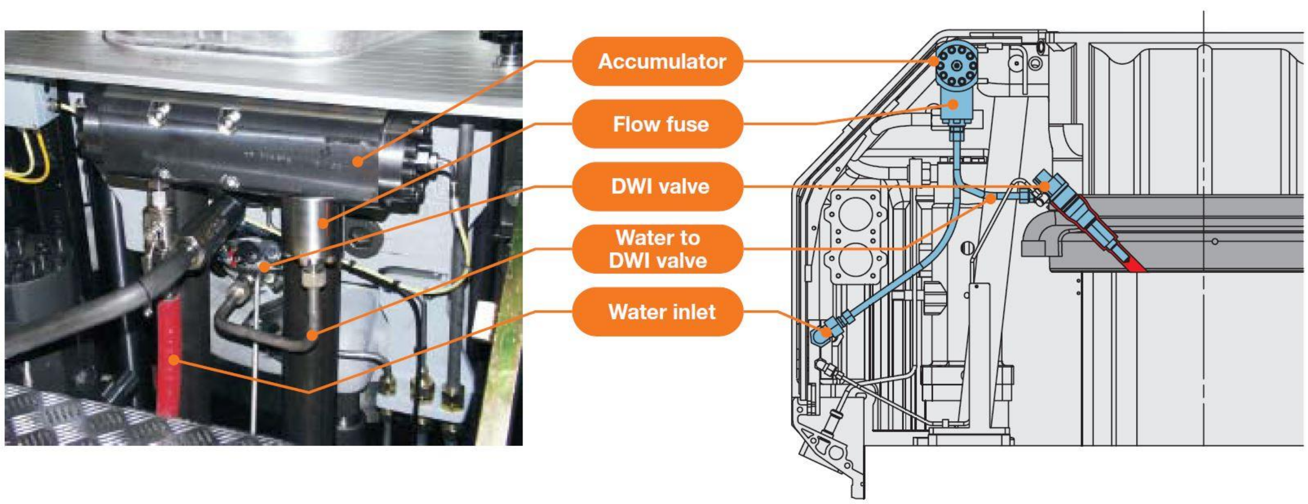
Continuous water injection system schematic

[13] www2.mst.dk/udgiv/publications/2011/08/978-87-92779-30-4.pdf

Direct water injection

In Direct Water Injection (DWI)[14], high pressure water is injected directly into the cylinder prior to the injection of fuel, with the purpose of cooling the cylinder prior to the next combustion event. The injection system can work on either common rail or conventional engine setups. Low sulfur fuels below 1.5% sulfur are required. DWI can achieve NOx reductions of up to 50% and the system works at all load ranges. Both MAN and Wärtsilä offer retrofitable versions of DWI.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions during all modes
Emissions	NOx – up to 50% reduction
	PM – tbd
Maturity	established technology, limited use onboard ships
Limitations	must use low sulfur fuel (<1.5%)
Implementation	*business case*



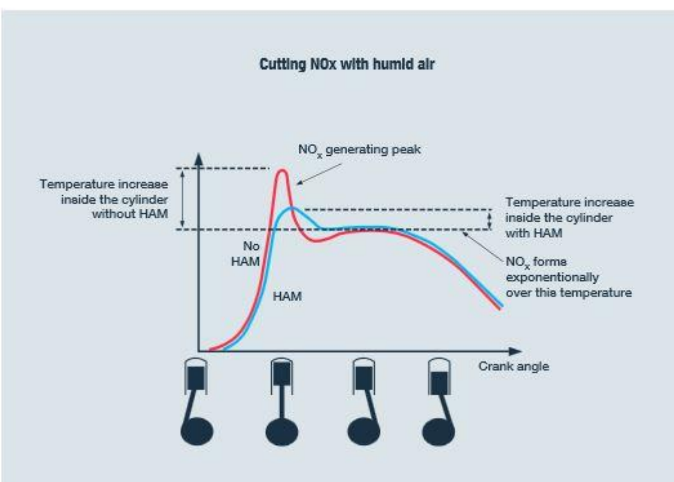
Direct water injection components, Wärtsilä

[14] http://www.marad.dot.gov/documents/NMREC_E_and_E_Workshop_-_broman.pdf

Scavenging air moistening/humid air motor

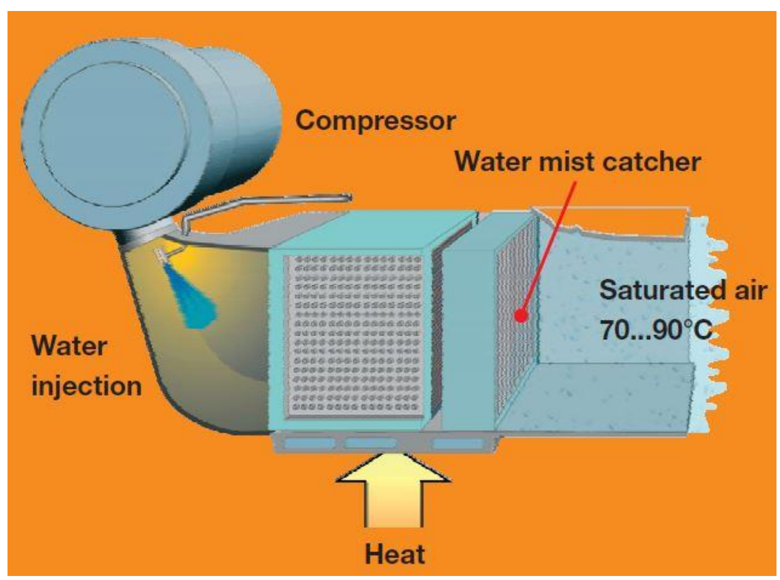
The scavenging air moistening (SAM), for large two-stroke engines, and humid air motor (HAM)[15], for four-stroke engines, both humidify hot charged air from the turbochargers' compressor, allowing it to absorb more heat, while at the same time reducing the oxygen content of the air. The humidified air is generated through heating seawater (unlike CWI) through a heat exchanger in the humidifier and then interfacing the humid air with the charged air from the compressor. The result is a lower combustion temperature in the cylinder, and thus NOx can be significantly reduced. Co-benefits from the system include: low operational costs (no reducing agent required), good engine performance via lower thermal loads, and the system requires no additional maintenance. The trade-off is that HC and PM are increased due to cooler combustion temperatures, and there is a fuel consumption penalty of approximately 3%. Both MAN and Wärtsilä offer retrofitable versions of SAM and HAM.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions during all modes
Emissions	NOx – up to 65% reduction
	PM – increase, cbc
	HC – increased, cbc
Maturity	established technology, limited use on board ships
Limitations	CO2 – ~3% penalty
Implementation	*regulation* – option to meet IMO engine standards
	business case



With the HAM system, the turbocharger charge air is saturated with sea water vapour before it enters the charge air channels and engine combustion chambers. As a result, the temperature peaks in the combustion process are lowered, and the formation of NO_x is reduced

Humid air NOx reduction by piston position illustration, MAN



Wetpac humidification system, Wärtsilä

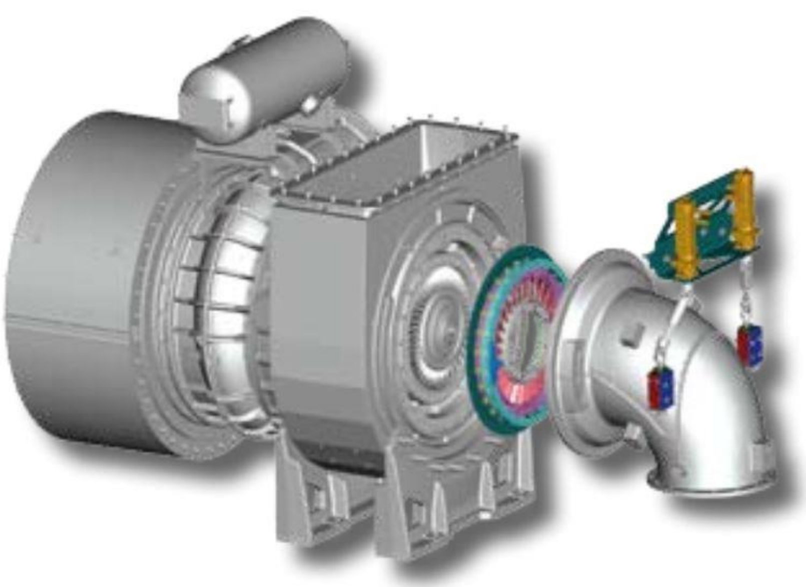
15 www.mandiesel.com.cn/files/news/filesof15964/DF_2010-4.pdf

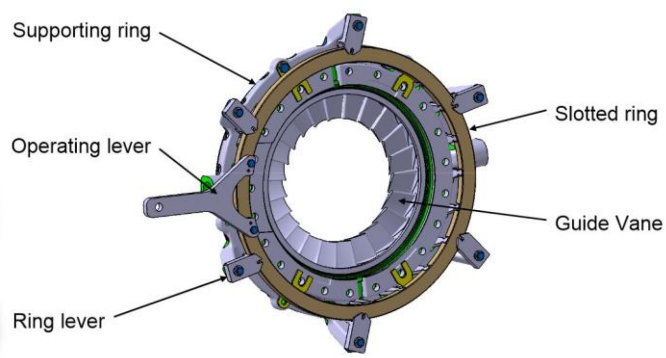
High efficiency turbochargers

Improvement in turbocharger technology is resulting in higher turbocharger efficiencies[16] in a wider load range compared to traditional turbochargers, especially at low engine loads at low ship speeds. The high efficiency turbochargers feature variable or controllable speeds or variable turbine geometry. This allows for variations in the amount of air compressed by the compressor, thus improving the combustion efficiency. The system brings turbocharger efficiency up to 75% during low loads and allows for variable turbocharging, which in turn improves the engine's fuel consumption, lowers NOx emissions, and reduces smoke. These enhanced turbochargers work well with other systems such as EGR and strategies such as slow steaming. High efficiency turbochargers are being designed and produced by ABB, MAN, Wärtsilä, and others.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions during all modes
Emissions	NOx and PM – reduction, cbc
	SOx, HC – cbc
	CO_2 – reduction in fuel consumption, cbc
Maturity	established technology, increased use related to fuel savings
Limitations	none identified
Implementation	*business case*

High efficiency turbocharger elements, MAN





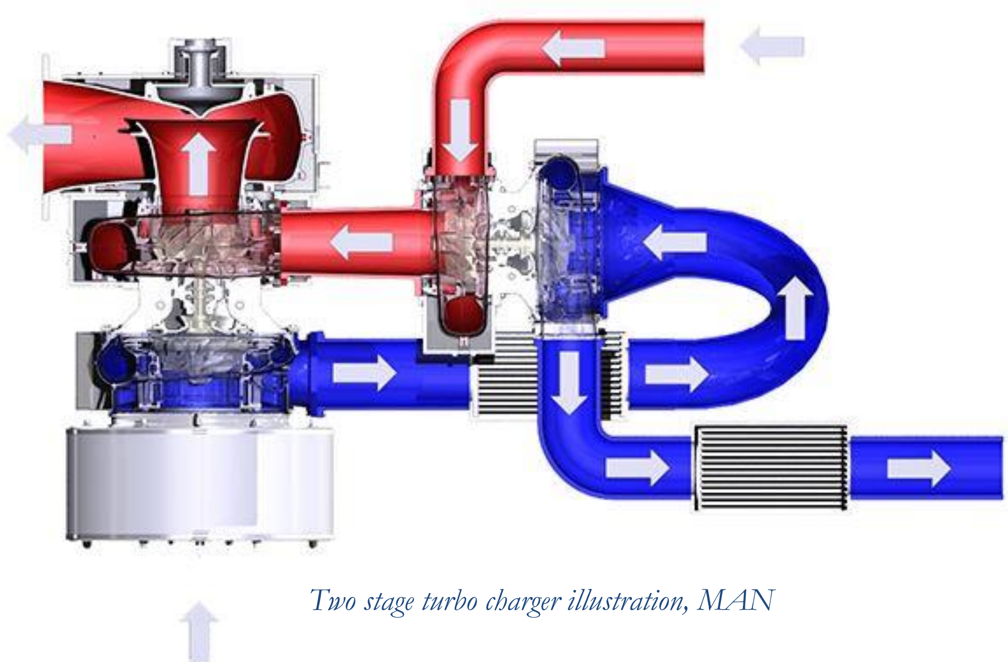
Variable van illustration, ABB

[16] www.mandieselturbo.com/files/news/filesof11812/Technology%20for%20ecology.pdf

Two stage turbocharging

High pressure, two stage turbocharging[17] combines the use of low pressure and high pressure turbochargers in series to generate increased air pressure, airflow, and more efficient turbocharging effect. Efficiency achieved with two stage turbocharging is up to 75%, which is extremely high and increases the energy density of the engine output by 10%. At the same time, NOx and CO_2 emissions, as well as fuel consumption are reduced. Both MAN, Wärtsilä/ABB, and other turbocharger companies offer retrofitable versions of two stage turbocharger solutions.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 40% reduction
	PM – tbd
	CO_2 – reduced, cbc
Maturity	established technology
Limitations	none identified
Implementation	*business case*



Two stage turbo charger illustration, MAN

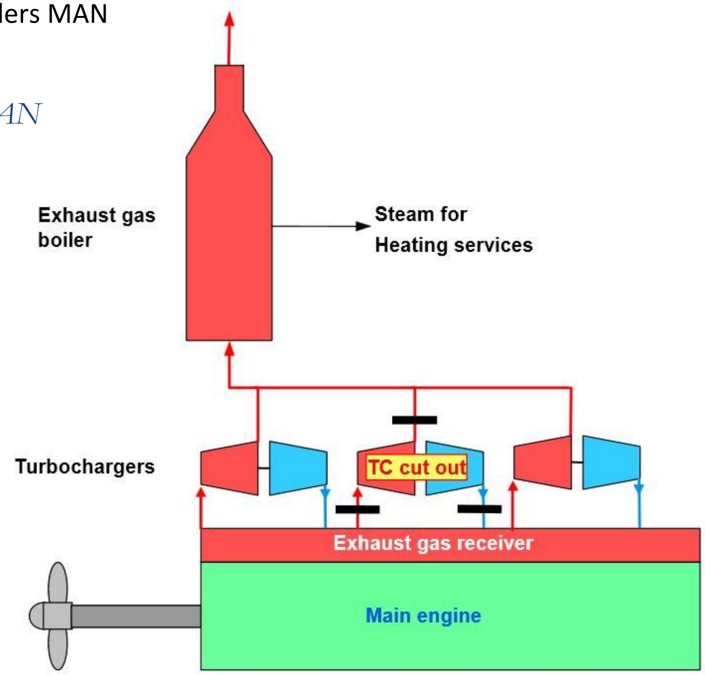
[17] turbocharger.man.eu/products/tcx; turbocharger.man.eu/technologies/2-stage-turbocharging

Turbocharger cut-off

Turbocharger cut-off systems[18] lower fuel oil consumption and improve propulsion engine performance during low load operation. Turbocharger cut-off can be achieved by two methods: installing swing gate valves on the turbocharger air outlet and exhaust inlet or installing blinding plates on the turbocharger air outlet, turbocharger exhaust gas inlet and outlet. By installing a turbocharger cut-off system with swing gates and controls, the ship operator has the option of disabling one of the turbochargers for low load operation. Fuel saving can be up to 7 grams/kilowatt-hr (g/kWh).

Applicability	propulsion engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	NOx – up to 40% reduction
	PM – tbd
	CO_2 – reduced fuel consumption, cbc
Maturity	established strategy
Limitations	none identified
Implementation	*business case* – over 200 orders MAN

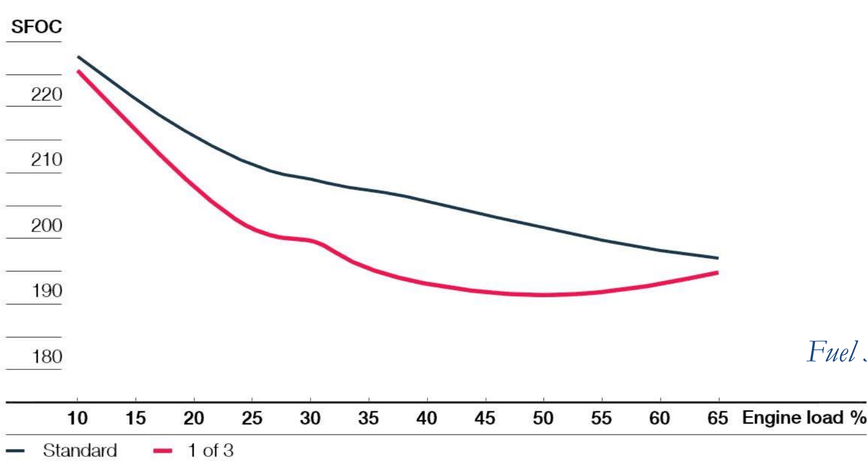
Turbocharger cutout illustration, MAN



Obtainable load range after one turbocharger cut-out

No. of TC	1 of 2	2 of 3	3 of 4
Load range	10-40% MCR	10-66% MCR	10-74% MCR

SFOC reductions recorded in service with a 12K98 MC



Fuel savings across engine load, MAN

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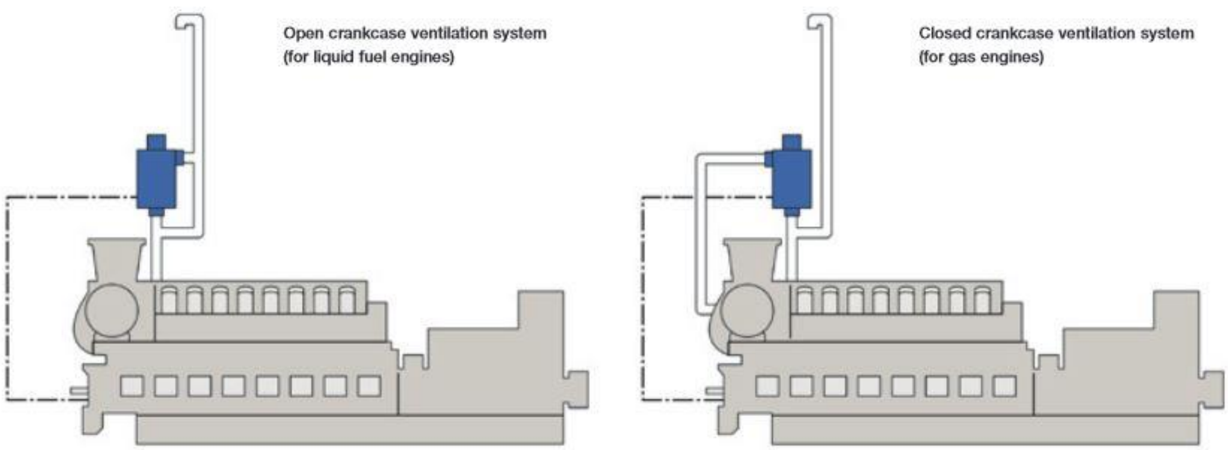
[18] www.mandieselturbo.com/files/news/filesof11363/1-16%20Turbocharger_Cut-Out.pdf; mari-tech.org/images/mari-tech2010/01-abb%20turbocharger%20presentation%20mari-tech%202010.pdf

Crankcase VOC leakage

Manufacturers are beginning to address the emissions associated with an engine's crankcase[19]. Currently crankcase designs allow VOC emissions to be ventilated out of the crankcase and released to the atmosphere. Oil mist separators are being used for cleaning crankcase gas instead of directly venting to the atmosphere. Recovered oil can be recirculated to the oil sump, which reduces oil consumption and oil filter maintenance intervals are extended. There are systems designed for both liquid fuel engines and for natural gas engines. For gas engines, the cleaned air can be redirected to the engine turbo chargers, which enhances engine performance and safeguards the engine, since it eliminates the risk of turbocharger fouling or oil accumulation in the intercooler.

Applicability	propulsion engines
Retrofitable	yes
Operational modes	potential to reduce emissions during sea, transition, and maneuvering
Emissions	PM – tbd
	HC – 100% for gas engines; tbd for liquid fueled engines
Maturity	established technology
Limitations	none identified
Implementation	*business case*



Crankcase VOC recovery, Alfa Laval

[19] local.alfalaval.com/de-de/wichtige-industrien/motoren/Oelnebenabscheidung/Documents/Defender500%20Englisch.pdf

Boiler technologies

Boiler technologies reduce emissions or improve efficiencies associated with steam plants and auxiliary boilers on board a ship. Table A2.2 provides a summary of the boiler technologies highlighted in this study with further details for each provided below.

Table A2.2: Summary of Boiler Technologies

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Boiler Technologies								
High Efficiency Boilers	B	Y	All	↓ cbc	tbd	–	–	↓ cbc
Auxiliary Engine Wast Heat Recovery	B	Y	All	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

Efficiency improvements related to boiler systems such as propulsion engine heat recovery can reduce CO_2 up to 12%. However, as stated in Section 1, CO_2 generation from most ships is typically a fraction of the total ship CO_2 emissions during the life of the ship. Since the propulsion engine will be transitioning to variable low loads and ultimately off while at-berth and at-anchorage for all non-diesel-electric configured ships, advanced heat waste recovery units could have minimal impact in the port area, depending on the geographical parameters of the port area modes.

High Efficiency Boilers

Boiler efficiency improvements[20] can provide co-benefits of fuel consumption and emissions. Boiler manufacturers continue to develop improvements in materials, thermal design, optimization of flue gas oxygen content, burner design, control systems, etc. These improvements can lead to efficiency increases of 90%, depending on boiler load conditions, which is on average 6% above typical boilers in similar capacity ranges. The result is less fuel consumption and lower NOx and CO_2 emissions.

Applicability	boilers
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx, CO_2 – reduction, cbc PM – tbd
Maturity	established technology
Limitations	none identified
Implementation	*business case*

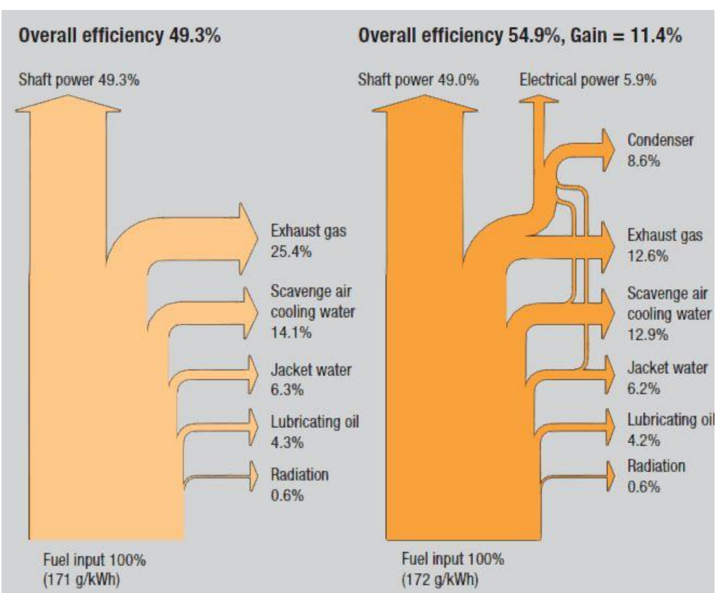
[20] www.alfalaval.com/industries/marine/steamandheatgeneration/boilers/aalborgos-tci/pages/aalborg-os-tci.aspx

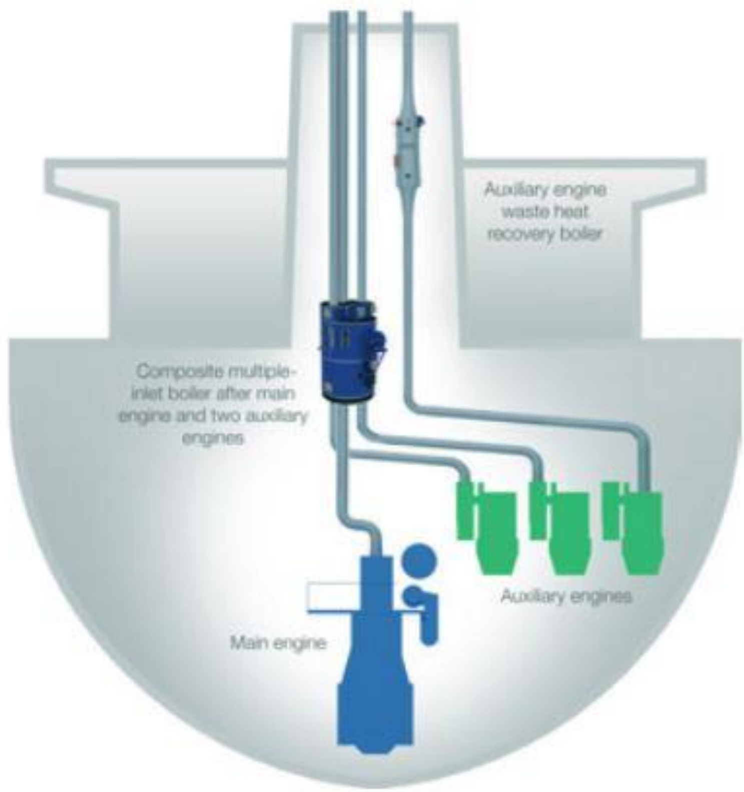
Auxiliary Engine Waste Heat Recovery

The concept of waste heat recovery, which has been a focus of propulsion engine design, is being expanded to auxiliary engine[21] applications. Waste heat recovery from auxiliary engines can provide steam needed while the ship is in port and can supplement main engine systems while at sea. A waste heat recovery boiler is fitted to the auxiliary engine exhaust stack and provides steam for direct use by the ship's steam consumers. The systems work best on ships that have high at-berth house loads and where a range of steam-driven processes can be supplied, such as cruise ships.

