



PORT EMISSIONS TOOLKIT

GUIDE | Development of port emissions
NO. 02 | reduction strategies



Port Emissions Toolkit

Guide No.2: Development of port emissions reduction strategies



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The GloMEEP Project is a cooperative initiative of the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and the International Maritime Organization (IMO) to assist developing countries in the uptake and implementation of energy efficiency measures for shipping, with the aim of reducing greenhouse gas emissions and preventing air pollution from ships. For more information, please visit <http://glomeep.imo.org>

The International Association of Ports and Harbors (IAPH) is a global alliance representing over 180 members ports and 140 port related businesses in 90 countries. The principal aim of IAPH revolves around promotion of the interests of Ports worldwide, building strong member relationships and sharing best practices among our members. For more information, please visit <https://www.iaphworldports.org/>

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List of abbreviations

ARFVTP	Alternative and Renewable Fuel and Vehicle and Technology Program
CAAP	Clean Air Action Plan
CARB	California Air Resources Board
CEA	Cost Effectiveness Analysis
CH ₄	Methane
CHE	Cargo Handling Equipment
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
DEF	Diesel Exhaust Fluid
DOC	Diesel Oxygenation Catalyst
DPF	Diesel Particulate Filter
DPM	Diesel Particulate Matter
ECT	Emissions Control Technology
EGR	Exhaust Gas Recirculation
ERS	Emissions Reduction Strategy
ESI	Environmental Ship Index
ETV	EU Environmental Technology Verification
EU	European Union
GEF	Global Environment Facility
GHG	Greenhouse Gases
GloMEEP	Global Maritime Energy Efficiency Partnerships Project
HC	Hydrocarbon
HFO	Heavy Fuel Oil
IAPH	International Association of Ports and Harbors
ICCT	International Council on Clean Transportation
IMO	International Maritime Organization
LF	Load Factor
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MW	Megawatts
NO _x	Nitrogen Oxides
OGV	Ocean-Going Vessel
OPS	Onshore Power Supply
PANYNJ	Port Authority of New York & New Jersey

PM	Particulate Matter
POLA	Port of Los Angeles
POLB	Port of Long Beach
RTG	Rubber-tyred gantry crane
SCR	Selective Catalytic Reduction
SO _x	Sulphur Oxides
SPBP	San Pedro Bay Ports
TEU	Twenty-Foot-Equivalent Unit
UNDP	United Nations Development Programme
US	United States
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
VSR	Vessel Speed Reduction
WPCI	World Ports Climate Initiative (IAPH)

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Preface

Maritime ports are major hubs of economic activity and are usually located in the vicinity of highly populated areas. The growth of global trade has resulted in a corresponding rapid increase in the amount of goods being shipped by sea. Despite the enormous growth of the marine shipping sector, in many parts of the world pollution prevention efforts have not focused on port-related sources. As more attention is focused on reducing emissions from the marine shipping sector, ports are driven to understand the magnitude of the air emissions impact from their operations on the local and global community and to develop strategies to reduce this impact.

The key to this effort is to provide a systematic approach to the assessment of air pollutant emissions from port-related sources through the development of port emissions inventories that provide the basic building block to the development of a port emissions reduction strategy. Without an emissions inventory, it may be difficult to determine where to best focus resources to reduce emissions. Further, without a baseline emissions inventory, and subsequent updates, it will be difficult to monitor the effectiveness of any emissions reduction strategy that is implemented.

This *Port Emissions Toolkit*, therefore, includes two individual guides as follows:

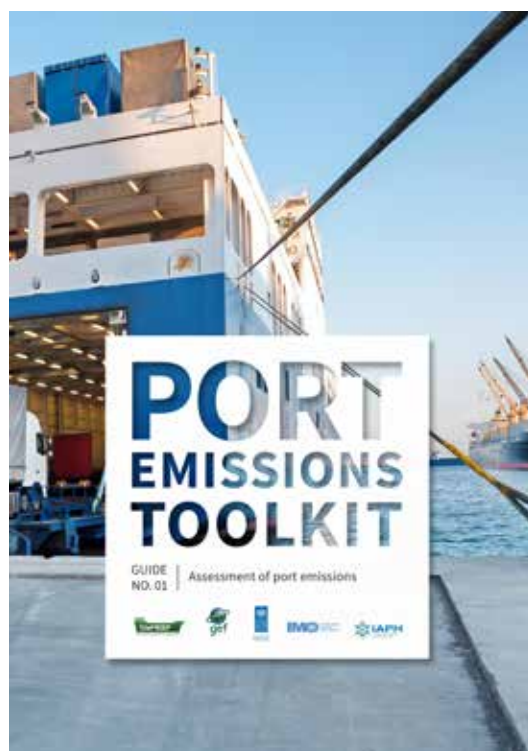
Guide No.1: Assessment of port emissions

This guide is intended to serve as a resource guide for ports intending to develop or improve their air pollutant and/or GHG emissions assessments. This guide builds on and updates previous work of IAPH and its members, incorporating the latest emissions inventory methods and approaches.