Applicability	waste heat converted to steam so auxiliary boilers are not utilized
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	Since the aux. boiler is not operated, all combustion emissions are reduced, including NOx, PM, SOx, VOC and CO_2. The specific reductions depend on the size and loads of the auxiliary boilers that are not being used.
Maturity	established technology
Limitations	does not work when connected to shore power; temperature
Implementation	*business case*

Comparison between waste heat recovery and high efficiency waste heat recovery, Wärtsilä





Auxiliary engine heat recovery, Alfa Laval

[21] www.alfalaval.com/industries/marine/wasteheatrecovery/Documents/WHR.pdf

After-Treatment Technologies

After-treatment technologies reduce exhaust emissions from propulsion and auxiliary engines as well as boilers/steam plants by treating the exhaust emissions of these sources. After-treatment technologies are not integral to the workings of the engine or boilers they are treating. Most after-treatment technologies have their origins in reducing emissions associated with land-based stationary sources, which have been adapted to land-based mobile sources and later "marinized" for use on board ships. Currently there are two primary after-treatment technologies being deployed on ships: selective catalytic reduction (SCR) and exhaust gas scrubbers (EGS). SCR significantly reduces NOx while scrubbers significantly reduce SOx and PM. Table A2.3 provides a summary of the scrubber technologies highlighted in this study with further details for each provided below.

Table A2.3: Summary of After-Treatment Technologies

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
After-Treatment Technologies								
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

Selective Catalytic Reduction

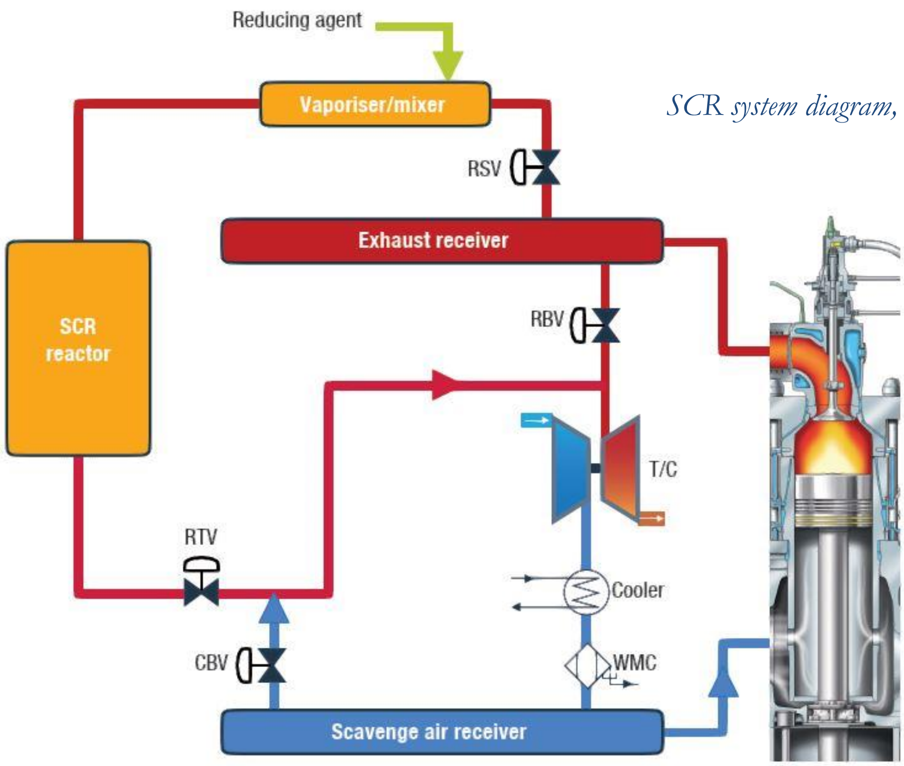
Selective catalytic reduction[22] (SCR) provides tremendous potential for reducing NOx emissions from marine diesel engines. There are several companies marketing SCR solutions. Exhaust gases are treated with ammonia or urea and fed through a catalytic converter at temperatures typically greater than 250^o Celsius (°C). A selective chemical reaction takes place in the catalyst that breaks down NOx to nitrogen and water. The limiting factor for the effectiveness of SCR systems is temperature. If the exhaust temperature is too low, the urea or ammonia forms hydrogen sulfate, which gradually blocks, or "plugs," the catalytic converter. With regard to engine operations in the port area, engine temperatures decrease throughout the transition and maneuvering modes and it is likely that exhaust temperatures could be below the 250^o C level. Further, if combined with scrubber or waste heat recovery systems, the exhaust will be even more likely to drop below the minimum required temperature. This issue is remedied by re-heating or pre-heating the exhaust prior to entry into the SCR unit. SCR catalysts are matched to the fuel to be burned in the ship and can work with all sulfur content ranges. Sulfur is not a poison to conventional marine SCR catalysts, which are made of vanadium; however, high sulfur content fuels can reduce the efficacy of an SCR at low loads due to ammonium bisulphate condensation, which clogs the catalyst matrix. Again a pre-heater is needed for low load operations, which are prevalent in the port area.

The vast majority of SCR systems installed on **over 500 marine ships**[23] over the last 30 years have been on 4-stroke engines, although there have been limited applications with large 2-stroke main/propulsion engines. SCR systems can have significant space requirements, which must also include urea system storage. Urea is typically used on ship SCR applications and is consumed at <7% of the fuel consumption rate. Procurement of urea must to be added to the ship's resupply list. SCR systems have the potential to reduce NOx emissions from 80 to 98%. MAN, Wärtsilä, and several other SCR providers offer retrofitable versions SCR systems for ships.

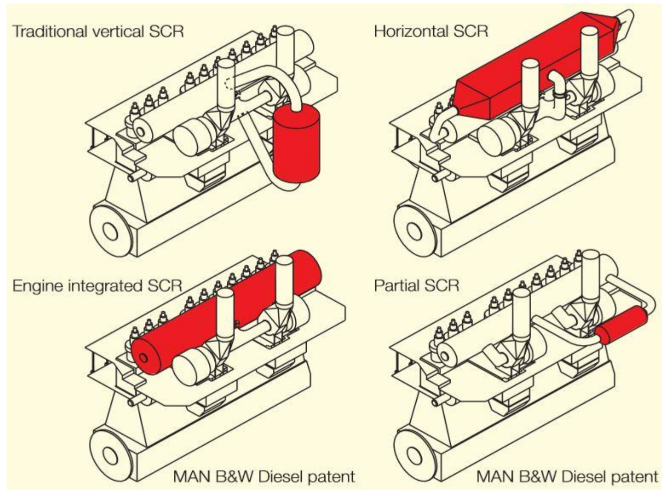
Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – 80% to 95% reduction
	CO_2 – minor increase over conventional engine due to pre-heating need for low load operations
Maturity	established technology, limited use on board ships
Limitations	needs pre-heating for low load operations; requires urea; size of the SCR system compared to available space on board

[22] www.wartsila.com/cs/static/flash/studio/assets/content/ss4/wartsila-nox-reducer-scr-system.pdf
[23] www.iaccsea.com/

Implementation *regulation* – IMO NOx Tier 3
grants – Norwegian NOx Fund[24]
mitigation – PANYNJ and USACE[25]
mbm – Swedish differentiated port and fairway dues[26], Environmental Ship Index[27], Clean Shipping Index[28]



SCR system diagram, MAN



SCR system diagram and SCR placement options, MAN

[24] www.nho.no/Prosjekter-og-programmer/NOx-fondet/The-NOx-fund/
[25] news.thomasnet.com/companystory/johnson-matthey-to-provide-scr-systems-for-the-john-a-noble-staten-island-ferry-to-significantly-reduce-nox-emissions-from-its-diesel-engines-845381
[26] www.sjofartsverket.se/en/About-us/Finances/Fairway-Dues/
[27] esi.wpci.nl/Public/Home
[28] www.cleanshippingindex.com/

Exhaust Gas Scrubbers - Wet

Exhaust gas scrubbers remove sulfur and PM from the engine exhaust stream through a wet or dry interface. One of the major benefits of exhaust gas cleaning are that the ship can use high sulfur fuels and meet IMO and Emissions Control Area (ECA) requirements. There are several companies marketing scrubber solutions[29]. There are two types of scrubbers: wet and dry. Wet scrubbers are the most common and utilize an open loop, closed loop, or hybrid configuration. Open loop systems utilize sea water, closed loop systems utilize freshwater, and hybrid systems can utilize either, depending on operational mode. There is uncertainty if ports will allow scrubber effluent discharges while in confined waters within the port area. Hybrid systems provide the highest operational flexibility.

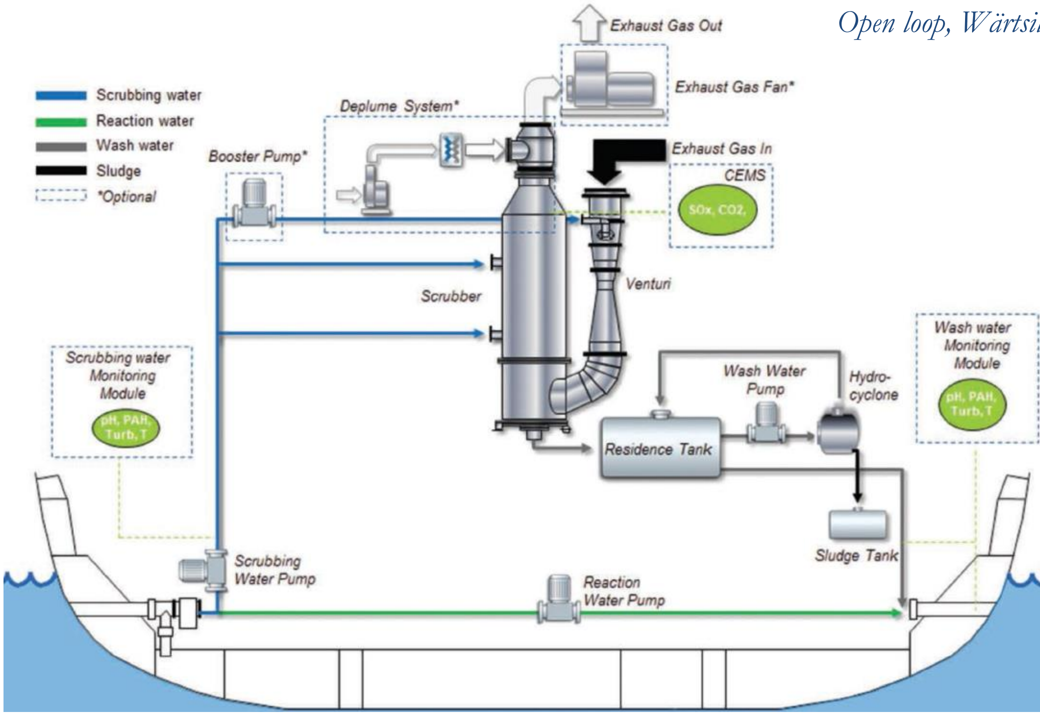
Open loop wet scrubber systems spray the exhaust gases with seawater (wash water) which causes the SOx to react with the wash water to form sulfuric acid. The sulfuric acid is then neutralized by the natural alkalinity of seawater. Seawater is fed into the system to be used as wash water, which is then treated after being used in the scrubber, and the treated wash water, meeting effluent IMO requirements, is discharged overboard. Closed loop scrubber systems[30] utilize fresh water that is generated on board and mixed with caustic soda (NaOH) as wash water. SOx is neutralized by the solution. Closed loop wet scrubber systems can operate in zero discharge mode, which requires a holding tank where the effluent can be periodically discharged for proper handling and disposal landside. Scrubber systems can be designed for treating both propulsion and auxiliary engines.

There are approximately 30 to 40 ships operating with wet scrubber systems and with the 2015 IMO sulfur requirements of 0.1% sulfur in the ECA and SECA, orders and installations have rapidly increased over the past two years to well over 300 globally[31].

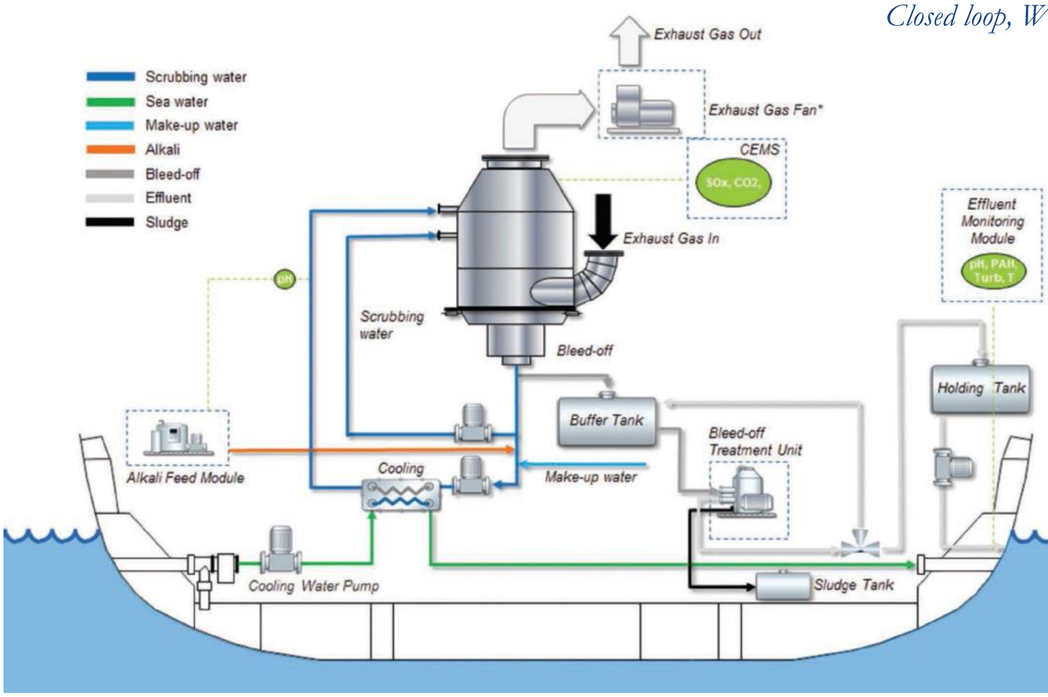
Applicability	propulsion and auxiliary engines
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 5% reduction
	PM – up to 80% reduction
	SOx – up to 98% reduction
	CO_2 – minor increase due to system energy requirements
Maturity	established technology
Limitations	closed loop systems need caustic soda; disposal of sludge; disposal of effluent if operated on zero discharge; size of scrubber system compared to available space; slight increase in fuel consumption
Implementation	*regulation* – IMO fuel sulfur requirements in ECA and SECA

[29] AEC Maritime, Alfa Laval, Belco Dupont, Clean Marine, CROcean, Green Tech Marine, MAN, MES, Saacke,
[30] www.wartsila.com/en/emissions-reduction/exhaust-gas-technology-hamworthy/scrubber; www.dupont.com/products-and-services/consulting-services-process-technologies/brands/sustainable-solutions/sub-brands/clean-technologies/products/belco-clean-air/sub-products/belco-r-marine-scrubber-details.html; www.marad.dot.gov/documents/Exhaust_Gas_Cleaning_Systems_Guide.PDF
[31] Personal conversation with Don Gregory, Director, Exhaust Gas Cleaning Systems Association, 2014

Open loop, Wärtsilä



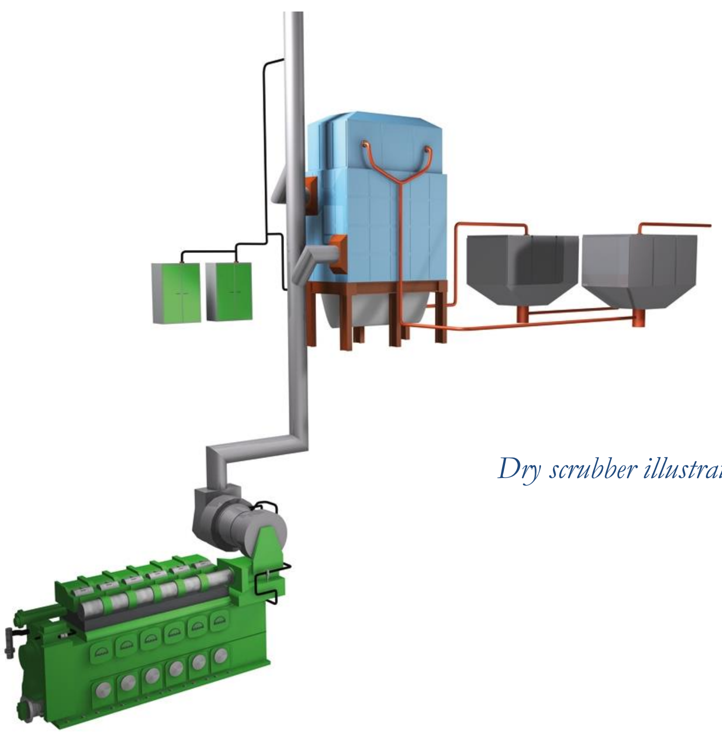
Closed loop, Wärtsilä



Exhaust Gas Scrubbers - Dry

Dry scrubbers[32] operate with an absorber utilizing granulated pellets of lime ($Ca(OH)_2$). The hot exhaust gases react with the lime to produce gypsum ($CaSO_4$). The lime pellets are moved through the system at an engine load-dependent rate, and the gypsum is removed from the system and stored for removal from the ship. The gypsum pellets are typically sent to land-based power generation stations where they are reused in dry scrubbers. An SCR can be located downstream of the dry scrubber. The benefit over a wet scrubber is that the exhaust gas is not cooled by interaction with water and is therefore more effective in combination with SCR.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 5% reduction
	PM – up to 80% reduction
	SOx – up to 98% reduction
	CO_2 – minor increase due to system energy requirements
Maturity	established technology, limited use on board ships
Limitations	storage volume needed on board for both the granulated pellets needed for scrubber and the gypsum by-product; slight fuel consumption increase
Implementation	*regulation* – IMO fuel sulfur requirements in ECA and SECA



Dry scrubber illustration, MAN

[32] www.mandieselturbo.com/files/news/filesof15107/07092010_Improved%20customer%20solutions%20(3).pdf

Shore/Barge Based-Aftertreatment Systems

Shore or barge based after-treatment systems[33] are currently being developed and evaluated at the Port of Long Beach and Port of Los Angeles. These systems are based on the concept of collecting ship stack emissions using special ducting and treating the emissions with shore/barge-sited emission control units that include exhaust gas scrubbing in combination with SCR. Similar systems were first attempted at the berth (shore-side), although terminal operations need to be considered when siting on a terminal. In addition to the ship emissions, emissions from the units that power the emission reduction equipment and the barge are also treated in the system. These systems aim to reduce ship emissions to levels on par or better than on-shore power (when considering grid-generated emissions). The systems are currently in final testing and are being evaluated by CARB. The barge systems are moved into position on the water-side of the ship and the ducting mechanism is connected remotely to the ship's auxiliary and boiler stacks. The advantage of this system is that it doesn't require expensive modifications to the ship, as is required with on-shore power systems. There are potential use limitations in narrow channels. Barge systems are capable of treating emissions when ships are at anchorage as well as at berth. The scrubber and SCR technologies utilized by these systems are already established methods for reducing ship emissions. The key evaluation effort is to demonstrate and quantify capture efficiency and effectiveness at a wide variety of exhaust loads.

Applicability	auxiliary engines and boilers
Retrofitable	na, system is independent of vessel
Operational modes	potential to reduce emissions at-berth and at-anchorage.
Emissions	NOx, PM, SOx and VOC – tbd, but expected to be above 85%, dependent on stack capture efficiency
	CO_2 – minor increase due to treatment system energy requirements
Maturity	established technology, systems in testing phase
Limitations	port channel/berth configurations; terminal space; interference with terminal operations (shore-based)
Implementation	*Incentive* – Port of Long Beach[34]

[33] www.advancedcleanup.com/index.php?article=31;
[34] www.polb.com/news/displaynews.asp?NewsID=1394andTargetID=1

Energy

The energy category includes fuels and alternative power systems.

Fuels

Fuels have been in the "spotlight" due to a number of requirements including IMO fuel sulfur limitations, upcoming IMO ECA and SECA requirements, EU at-berth requirements, CARB marine fuel requirements, and various market based measures (mbm) that incentivize the use of cleaner fuels. Table A2.4 provides a summary of the different types of fuels based measures highlighted in this study with further details for each provided below.

Table A2.4: Summary of Fuels

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Fuels								
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

Low sulfur fuels

Use of low sulfur diesel fuels instead of residual fuel with high sulfur content has been one of the most effective strategies utilized in the port area to significantly reduce PM and SOx emissions and to achieve modest reductions in NOx. It is the basis for the IMO ECA and SECA regulations, as well as the global fuel sulfur caps. The reason low sulfur fuels have been so attractive is that their use typically doesn't require significant CAPEX to implement. However, the disadvantage is that the strategy can significantly raise OPEX because a major component of ship operating costs is fuel cost. In addition, due to lower viscosity and density of the low sulfur fuel, during fuel switching the ship operators must follow certain operating practices for their engines and other components such as fuel lines and valves. The significant rise in OPEX comes from 1) the cost differential between high sulfur and low sulphur fuels, which can run over $300 per tonne; additional service and maintenance guidelines to be followed by fuel switching crew to avoid damage to fuel lines and valves due to lower viscosity and density of the low sulfur fuel. In addition, the increased cost of low sulfur fuel may encourage a mode shift from sea to over-the-road for current short sea transportation services. Therefore, careful evaluation is needed while considering fuel switching for short shipping routes.

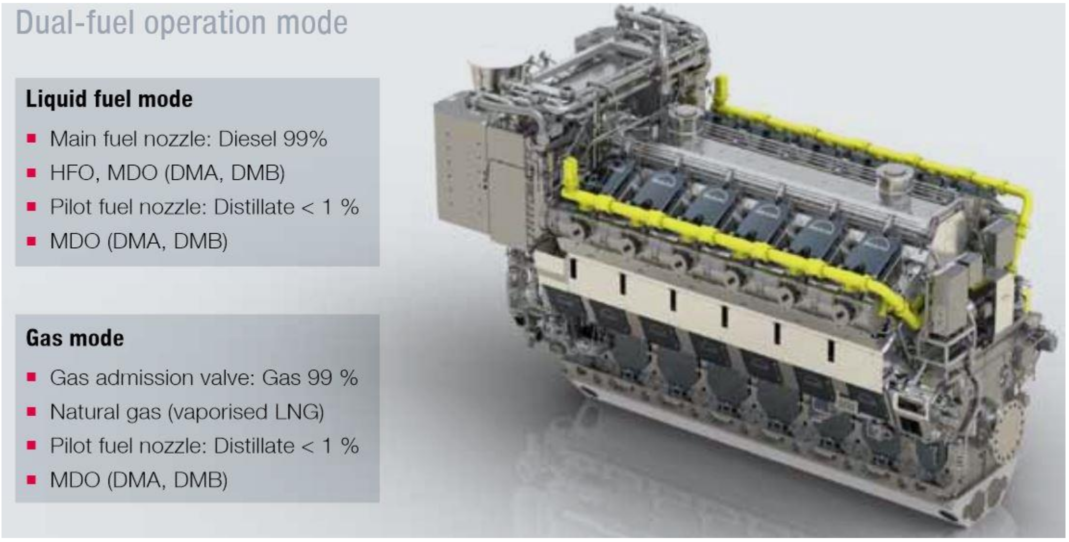
Applicability	propulsion and auxiliary engines
Retrofitable	na
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 6% reduction PM – up to 80% reduction (depending upon the sulfur content of the base fuel being used) SOx – up to 98% reduction (depending upon the sulfur content of the base fuel being used) CO_2 – minor increase due to lower energy content
Maturity	established compliance strategy; fuel switching is already taking place at various ports
Limitations	storage capacity; cost differential with higher sulfur fuel; switching fuels requires certain guidelines to be followed for safety and proper functioning of fuel components
Implementation	*regulations* – IMO fuel sulfur requirements in ECA, SECA, global cap; EU at berth regulation, CARB fuel switch requirements *mbm* – ESI, port incentives, CSI

Liquefied natural gas

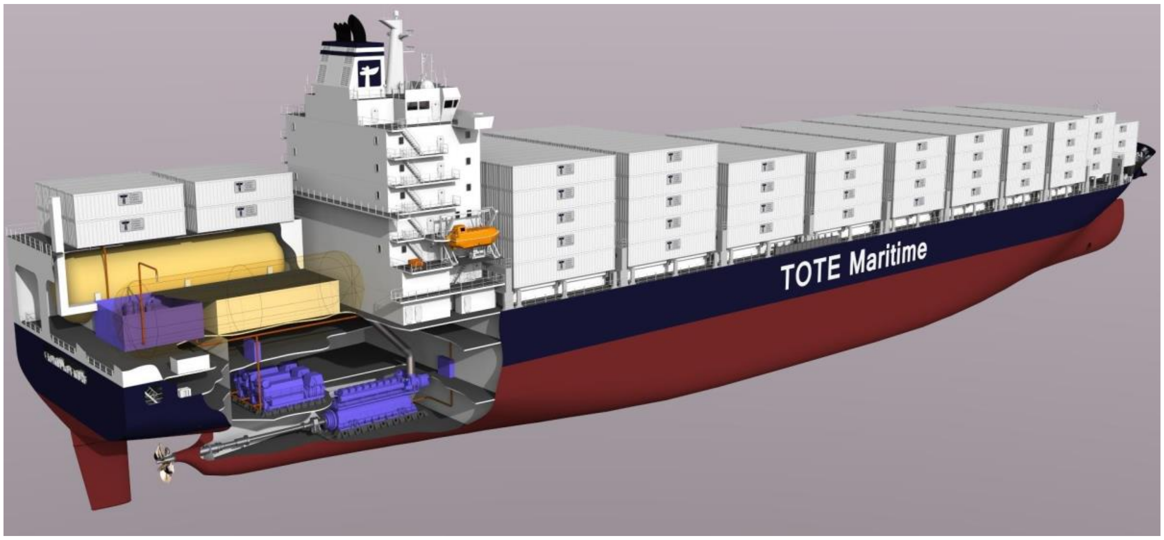
Liquefied natural gas (LNG) is gaining acceptance in maritime applications as an emission control measure for NOx and compliance with ECA/SECA fuel requirements. When evaluating the potential CO_2 emissions benefits of LNG as a fuel in the marine sector, it is important to consider the type of engine that is going to use natural gas and, relating to carbon, the extraction and transportation networks used to bring LNG to the port. Two engine types can be fueled with LNG: Otto Cycle and Diesel Cycle. Otto Cycle engines use a spark to ignite the gas in the cylinder and are dedicated to burn only natural gas. Diesel Cycle engines use a feeder quantity (<5%) of diesel fuel to ignite the natural gas, and have the flexibility to burn either 100% diesel or natural gas (these are known as duel-fuelled engines). Otto Cycle engines can reduce NOx by 88%, PM by 98%, and eliminate SOx entirely compared to burning fuel oil, while Diesel Cycle engines burning natural gas have a slight increase in NOx (Tier III cannot be met!) over diesel fuel due to tuning, reduce PM by 95% and reduce SOx by 97%. CO_2 emissions from the engines are typically lower than diesel powered engines; however Otto Cycle engines have issues with methane slip at low/variable loads, which are associated with the port area.

LNG refueling infrastructure typically must be established to support maritime uses. Ports are developing standards for port-side LNG infrastructure, and bunkering operations are typically found in Scandinavian countries. Over 500 ships are currently powered by LNG, approximately 400 of those are LNG carriers and approximately 150 various other ship types, typically roll-on/roll off (roro) and roll-on passenger (ropax) ships. Most engines in service are of the Otto Cycle type.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – LNG only up to 88%; dual-fuel slight increase, cbc PM – LNG only up to 98%; dual-fuel up to 78%, cbc SOx – LNG only 100%; dual fuel up to 97% CO_2 – generally there are CO_2 reductions from natural gas at the stack, however methane slip at low loads (LNG only) could offset the reduction, cbc
Maturity	established technology, limited but growing use on board ships
Limitations	storage capacity; fuel availability
Implementation	*regulation* – IMO fuel sulfur requirements in ECA, SECA, global cap; EU at berth regulation, CARB fuel switch requirements, NOx fund *mbm* – ESI, port incentives, CSI



Dual fuel and gas modes, MAN

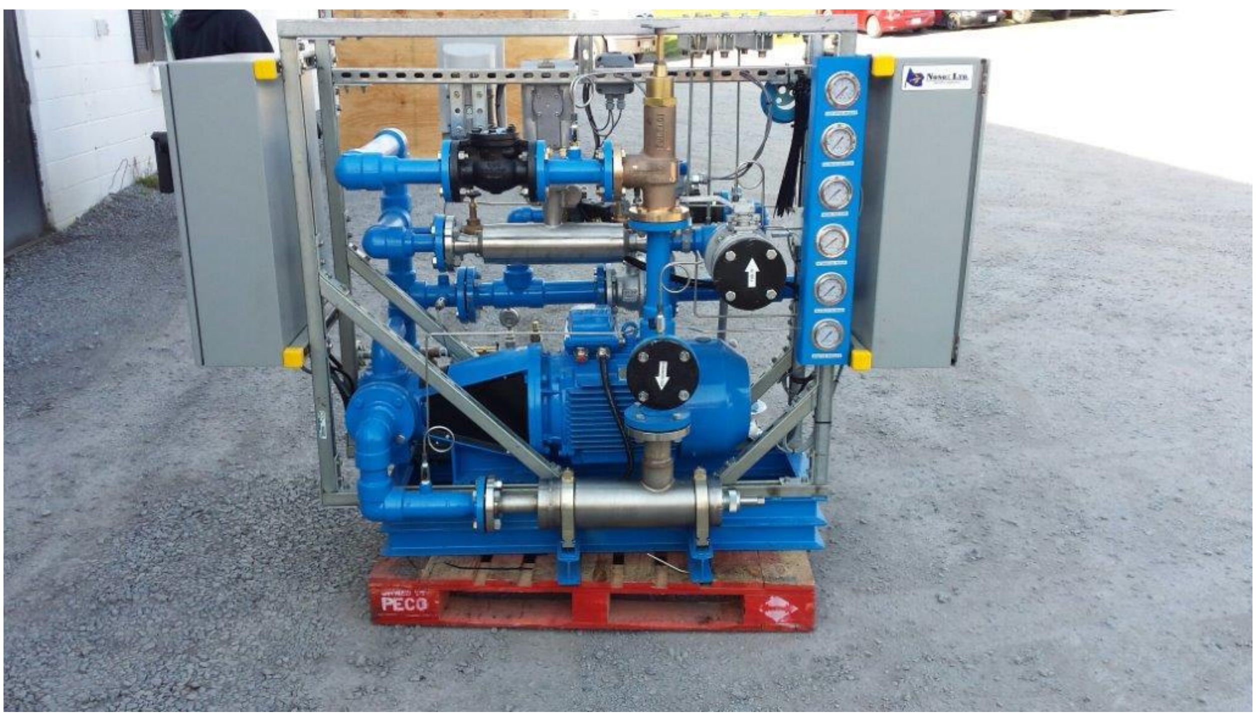


LNG dual fuel container ship illustration, TOTE

Water in fuel

Fuel-water emulsions[35] are created when fuel and water are mixed on board the ship prior to entering the engine. Fuel-water emulsions use a surfactant to disperse the water inside the fuel to ensure the engine is not corroded by the water. The result is that the water evaporated in the cylinder in direct proximity to the injected fuel causes local cooling during combustion, and the lower temperature reduces NOx formation. The percentage of water mixed with the fuel reduces NOx emissions by the same percentage, with 30% typically the maximum amount of water and the maximum achievable NOx reduction. Only fresh water is used in the emulsion.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – up to 30%; up to 50% in some cases
	PM – tbd
	CO_2 – can improve fuel consumption, tbd
Maturity	established technology, limited use onboard ships
Limitations	storage capacity; fresh water generation
Implementation	*regulation* – IMO engine standards
	mbm



Emulsification equipment, Nonox

[35] www.nonoxltd.com/Marine.html; www.mandiesel-greentechnology.com/0000509/Technology/Secondary-Measures/Fuel-Water-Emulsion.html

Methanol

Methanol[36], similar to LNG, has no sulfur and thus is a candidate energy source for ships operating in ECAs and SECAs. Similar to natural gas, methanol generates less CO_2 emissions at the stack and doesn't have the methane slip at low loads like Otto Cycle LNG engines. This could be an advantage when it comes to the IMO Energy Efficiency Design Index (EEDI). Bio-methanol can be produced from a variety of biomasses and mixed with methanol produced from fossil fuels. Methanol is used in Otto Cycle engines and is a liquid at ambient temperature and pressure. Emission estimates for methanol as fuel are not established at this time, however it is anticipated that for methanol-fueled engines to meet IMO Tier III, additional emission control technologies will be needed, such as EGR. There is potential for 4-stroke Otto Cycle engines to generate formaldehyde emissions due to fuel slip; therefore additional abatement will be needed. Methanol can be used in 4-stroke dual fuel engines and 2-stroke dual fuel engines will not have the issue of formaldehydes like the 4-stroke engines because they do not have fuel slip; EGR would still be needed. Methanol is toxic if ingested and is miscible in water thus easily degrades in the environment. Methanol is nearly half the energy density of diesel. Methanol infrastructure on both the land and ship-side are considerably cheaper than LNG since methanol does not need to be cryogenically stored, the cost is more similar to HFO infrastructure.

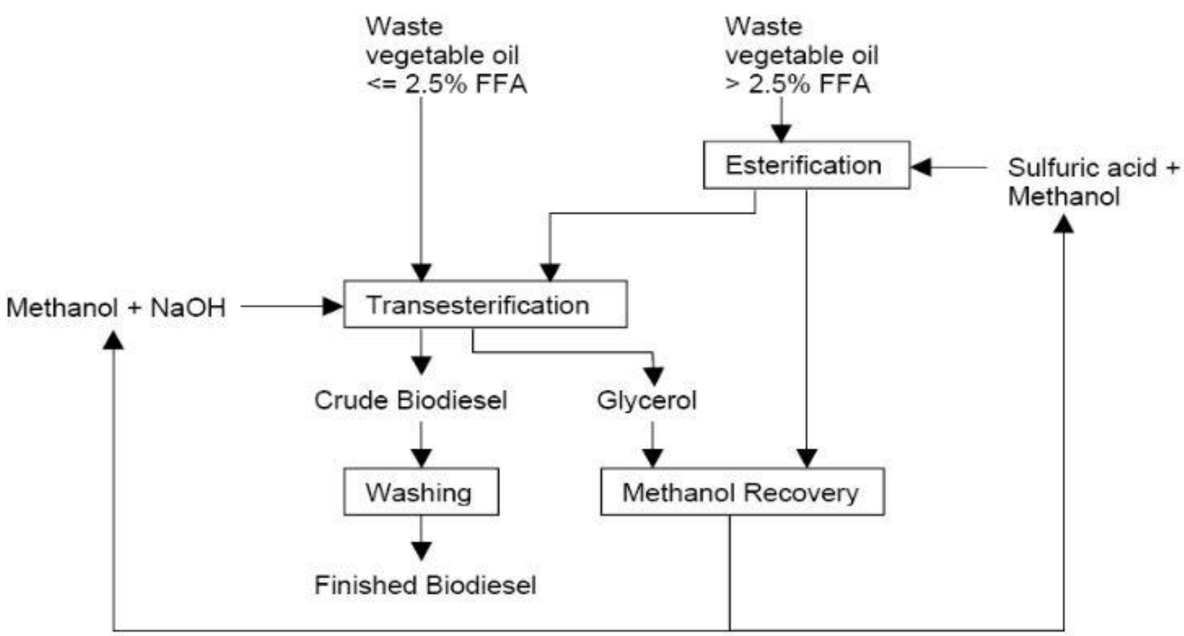
Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – reduced, tbd
	PM – tbd
	SOx –100% reduction
	HC – tbd
	CO_2 – reduced at the stack, tbd
Maturity	established technology, limited use onboard ships
Limitations	emissions testing; supply and distribution infrastructure
Implementation	*regulation* – IMO fuel sulfur standards, ECA, and SECA requirements

36 www.corporate.man.eu/man/media/content_medien/doc/global_corporate_website_1/verantwortung_1/megatrends_2/klimawandel/me_gi_dual_fuel_en_01.pdf; www.marinemethanol.com/phocadownload/promsus/promsus_folder-web.pdf

Biofuel

Biofuels[37] include bio-methanol (see above) and other fuels that are manufactured from biomass, vegetable oils, animal fats, or recycled grease. Biofuels are typically blended with traditional fuels. Biofuels have no sulfur content, but could potentially increase NOx. The primary concern for their use in the maritime sector are associated with safety relating to inconsistent quality, lack of marine standards, and impact on engine seals, engine manufacturer's warranties, disadvantageous hydrophilic properties, cold weather limitations, and its ability to remain stable in a marine environment over a period of time. Cost of pure biodiesel, B100, is typically higher than the cost for diesel, while blends of up to 20% (B20) can run similar price. Biofuel limitations include availability and distribution. Additional costs arise from tank cleaning, engine and fuel system equipment seal change-outs, testing, filters, repairs, etc. when switching to biofuels.

Applicability	propulsion and auxiliary engines
Retrofitable	yes
Operational modes	potential to reduce emissions across all modes
Emissions	NOx – potentially increase, cbc
	PM – tbd
	SOx and HC – dependent on % biofuel used, reductions up to 100%
	HC – dependent on percent biofuel used, reductions up to 100%
	CO_2 – reduced at the stack, tbd
Maturity	established technology, limited use onboard ships
Limitations	safety, maintenance, supply and infrastructure
Implementation	*regulation* – IMO fuel sulfur standards
	business case



Basic biodiesel production process, MARAD

[37] www.marad.dot.gov/documents/The_Use_of_Biodiesel_Fuels_in_the_US_Marine_Industry.pdf

Alternative power systems

Alternative power systems utilize power sources other than onboard auxiliary engines to meet onboard power requirements. Current projects range from on-shore grid power (OPS), alternative power generation while at berth such as solar and LNG. The important aspect of use of alternative power systems is that it reduces the generation of emissions by ships with diesel powered engines while at berth near the populated area and requires use of alternative power systems such as solar, LNG and power plants which are lower in emissions compared to diesel powered engines on board the ship For each type, the following information is provided: overview description of the system, if the system is applicable to new builds and/or existing ships, the applicable operation modes where the system is effective, if the system is applicable to propulsion and/or auxiliary engines, what pollutants are reduced, if there are CO_2 benefits (i.e., fuel consumption improvements), potential limitations of the system, and other pertinent information. Table A2.5 provides a summary of the scrubber technologies highlighted in this study with further details for each provided below.

Table A2.5: Summary of Alternative Power Systems

	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Alternative Power Systems								
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	↓ cbc	↓ cbc	↓ cbc	↓ cbc

On-Shore power supply/shore power

One of the first applications of on-shore power supply (OPS)[38] was in Alaska and focused on reducing cruise ship emissions while at-berth. The concept is to supply the ship's power needs, at-berth, with grid power supplied from the shore. Switching onboard power generation to the grid shifts this function to (typically) to more efficient generation methods (i.e., power plants generating power at the 10s to 100s megawatt levels compared to onboard generation). Switching from onboard-generated power to the use of grid power shifts to more efficient power generation methods (i.e., power plants generating power at the 10s to 100s megawatt levels compared to onboard generation). In countries where stationary sources are regulated, power generating plants are typically covered by these regulations and therefore in addition to more efficient generation, the ship benefits from emissions controls required by the power plant (i.e., the grid-based power has a reduced emissions impact). There are several challenges that arise in the design of the shore-based infrastructure and electrical equipment which include: frequency of the grid and the ships being shore powered, the voltage system onboard the ship, dynamic or static loading of power, grounding, berth configuration, berth condition, number of connecting points, available power shore-side, ship infrastructure/retrofit approach, cost of electricity. Since ships have to be equipped to receive shore power, liner service or frequent callers are typically the best candidates. Shore power is not a "silver bullet" and needs evaluated on a case-by-case basis to determine if it's an effective reduction solution. CARB has adopted the most significant regulation to date mandating the use of shore power for several California ports.

Applicability	auxiliary engines
Retrofitable	yes
Operational modes	at-berth
Emissions	All emissions – up to 100% at the stack while using grid power
Maturity	established technology, international standards for equipment
Limitations	both ship and terminal need to be equipped for shore power
Implementation	*regulations* – CARB Shore power Regulation; opacity regulations *CSR* - although, not mandated, over 16 non-California ports[39] in Europe, Canada, USA, and Asia, have shore power ready berths and at various phases of implementing OPS.

[38] www.ops.wpci.nl/; www.arb.ca.gov/ports/shorepower/shorepower.htm

[39] wpci.iaphworldports.org/onshore-power-supply/ops-installed/ports-using-ops.html

Barge power supply

Barge power supply[40] provides power to a ship at-berth, similar to on-shore power however the power is generated by a cleaner engine than located on the ship and typically using an alternative fuel, such as LNG. Multiple systems are in development. A barge equipped with an LNG Otto Cycle only engine that can provide up to 7.5 megawatts and will be used by cruise ships calling at Hamburg Port Authority. The advantage of the barge system compared to terminal-based shore power is that it does not require costly terminal infrastructure improvements and the system can be moved from one berth to another. There is potential that mooring infrastructure needs to be constructed so that the barge is secured while in use and not in the way of other ship traffic. The ship to be powered still needs to have the connection and electrical equipment onboard to receive the barge-based power (similar to on-shore power supply). The potential emission reductions are based on the difference in emissions of the engine, fuel, and after-treatment system of the power barge compared to the onboard power that is otherwise used to generate power.

Applicability	auxiliary engines
Retrofitable	yes
Operational modes	at-berth
Emissions	NOx – up to 80% reduction (assuming LNG powered Otto Cycle engine), cbc PM – up to 98% reduction, (assuming LNG powered Otto Cycle engine), cbc SOx – 100% reduction, (assuming LNG powered Otto Cycle engine), cbc CO_2 – up to 30% reduction at the stack (assuming LNG powered Otto Cycle engine), cbc
Maturity	established technology; limited use in the maritime sector
Limitations	ship receiving power needs to have appropriate connection and electrical equipment; barge may need additional mooring infrastructure installed depending on port/terminal/berth layout
Implementation	*regulation* – IMO fuel requirements, EU At-Berth Fuel Regulation *CSR*

LNG fueled alternative power barge, LNG-Hybrid

[40] www.lng-hybrid.com/index_e.html; www.iaph2015.org/smartnews/first-lng-hybrid-barge-for-cruise-ships-in-Hamburg/

Solar power

Solar power has been installed on some ships to demonstrate the technology in a marine environment. For example, NYK and Toyota Motor Corporation developed the MV Auriga Leader, which has a 328 solar panel array capable of producing 40 kW of electrical power, however this only makes up 7-8% of auxiliary power needs of the ship. Challenges for solar array deployment on ships include harsh ocean conditions and developing significant energy generation from limited space on-deck.

Applicability	auxiliary engines
Retrofitable	yes
Operational modes	all modes
Emissions	reductions come from reduced load on the auxiliary engines, cbc
Maturity	established technology, limited use onboard ships
Limitations	potential generation capacity onboard; harsh marine environment
Implementation	*business case* – offset fuel costs
	CSR

MV Auriga Leader with solar power array, NYK Lines

Operational

The operational category includes operational ship operational efficiencies, port and terminal operational efficiencies, and VOC working losses from bulk liquid ships.

Ship operational efficiencies

Ship operational efficiencies are improvements that reduce fuel consumption in the port area. Depending on the port configuration, optimization of a ship's movement through water may or may not have a significant impact. This is dependent on the distance and speed a ship is moving in a particular port area. Port areas that have extended open-water transit can materially benefit from emission reductions associated with ship movement efficiency improvements. Typically, in the port area auxiliary engines have a much higher contribution to emissions than during the open-water transit mode, however this is dependent on the distance and characteristics associated with the area's open water transit mode.

For this group, retrofitable is replaced with applicability for new and/or existing vessels, as retrofitable is not applicable.

Table A2.6 provides a summary of ship operational efficiencies highlighted in this study with further details for each provided below.

Table A2.6: Summary of Ship Operational Efficiencies

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

Vessel speed reduction/slow steaming

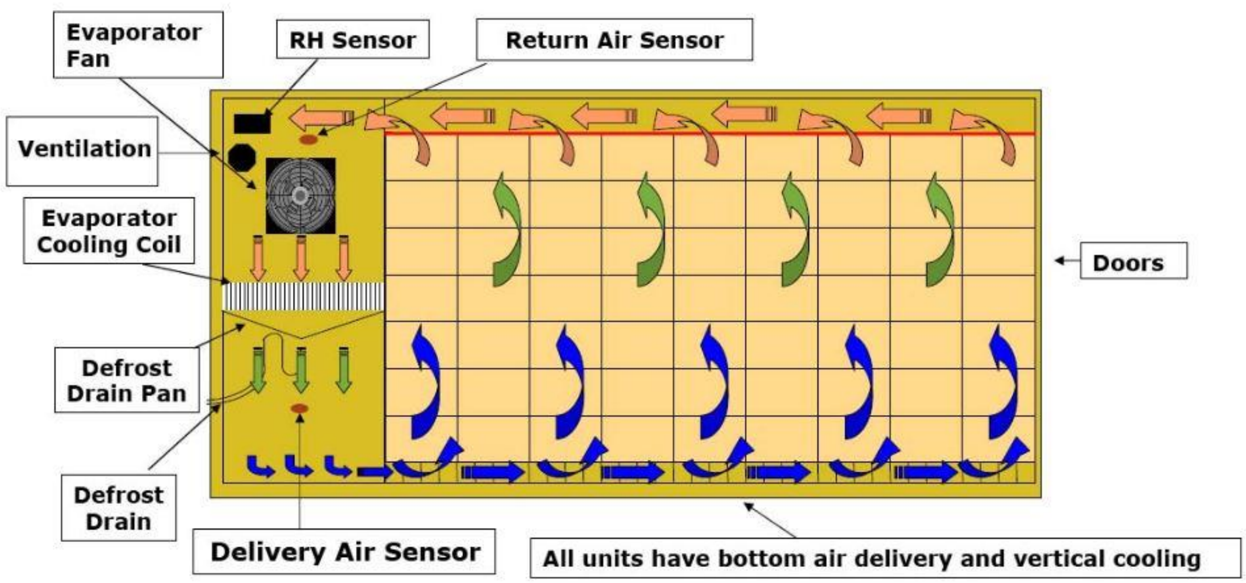
Pioneered in 2000, with implementation in the 4th quarter 2001, ship speed reduction (VSR) became a significant voluntary emission reduction measure utilized by the Ports of Los Angeles and Long Beach and is still ongoing. The premise of VSR is the reduction is ship speed that results into the emissions reduction due to significant reduction in propulsion engine load (propulsion engine load can be generally considered to have a cubic relationship with ship speed). The reduction in speed increases running time that the auxiliary and boiler engines are on (due to longer transit times). However, emissions reduction from propulsion engines running at lower speed thus lower load outweighs increase in emissions from auxiliary engines due to longer running time. In addition to reduction in emissions, there is a net ship fuel consumption reduction over a given distance, which acts as an incentive for ship owners to slow their ship speed. In the 2008-2010 timeframe ship operators started to utilize this concept to reduce fuel consumption in response to the global economic downturn. VSR is most effective in the open water transit mode followed by the transition mode. By setting the VSR zone at the transition mode and open water transit mode boundary, ships shift their transition mode location accordingly and are then operating at reduced speeds during transit to port. VSR zones typically have speed targets set at 10 to 12 knots. VSR does not need any engine retrofits and special equipment. VSR works best on faster ships with relatively low auxiliary engine and boiler loads. Large cruise ships can benefit from VSR; however they need to be evaluated on a case-by-case basis, taking into consideration the distance of the zone, proximity of the zone to the populated area and ship's auxiliary engine load. Alternative compliance plans (ACPs) can be used to tune a VSR program to ships with high auxiliary loads.