Recognising that ships do not operate independently from shore-based entities in the maritime transportation system, port emissions considerations therefore must extend beyond the ships themselves to include all port-related emissions sources including: seagoing vessels, domestic vessels, cargo handling equipment, heavy-duty vehicles, locomotives and electrical grid.

This guide is intended to be relevant to users at different levels of experience, from those just beginning the emissions inventory process, to those having extensive experience with developing port-related emissions assessments.

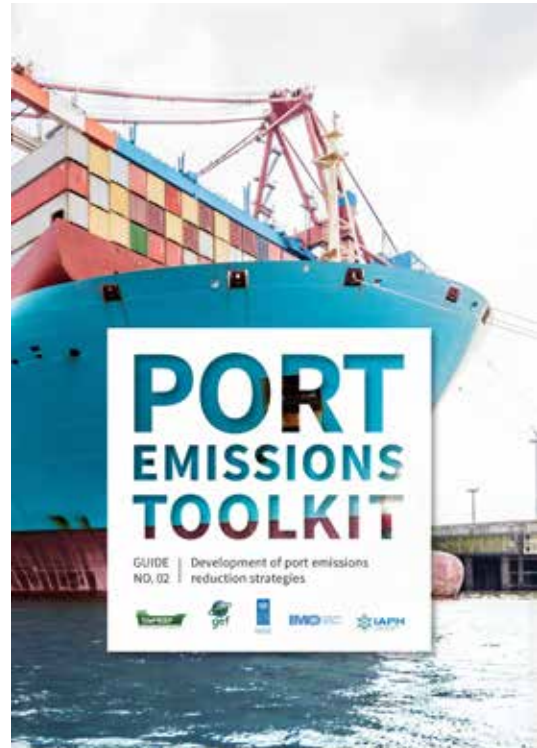
This guide focuses on planning and key decision steps related to port emissions assessments. As the technical methods for estimating activity levels and related emissions from port-related sources continue to be updated and improved, this guide also points the reader to those organisations and ports that are at the forefront of emissions inventories, metrics and forecasts and, through their published work, provide up-to-date methods and proxy data for the development of port emissions assessments.



Guide No.2: Development of port emissions reduction strategies

This guide is intended to serve as a resource guide for ports intending to develop an emissions reduction strategy (ERS) for port-related emissions sources. This guide builds on the principles discussed in Guide No.1 and describes the approaches and methods that can be used by ports to develop, evaluate, implement and track voluntary emissions control measures that go beyond regulatory requirements.

This guide focuses on measures to be considered as part of an ERS plan for those port-related mobile emissions sources that are associated with cargo movement. This guide highlights key elements that ports should consider when developing an ERS, which includes evaluating, planning and implementing mobile source emissions control measures as part of an overall ERS. This guide also contains links to resources that provide further details into specific areas.



1 Introduction

This Guide is for ports interested in developing an emissions reduction strategy (ERS) plan that will guide its voluntary efforts to reduce air pollutant and/or greenhouse gas (GHG) emissions beyond regulatory requirements.

An ERS plan contains measures a port will undertake that go beyond regulatory requirements, because everything else is just compliance. Emissions controls voluntarily adopted by a port, by definition go beyond regulation – including where there is no regulation. Undertaking GHG emissions reductions when there is only a long-term national or regional goal, but no short-term emissions regulation, also goes beyond regulation. Measures solely undertaken to meet regulatory requirements belong in a compliance plan. Compliance plans are not the subject of this Guide.

This Guide focuses on measures to be considered as part of an ERS plan for port-related mobile emissions sources that are associated with cargo movement. This document highlights key elements that ports should consider when developing an ERS, which includes evaluating, planning and implementing mobile source emissions control measures as part of an overall ERS. The document also contains links to resources that provide further details into specific areas.