Applicability	emissions reduction at the ship level
New or existing vessels	both
Operational modes	transit and transition
Emissions	PM, NOx, CO_2, and potentially HC depending upon engine load
Limitations	high auxiliary load ships need to be evaluated to find the optimum speed or engine load conditions to achieve a reduction and avoid an overall emission increase
Maturity	established strategy
Implementation	*voluntary incentive* – Port of Los Angeles, Port of Long Beach, Port Authority of New York and New Jersey *business case*

Optimization of ship reefer systems

Refrigerated containers or reefers can be the source of significant energy demand for ships carrying them in large numbers. While onboard, the reefers are plugged into the ship's auxiliary power grid. Shipping lines have been improving the efficiency of reefers for nearly a decade. From improvements in installation materials, airflow, ventilation, sensor location and type, and humidity control. The primary improvements relating to energy consumption are insulation and temperature control optimization. The improved reefers[41] can reduce a reefer's power consumption profile by up 65%.

Applicability	auxiliary engine load
New or existing vessels	na
Operational modes	all port area modes
Emissions	auxiliary engine load can be reduced which equates to reduction in emissions, cbc
Maturity	established strategy
Limitations	none identified
Implementation	*business case*



Reefer systems illustration, Maersk

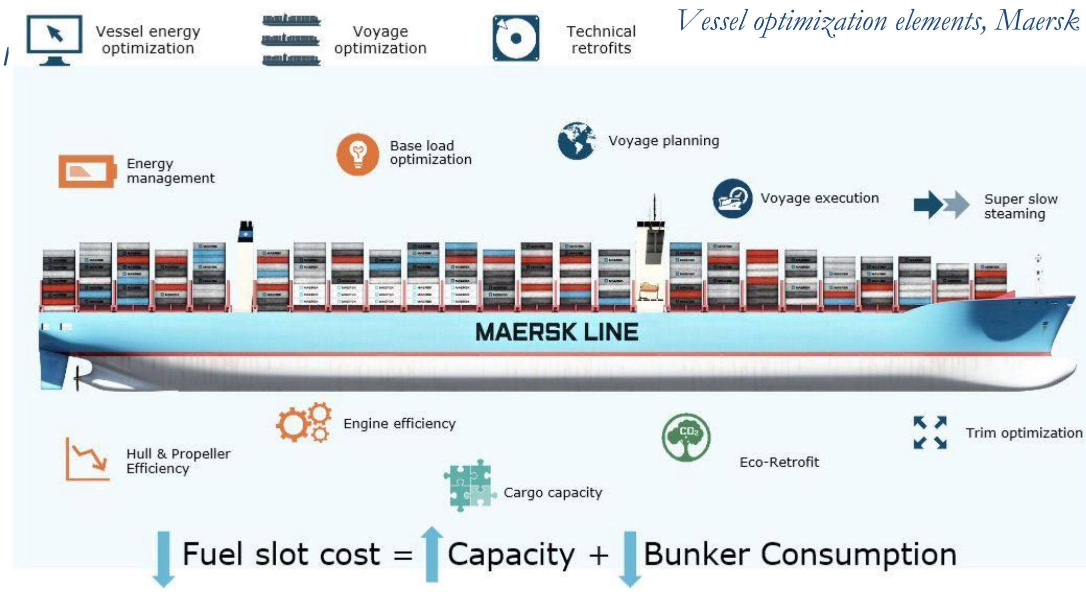
[41] www.maersklinereefer.com/quest/QuestII-PDF.pdf; ec.europa.eu/enterprise/archives/e-business-watch/studies/case_studies/documents/Case%20Studies%202009/CS09_EII5_Moller-Maersk.pdf; www.wageningenur.nl/en/show/Quest-II-container-refrigeration-with-65-less-CO2-emission.htm

Optimization of ship systems

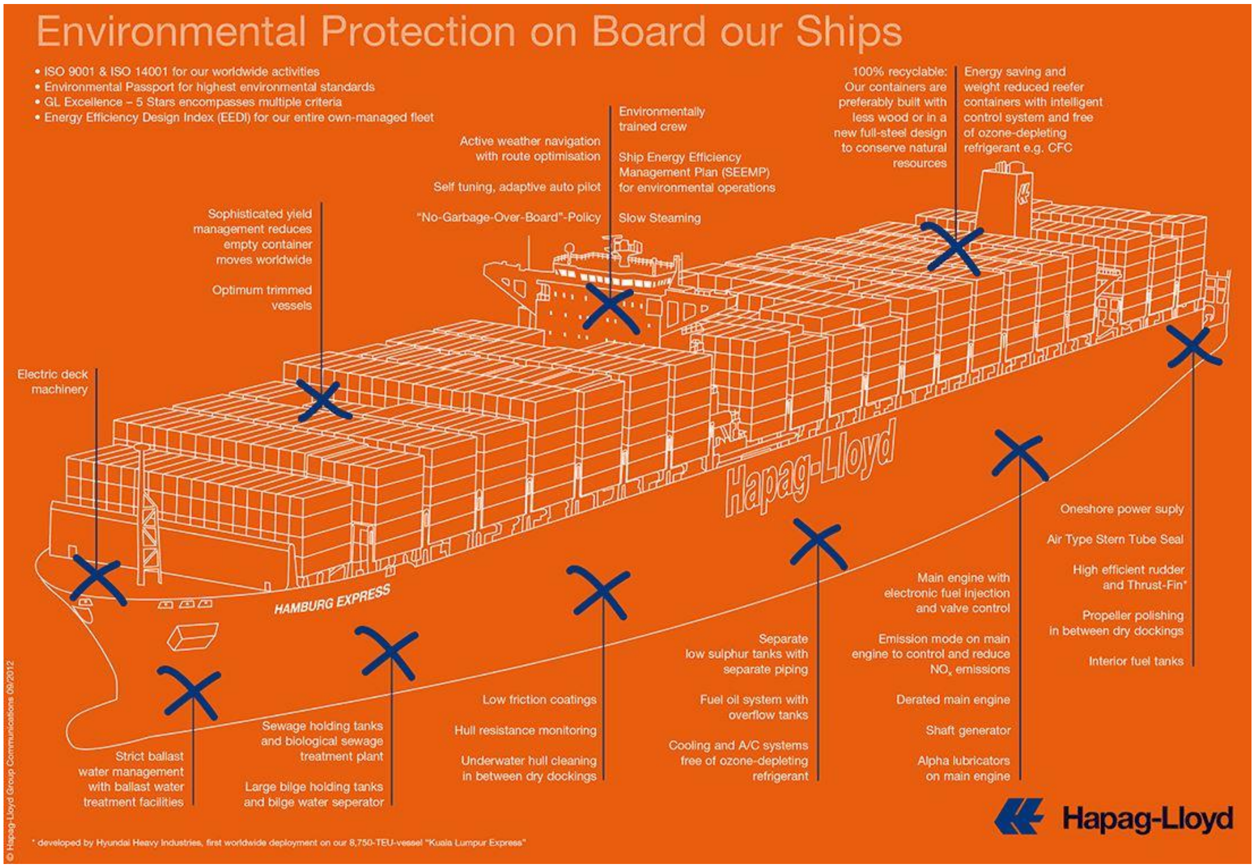
Several carriers are currently working on ship systems optimization,[42] including ship base loads, bow thrusters, pumps, cooling water treatment, heat recovery, movement through water, retrofits, trim optimization, energy management, cargo capacity, etc. Ship owners are looking at various efficiency improvements to gain a competitive edge and reduce fuel costs. Efficiency improvements therefore typically reduce CO_2 emissions and have pollutant emission reduction co-benefits. Not all efficiency improvements will have a benefit in the port area (e.g., weather routing). The improvements that reduce auxiliary engine loads, boiler loads, and propulsion loads (mostly at slow speeds) will typically have emissions benefits in the port area. The level of the benefit is directly related to the reduction in load of these systems. Some owners are looking at comprehensive efficiency improvement programs and some are focusing on a narrower spectrum of measures. The challenge with these measures from the port's/terminal's perspective is collecting information on the reduced loads, ensuring the reductions are stable over time, and for efficiency measures requiring maintenance, that the maintenance is completed at regular intervals. For example, hull fouling has a decreased impact at slow speeds such as during maneuvering. If a port area made up of mostly maneuvering then hull cleaning will not have a significant effect on propulsion engine emissions. However, for port areas that have any significant open-water transit distances, hull cleaning can have a significant emission reduction potential.

Applicability	potentially all three emission source categories
New or existing vessels	both
Operational modes	potential for reductions across all port area modes
Emissions	propulsion and auxiliary engine loads or boiler loads can be reduced which equates to reduction in emissions, cbc
Maturity	established strategy; increasing used over the past decade
Limitations	data gathering/sharing and verification
Implementation	*business case*

Vessel optimization elements, Maersk



[42] 9ad15a9cda9f8c0a8ae0-c57d01126cd8bb50ffacd79831479348.r20.cf1.rackcdn.com/jacobsen.pdf; www.hapag-lloyd.com/en/about_us/environment_on_board.html; www.alfalaval.com/industries/marine/on-board/pages/on-board.aspx;



Vessel optimization elements, Hapag-Lloyd

Vessel optimization elements, Alfa-Laval

Optimization of fleet sizing to maximize ship efficiency

Fleet sizing optimization is carried out in differing degree amongst ship operators in liner services like container, auto carriers, and reefers. Emission benefits can be realized in the port area if the ships serving the port/terminals are running at higher capacity efficiencies, which in turn reduces the potential number of ships calling a port each year and from ships showing up significantly under-utilized. The use of metrics such as container twenty-foot equivalent units (teus) per ship call, passengers per ship call, or metric tons per ship call, on either a call-basis or annual average-basis can help highlight efficiencies associated with fleet optimization. Ports and terminals can setup metrics based on their available data streams.

Applicability	all ship emission sources
New or existing vessels	both
Operational modes	potential for reductions across all port area modes
Emissions	propulsion and auxiliary engine loads or boiler loads can be reduced which equates to reduction in emissions, cbc
Maturity	established strategy
Limitations	reductions are compared to a baseline year.
Implementation	*business case* – from the ship operator's side

Port and terminal operational efficiencies

Port and terminal operational efficiencies can bring co-benefits to operational bottom lines through reduced fuel consumption, fees, taxes, as well as emission reductions in the port area. For each approach, the following information is provided: overview description of the approach, if the approach is applicable to new builds and/or existing ships, the applicable operation modes where the approach is effective, if the approach is applicable to propulsion and/or auxiliary engines, what pollutants are reduced, if there are CO_2 benefits (i.e., fuel consumption improvements), potential limitations of the approach, and other pertinent information.

For this group, retrofitable is replaced with applicability for terminals or vessels, as retrofitable is not applicable. Table A2.7 provides a summary of the port and terminal operational efficiencies highlighted in this study with further details for each provided below.

Table A2.7: Summary of Port and Terminal Operational Efficiencies

	Applicable Emission Source	Terminal/Vessel	Applicable Operational Modes	NOx	PM	SOx	HC	Energy Consumption
Port/Terminal Operational Effiicencies								
Automated Mooring Systems	AB	T	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Optimization of Terminals & Ports to Reduce At-Berth Time	AB	T	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Electric Shore Side Pumps for Bulk Liquids	B	T	B	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc
Mid-Stream Operation	All	V	A	↓ cbc	↓ cbc	↓ cbc	↓ cbc	↓ cbc

Automated mooring systems

Pioneered in the late 1990's, automated mooring system installation continues to increase. Ships utilizing automated mooring systems save up to 1.5 hours from the mooring process and thus reduce associated emissions. The systems are remote-controlled vacuum pads, recessed or mounted to the quayside and attached to hydraulic actuated arms, which extend, attach, and moor a ship under a minute. The systems can be designed to handle any size ships including today's largest ships. The systems provide faster ship-turnaround times, allow ships longer than berths to be moored with overhang, speeds up disembarking of passengers and crew, and reduces ware on ship winches, hull, and plating.

Applicability	propulsion and auxiliary engines
Terminal/vessel	terminal
Operational modes	at-berth
Emissions	All emissions can be reduced dependent on amount of time saved, cbc
Maturity	established technology
Limitations	none identified
Implementation	business case

Automated mooring systems, Cavotec

Optimization of terminals and ports to reduce at-berth time

Increasing terminal efficiencies such that ship at-berth times are reduced will reduce overall at-berth emissions. Efficiency improvements could include newer, more efficient quay cranes, streamlining administrative delays, improved terminal land-side bottlenecks, improved ship positioning considerations, automated mooring systems (discussed separately above), terminal automation, and other efficiency improvements that focus on minimizing a ship's time at berth. In addition, providing adequate lay-berth facilities in and around ports, such ship shift distances are minimized when a ship needs to visit multiple terminals and space is not available. For inland terminals/ports, adequate lay-berth facilities could significantly reduce inefficient movements of ships over long distances, such as not having to go back out to deep-water anchorages.

Applicability	propulsion, auxiliary engines, and boilers
Terminal/vessel	terminal
Operational modes	at-berth
Emissions	reduction potential for all pollutants, dependent on amount of time reduced, cbc
Maturity	established strategy
Limitations	land ownership issues; jurisdictional limitations
Implementation	business case

Near ship electric shore side pumps for bulk liquids

This approach places shore-side pumps and limited storage capabilities near ship offloading facilities with the aim of reducing how "hard" the ship's pumps need to work. The result is that the ship's pumps only need to move bulk liquid cargos to the nearby electric pumps instead of pumping cargo further into the pipeline and storage system. This would allow the shore-side electric pumps to handle most of the work associated with cargo movement. This method works best for locations where the ship is pumping to inland storage facilities or elevated storage facilities.

Applicability	auxiliary engines (diesel-electric pumps) and boilers (steam pumps)
Terminal/vessel	terminal
Operational modes	at-berth
Emissions	reduction potential for all pollutants, dependent the reduced pumping load needed, cbc
Maturity	established technology; limited use as a terminal strategy
Limitations	none identified
Implementation	*business case*

Mid-stream operation

Mid-stream operation is the practice of loading and unloading cargo containers between ships at non-berth locations. Hong Kong is probably the only port in the world that uses this cargo transfer method in an extensive manner. Mid-stream operators handled approximately twenty percent of Hong Kong's container throughput in 2013.

Back in the 1990s, the main driver for transferring cargo containers mid-stream in Hong Kong, was to provide for additional handling capacity away from the container terminal. Land has always been a scarce commodity in Hong Kong, and terminal expansion could not quite keep pace with the rapidly growing marine trade and traffic. Cost savings from the expensive terminal handling charge and tugboat service, as well as faster turnaround time are other major advantages over cargo transfer at berth.

In terms of operation, container ships are anchored at designated harbor areas, where cargo lighters and barges equipped with derrick cranes will work alongside the ships to load and unload containers. One container ship can be serviced by up to 6 or 8 barges at the same time, each capable of carrying some 50 container boxes. These barges, which are often non-mechanized, will be towed by a tugboat to one of the twelve land-based sites for transferring the containers onto trucks. Some barges will be towed directly to the Pearl River Delta ports.

Applicability	<= 6,000 TEU container ships
Terminal/vessel	vessel
Operational modes	Potential to improve cargo handling efficiency, reduce ship turnaround time, reduce land-based onward cargo transportation
Reductions	Modest reduction of air pollutants across the board
Maturity	Established practice in Hong Kong; limited application outside Hong Kong
Limitations	Only practical in calm waters; larger ships prefer at-berth cargo transfer for safety and cargo risk considerations; accident-prone due to the working environment
Implementation	*mbm + safety* - Safety code drafted by Marine Department; service provided by private mid-stream operators and service agents

Mid-stream operations, Hong Kong, China

VOC working losses

Working losses on tankers due to fugitive emissions from valves, flanges, fittings, and pressure relief valves are not include as the most significant emission source in the port area is during the ship loading operation. Vapor recovery of volatile organic compounds or VOCs has been a strategy utilized by several countries to require emissions from tanks being filled to be controlled to reduced health and environmental impacts. Table A2.8 provides a summary of the VOC working losses measure highlighted in this study with further details for each provided below.

Table A2.8: Summary of VOC Working Losses

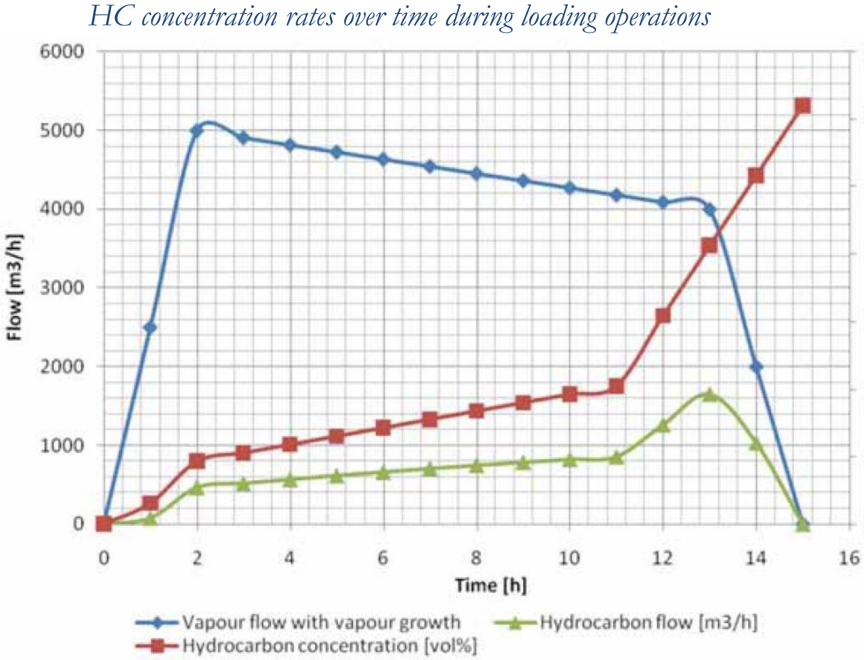
	Applicable Emission Source	Retrofitable?	Applicable Operational Modes	NOx	PM	SOx	VOC	Energy Consumption
VOC Working Loses								
Vapor Recovery for Volatile Bulk Liquids	Tank	Y	B	–	–	–	↓	–

Vapor recovery for volatile bulk liquids

Environmental regulation at the national level is the primary driver behind the use of vapor recovery systems for ship loading operations, supported by worker/facility safety as a close second. As a ship is loaded, vapors from the cargo tanks are displaced, which are either vented to the atmosphere or captured and routed through an onshore vapor manifold to a nearby vapor recovery system. There are instances where vapor recovery units are mounted onboard (ships that load at sea such as shuttle tankers). Displaced vapors will typically contain volatile organic compounds or VOCs in either an inert atmosphere (nitrogen or engine exhaust gases) or air. The concentration of VOCs increases over time during the loading operation.[43] The United States Coast Guard regulation covering marine vapor control systems (33 CFR 154 Subpart P[44]) is extensive and addresses ship and land requirements as well as shore-side facilities. VOCs combine with NOx and sunlight to form ozone, and well as many of the VOCs have associated health risk impacts, therefore control of VOCs in the port area is important to surrounding communities. Recovered product can help offset costs. See Annex 2 for a case study on how VOC recovery was implemented in the Port of Amsterdam.

Applicability	VOC cargo tanks when loaded
Retrofitable	yes
Operational modes	at-berth
Emissions	VOC – up to 99% reduction
Maturity	established technology; growing use globally
Limitations	vessel to vessel operations
Implementation	*regulation* – national regulations
	safety

HC concentration rates over time during loading operations



On-shore vapor recovery unit

[43] www.porttechnology.org/technical_papers/safe_vapor_handling_during_loading_of_volatile_organic_compounds/; ec.europa.eu/environment/archives/air/pdf/vocloading.pdf

[44] www.ecfr.gov/cgi-bin/text-idx?SID=23d470f5d67681ef92b9e21aa71466dbandnode=sp33.2.154.pandrgn=div6

FUTURE ECEEMs

The goal of this section is to identify and appraise possible innovative or emerging emissions reduction and energy efficiency measures, programs and strategies that optimize the energy efficiency and reduce ship emissions when in the port area. Unlike Section 2.1, which focuses on readily deployable measures, this section discusses specific measures that are still being developed. It also discusses measures that are market ready with substantial potential for growth if certain barriers such as cost can be overcome in the future. While some of the measures may be the same as measures described in Section 2.1, this section focuses specifically on the future potential of these measures. In cases where the future potentials are similar and details of individual measures have been already given, measures are aggregated into a more general category.

Because the terms "innovative" and "emerging" can imply a variety of meanings, for this study we define these terms as limited to any of the following:

- A distinctly novel technology or strategy with 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.
- A technology or strategy that is available and ready to deployed and is in limited or niche use, but with a substantial potential for expansion if certain key barriers like cost can be overcome.
- A technology or strategy that is being used on land-side or in others application from which it can be re-envisioned or otherwise utilized for the maritime sector.

The measures described in this section are intended to be restricted to measures that have substantial potential to affect emissions or efficiency of ships in the port area. As such, measures that are relevant primarily to the ocean transit portion of a ship's voyage are not addressed here. The following are examples of technologies that may be innovative or emerging according to the above definitions, but not likely to be most effective when a ship is within the port area:

- Hull technologies, including advanced coatings and air lubrication
- Vessel hydrodynamic, aerodynamic, and other major alterations to reduce friction while under way. These include propeller changes, bow adjustments, and other major alterations.
- Engine modifications that are mainly active or effective at higher loads, including waste heat recovery and engine de-rating.
- Alternative or augmentative propulsion technologies such as kites, fixed sails, and Flettner rotors

For each measure, a brief description provides relevant summary information about the measure as well as discussion about what "emerging" means in this specific case. For measures that have been discussed in the previous section, detailed descriptions are assumed to already have been covered and the text focuses more on the future potential. Similar to the "existing measures" section, summary information follows the narrative for each measure but will cover slightly different information including:

- System Applicability – describes which emission sources can be affected by the measure. These include:
    - propulsion engines (P)
    - auxiliary engines (A)
    - auxiliary boilers (B)

  - electrical (E)
  - other or operational measures (O)
- Retrofitable – denotes if the measure is retrofitable on existing ships (Yes – Y) or limited to only new builds (No – N).
- Market maturity – denotes the status of maturity for the ECEEM (e.g., is it in the development stage, undergoing validation testing or being applied to a new application, etc.). Each measure is designated with one or more of the following:
  - market ready (M)
  - emerging (E)
  - limited production (L)
  - theoretical (T)
- Emissions and energy efficiency – for each measure the anticipated change in NOx, PM and efficiency improvements are indicated as follows:
  - ↑ for increases
  - ↓ for decreases
  - ↕ for either increase or decrease depending on various factors

  As stated above, each measure and application must be evaluated on a case-by-case basis.

- Cost – an indication as to whether a measure is likely to be one of the following
  - ↓ - cost negative, implying that it will likely reduce cost over the long term even with all costs associated with the measure taken into account. This will mainly be for measures that have energy efficiency as a central benefit.
  - ↕ - cost neutral, implying that the financial costs and savings associated with the measure are likely to be near even or slightly higher or lower depending on the specific application of the measure.
  - ↑ - cost positive, implying that a measure will not pay for itself and will likely need regulatory or other incentive to overcome net additional costs associated with the measure.

More detailed descriptions, illustrations, and related information for each future ECEEM are provided in Annex 2. In addition to the above elements, the detailed descriptions in Annex 2 include the following additional items for each measure:

- limitations – known or anticipated limitations associated with a measure
- key challenges to deployment – known or anticipated critical challenges relating to the measure's deployment
- potential fleet penetration – theoretical potential of a measure's fleet penetration
- theoretical reductions – theoretical maximum potential reduction based on published literature or survey data

The summary table below indicates two general sets of measures: those that are presented previously as existing measures, and those that are new to this section. For each measure, the summary includes the measure title, applicability, retrofitability, likely market readiness, and indicators for their effectiveness for NOx, PM, and energy efficiency, as applicable. For measures that are reiterated from the previous section, all of the summary denotations and associated information may not be precisely the same. This is a result looking at these measures in the context of how they will most likely exist in the future as opposed to how they exist now.

Table A2.10: Summary of innovative and emerging measures and attributes

	System Applicability	Retrofitable	Market Maturity	NO_x	PM	Efficiency Improvement	Cost
Measures from Existing List							
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	↓	↓	↑	↓$
"New" Measures							
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	↓	↕	↕	↑$
Eletrical 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	↓	↓	↑	↓$

Engine optimization technologies **Measure Category: On Ship**

Section 2.2 describes a number of specific approaches to improving efficiency and reducing emissions from ship engines. In some cases, such as slide valves, common rail fuel injection, and engine gas recirculation (EGR), the approaches are based on a specific technology. In other cases, specific systems such as lubrication and valve timing are optimized to improve efficiency and performance over a wider range of operating conditions. Some of these strategies are commonly being installed as options on new ships, but retrofits for the existing fleet, even when available, are less commonly applied. Applications for existing vessels -- and specifically applications that target emissions and efficiency around ports -- are possible, but further adaptation and adoption of these strategies to a wider portion of the existing fleet requires both technical and market innovation.

System applicability	propulsion and Auxiliary Engines
Limitations	varies
Key challenges to deployment	business case, customization requirements
Potential fleet penetration	most vessels could achieve efficiency or emission benefits with emerging engine technologies
Retrofitable?	varies
Theoretical reductions	emerging engine technologies offer potential for NOx reductions up to 80% in the case of EGR, and PM reductions up to 40% with rotating cylinders. Some technologies that achieve emission reductions through improved combustion can also improve efficiency by up to 5%.
Market maturity	engine technologies referenced here are market ready and deployed in limited applications. Further development and incentives are needed to make emerging technologies available to the wider fleet.
Potential cost effectiveness	varies - most technologies that focus on emission reductions will not be cost neutral and will require some level of incentive to affect greater uptake.

Engine automation and data collection **Measure Category: On Ship**

As detailed in section 2.2, automating controls that maximize efficiency of propulsion and auxiliary engines and other systems can yield significant potential efficiency and emissions savings. These measures are especially relevant to the ship-port interface because they are mainly for fine tuning engines for lower and intermittent loads. The times these loads occur are minor compared to the time a ship is in transit mode, but increasing concern over fuel savings is pushing vessel operators to investigate new strategies. Automation is mainly available for newer, electronically-controlled vessels, but systems for automation of mechanical engines are currently being tested. If proven to be cost effective, this technology is likely to be deployed widely in the existing fleet and become standard on new vessels.

These systems are further complemented by the growing trend of collecting data on all aspects of ship operation that affect fuel use and system performance. In many cases, data collection is an extension of the SEEMP that formalizes review and implementation of SEEMP measures. Prior to the SEEMP, data on fuel use was generally collected daily and manually. With automated data collection, fuel use from flow meters and other system parameters can demonstrate the benefits of various operational strategies with better resolution. Analysis and evaluation of this data allows for iterative improvements to operation over time. Fuel use data may also soon be required by the IMO as part of efforts to improve fuel efficiency throughout the fleet.

System applicability	mainly propulsion and auxiliary engines
Limitations	vessels with electronic controls are more readily automated
Key challenges to deployment	system cost and design, integration to ship management program
Potential fleet penetration	once automation systems for mechanically controlled engines are available, this type of technology could be available to most of the fleet
Retrofitable?	yes
Theoretical reductions	cbc – depends on activity
Market maturity	existing solutions for some vessels with applications being designed to apply to more
Potential cost effectiveness	likely to be cost negative or cost neutral

Turbocharger technologies **Measure Category: On Ship**

Section 2.2 discusses the specific details of three turbocharging systems including high-efficiency and two-stage turbochargers and turbo charger cut-off systems. Improvements to turbocharging technologies are a key step for further reducing NOx emissions during the combustion process. These systems are particularly relevant to the port area because optimized turbochargers will continue to provide emission improvements even at lower loads. For traditional turbocharging systems that are optimized for higher loads, retrofitting with cut-off systems can improve both efficiency and emissions. They are re-listed in this section because there are so far limited installations of these systems with clear potential for growth.

System applicability	propulsion engines
Limitations	na
Key challenges to deployment	low-load emission reductions are not a high priority in most areas. Associated NOx reductions are not alone sufficient to meet existing standards. Modest efficiency improvements may take many years to
Potential fleet penetration	many vessel types with turbocharged low-speed engines. 200 installations on MAN vessels so far.
Retrofitable?	yes
Theoretical reductions	NOx – up to 40%; PM – TBD; Efficiency -- cbc
Market maturity	turbocharger cut-off systems are market ready for many systems with substantial opportunity for adaptation to new systems and applications throughout the fleet.
Potential cost effectiveness	likely to be cost neutral or cost negative over the life of the vessel if modest efficiency improvements are realized; otherwise may require incentive.

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Combustion water technologies (CWT) **Measure Category: On Ship**

Discussed more thoroughly in Section 2.2, adding water in some form to the combustion process decreases NOx production and can result in either a slight increase or slight decrease to engine efficiency. These technologies have generally existed for over a decade but have had minimal installation and testing on vessels. This is largely due to the lack of drivers – CWT cannot meet IMO Tier 3 standards alone. It is also partially due to the perception that the technology still needs to be proven and standardized. Despite the slow uptake, these technologies can be a relatively straightforward way to reduce NOx emissions on vessels with the least cost or impact. As NOx emissions reductions become increasingly urgent in certain areas, combustion water technologies could become a standard tool for minimizing emissions.

System applicability	most combustion systems can accept some form of CWT if space is available for system components
Limitations	cbc
Key challenges to deployment	vessels would need to be incentivized to reduce NOx emissions at the levels available with CWT
Potential fleet penetration	most vessel types
Retrofitable?	yes, depending on the technology
Theoretical reductions	20-80% NOx reduction depending on technology and application; PM reductions are also possible with certain technologies.
Market maturity	existing and in limited protoype/pre-market
Potential cost effectiveness	will likely need incentive to achieve cost neutrality

Barge and shore-based exhaust treatment systems **Measure Category: Off Ship**

As described in Section 2.2, exhaust treatment technologies deployed from a terminal[45] or a nearby barge[46] can help reduce emissions from vessels that are not equipped with their own systems or able to form a shore power connection. The potential or these systems is significant for ports around the world who cater to intermittent or infrequently calling ships but still want to minimize emissions at berth. These systems can achieve nearly the same results as shore power by virtue of eliminating emissions, but the vessel will still be burning fuel to run auxiliary engines.

Currently two companies have demonstrated non-ship-based aftertreatment solutions using two formats. The first permanently mounts to a terminal while the second brings capture and treatment systems on a barge alongside the vessel. Barge based systems maximize flexibility at a somewhat higher cost, while shore-based systems may be relatively less expensive and faster to deploy. So far, interest in these systems has been limited to a few ports in the United States that have the most stringent emission requirements. Developing a market outside of these areas will require strong local interest in minimizing at-berth emissions, likely matched with other incentives to help overcome costs.

System applicability	exhaust aftertreatment
Limitations	some stack configurations or ship sizes may not be compatible with existing systems, but the flexibility of the concept should allow adaptation. Terminal/berth configuration and channel size may limit certain applications.
Key challenges to deployment	capital and operating costs, lack of drivers
Potential fleet penetration	most vessel types, though mainly intended for larger vessels
Retrofitable?	na
Theoretical reductions	NOx, PM, SOx and VOC – tbd, but expected to be above 85%, dependent on stack capture efficiency
Market maturity	existing and in limited prototype/pre-market
Potential cost effectiveness	will require substantial additional incentive to recover costs; may be less expensive than shore power retrofits or other at-berth emission reduction alternatives for infrequent vessels

[45] www.tri-mer.com/images/ships-at-port.jpg
[46] advancedemissioncontrol.com/wp-content/uploads/2014/07/DSC07014.jpg

Land-based after-treatment technology demonstration, Tri-Mer

Barge-based after-treatment technology demonstration, Advanced Emissions Controls

Automated berthing **Measure Category: Off Ship**

The process of berthing a large ship can take nearly an hour and require a team of workers to place and tension lines. Automated berthing solutions have the potential to reduce this time to a few minutes. This is significant for emissions in the port area because it is time when both the propulsion engines and auxiliary engines will otherwise be running. Even though vacuum-style[47] mooring systems have existed for nearly two decades and pin and boom systems[48] have proven to be robust for ferry applications, automating this process has yet to attract widespread interest. Part of this is certainly because of the capital costs involved with purchase and installation, but there are insufficient drivers to overcome the simplicity and tradition of line-to-cleat mooring, even when systems can be shown to be reliable and cost effective. Even so, new installations are gradually being deployed with new applications are further envisioned for ship-to-ship applications and offshore facilities such as floating storage and re-gasification units.

System applicability	reduces all at-berth related emissions due to reduced time
Limitations	vacuum systems can be adapted to most berths and vessels pin and boom systems require special hardware to be installed on a vessel and must be matched to the shore-based boom system requires electricity and back-up generation to be available at the berth.
Key challenges to deployment	capital cost, simplicity and reliability of existing systems, low incentive to mooring time
Potential fleet penetration	most ships and terminals subject to above limitations
Retrofitable?	yes, these systems are primarily used as retrofits
Theoretical reductions	reduction of fuel and emissions associated with time saved during moorage operations.
Market maturity	market ready. May require custom design.
Potential cost effectiveness	likely to be cost neutral or negative over the life of the equipment

Vacuum automated mooring system, Cavotec

Pin and boom style automated mooring system, TTS

[47] www.porttechnology.org/images/uploads/technical_papers/052-054.pdf
[48] img.nauticexpo.com/images_ne/photo-g/automatic-mooring-systems-30596-174097.jpg

Alternative fuels **Measure Category: On Ship**

Most fuels that are considered "alternative" are actually common for niche applications in the maritime industry or for landside operations. Several of these fuels are emerging to become more mainstream as a result of international emission regulations combined with energy efficiency concerns from an increasingly competitive marketplace. Chief among these is liquefied natural gas (LNG), which has generated a surge of interest in recent years. While overall fleet penetration will remain low relative to fuel-oil powered ships, the rate of development of new LNG ships and the facilities to support them have compounded in recent years. As described in Section 2.2, and shown in the figure below, LNG is projected to continue to grow more than any other fuel option because of the maturity of the technology, the flexibility of having dual-fuel engines or LNG-only, and the increasing supplies and price stability of LNG in the world marketplace. This growth will largely be with mid-sized ferries and work vessels that spend a large amount of time in ECA's but will gradually be adopted for larger vessels.

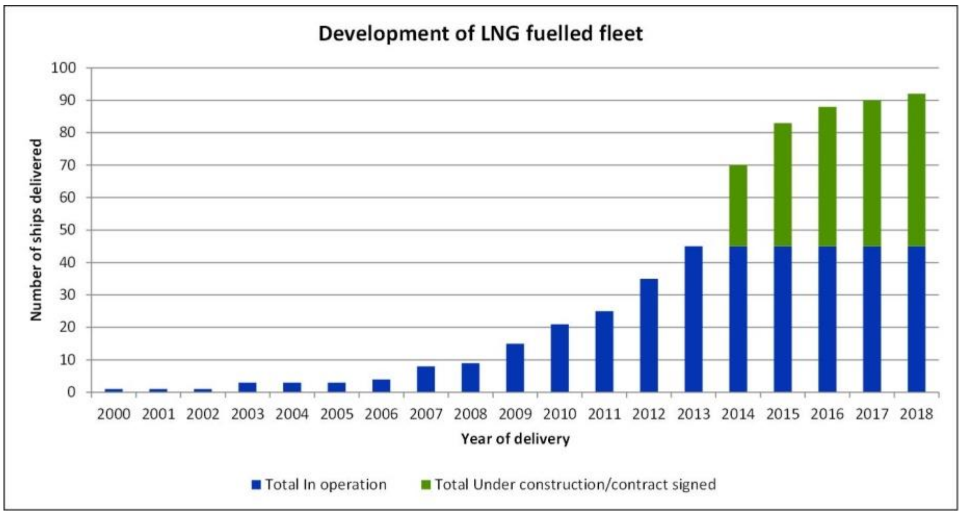
What may be considered the "second tier" of fuel alternatives for ships generally have some major downside that needs to be overcome before they may share the level of emergence that LNG has had. This downside is usually that the benefits of a particular fuel do not outweigh a higher price, immature market, or other operational concerns. This is the case for methanol and it's derivative, DME. Methanol has attracted attention because it is possible (if unlikely) to be produced from natural sources such as wood waste and it liquid at room temperature making handling easier. These benefits have still not made it more attractive than its likely feedstock, LNG, and its toxicity to humans creates additional downsides. DME is a derivative of methanol that is less toxic and can be used as an alternative to diesel fuel, but its synthesis adds significant costs over LNG and its lower fuel density adds storage burdens. Despite these limitations, both of these fuels have recently been demonstrated by the SPIRETH project[49] to be viable as ships' fuel and to be retrofit to existing engines.[50]

Also in this second tier are most biofuels in their current and envisioned forms. Biofuels, either in the form of Bio-Oil or Bio-Gas have three main origins that are referred to as their "generation." First generation fuels come directly from commercial crops such as corn or soybean. Second generation fuels come from waste products containing cellulosic materials. Third generation fuels come from algae or some other source that uses a dedicated feedstock with low environmental footprint. Biofuels are appealing because they have low toxicity and can be made to specifications that suit marine applications. The downside continues to be the cost of production for later generation fuels and the environmental impact of early generations. The drawbacks of later generation fuels are expected to diminish as research improves production. Future scenarios building on recent science[51] even envision ships that can harvest or grow algae to supplement their fuel supply.[52]

In the third tier of fuels are those that have very substantial hurdles that make their use as a ships fuel either unlikely or mainly for niche applications. These include nuclear power, which depends on development and acceptance of new reactor technologies, and hydrogen, which requires development of fuel cells and substantial development and investment in generation. Though less likely in the foreseeable future, the great benefits of both nuclear and hydrogen are attractive enough that their development and consideration will continue to be part of this discussion.

[49] www.spireth.com/
[50] www.nordicenergy.org/project/alcohol-spirits-and-ethers-as-marine-fuel/
[51] T. Nguyen,"Scientists Turn Algae Into Crude Oil In Less Than An Hour" Smithsonian magazine, Dec 2013
[52] Concepts for the Shipping Scenarios 2030 - Wärtsilä

System applicability	propulsion and auxiliary power
Limitations	fuel supply and bunkering, system compatibility
Key challenges to deployment	capital costs, fuel costs, supply, industry experience
Potential fleet penetration	most ships could be adapted for some form of alternative fuel
Retrofitable?	yes, in many cases
Theoretical reductions	varies by fuel type
Market maturity	LNG market is reasonably mature[53], though non-dedicated bunkering facilities are uncommon. Other fuels are in pre-market stage for ships
Potential cost effectiveness	LNG is likely to be cost negative while other fuels are likely to require some level of incentive to achieve cost neutrality.



Current and future LNG fuel vessels, DNV-GL

[53] blogs.dnvgl.com/lng/wp-content/uploads/2014/02/LNG-fueled-ship-orders-end-2013.jpg

Solar power **Measure Category: On Ship**

As with advanced batteries and other technologies related to electrification, photovoltaic technologies have improved substantially while becoming much less expensive[54]. In the past five years alone, the commercial price for solar panels has fallen by two-thirds, improving its cost effectiveness for a wide range of applications. The use of solar panels on ships has so far been limited. Even as the capital cost of solar continues to fall, the amount of power that it could potentially offset is minimal and many vessels lack the large flat surfaces needed to install panels.

Even so, the supplemental power that solar panels produce can pay back substantially over the life of a ship. The NYK Ro-Ro vessel "Auriga Leader" installed 328 solar panels that produce 40kW of electricity. This amounts to approximately 0.05% of its required propulsion energy, 1% of the electricity required at sea, and 10% of electricity needed at berth. Despite these small increments, over the course of a year, the solar panels offset thirteen tons of fuel. On an even larger scale, Royal Caribbean's massive vessels, "Oasis of the Seas" and "Allure of the Seas" each have solar panels covering 2000m^2 producing 111,108 kWh of energy every year.

System applicability	electrical system/generation
Limitations	solar panels are relatively easy to install, though they require space that open to direct sunlight and safe from impact.
Key challenges to deployment	cost, installation space
Potential fleet penetration	nearly any vessel could install solar panels, but few vessels have sufficient flat space to allow significant generation.
Retrofitable?	yes
Theoretical reductions	NYK currently generates 10% of necessary shore power (40kW) but hopes to achieve 100% in the future, offsetting all fuel use and emissions associated with auxiliary engine use.
Market maturity	solar panels have evolved substantially in the past 2 decades with prices continuing to fall. Panels can be built to industrial marine specification.
Potential cost effectiveness	likely to be cost neutral or negative over the life of a vessel.

Solar panels on NYK's Auriga Leader

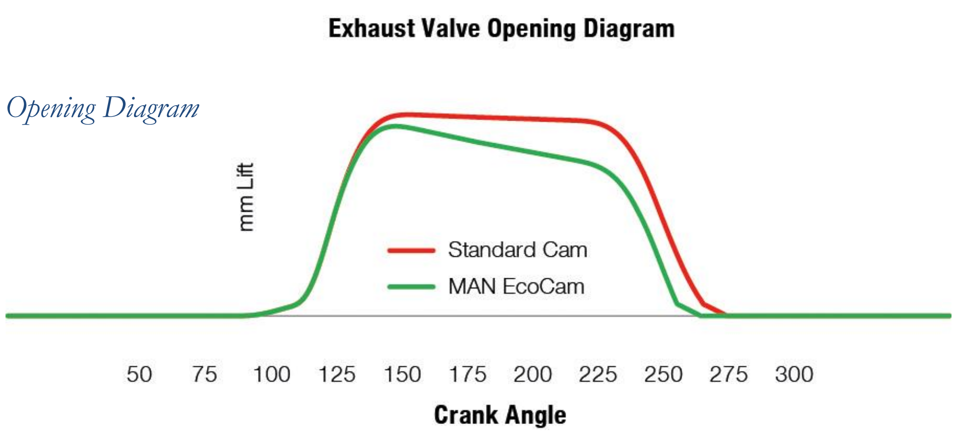
[54]; www.nyk.com/english/release/1414/NE_110525.html

Variable camshaft timing **Measure Category: On Ship**

Variable camshaft timing systems are just entering the market that enables an engine to operate with variable cam profiles without any mechanical modifications of the camshaft or engine. MAN Diesel and Turbo are introducing their "EcoCam[55]" which is a hydraulic exhaust valve timing system. The system allows for the engine to run at a lower load with reduced fuel consumption and can be deactivated when not needed. This allows an engine to run more efficiently at low loads. Theoretically in the port area, pollutant reductions could be achieved by using either high efficiency profiles (to reduce PM) or lower efficiency profiles (to reduce NOx).

System applicability	mechanically controlled 2 stroke engines with single turbocharger
Limitations	profile availability
Key challenges to deployment	none identified
Potential fleet penetration	current EcoCam system could be utilized on most two stroke MAN engines
Retrofitable?	easily retrofitable
Theoretical reductions	NOx, PM, and CO_2 reduction efficiencies: cbc depending on profile utilized
Market maturity	systems emerging on the market place
Potential cost effectiveness	likely to be cost negative, depending on profiles utilized; MAN is stating a 1-2 year payback time

MAN EcoCam Exhaust Valve Opening Diagram



[55] www.man-ecocam.com; www.corporate.man.eu/en/press-and-media/presscenter/New-Retrofit-Cuts-Fuel-Budgets-109056.html

Selective non-catalytic reduction (SNCR) **Measure Category: On Ship**

Selective Non-Catalytic Reduction (SNCR) is a chemical process for removing nitrogen oxides (NO_X) from flue gas. In the SNCR process, a reagent, typically urea or anhydrous gaseous ammonia, is being injected into the hot flue gas, reacts with the NO_X and converts it to nitrogen gas, water vapor and small amount of CO. This process takes place only in a narrow 390°F (200°C) temperature range (900°-1,100°C). No catalyst is required for this process. Instead, it is driven by the high temperatures normally found in combustion sources.

System applicability	exhaust stream of propulsion and auxiliary engines
Limitations	temperature and reagent control to prevent thermal decomposition of ammonia from over-heating and ammonia slip from under-heating, no opportunity for effective feedback to control reagent injection; nitrous oxide (N_2O) contributes to greenhouse effect
Key challenges to deployment	customization requirements; Narrow temp window leads to decomposition or slip of ammonia
Potential fleet penetration	most vessels could achieve this efficiency or emission benefits
Retrofitable?	easily retrofit with minimal downtime limited space and low capital expenditure are required systems like injection equipment; control hardware and software and modular equipment needed to be installed
Theoretical reductions	NOx Reduction Efficiency: 30% to 50%[56] ammonia/NOx (Molar Ratio): 1.0-1.5 urea/NOx (Molar Ratio): 0.5 – 0.75 energy consumption: Low thermal efficiency debit: 0-0.3% no solid or liquid wastes generated [57]
Market maturity	existing and market ready SNCR is a proven and reliable technology. SNCR was first applied commercially in 1974, and significant advances to improved NOx removal and ammonia slip control since then
Potential cost effectiveness	likely to be cost negative or cost neutral within a few years of implementation

[56] www.iea-coal.org.uk/site/ieacoal/databases/ccts/selective-non-catalytic-reduction-sncr-for-nox-control
[57] c.ymcdn.com/sites/www.icac.com/resource/resmgr/Standards_WhitePapers/SNCR_Whitepaper_Final.pdf

Low-temperature SCR **Measure Category: On Ship**

Low-temp SCR refers to SCR equipment that incorporates lower temperature catalysts. These catalysts operate at 350°F to 700°F. They typically become effective at 350°F, with efficiency climbing to 90% at temperatures higher than 400°F. Low-temp SCR makes NOX reduction for boilers, incinerators, and many other applications the smart choice. In the low-temp SCR units, the catalyst is in block instead of powder form. [58]

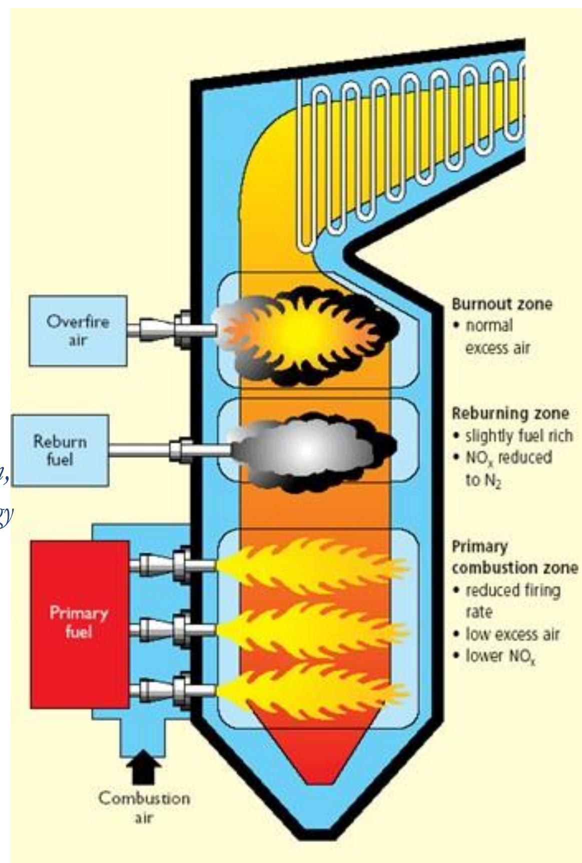
System applicability	exhaust Stream of Propulsion and Auxiliary Engines
Limitations	SCR at low temperatures present unique technical challenges over production of N2O by low-temp SCR catalysts59
Key challenges to deployment	customization requirements ammonia slip at low-temperatures (below 200 °C) stand-alone low-temp SCR units must have effective PM removal in order to prevent chemically catalytic reactions
Potential fleet penetration	low-temp SCR eliminates the need to heat the gas if the source cannot supply sufficient temperature most vessels could achieve this efficiency or emission benefits
Retrofitable?	low-temp SCR has been successfully retrofitted on gas turbines, ethylene cracker furnaces and process heaters. It allows installation with no modification or impact on the existing combustion equipment within minimum downtime the catalysts can improve NOx removal efficiency during diesel engine cold-start and cooler low-speed driving cycles
Theoretical reductions	test results demonstrate that the catalysts remove NO with >90% conversion at T≤ 150°C and do not deactivate over time in the presence of sulfur and water.60
Market maturity	existing and market ready companies like Shell has come to the market with a proprietary de-NOxing technology for industrial application of low-temp SCR61
Potential cost effectiveness	likely to be cost negative or cost neutral within a few years of implementation highly cost-effective retrofit for existing facilities where exhaust temperatures are low

[58] www.tri-mer.com/low-temperature-SCR.html
[59] web.ornl.gov/~webworks/cppr/y2001/rpt/122009.pdf?origin=publication_detail
[60] www.nexceris.com/Low%20Temperature%20SCR%20Catalysts%20(2).pdf
[61] www.crcpress.com/product/isbn/9780824723439

Low-NOx burners **Measure Category: On Ship**

Boilers that produce low-NOx emissions[62] are common in land-based applications that are located in areas where NOx emissions need to be permitted. Boilers generally achieve lower NOx output by staging the combustion process. Either by introducing the air or fuel into the combustion process incrementally; partial delays are made to the process. This reduces flame temperature and results in lower NOx. Land based low-NOx burners often use combustion staging in combination with flue gas recirculation to maximize NOx reduction, resulting in up to 90% lower NOx levels in the exhaust. Low NOx burners are not readily available for vessels due to lack of drivers, but growing interest from stakeholders is prompting vessel exhaust treatment manufacturers to begin investigating the technology.

System applicability	auxiliary boilers
Limitations	none identified
Key challenges to deployment	still in development for large-scale marine use, low demand
Potential fleet penetration	vessels with boilers
Retrofitable?	not currently available
Theoretical reductions	40-85% reduction in NOx relative to uncontrolled
Market maturity	in design/development stage; established on land-based sources
Potential cost effectiveness	will likely need some incentive to make cost neutral



Staged combustion for low NOx boilers illustration, Hangzhou Zheda Tianyuan Science and Technology

[62] www.zdty.com.cn/en/product.aspx?id=3

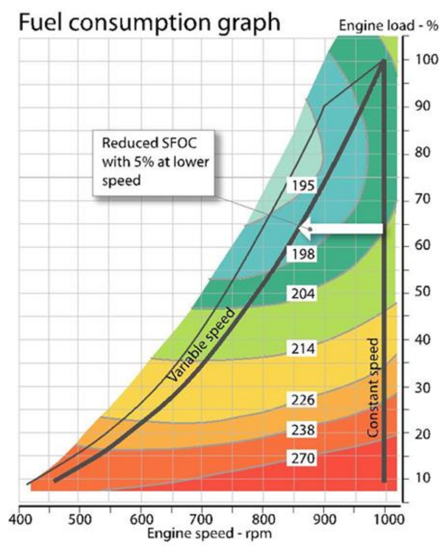
Electrical system improvements **Measure Category: On Ship**

Compared to propulsion systems, auxiliary power systems consume a meager amount of fuel and have generally been neglected in designs to improve efficiency on new vessels. Because of this, auxiliary generators and the systems that use their power have substantial potential for optimizations in both the design and retrofit stage. From the generation side, Variable Speed (VSD)[63] and Variable Frequency (VFD) drive generators offer a substantial benefit in their ability to vary their peak efficiency according to electric demand. Even though they will create substantial savings with fuel efficiency, most ships lack these advanced systems because of they are relatively new to the market, they can cost nearly double the price of a standard generator, and their complex circuitry makes repairs more difficult.

Many other electrical system components and load sources can similarly yield incremental gains with new and more expensive technologies. Of all of the electrical equipment on a vessel, the pumps and motors used in many systems create some of the largest loads but also have the potential for up to 60% efficiency improvement using VFD technology.[64] Other electrical system components and loads that can be improved with advanced technologies include lighting ballasts, power transformers, and motor starters. Additionally, power factor correction, a technique to reduce energy loss in circuits is rarely used aboard vessels, but can reduce energy consumption for numerous components including motors that regularly run at low load lower loads.

System applicability	auxiliary generation and shipboard electrical systems
Limitations	none identified
Key challenges to deployment	capital costs, complexity, incremental efficiency gains
Potential fleet penetration	most vessels and electrical systems have potential for efficiency improvements with advanced technologies
Retrofitable?	yes, depending on the system
Theoretical reductions	up to 60% electrical efficiency improvement for system pumps and motors, 2-3% fuel efficiency improvement for VSD generators.
Market maturity	market ready. May require custom design.
Potential cost effectiveness	likely to be cost neutral or cost negative over the life of the vessel

Specific fuel consumption comparison between and constant speed generators, gCaptain



[63] gcaptain.com/wpcontent/uploads/2012/01/Picture-116.png
[64] J. Räsänen and E. Schreiber (2012) "Using Variable Frequency Drives (VFD) to save energy and reduce emissions in newbuilds and existing ships" ABB White Paper

Low energy lighting **Measure Category: On Ship**

Compared to standard incandescent bulbs, modern LED lighting can last 50-100 times as long and use 60-80% less energy. This reduces maintenance costs in bulb changes, which may be in areas that are difficult to access. For cruise ships, on which lighting accounts for 25% of non-propulsion energy demand, the savings can be even greater. Celebrity's 315-meter Solstice[65] class vessels use 50,000 LED lights to accommodate 2,500 passengers with an estimated annual cost savings of €200,000. For large area lighting, compared to high intensity discharge (HID) lights such as metal halide and high-pressure sodium (HPS) that are commonly used, LEDs show better overall efficiency, less fragility, 4-5 times longer life span, and lower lumen deterioration over time. Compared to HID lamps which can require 5-10 minutes of start-up time, LEDs turn on instantly. Because flood lights are most used and needed at berth to facilitate cargo transfer and other deck operation, reduction of fuel from auxiliary engines can reduce emissions in the port area by a few percent.

LED lighting on Celebrity Solstice, Celebrit Cruise Lines

System applicability	electrical - lighting
Limitations	LED lights are now available for nearly any specification, but are less only recently available for higher output applications such as mast lighting. Environmental and electrical system factors can affect the longevity and effectiveness of LEDs.
Key challenges to deployment	high capital cost, relatively new in industrial maritime settings
Potential fleet penetration	potentially all vessels, but need a long enough life to repay capital investment.
Retrofitable?	yes. LED lamps are available to match most color, output and duty specifications.
Theoretical reductions	60% - 80% reduction to lighting energy use compared to incandescent lights[66]. ~10%-20% savings compared to HID.
Market maturity	LED's are available for most new-build and retrofit applications. The technology is continually improving with high capital costs gradually declining.
Potential cost effectiveness	likely to be cost neutral or negative over the life of the vessel

[65] www.ledsmagazine.com/content/dam/leds/migrated/objects/features/8/7/4/SharpShips1.jpg
[66] apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_energy_efficiency.pdf

Multi-mode ship propulsion **Measure Category: On Ship**

The traditional "single screw" propeller approach to ship propulsion is by far the most simple and common means of moving a ship, but not necessarily the most efficient or most conducive to maximizing efficiency during the ship-port interface. In addition to new hull and propeller designs that enhance efficiency during transit, several technologies that have been common for specialized vessels in the past could be adapted to larger vessels.

Examples of these include the contra-rotating propeller (CRP) Azipod design introduced in the early 1990's and became common on cruise vessels, the Voith Scheider Propeller (VSP) used on offshore vessels, and several different thruster technologies including detachable, encapsulated and retractable versions. These systems have commonly been deployed in applications where "dynamic positioning" (DP) is a critical aspect of a ship's function, but some companies envision wider use of thrusters to complement the propulsion efficiency at sea while improving positioning capabilities during port arrival. The potential for reducing or eliminating the need for tugs can potentially save 1-2 hours during berthing[67].

System applicability	propulsion and thruster systems
Limitations	enhanced thruster systems are likely limited to small and mid-sized vessels
Key challenges to deployment	demonstration and acceptance of new designs, adaptation of technologies to new applications
Potential fleet penetration	mainly small and midsize vessels including ferries and work boats. Potential for larger vessels in the future.
Retrofitable?	no
Theoretical reductions	varies by how much time can be saved during berthing and maneuvering
Market maturity	varies – most technologies have been demonstrated, but adaptation to new and different vessel types is ongoing
Potential cost effectiveness	likely cost negative or cost neutral over the life of the vessel

[67] "The CRP Azipod Propulsion Concept" ABB document #3BFV000388R01 REV B, 2001

Battery hybrids **Measure Category: On Ship**

Battery-electric hybrids are most commonly associated with passenger vehicles and less frequently with heavier-duty vehicles and equipment. Applications to maritime operations are only recently emerging as hybrid system sophistication increases and batteries needed are decreasing in price. The ideal application for battery hybrid systems is equipment with widely varying loads, which is why on-road hybrids get their best efficiency gains during city driving. Most waterborne transportation operates much differently from cars and trucks, with a large percentage of time spent under constant load. Engine manufacturers therefore design vessel engines to achieve their peak efficiency at the most common loads, negating much of the room for benefits from a hybridized system. The exception is for certain types of work vessels that have highly intermittent loads, such as assist tugs[68] and dredges[69], though recent applications on work boats such as the *Viking Lady*[70] and ferries like the *Prinsesse Benedikte*[71] demonstrate the potential for broader application.

With much larger ships, propulsion engines would not benefit substantially from battery hybrids during sea transit, but large banks of batteries could be charged by propulsion engines while at sea and be used to offset auxiliary engine power or shore power near ports. During dynamic positioning in the vicinity of ports and for house loads at berth, batteries charged during transit could substantially offset or eliminate generator operations. While these applications are largely theoretical, the increasing number of applications on mid-sized vessels combined with standalone systems developed explicitly for large marine applications[72] and the emergence of class guidance[73] for large maritime battery systems, indicate that battery hybrid applications on large ships may become more common in the near future. Class society DNV-GL also recently revealed their "ReVolt" concept[74] for a battery-only powered vessel for short-sea shipping, noting that the concept is entirely possible with today's technology.

System applicability	propulsion and auxiliary engines
Limitations	benefits require periods of varying engine loads
Key challenges to deployment	currently, battery hybrid applications on vessels have been custom-designed for individual system. Greater standardization and in-use testing will increase acceptance
Potential fleet penetration	most vessels
Retrofitable?	theoretically, yes.
Theoretical reductions	cbc, but existing marine applications show efficiency improvements of between 10-30% with projections up to 40%
Market maturity	some existing and limited prototype systems for midsized vessels. Large vessel applications in design/development stage
Potential cost effectiveness	cbc, but likely to be cost neutral or cost negative over the life of the vessel

[68] www.foss.com/foss-innovation/the-hybrid-tug/
[69] T Keyser, G Lee; "Sustainable and green improvements in Army Corps hopper dredges." Proceedings, WEDA XXXI Technical Conference and TAMU 42Dredging Seminar, 2011
[70] worldmaritimenews.com/archives/143249/dnv-gl-champions-battery-hybrid-propulsion-system/
[71] Corvus Energy, "Case Study: Scandlines", 2014.
[72] www.saftbatteries.com/press/press-releases/saft-launches-seanergy%C2%AE-marine-lithium-ion-modules-clean-propulsion
[73] DNV GL, "Guideline for Large Maritime Battery Systems" October, 2014
[74] www.dnvgl.com/news-events/news/revolt.aspx

Fuel cells **Measure Category: On Ship**

Fuel cell technology was first invented in the mid 1800's, but wasn't used in commercial applications until new power supplies were being developed for rockets and satellites. As a power source, the ability to convert chemical energy directly into electrical energy at nearly twice the efficiency of a diesel engine is compelling. But fuel cells have had difficulty achieving scale and market viability for a range of reasons, often including high costs and varying longevity.

Similar to batteries and solar panel technologies, fuel cells continue to achieve new milestones for both cost and robustness over the last decades and are more frequently being demonstrated in the types of applications that have preceded marine use for other technologies. Direct marine applications have been limited but instructive. The first commercial vessel to use a fuel cell, Eidesvik Offshore's supply vessel "Viking Lady," logged over 18,000 hours generating 330kW of supplementary power[75]. Fuel cells in maritime applications are also getting a boost from the increasing acceptance and use of LNG, a combustion fuel whose derivatives are also a commonly used for fuel cells.

System applicability	auxiliary and small propulsion engines
Limitations	the idea of fuel cells is compelling because of their potential to replace almost any combustion engine. Scaling the technology may present new barriers.
Key challenges to deployment	capital costs and longevity, lack of standardization
Potential fleet penetration	potentially all types of ships.
Retrofitable?	yes
Theoretical reductions	fuel cells a considered "zero emission" but may emit small amounts of NOx and other pollutants depending on fuel source. Energy conversion efficiency is approximate double.
Market maturity	fuel cells are commercially available for small land-based operations. Larger and marine-based applications require customized designs and are largely in prototype stages.
Potential cost effectiveness	fuel cells may initially be introduced as a means to improve emissions around ports and in ECA zones, but improved designs and lower costs in the future may allow them to become cost-negative.

[75] DNV-GL, "Fuel cells for ships," Research and Innovation, Position Paper 13 - 2012

Vessel size increase **Measure Category: On Ship**

Increasingly large vessels take advantage of an economy of scale that allows more transport work to be done compared to the size of the vessel. This means more cargo traveling the same speed and distance using less energy. The largest vessels in the container fleet, the Maersk Triple E class, are designed to be 50% more efficient per container than the fleet average and 20% more efficient than the previous largest ship. In general, a ship that is 10% larger will achieve a 4-5% improvement in transport efficiency. Even though the specific technologies and ships being introduced are market-ready, the underlying trend of upsizing the fleet at all levels speaks to an emerging trend that will affect port areas around the country. Rather than innovating on a single technology, entire ports are being redesigned to accommodate ships that are larger than they have historically served.

System applicability	all
Limitations	very large vessels are not appropriate for many business models because they require special berthing facilities and substantial amounts of steady volumes of cargo moving over regular times and routes.
Key challenges to deployment	berth facilities and navigable waterways, capital investment, appropriate business models. Only certain routes worldwide can accommodate the largest vessels in the fleet.
Potential fleet penetration	cbc – depends on the port, ship type, type of service, etc.
Retrofitable?	no
Theoretical reductions	up to 50% efficiency improvements (cbc)
Market maturity	Market ready for vessels. Emerging design approaches for port areas.
Potential cost effectiveness	upsizing vessels as a strategy for reducing costs within a fleet operation as older vessels are retired would theoretically be short-term cost effective if cargo volumes scale appropriately.

Megaboxes and alternative freight modules **Measure Category: On Ship/Off Ship**

Standardized containers revolutionized the shipping world nearly 65 years ago leading to substantial efficiency increases in all aspects of freight transport. These containers and the standardized equipment used to move them around on land and at remain a mainstay of the goods transportation industry. What originally seemed like a large volume to fill and move in a twenty-foot container and later in forty and forty-five-foot containers is now much smaller relative to the ever growing sizes of ships and terminals used to move them around.

Moving these individual units is now becoming one of the choke points for ships at berth when each container needs an individual lift by large ship to shore cranes and the terminal equipment that handles them after the lift. The massive size of the new cranes required to service the largest container vessels have a higher and longer lift period for every container meaning they can move fewer containers per hours. The solution so far has been to optimize terminal container management coupled with using as many cranes as possible at one time to unload the ship. With larger ships becoming the norm and with increased connections among carriers, terminals, and other parts of the supply chain, a larger container or consolidated package of containers could be moved in entirely different ways. Wärtsilä envisioned (xx ref) a container that is sixteen times the size of the standard twenty-foot container. Larger containers or container clusters could reduce the handling time needed to load and unload ships and enhance the efficiency offered by larger ships.

System applicability	na
Limitations	alternative modules would require dedicated ships, terminals, and handling equipment designed specifically for the format.
Key challenges to deployment	larger containers or container clusters would require substantial planning and investment in the concept.
Potential fleet penetration	megaboxes would be an option initially best suited to the largest vessels and terminals involved in goods transport as well as specialized niche transloading operations.
Retrofitable?	It is possible that a megabox could be designed to be compatible with some existing container ships.
Theoretical reductions	if larger containers or container clusters could be moved from the ship at half the speed of current forty-foot containers, ship berth time would be reduced up to 75%.
Market maturity	theoretical; though certain limited barge operations are using larger “SECU” containers for shipping paper products.
Potential cost effectiveness	na

Alternative cargo loading **Measure Category: On Ship/Off Ship**

With increasingly large ships being deployed to the container fleet, loading and unloading containers using ship-to-shore cranes becomes more time consuming and reduces the overall efficiency of the ship-port transaction. As new containerization concepts are being envisioned that involve either larger containers or container clusters, new or hybrid approaches to loading and unloading containers could improve port transaction efficiency. One of Wärtsilä's future ship scenarios[76] envisions simultaneous overhead crane and rear stern unloading of megaboxes. In addition to entirely different ships, cargo terminals would have to be completely revised with surfaces designed for much higher weight and backlands infrastructure to conduct intermediate transloading or cargo reconfiguration.

System applicability	na
Limitations	similar to adopting alternative freight modules, new transfer schemes would require dedicated ships, terminals, and handling equipment designed specifically for the format.
Key challenges to deployment	alternative loading schemes would require substantial planning and investment for dedicated facilities.
Potential fleet penetration	alternative loading schemes would best be piloted at small scale with dedicated ships and routes. Large ships would benefit most from more efficient loading schemes.
Retrofitable?	unlikely
Theoretical reductions	reductions to emissions and energy use would be consistent with reduced time at berth.
Market maturity	theoretical; though many exiting specialized and niche operations such as RoRo and breakbulk may indicate possible new solutions.
Potential cost effectiveness	na

[76] "ShippingScenarios 2030" www.wartsila.com/shippingscenarios

Non-berth transloading and floating harbors **Category: Operational**

As described previously, transloading containers from larger ships directly to smaller vessels or barges without being tied up to a berth on land is a common practice in Hong Kong, but not in the rest of the world. This is because the practice involves higher risk for the vessels and cargo owners. On the other hand, the practice reduces congestion on land by taking advantage of relatively calm near-shore waters to conduct transloading activities.

If the risk of this activity could be substantially lowered, transloading operations away from land could be an effective alternative in many parts of the world, creating a wide range of new logistic options for staging and distributing cargo for coastwise transport and expanding the accessibility of land areas with shallow waters. Safer options for this type of system of have proposed, often involving offshore platforms and secure anchorages[77]. Another alternative was also recently theorized and tested using the automated berthing systems referenced in a previous measure.[78] In this trial conducted in the Republic of Korea, a barge equipped with vacuum berthing system and automatic winches was fastened securely to a larger vessel, demonstrating that validity of the concept. Ship-to-ship transfers in this manner could negate the need for any external facility and further improve the efficiency of the non-port cargo operations. As much an answer to port congestion as improved efficiency, these types of solutions – and others – will be the likely result of an evolving system of freight management.

System applicability	all (cbc)
Limitations	only practical in calm or otherwise protected waters;
Key challenges to deployment	extensive testing on a variety of vessels and environments needed. Organization of support fleet and safety protocols
Potential fleet penetration	dependent on the port
Retrofitable?	possibly
Theoretical reductions	modest reduction of air pollutants with improved transfer efficiencies
Market maturity	established practice in Hong Kong; limited current application outside Hong Kong, China. Limited
Potential cost effectiveness	cbc

[77] Morrison JR, Lee T (2009) "Decoupling (un)loading operations from the land-sea interface in port service: the mobile floating port concept." In: Proceedings of the fifth international conference on axiomatic design
[78] Y Kim, et al, 2014 "A ship-to-ship automatic docking system for ocean cargo transfer,: Journal of Marine Science and Technology, Volume 19, Issue 4, pp 360-375

Virtual arrival and alternative service policies **Measure Category: Operational**

Congestion and other factors at busy ports can occur on both the land and waterside but both result in ships spending longer time than necessary in the port area. The concept of a ship's virtual arrival has been theorized as a means to mitigate congestion due to delays. Under this concept, a ship being loaded at one port would receive notice that required berth time at the next port is being delayed. The ship could then adjust its voyage speed in order to arrive at the berth at the appointed time while minimize its speed and fuel use[79]. This theoretically reduces energy and emissions both during the ocean transit and in the port area.

The concept depends on a specific model for berthing assignments that assumes flexible berthing times. The traditional "first-come first-served" model, for instance, may support this type of arrangement while models that have set berthing times for regular liner service customers would not. Terminal service policies vary widely among ports in the world and often involve multiple tiers of policy based on individual contracts (Terminal Service Agreements) and berth availability. Vessels that have greater ability to schedule berths regularly and in advance will generally be able to negotiate fewer delays and better terms with terminal operators. It would be assumed therefore that vessels that require greater flexibility will be subject to more delays, but analyses have shown that tailoring service policies to match ship behaviors can yield significant energy savings during transit and in the port area.[80]

System applicability	na
Limitations	only applicable to vessels and ports with amenable operation models
Key challenges to deployment	terminal contract obligations and prioritization, difficulty in coordinating among multiple parties
Potential fleet penetration	most applicable to non-liner service vessels and vessels without regular berth contracts
Retrofitable?	na
Theoretical reductions	varies case-by-case
Market maturity	na
Potential cost effectiveness	likely to be cost negative

[79] "Virtual Arrival: Optimising Voyage Management and Reducing Vessel Emissions - an Emissions Management Framework" OCIMF, Intertanko, Novemeber 2010.

[80] C. Kontovas and H. Psaraftis (2011): "Reduction of emissions along the maritime intermodal container chain: operational models and policies", Maritime Policy and Management, 38:4, 451-469

ANNEX 3 – Case Studies

1. Volatile Organic Compounds (VOCs) Recovery at the Port of Amsterdam
2. California's At-Berth (On) Shore Power Regulation
3. Port due discounts based on Environmental Ship Index (ESI)
4. Implementation Strategies for Clean Air Action Plan Ship Measures
5. Comparison of Two Incentive Schemes at PANYNJ
6. Differentiation of fairway dues (2015 proposal)
7. Vessel Speed Reduction Programs (VSR) in USA
8. Norwegian NOx fund (NOx tax)
9. Clean Air Action Plan (CAAP)
10. Finnish investment aid
11. The Fair Winds Charter (FWC), Hong Kong, China
12. Shenzhen Incentive Scheme to Reduce Ship and Port Emissions
13. Maritime Singapore Green Initiative
14. CAAP Technology Advancement Program (TAP)

Volatile Organic Compounds (VOCs) Recovery at the Port of Amsterdam	
Stakeholder(s)	• Port of Amsterdam Terminals • Provence of North Holland (PNH) - regional regulator • Communities of Amsterdam and Zaanstad • Amsterdam Fire, Police and Health departments
Location	Port of Amsterdam, The Netherlands
Objective(s)	Find a viable solution to allow the terminals to continue to operate and grow (green), while reducing impacts on the surrounding community and vessel congestion (due to limitations on ship/vessel operations) at the port.
Drivers	• Community complaints to the regional regulator associated with the marine-related operations at the Port's petroleum products terminals. Fugitive VOC emissions were being generated from various terminal-related operations including: loading seagoing vessels (main source), cleaning landside storage tanks, degassing inland vessels, ship tank cleaning, and ship-ship transfers. • The initial PNH response was to stop loading when complaints were received. This in turn slowed vessel operations and increased congestion for ships and inland vessels. • Finding a sustainable solution to allow the terminals to continue to operate at efficient and effective levels and allow for 'green' growth.
Pollutants	Fugitive VOCs
Barriers	• Costs for shore side facilities (born by terminals). • Air quality permit (terminal and regulator). • Maintaining a level playing field for ship-to-ship transfers. • Solution for cleaning sea-going ship cargo tanks, ship to ship operations, and degassing inland tankers. • Inert gas issues had to be solved.
Technical/Operational Measures	• The Port, terminals, and PNH developed and agreed upon operational guidance procedures when operations need to be limited or stopped. • PNH required landside VOC recovery systems for all terminal as part of the permit renewal process. • Mobile VOC recovery solutions to – testing phase. • The Port amended port by-laws to preclude emissions of VOCs from loading operations during ship-ship transfers. • The terminals developed guaranteed loading rate (by terminal, product, and type of ship).
Implementation	• Landside VOC recovery systems were required for permit renewal.

	• Modification of the Port by-laws forbidding ship-to-ship operations, unless vapour return connected between ships or other solution (e.g. mobile vapour recovery unit) to prevent emissions. • Outreach to communities affected by the fugitive VOC emissions to inform them on measures being taken to reduce impacts and resolve the issue. • Demonstration of a mobile VOC recovery unit that can be used on land or directly on a vessel. • The Port requires all inland vessels to obtain a Port permit to degas cargo tanks in advance of starting degasing operations. • Notification to IMO of VOC recovery operations. (see GISIS, regulation 15.2 of Annex VI).
Monitoring/Certification Requirements	Terminal permit recordkeeping and reporting requirements. Inland vessels, berthed in the port, need a port permit (Port By-Law) prior to degassing their cargo tanks.
Financial Implications	• Port's cargo throughput declined, outreach and facilitation costs. • Terminals – landside equipment ~10 mil euros/terminal for sea going vessels (inland was already required by EU). • Financial benefit to shippers – no delays in port. • Social and health impacts avoided. • Product recovery.
Vessel Applicability	All tank-vessels loading VOC cargo must have vapour recovery connection (petroleum tankers, chemical tankers, inland tank-barges).
Applicable Emission Source & Mode(s)	• Petroleum cargo storage tanks on ships and inland vessels. • At-berth.
Wider Applicability	World wide
Measured Effectiveness	• Number of complaints and incidents significantly reduced. • Terminal permit conditions and reporting requirements. • Number permits for ship-to-ship operations and inland vessel tank degasing. • Port enforcements. • In general in the end: win-win-win (no congestion-guaranteed loading speed- no VOC-emissions: image improved).
Industry Impacts	• Shore-side vapour recovery has been successful in allowing the terminals to work efficiently and effectively without significant delays related to work stoppage due to community complaints. • Terminal and vessel operators are happy with the reduction in port congestion associated with petroleum cargo operations. • Still challenges with: o Degassing inland vessels;

	○ Ship-to-ship transfer of VOC cargo between an inerted tanker and a non-inerted tanker not possible.
Resources	[1] www.amsterdamports.com/Eng/business-english/liquid-and-dry-bulk/liquid-and-dry-bulk-Overview-liquid-bulk-terminals.html

California's At-Berth (On) Shore Power Regulation	
Stakeholder(s)	United States Environmental Protection Agency (EPA); California Air Resources Board (CARB); California Ports (Los Angeles, Long Beach, Oakland, San Diego, San Francisco, and Hueneme); Marine Terminal Operators; Vessel Fleet Operators
Location	California, USA
Objective	The objective is to reduce emissions and the associated health risks from on board diesel auxiliary engines on container ships, passenger ships, and refrigerated-cargo ships while hotelling at berth.
Drivers	Since the 1990s, the Clean Air Act[1], designation of diesel PM (DPM) as toxics[2] and a recent mandate (AB 32)[3] to reduce California's GHG emissions to 1990 levels by 2020 requires the state of California to develop strategies to combat high ozone, DPM and GHG emissions in many of its regions and sectors, including goods movement. The ports play a significant role in goods movement and ships or ocean going vessels are one of the largest sources of emissions. The 2006 Ports of Los Angeles and Long Beach Clean Air Action Plan[4] (CAAP) included shore power as a port-led emissions reduction measure. The health risk associated with shore power emissions led CARB, in 2007, to adopt an at-berth emissions control regulation[5] in order to help meet state wide health, air pollution, and GHG abatement related goals.
Pollutants	Use of shore power will reduce DPM, PM, NO_x, SO_x, HC, CO and GHG emissions. If an alternative technology option is used, DPM and NO_x must be reduced by at least 85-90 percent.
Barriers	Implementation required 1) significant cost to be incurred by ports/terminals and ship operators; 2) compatibility with at-berth infrastructure and a significant number of visiting vessels retrofitted with still-emerging technologies; 3) assurance of adequate power from utility companies all year around; and 4) the provision of this utility power at a reasonable cost. Steps taken to overcome barriers: 1) International Organization of Standards (ISO) standards critical for ensuring that shore power technologies could be used worldwide were developed; 2) Individual ports worked with their electricity suppliers. As an example, the Port of Long Beach and Southern California Edison, the local electric utility, installed two miles of electrical lines into and throughout the port and built new substations to ensure a reliable power grid for the port; 3) CARB provided grant funding assistance to help install shore power infrastructure at berth.

	Operational problems encountered through the use of these systems were addressed through amendments to CARB's shore power regulation prior to coming into effect in 2014.
Technical/ Operational measures	Turning off ship auxiliary engines and utilizing shore side power for ships' operations while at berth; evaluation of two systems that capture emissions and treat with mobile barge mounted control devices as an alternative to shore power is underway.
Implementation	The CARB At-Berth Regulation is applicable to container and refrigerated cargo fleet with annual calls ≥ 25 and cruise vessels fleet with annual calls ≥ 5. It provides two compliance options: 1) Turn off auxiliary engines and connect the vessel to dock-based power such as grid-based shore power; or 2) Use alternative control technique(s) that achieve equivalent emission reductions. The compliance phase-in schedule is: 10% of calls in 2010, 50% of calls in 2014, 70% of calls in 2017 leading up to 80% of calls in 2020 to be under compliance. The regulation requires several record keeping requirements from ports and terminal operators.
Monitoring/Certification requirements	The regulations require several record keeping requirements from ports and terminal/vessel fleet operators. Emission reductions from new alternative systems need to be verified by regulatory entities (CARB or EPA). Shore side power retrofits on ships need to be certified by their classification society.
Financial Implications	Ports cost for shore power infrastructure: • Port of Los Angeles -US$ 180 million - 25 container berths and 3 cruise berth; • Port of Long Beach -US$ 185 million - 12 container berths; • Port of Oakland - US$70 million - 11 berths; • Port of San Diego - US$ 4.25 million - one terminal. Vessel retrofit cost - US$ 500,000 to US$ 1.1 million Regulatory agencies provided partial grant funding - US$74 million
Vessel Applicability	Both new and existing ships.
Applicable Emission Source & Mode(s)	Auxiliary engines while at berth.
Wider applicability	World wide
Measured effectiveness	~200 vessels have been retrofitted to receive shore power while at berth and 63 berths at 23 terminals in California are ready with shore power infrastructure. Once connected to shore power, emissions are reduced approximately 90 percent.
Industry Impacts	The financial impacts are very significant, since regulators, ports and vessel owners have already invested over $450 million to implement the regulation, and implementation is not yet complete. Redeployment, which is an on-going reality for fleets, becomes a challenge as shore powered-equipped ships scheduled for

	California routes, if redeployed could result in non-compliance with the regulation's phase-in schedule.
Resources	[1] www.epa.gov/oar/caa/partnership.html [2] www.arb.ca.gov/research/diesel/diesel-health.htm [3] www.arb.ca.gov/cc/ab32/ab32.htm [4] www.cleanairactionplan.org [5] www.arb.ca.gov/ports/shorepower/shorepower.htm

Port Due Discounts Based on Environmental Ship Index (ESI)	
Stakeholder (s)	IAPH/WPCI, ports, ship operators
Location	Mainly discounts at mainly EU and US ports
Challenges	Ports are taking their responsibilities in maintaining a clean and healthy environment in the port area. Clean and efficient land based operations in ports are part of that responsibility but ports also try to improve the performance of ships visiting their ports areas by encouraging them to reduce their air emissions as much as possible. Ports are faced by the following challenges: • Increased stakeholder acceptance (license to operate) • Air quality legislation (e.g. EU Directive 2008/50) • Air quality concerns of regulators
|	NO_x, SO_x, CO_2 (PM indirect)
Barriers	Implementation of NO_x reducing techniques require significant investments for operators that are generally are no taken on the basis of business considerations only. ESI contributes to closing the 'business case gap' and illustrates the increased attention of ports for clean shipping.
Implementation	The Environmental Ship Index (ESI) identifies seagoing ships that perform better in reducing air emissions than required by the current emission standards of the International Maritime Organization. The ESI evaluates the amount of nitrogen oxide (NO_X), sulphur oxide (SO_X) that is released by a ship and includes a reporting scheme on the greenhouse gas emission of the ship. The ESI is a good indication of the environmental performance of ocean going vessels and assist in identifying cleaner ships in a general way. Formulas can be found at: www.environmentalshipindex.org/Content/Documents/ESI-Fundamentals.pdf A ship can get a maximum score of 100 points at maximum, if it has zero pollutant emissions and reports CO_2 emissions. There are around 30 ports worldwide that provide discounts on port dues, on an individual basis, if a ship has an ESI score above a certain threshold that varies between ports. See below for details.
Technical/ Operational Measures	ESI incentives the implementation of all possible measures. In addition, a bonus is given for ships that are able to connect to OPS.
Monitoring/certification requirements	Ship-owners have to report to the ESI administration about their performance by submitting data to the ESI database.

	The ESI approach is relying on self-declaration and does not require any data to be verified or certified by third parties
Financial Implications	Ship-owners do not pay for participation. Participating port share the costs of running the system. Ship-owners receive bonuses from ports on the basis of the score of their ships and the port specific discount criteria.
Vessel Applicability	All ships, new and existing.
Applicable Emission Source & Mode(s)	The ESI score depends on all fuels onboard, and the weighted average NO_x scores from the EIAPP certificate for all engines onboard.
Wider Applicability	The system can be expanded if more ships/port participate.
Measured Effectiveness	There is no information about the effectiveness of the system. The closure of the business case gap strongly depends on the number of port calls and if the ports where ships call Generally, limited discounts on port dues cannot close the whole business case gap, but contributes. 29 of the registered ships had a score of above 50 points. See below for details.
Industry Impacts	Around 3% of all seagoing vessels have subscribed to the ESI database. ESI based port discounts may contributed further development of the market for clean technologies, especially the programme further expands.
Resources	www.environmentalshipindex.org/Public/Home

Implementation Strategies for Clean Air Action Plan Ship Measures	
Stakeholder(s)	• Ports of Los Angeles (POLA) and Port of Long Beach (POLB) • Ship operators serving POLA and POLB terminals • Local Regulatory Agencies
Location	POLA and POLB, California, USA
Objective(s)	The goal of the Clean Air Action Plan (CAAP) was to develop and implement strategies and programs necessary to reduce air emissions and health risks while allowing port development to continue. The two ports are responsible to ensure that these measures are effectively implemented to achieve emissions reduction goals.
Drivers	• CAAP Emissions Reduction Goals • CAAP Emissions Reduction Measures for Ships
Pollutants	NO_x, PM, & SO_x
Barriers	• Ports' authority – no direct control. • Administrative – how to monitor and pay if incentives are offered. • Terminal or Vessel operator participation. • Some implementation strategies such as potential tariff changes need to undergo legal evaluation prior to being enacted.
Technical/Operational Measures	• Not a measure.
Implementation	• Lease Requirements – During renegotiated, amended, and new leases, opportunity exists for the Ports, as proprietary landlords, to negotiate and require control measures in a terminal's lease. Several terminals at the two ports have been switching to low sulphur fuel, using shore power for vessels while at-berth ahead of any regulation due to the port's negotiated lease requirements. • Tariffs Changes to Influence Activity – Since a tariff is applicable to all tenants and users of port facilities, a potential change in tariff allows more uniform application of resources to customers of a port. Incentive Funding Targeted for Specific Sources to Accelerate Emissions Reductions - Incentive-based measures provide a business incentive for the participant to reduce emissions beyond what is currently required by regulation or lease requirements. Grants - Grant programs can offer significant encouragement and can be used to spur early action by port operators to move forward with replacement, repower or retrofit projects in advance of regulatory or port requirements.

	• Voluntary Measures and Recognition Programs - Voluntary measures are non-compensated actions agreed to and undertaken by operators generally for measures that provide win-win situations for participants, which could include positive public relations press about the programs, regulatory agency or port recognition, environmental awards. • Requirements Imposed by Regulatory Agencies - Regulations from state, federal or international regulatory agencies developed with input from ports and other stakeholders are effective to create the level playing field and minimize any competitive disadvantage experienced by operators doing business at the two ports.
Monitoring/Certification Requirements	• Program specific
Financial Implications	• Program Specific
Vessel Applicability	All vessels calling POLA and POLB terminals.
Applicable Emission Source & Mode(s)	All three ship emission source categories. All port area modes.
Wider Applicability	World wide
Measured Effectiveness	• Examples of successfully implemented incentive-based programs at the ports include: POLB's Green Flag Program, Green Ships Incentive Program and Incentive for Pollution-Control Testing for vessel operators needed help with at-berth clean air technology. POLA's Environmental Ship Index Incentive program. Both ports have vessel speed reduction programs which provides incentives in the form of reduced dockage fees for vessel operators that reduce their speed to 12 knots or below near the port. Also, in 2008, both ports implemented the Main Engine Fuel Incentive Program to encourage use of low-sulfur fuel in main engines. • There are several Grant funding programs offered by local, state and national regulatory agencies that stimulate early adoption of emissions reduction technologies. The two ports have applied and received funding through these programs. • Clean Air Action Plan Air Quality Awards was developed to recognize industry efforts to reduce port-related air pollution consistent with CAAP goals. Since CAAP's adoption, annual awards ceremonies have been held starting in 2008. • Since the CAAP was adopted, low-sulfur fuel regulations for ships was adopted by the California Air Resources Board.
Industry Impacts	• Lease requirements add financial burden on the terminal and vessel operators.

	• Industry gets recognized for their efforts if they go beyond the existing requirements. It works well with their Corporate Social Responsibilities goals. • Engine and technology manufacturers get encouraged when grants are offered.
Resources	www.cleanairactionplan.org/ www.polb.com/environment/air/default.asp www.portoflosangeles.org/environment/ogv.asp

Comparison of Two Incentive Schemes at PANYNJ

Stakeholder(s)	Port Authority of New York & New Jersey (PANYNJ); Ship operators serving PANYNJ terminals; Surrounding communities
Location	PANYNJ, New York Harbor, USA.
Objective(s)	Reduce ship emissions by incentivising cleaner fuels. The Port's first program was the Low Sulfur Fuel (LSF) incentive program that paid for half the cost differential between HFO fuels and MDO/MGO fuels less than 0.5% sulphur. Over the program's three year life, the Port paid $ 369,239 in incentives to four participating shipping lines. The Port's next program, the on-going Clean Vessel Incentive (CVI), was formed around the Environmental Ship Index (ESI) scheme that was utilized by several ports. The Port developed an innovative approach by adding a Vessel Speed Reduction (VSR) component to the total CVI score. This innovation allows vessels that couldn't get an incentive on ESI score alone, have the opportunity to slow to 10 knots, 20 nautical miles from the harbour entrance.
Drivers	• Area is in nonattainment for national ambient air standards. • Green Port program needed ship component. • Encourage changes in behaviour that reduce emissions.
Pollutants	NO_x, PM, & SO_x
Barriers	• Administrative – how to pay ship operators an incentive when the Port does not collect vessel specific fees and has no legal relationship with the operator? • Vessel operator participation.
Technical/Operational Measures	• Fuel switch to cleaner fuels.
Implementation	• Funding was provided by the PANYNJ board as an operational line item. • Conducted outreach meetings with ship operators calling the Port's terminals. • Established an administrative relationship with ship operators by having them sign up as a Port Vendor and submit a vessel participation form (both programs used different versions of the vessel form). • The Port's LSF program required fuel switch data stating the type and sulphur content of the fuel used, confirmation of that the switch occurred and was completed prior to 20 nm from the entrance of the harbor. • Replaced the LSF program after three years with the CVI program, which includes ESI scores plus VSR element. • Each program paid the applicable incentive amount directly to the ship owners.

Monitoring/Certification Requirements	• For both programs, a summary of the quarter's ship activity and compliance on a call-by-call basis was provided to the ship operators for their confirmation, which was signed and sent back to the Port for reimbursement through the vendor system. This made the confirmation legally binding. • Random vessel or office audits were conducted to verify data provided.
Financial Implications	• The LSF program was budgeted to a maximum of US$1 million per year for three years. • The CVI program is funded to a maximum of $1.6 million per year for three years - January 1, 2013 to December 31. 2015.
Vessel Applicability	All vessels calling PANYNJ terminals.
Applicable Emission Source & Mode(s)	All three ship emission source categories. All port area modes.
Wider Applicability	World wide
Measured Effectiveness	• The LSF program had four participating shipping lines with a total of 30 vessels. The Port incentivised a total of $ 369,239 from 2010 through 2012. • The CVI program paid participating shipping lines a total of $ 1,936,000 as of December 2014. • There are 15 shipping lines and 581 vessels participating in the CVI program. The overall VSR compliance rate is 18%.
Industry Impacts	• LSF had limited industry impact. The administrative conditions of the first program limited the participation. • Some of the LSF operators never submitted the pre-filled out quarterly invoices. • CVI has had significant uptake.
Resources	www.panynj.gov/about/clean-vessel-incentive-program.html www.panynj.gov/about/low-sulfur-fuel.html

Differentiation of fairway dues (2015 proposal)	
Stakeholder (s)	Swedish Maritime Authority, ship operators
Location	Swedish fairways
Challenges	Recognising the need for abatement measures, the Swedish Maritime Administration, the Swedish Port and Stevedores Association and the Swedish Shipowners' Association in 1996 arrived at a Tripartite Agreement to use differentiated fairway and port dues to reduce emissions of NO_x and SO_x by 75% by the end of the first decade of the new millennium. The objective as to reduce pollution of the Baltic Sea. The Swedish Maritime Administration (SMA) is responsible for establishing and maintaining safe and environment-friendly seaways. The fairway dues cover the costs for activities that render services to merchant shipping, besides services where the individual user of services is identifiable. The basic principle for the design of the fairway dues system is to include the environmental costs, where the most important factor is the airborne emissions from vessels. Before 2015, also SO_x emissions were covered. However, since the SECA rule is 0,1% from 1-1-2015, this has been dropped. Before 2015, a fee had to be paid for ships with a sulphur level over 0.20%. Both ships in national and international traffic are liable for fairway dues.
Pollutants	NO_x
Barriers	Implementation of NO_x reducing techniques require significant investments for operators that are generally no taken on the basis of business decisions. In Scandinavia, a number of incentive schemes contribute to an improved business case, reducing the barrier for investment for the maritime industry.
Implementation	The Swedish Maritime Administration (SMA) raises fairway dues. These dues have three main components: 1. A cargo based component, . 2. A gross tonnage based component, and 3. A NO_x reduction fee. For passenger vessels, railway ferries and cruising vessels, a maximum of five calls per calendar month are suggested to be charged. For other vessels, a maximum of three calls per calendar month are suggested to be charged.

	The gross tonnage (GT) based fee to be charged in SEK (SEK/ton) as presented in the table below, where all vessels except passenger and cruising vessels are to be charged in accordance to a descending scale.

Call of the month	Ro-ro vessels, barges	Passenger vessels	Cruising vessels	Other vessels
1:st	2.60	3.00	1.50	3.00
2:nd	2.00	3.00	1.50	2.60
3:rd	1.30	3,00	1.50	1.30
4:th	0	3.00	1.50	0
5:th	0	3.00	1.50	0

The GT based fee is suggested to be differentiated in relation to emission of nitric oxides (NO_x). In the table below the reductions in percentages on the fee are presented.

NO_x-emissions, g/kWh	Reduction of the fee, %
0,00 – 0,49	95
0,50 – 0,99	90
1,00 – 1,99	60
2,00 – 2,99	50
3,00 – 3,99	45
4,00 – 4,99	37,5
5,00 – 5,99	30

Technical/ Operational Measures	All technical measures that reduce the emissions of NO_x. This an be LNG, OPS, engine internal measures, scrubbers, etc.
Monitoring/certification requirements	NOx certificate (Either EIAPP of a certificate issued by a classification society). In addition, there must be a sealed, continuously recording method of measurement or some other method approved by the Swedish Maritime Administration for checking the systems operation.
Financial Implications	Since the number of ships applying for a reduced rate is limited, the scheme has relatively limited impact. The relative reduction is, however, high.
Vessel Applicability	Fairway dues have to be paid by all ships, new and existing.
Applicable Emission Source & Mode(s)	An average KW based NOx emission level is calculated for all engines onboard. The instrument incentivises thus all emissions produced.
Wider Applicability	Differentiation of dues is also applied by Swedish ports. In principle, other stakeholders/ports can join the scheme as well. Fairway dues are not widely applied in other waters.

Measured Effectiveness	By July 2009, 37 ships had a valid NO_x certificate that allows them a NO_x-related discount on the fairway due (excluding vessels owned by the Swedish Maritime Administration). Among them 34 have installed SCR, two apply water injection, one has installed HAM, one is a cargo vessel that has relatively low emissions (7-8 g/kWh) without having installed SCR, and one is a high-speed craft powered by low-NO_x emitting gas turbine engines.
Industry Impacts	The differentiation of port dues is part of a larger system regime of incentives of NO_x emissions reduction. In addition, around 25 Swedish ports provide incentives to reduce NO_x emissions. The Norwegian NO_x fund also impacts the decision of ship operators to implement measures.
Resources	www.sjofartsverket.se Airclim, 2009; Market-based Instruments for NO_x abatement in the Baltic Sea

Vessel Speed Reduction Programs (VSR) in USA

Stakeholder	United States Environmental Protection Agency (EPA); California Air Resources Board (CARB); Ports of Long Beach and Los Angeles, Local Residents; Environmental Groups, Marine Terminal Operators; and Marine Industry
Location	Port of Los Angeles (POLA), Port of Long Beach (POLB), Port of San Diego (POSD), Port Authority of New York & New Jersey (PANYNJ), USA
Objective	Reduce ship transit NO_x and PM/DPM emissions in the vicinity of Port area.
Drivers	• VSR is one of the emissions control measure for POLA and POLB's Clean Air Action Plan, POSD's Clean Air Program and PYNYNJ's Clean Air Strategy for the Port of New York and New Jersey. • Ports emissions inventory show near port transit emissions from ships are one of the biggest contributor of NO_x and DPM/PM. • Currently, very few emissions control strategies exist that reduce NO_x emissions. VSR has been identified as one of the operational measures to effectively reduce NO_x emissions during ship transit. • Co benefit of this program is reduction in GHG and fuel consumption. • VSR program can be implemented in short time frame with no capital expenditure. • VSR program can be monitored and verified by accessing automatic identification system data transmitted by all ships. • Administrative cost is low.
Pollutants	Reduce NO_x, DPM, PM, SO_x and GHG - fuel consumption reduction is a co benefit
Barriers	Implementation requires: • Lost hours while a ship is complying with VSR program can lead to financial loss for carriers and their shipping customers • Limitation due to geography (constrained navigation channel) and domain of the port boundary – due to geography sometimes ships have to travel slow for safety reasons • Fleet mix – Tankers and integrated barges naturally travel at low speed • Ships that have auxiliary engine loads very similar to main engine loads during transit mode near the port Steps taken to overcome barrier: • The Ports have overcome the delays in reaching the berth by moving work assignment from dockside to VSR zone

	boundary; • Except the Port of San Diego, all other VSR program implementing ports provide financial incentives. POLA and POLB provide dockage fees reduction to those shippers that volunteered to comply with the program; PANYNJ provide financial incentives; • POLA and POLB take the opportunity to implement VSR program during terminal redevelopment projects, new major leases and lease amendments that could be approved and implemented in near future.
Implementation	VSR is a volunteer program backed up by environmental achievement awards, work assignment allocation modifications to accommodate later arrival of ships at berth and financial incentives which vary by port. Based on geography, vicinity of human population near ship transit zone, each port created VSR zone where ships slow down to certain speed – POLA[1] and POLB[2]: 12 knots or below; POSD[3] – 15 knots or below for cruise ships and 12 knots or below for other ships; PANYNJ[4] – 10 knots or below. To be considered VSR compliant, POLA, POLB and POSD require 90% of the trips for a shipping line in a given calendar year to comply with VSR speed. PANYNJ's VSR program part of their three year Clean Vessel Incentive programs which provides incentives on first come first basis
Technical/ operational measures	Ships slow down their speed from open sea transit speed to VSR speed which ranges between 15 knots to 10 knots. This reduces total load of propulsion engines and increase total load of auxiliary engines as they have to run for longer duration as it takes the ship longer time while complying with VSR speed compared otherwise higher speed during transit
Monitoring/certification requirements	Availability of AIS data
Financial implications	POLA and POLB each have committed as much as US $ 2.2 million a year in dockage fees reduction[5]. POSD's program has no financial incentive element. PANYNJ has a funding cap of US $ 1.6 million per year for clean vessel incentives to be reimbursed on first come first basis. VSR incentive is one of the three incentives covered under this program.
Vessel Applicability	All vessels with the exception of those which naturally operate at slow speeds or those with auxiliary engine load as high as propulsion engine load.
Applicable Emission Source & Mode(s)	Propulsion and auxiliary engines. During transit mode.
Wider applicability	Worldwide with constraint of geography of navigating transit are near ports and strong water currents

Measured effectiveness	VSR compliance rate – POLA: In 20 nm zone, VSR compliance increased from 65% in 2005 to 98% in 2013, in 40 nm zone, VSR compliance increased from none in 2005 to 83%; POLB: In 20 nm zone, VSR compliance increased from 68% in 2005 to 99% in 2013, in 40 nm zone, VSR compliance increased from none in 2005 to 88%; POSD in 2013: 59% in 20 nm zone, PANYNJ: 12 shipping lines have received clean vessel incentives program incentives, VSR program is a great example of an operational emissions control measure, if designed properly, which is good for the regulatory authorities as well as industry as it results into emissions reduction which has environment benefits and fuel saving which reduces cost of operation for shippers
Industry Impacts	Overall shipping lines have volunteered to comply with VSR speeds as they realize fuel consumption saving along with financial incentives from ports.
Resources	[1] www.portoflosangeles.org/environment/ogv.asp [2] www.polb.com/environment/air/greenflag.asp [3] www.portofsandiego.org/environment/clean-air.html [4] www.panynj.gov/about/clean-vessel-incentive-program.html [5] wpci.iaphworldports.org/iaphtoolbox/vsp_project.html

Norwegian NO_x fund (NO_x tax)	
Stakeholder (s)	(agencies, ship-owners, ports, etc., as applicable) Norwegian NO_x tax and NO_x fund
Location	Norway
Challenges	In Norway, a NO_x tax was introduced 1st of January 2007 of 1,9 € (15 NOK) per kg NO_x, to meet the objectives of the Gothenburg protocol (emission cap). The Gothenburg protocol is an UNECE initiative that requires countries to reduce its emissions, below a certain agreed level.
Pollutants	NO_x
Barriers	NO_x emission reduction measures do not provide business benefits. The Norwegian system significantly reduces the financial gap between low and high NO_x alternatives
Implementation	The NOx fund was set up by 15 co-operating business organisations. Affiliated companies pay € 0,5 per kg NO_x to the NO_x Fund, instead of paying the government NO_x tax. Undertakings that join the Environmental Agreement are obliged to apply for support for measures to reduce NO_x emissions in situations with a return-on-investment time shorter than three years, taking the fiscal NO_x tax and the support from the fund into account. Support will be granted for investment costs (up to 80% of overall additional costs) as well as operating costs (urea). Between 2011 and 2016, The NO_x fund is committed to reduce emissions by 34 kton per annum (2012: 180 kton in baseline). The NO_x fund has granted significant parts of the overall granted budget for LNG and SCR investment projects, mainly for seagoing ships. Support is not granted for NO_x reductions resulting from NO_x requirements laid down by the authorities (e.g. IMO-requirements). Support is not granted for NOx reductions resulting from requirements stipulated in public tenders. Propulsion engines exceeding 750 kW -aimed at marine engines- are subject to taxation. Emissions from sources that are subject to the so-called Norwegian Environmental Agreement are exempted from the NO_x tax. The tax and fund apply to domestic shipping only.
Technical/ Operational Measures	All technical measures that reduce the emissions of NO_x. This is mainly LNG, but also SCR, etc.
Monitoring/certification requirements	A third party approved measurement is required. The NO_x fund uses a reporting tool that has to be filled out by companies, on regular basis. Urea consumption must be monitored.
Financial Implications	The Fund has about 75 million € each year available for support of NOx reducing measures (~ 50% to LNG-projects last 3 years).

Vessel Applicability	Both new and existing ships.
Applicable Emission Source & Mode(s)	The application is mainly main engines, as only engines over 750 kW are subject to the NO_x tax.
Wider Applicability	To date, this system is only applied in Norway. In principle the scheme can be broadly applied, but is conditional to a stick type of instrument that drive ship-owners to joining a business fund. National application may impact the level playing field between ports, and for international application, it may be difficult to find the right stick, since taxation is a national matter.
Measured Effectiveness	The NOx Fund has granted support to over 60 ships, converted to LNG or newbuilds. Applications for 30 more ships received by the end of 2013.
Industry Impacts	The impact on industry is significant, as the economic viability of projects focussing on emission reduction is increased significantly. Norway is leading on the roll out of LNG as a fuel for shipping.
Resources	www.nho.no/en/NOx

Clean Air Action Plan (CAAP)

Stakeholder	United States Environmental Protection Agency (EPA); California Air Resources Board (CARB); Ports of Long Beach and Los Angeles, Local Residents; Environmental Groups, Marine Terminal Operators; and Marine Industry
Location	Port of Los Angeles and Port of Long Beach, California, USA
Objective	In 2006, SPBP worked proactively with air quality regulatory agencies and other stakeholders to develop a one of a kind comprehensive CAAP[1] that addressed emission reductions goals from all port-related emissions source categories. This plan was further updated in 2010 and continues to be implemented today.
Drivers	• Ports recognize that their ability to accommodate the projected growth in trade will depend upon their ability to address adverse environmental impacts (and, in particular, air quality impacts); • Minimize health risk from port operations and reduce ports "fair share" emissions as the predicted future economic growth occurs at the SPBP; • Accelerate existing emissions reduction efforts; • Prevent port-related contribution towards violation of National Ambient Air Quality Standards (NAAQS); • Set consistent project and source category specific standards that can be implemented in a uniform manner; • Ships are largest contributor of emissions and health risk impact due to their proximity to surrounding communities while at berth.
Pollutants	Reduce DPM, PM, NO_x, SO_x and prioritise GHG reductions co-benefit when deciding between emissions reduction strategy options
Barriers	Implementation requires: • Significant cost to be incurred by ports, terminals and ship operators; • Availability of technologies and promoting demonstration of commercial viability of still-emerging technologies; • Development of implementation strategies given the Ports do not have jurisdiction to regulate emissions from ships (which are subject to international regulatory standards); • Ensuring the Ports remain competitive. Steps taken to overcome barriers: • The Ports and the regulatory agencies committed funding to jump start the implementation of several key CAAP emissions control measures; • The two largest container ports in the United States are together in this commitment which helps maintain competitiveness;

	• The Ports take the opportunity to implement CAAP measures during terminal redevelopment projects, new major leases and lease amendments that could be approved and implemented in near future.
Implementation	Emission reductions from ships were addressed through a combination of measures that include operational controls, (on) shore-power, cleaner fuels, and a research and development initiative to help identify and demonstrate new technologies to reduce at berth emissions.
Technical/ operational measures	Following measures were developed for ships[2]: • Vessel Speed Reduction Program -requires ships to reduce their speeds at or below 12 knots when approaching the port; • Reduction of At-Berth Emissions - requires use of shore-power or alternative hotelling emissions reduction technologies; • Auxiliary Engine Low Sulphur Fuel Standards - requires use of low sulphur fuel in auxiliary engines when operating within port over-water boundary and at berth • Main Engine Low Sulphur Fuel Standards –requires use of low sulphur fuel in main engines when operating within port over-water boundary would phase in the use of ≤0.2% S MGO fuels in auxiliary engines within port over-water boundary • OGV Main and Auxiliary Engine Emissions Improvements- It requires incorporation of successfully demonstrated technologies or technologies into existing and new ship engines to reduce NO_x, PM and SO_x. • Established the Technology Advancement Program to evaluate, demonstrate, pilot, and incorporate new emission reduction strategies to achieve significant reduction in DPM and NO_x from ships operating in port.
Monitoring/certification requirements	The CAAP measures are included into new lease and redevelopment projects as condition for approval of those projects. At-berth emission reductions and low sulphur fuel standards for auxiliary and main engines measures were later adopted as regulations in California by CARB. Further, the International Marine Organization has now adopted low sulphur fuel standards.
Financial implications	There is significant cost incurred by ports, terminal operators and vessel operators to implement CAAP measures. These are on-going costs which cannot be quantified at this time.
Vessel Applicability	Both new and existing ships.
Applicable Emission Source & Mode(s)	Main and Auxiliary engines during all modes of operation

Wider applicability	Worldwide - Port specific depending upon the challenges and drivers faced by each port.
Measured effectiveness	• In 2013, Over 95% of SPBP ship calls within 20 nm zone of the ports and over 80% of ship calls within 40 nm zone of the ports slowed down to 12 knot or lower. • Per CARB regulation, in 2014, with few exceptions, majority of the applicable container and cruise calls at California ports are meeting 50% reduction in at-berth emissions by utilizing shore power. • Per IMO's requirement in the Emissions Control Area, in 2014, all main and auxiliary engines in ships arriving and departing from the ports are using 0.1% S fuel within 200 nm. • Ports developed incentive programs that provide financial incentives to vessel operators that bring Tier 3 vessels or existing Tier 0 - Tier 2 vessels retrofitted with emissions control systems that further reduces emissions. • Ports develop annual emissions inventories3, 4 from their all mobile source operations to track progress of CAAP measures. • The Ports' OGV emission reductions between 2005 and 2013: 80% in DPM/PM, 35% in NO_x, and 90% in SO_x.
Industry Impacts	Overall cost to comply with CAAP measures is significant Industry has to adjust their operations depending upon the control measure
Resources	[1] www.cleanairactionplan.org [2] www.cleanairactionplan.org/reports/documents.asp [3] www.polb.com/environment/air/emissions.asp [4] www.portoflosangeles.org/environment/studies_reports.asp

Finnish Investment Aid

Stakeholder(s)	The Finnish government, vessel fleet operators, European Commission
Location	Finland
Challenges	Maintaining the competitiveness of the Finnish maritime industry whilst aiming at sustainable maritime transport – in particular SO_x emissions. 80 % of foreign trade of Finland is transported by sea. The objective of the scheme is to: • To encourage ship-owners to make environmentally friendly investments • To speed up commercial use of environmentally friendly technology • To simplify the adaptation to new emission requirements • Especially SO_x emissions
Pollutants	Mainly SO_x and PM to a lesser extent, due to the 2015 0.1% S requirement for SECAs. NO_x emission reduction is less relevant.
Barriers	The scheme intends 1) to ease the early adaptation to future EU standards for Finnish shipping companies, and 2) to develop an innovative marine technology. It contributes to developing an attractive business case for ship-owners.
Implementation	Aid is only eligible for vessels under the Finnish flag, and covers extra investment costs necessary for reaching a higher level of environmental protection, including operational costs and benefits. The aid intensities are between 15 and 70%, depending on: • The size of the company (smaller companies receive higher grants) • New build or retrofit investment (retrofits receive 50% of eligible costs) The European Commission has approved the Finnish scheme, on the basis of its State aid guidelines. The maximum aid per vessel is EUR 30 million. Individual aid exceeding EUR 7.5 million shall be notified to the European Commission. The aid scheme was in force between March 2013 and December 2014. After this date the 0,1% SECA regulations came into play, and aid was not possible anymore.
Technical/ operational measures	Scrubbers, MGO conversions, LNG conversions.
Monitoring/certification requirements	Grant requests have to be accompanied by an expert opinion of the VTT technical centre of Finland.
Financial Implications	The budget of the notified amendments of the scheme is EUR 100 million for the period 2013-2014
Vessel Applicability	Both new and existing ships.

Applicable Emission Source & Mode(s)	Mainly main engines. There was already a requirement in EU ports for the use of 0,1% sulphur.
Wider applicability	Worldwide in principle. The Government of Finland has also issued a decree on the general terms for granting investment aid for liquefied natural gas (LNG) terminals, with a budget of 33 million euro in 2014 and 90 million euro in 2015. 20-30% of total investments would be granted.
Measured effectiveness	Newbuilds: 2 ships, approx. EUR 30 millionv (LNG/bio-oil) Retrofits: 58 ships, approx. EUR 20 million Status: April 2014.
Industry Impacts	The industry impacts are large for the companies involved in the scheme, but limited in
Resources	Finnish government support policy for clean shipping, 3. Hamburger Schifffahrtsdialog “Handlungsoptionen für Schiffsfinanzierung Und “Green Shipping”, 17.4.2014, Janne Peltola, Ministry of Employment and the Economy SA.35686 (2012/N) - Finland – Amendments to the Scheme on General Guidelines on Investment Aid to Vessels for the Purpose of Improving Environmental Protection Brussels, 23.01.2013, C (2013) 101 final

The Fair Winds Charter (FWC), Hong Kong, China	
Stakeholder(s)	Shipping lines, Hong Kong Shipowners Association, Hong Kong Liner Shipping Association, Civic Exchange
Location	Hong Kong, China
Objective(s)	◆ Reduce ship-induced air pollution in Hong Kong by switching to marine fuel of 0.5% sulphur content or less while at berth in Hong Kong on a voluntarily basis, with additional fuel cost paid by the shipping lines. ◆ By demonstrating good will from the industry through this Charter, to urge the Hong Kong SAR Government to introduce regulation on ship emissions consistent with international practices and standards, so as to provide a level playing field for the industry. ◆ Urge the Hong Kong SAR Government to work with regional governments in ship emission control and uniform regulations/requirements in the Pearl River Delta.
Drivers	A study commissioned by the Hong Kong Environmental Protection Department and completed in 2012 shows that ships are a major source of air pollution in Hong Kong, which will pose significant, adverse health impact on the population. In 2012, ships were the top emitter of SO_2, NO_X, PM_{10} and $PM_{2.5}$ in Hong Kong, contributing 50%, 32%, 37% and 43% of the emissions, respectively. Despite the staggering figures, ship emission control has been a neglected policy area in Hong Kong, as well as in the rest of Asia. The regulatory regime developed in the United States and in Europe have shed lights on what can be done in a major seaport like Hong Kong, especially when a big portion of the ship companies operating in Hong Kong are international carriers, who are already required to comply with tighter fuel standards and environmental practices in American and European ports.
Pollutants	FWC encourages the voluntary practice of at-berth fuel switching to low sulphur fuel with sulphur content of 0.5% or less, and offers the potential to reduce at-berth SO_2 emissions by 80-90% and PM emissions by 70-80%.
Barriers	◆ Not all shipping lines operating in Hong Kong signed the Charter, mostly due to cost implication and the lack of confidence in the government's long-term policy development/regulation. ◆ Some of the carriers only operate in Asia, where ship emission control is non-existent. They have little intention or experience to get themselves ready (both financial and operational) for tighter ship emission requirements.

	◆ Generally speaking, the availability of low sulphur fuel is less favourable in Asia.
Technical/Operational Measures	For a ship to be able to switch fuel, it has to carry at least the heavy fuel oil and a low sulphur fuel. A separate fuel tank has to be used for the storage of low sulphur fuel. There is also the process of fuel change-over, and it could take a couple of hours due to different reasons (common fuel distribution system, flushing, etc.). For the recently built vessels, fuel switching may only involve pressing a few buttons on the computer screen, but for the older vessels, the crews have to be trained and well-drilled to switch fuel.
Implementation	This is an industry-led, voluntary programme. Signatories agreed to have their vessels switched to low sulphur fuel while at berth in Hong Kong to the maximum extent possible.
Monitoring/Certification Requirements	Not applicable, as this is a voluntary initiative.
Financial Implications	One of the signatories quoted at the beginning of the FWC that they have to pay an extra US$1 million each year for fuel switching in Hong Kong. The number would vary from one company to another due to their different scales of operation in Hong Kong.
Vessel Applicability	Exclusively for ocean-going vessels berthing in Hong Kong.
Applicable Emission Source & Mode(s)	Ocean-going vessels at berth, including at the container terminals or at anchorage. Reduction of emissions during the hotelling mode.
Wider Applicability	Not applicable. Only in Hong Kong.
Measured Effectiveness	◆ 17 major shipping lines operating in Hong Kong signed up for the first FWC, from 2011 to 2012. These 17 carriers contribute about 5,000 calls a year. ◆ Over 3,000 vessel calls in 2011 had switched to low sulphur fuel under the Fair Winds Charter. ◆ According to Hong Kong SAR Government's estimation, the FWC has contributed a reduction of 890 and 670 tonnes of SO_2 in 2011 and 2012, respectively. ◆ After the launch of the FWC in 2011, the Hong Kong SAR Government also announced an incentive scheme in September 2012 to encourage ocean-going vessels to switch to low sulphur fuel at berth in Hong Kong. ◆ Driven by the success of the FWC and the request of the shipping industry, the Government decided to regulate at-berth fuel switching in Hong Kong, with the hope that regulation will become effective in early 2015.
Industry Impacts	◆ A successful example of evidence-based policy development. ◆ A case of the industry owning up to their responsibility and being part of the solutions by taking voluntary actions even before government regulations.
Resources	www.civic-exchange.org/materials/theme/files/FWC.html

Shenzhen Incentive Scheme to Reduce Ship and Port Emissions	
Stakeholder(s)	The People's Government of Shenzhen Municipality, and major shipping lines.
Location	Shenzhen, China
Objective(s)	Reduce ship and port related air pollution in Shenzhen by providing subsidy to ship and port operators who are practising at-berth fuel switching, as well as the construction and use of shore power on a voluntary basis.
Drivers	Shenzhen is the world's third largest container port. Studies show that 66 per cent of sulphur dioxide, 14 per cent of nitrogen oxide and 6 per cent of fine particulates emitted in Shenzhen are related to ship and port activities. One major reason is that without regulation, ocean-going vessels are burning bunker fuel.
Pollutants	The scheme aims to reduce SO_2 and PM emissions through the use of low sulphur fuel, and to reduce other air pollutants and greenhouse gases with the use of shore power.
Barriers	◆ This is the first incentive scheme in mainland China (except Hong Kong) that targets ship emissions. It may take some time to get the support from all the shipping lines. There is no guarantee on the participation rate. ◆ While Shenzhen has rolled out the scheme, other neighbouring ports such as Guangzhou have yet to offer similar incentives. ◆ Ships and ports as an emission source is slowly getting some attention, but it is still not considered as a priority.
Technical/Operational Measures	Not applicable
Implementation	The Shenzhen Government has set aside up to 200 million RMB a year for three years for this scheme. There will be an application procedure for operators to ask for rebates.
Monitoring/Certification Requirements	Not applicable.
Financial Implications	200 million RMB a year for three years to be covered by the Government.
Vessel Applicability	For ocean-going vessels visiting the port of Shenzhen (including Shekou, Yantian, and other small ports). Another part of the scheme is for shore power, which will involve land-based terminal operators.
Applicable Emission Source & Mode(s)	Ocean-going vessels at berth.
Wider Applicability	Not applicable.
Measured Effectiveness	This was only launched in 1 October 2014, and it is too soon to comment on its effectiveness.
Industry Impacts	Too soon to comment.
Resources	Not available in English.

Maritime Singapore Green Initiative	
Stakeholder(s)	Ship owners, shipping lines, Singapore-registered maritime companies
Location	Singapore
Objective(s)	• Reduce the environmental impact of shipping and related activities and promote clean and green shipping in Singapore, through 3 distinct programmes: 1. Green Ship Programme. 2. Green Port Programme. 3. Green Technology Programme.
Drivers	A means to underscore Singapore's commitment as a responsible flag and port state to clean and green shipping.
Pollutants	Mainly carbon dioxide, sulphur oxides and nitrogen oxides.
Barriers	• As a voluntary initiative for Singapore-flagged ships or Singapore-registered companies, not all shipping lines operating in the port of Singapore are eligible to the programmes (Green Ship Programme and Green Technology Programme).
Technical/Operational Measures	• Under the Green Ship Programme, qualified ships are adopting approved SO_x scrubber technology exceeding IMO's emission requirements. • Under the Green Port Programme, qualified ships are either using type-approved abatement/scrubber technology or burning clean fuels with sulphur content of not less than 1.00% m/m.
Implementation	The Maritime and Port Authority of Singapore (MPA) pledged in 2011 to invest up to S$100 million over 5 years to support the Maritime Singapore Green Initiative. Applications have to be submitted to MPA for approval. Under the Green Ship Programme, a "Green Letter of Recognition" will be issued by MPA to qualified ships and ship owners.
Monitoring/Certification Requirements	Supporting documents to be submitted to MPA for approval.
Financial Implications	• S$ 100 million investment over 5 years by the Singaporean Government. • Under the Green Ship Programme, ships will get a reduction of Initial Registration Fees (25-75%) and a rebate on Annual Tonnage Tax (20-50%) based on the level of adoption of emission reduction and energy efficiency technologies/design. • Under the Green Port Programme, ocean-going vessels will get a reduction of port dues (15-25%), determined by whether abatement technology or clean fuel is used only at berth or throughout entire port stay.

	• Under the Green Technology Programme, Singapore-registered companies may receive grants capped at S$ 2 million per project, with an increase cap of S$ 3 million per project for solutions or systems developed and adopted that can achieve over 10% reduction in emission levels.
Vessel Applicability	Exclusively for Singapore-flagged ships under the Green Ship Programme, and only for ocean-going vessels under the Green Port Programme
Applicable Emission Source & Mode(s)	Both ship and port sources under the three programmes
Wider Applicability	Not applicable.
Measured Effectiveness	• To date, 40 companies have pledged their commitment to promote and support clean and green shipping in Singapore. • 174 vessels participated in the Green Ship Programme as of end July 2014. • Over 2,000 vessel calls from the top five shipping lines have participating in the Green Port Programme as of end July 2014. • 18 projects approved under Green Technology Programme, with 50 Singapore-registered ships participating in the Programme as of end July 2014. • No information regarding the impact on emissions and energy efficiency.
Industry Impacts	No information
Resources	www.mpa.gov.sg/sites/maritime_singapore/msgi/maritime-singapore-green-initiative.page

CAAP Technology Advancement Program (TAP)	
Stakeholder(s)	Port of Los Angeles, Port of Long Beach
Location	Ports of Long Beach and Los Angeles, California, USA
Objective(s)	Demonstrate new technologies or new applications for existing technologies that have significant potential to reduce air pollution emissions from all port source categories including ships. Currently, the ports contribute up to $3 million per year (combined), as potential projects are reviewed and approved.
Drivers	The ports adopted their joint Clean Air Action Plan in 2006 (updated in 2010) to "develop and implement strategies and programs necessary to reduce air emissions and health risks while allowing port development to continue". To ensure effective air pollution reduction strategies are commercially available to facilitate implementation of CAAP measures, the ports developed and are currently implementing the Technology Advancement Program (TAP). When applicable, TAP-funded projects include certification/verification of emission reduction capability; this is critical for ports to be able to document the benefits of the technologies under evaluation.
Pollutants	TAP primarily focuses on technology demonstrations with a strong potential to reduce DPM, NO_x and SO_x, however the technologies demonstrated under TAP often reduce greenhouse gases (GHG) and fine particulate matter (i.e., particle sizes on the order of 2.5 micron in diameter or smaller). While not a requirement, the reduction potential of GHG is considered in the evaluation for each technology proposed for TAP demonstration.
Barriers	• Applicant must have port equipment owner as a demonstration partner. • Applicant must fund a minimum of 50 percent of project costs. • Port funding is limited, so not all projects that apply are selected. • Emission testing to support certification/verification is expensive; testing protocols are not consistent among agencies/regions.
Technical/Operational Measures	NA
Implementation	The TAP Guidelines[2] specify application format and content requirements. Each proposal is reviewed by the TAP Advisory Committee; this committee includes members from local, state and federal air quality regulatory agencies, as well as port staff. The ports contract with approved applicants once a project scope and budget is finalized. Most projects include emissions testing; all projects include a technology demonstration period, as well as progress and final reports.

Monitoring/Certification Requirements	Data collection and analysis results from the technology demonstration phase are provided in progress and final reports. For projects that include certification/verification, CARB approval of emissions testing plan and results is also required.
Financial Implications	To date, 23 TAP projects were completed and two additional projects are currently underway, at a total project cost of over US$30 million. Of this total, the ports contributed over US$7.6 million and public agency partners contributed just over US$8.1 million. Four of these projects were ship-related, where the TAP contributed over $3 million toward more than $5.5 million in total project costs.
Vessel Applicability	Both new and existing ships, harbor craft and cargo handling equipment, depending on technology.
Applicable Emission Source & Mode(s)	All port sources, but in the case of ship-port interface: ocean-going vessels, cargo handling equipment and harbor craft. All port-ship interface modes.
Wider Applicability	World wide
Measured Effectiveness	• An annual report[3] is published for the TAP documenting progress from year to year. • Projects that include emissions testing often result in official verification or certification of emission reductions. • Final reports are published at the ports' TAP website (see resource #3). • Commercial implementation of a technology is the best demonstration of a TAP project's effectiveness. • Even projects that do not result into expected emissions reduction under TAP contribute to the ongoing effort to reduce port emissions, by documenting results so other ports or agencies will not start all over again instead look for ways to improve it if possible.
Industry Impacts	Successful demonstration and certification/verification of new emission reduction technologies (or the application of existing technologies in new applications) provides additional tools to assist ports to reduce emissions at the ship-port interface. Technology manufacturers are provided and encouraged to participate with a structured TAP guidelines and follow up process to demonstrate the potential of their emerging technologies.
Resources	[1] www.cleanairactionplan.org/ [2] www.cleanairactionplan.org/default.asp [3] www.cleanairactionplan.org/programs/tap/techdemos.asp