1.1 Undertake an emissions inventory

Before developing an emissions reduction strategy, it is recommended that an emissions inventory be conducted. An emissions inventory is the basic building block of a port emissions assessment, which is the subject of *Port Emissions Toolkit, Guide No.1: Assessment of port emissions*. Without an emissions inventory, it may be difficult to determine where to best focus resources to reduce emissions. Further, without a baseline emissions inventory, and subsequent updates, it will be difficult to monitor the effectiveness of any ERS that is implemented.

1.2 Growing awareness of the need to reduce port-related emissions

The global logistics chain relies primarily, at present, on fossil fuels for its energy needs. These fuels produce harmful air pollutant and GHG emissions. Ports are multi-modal nodes within the logistics chain where the various modes of cargo movement come together. Ports are therefore concentrated areas of high fuel oil and diesel fuelled activities, producing air pollutants that have direct health impacts on local and regional populations.

Over the past two decades, the pressures applied to ports to reduce port-related emissions have been increasing across the globe. With growth in international trade, port-related activities have increased dramatically in some parts of the world.¹ With this growth and emissions reduction strategies already implemented for non-port sources in many parts of the world, such as light duty vehicle fleet and public transportation and for stationary sources such as power plants, the relative contributions of port-related air pollutant and GHG emissions have increased. While growth in trade has positive economic benefits for port cities and their surrounding regions, this growth has also put surrounding communities under pressure through increased health risks associated with air pollution from port operations. Port communities are seeking solutions to reduce these risks. Addressing this pressure is challenging since reducing emissions requires significant financial investment or operational modifications and without regulation of port-related mobile emissions sources, which is limited in many jurisdictions, there is not much interest on the part of the operators to reduce emissions.

¹ Sharma DC. Ports in a Storm; Environmental Health Perspectives. 2006; 114(4): A222-A231.

In addition to the historical concern about air pollutants, concern about GHG emissions has significantly increased over the past decade. The entire logistics chain has come under pressure to reduce its associated carbon footprint. The IMO, in April 2018, adopted an Initial IMO Strategy on reduction of GHG emissions from ships that confirms IMO’s commitment to reducing GHG emissions from international shipping and, as a matter of urgency, to phasing them out as soon as possible in this century. The Initial Strategy envisages for the first time a reduction in total GHG emissions from international shipping which, it says, should peak as soon as possible and reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008, while, at the same time, pursuing efforts towards phasing them out. The Strategy sends a strong signal to the shipping sector as a whole of the need to stimulate investments in the development of low-carbon and zero-carbon fuels and innovative energy-efficient technologies. The Strategy recognises, as possible short-term further action to reduce GHG emissions, the consideration and analysis of measures to encourage port developments and activities globally to facilitate reduction of GHG emissions from shipping, including provision of ship and shoreside/onshore power supply from renewable sources, infrastructure to support supply of alternative low-carbon and zero-carbon fuels, and to further optimise the logistics chain and its planning, including ports.

1.3 Port-related mobile sources

This document focuses on measures to reduce emissions from port-related mobile sources that are associated with the movement of cargo. According to the US EPA² definition, motor vehicles, engines and equipment that move, or can be moved, from place to place are mobile sources. Mobile sources include vehicles that operate on roads and highways, as well as non-road vehicles, engines and equipment. Note that stationary sources, which do not move, are usually excluded from port-related emissions reduction strategies, as those sources are usually under separate regulatory and administrative authorities. The identification and categorisation of cargo-related emissions from mobile sources focus on port controlled or influenced activities. Equipment and vessels are usually grouped by emissions source category and energy type. Common port-related mobile source categories and their energy types are presented in Table 1.1.

Table 1.1: Port-related mobile source categories and energy types

Source type	Emissions source category	Energy types
Mobile	Seagoing vessels	fuel oil, diesel, natural gas (NG), methanol
	Domestic vessels	fuel oil, diesel, NG
	Cargo handling equipment	diesel, NG, propane, gasoline, methanol, electricity
	Heavy-duty vehicles	diesel, NG, electricity
	Locomotive	diesel, NG, electricity
	Light-duty vehicles	diesel, NG, propane, gasoline, electricity

There are many types of mobile sources associated with port operations, but not all source categories will be found in every port.

1.4 Emissions reduction challenges and opportunities

As discussed in the *Port Emissions Toolkit, Guide No.1: Assessment of port emissions*, there is growing public and political pressure on ports around the world to address air pollution generated by cargo movement operations and to reduce their impacts to human health and the environment. This has led some port authorities to develop and implement ERS plans, which are comprehensive ‘clean air’ programmes covering multiple emissions control measures for various sources. In the port context, emissions control measures (or, simply, measures) are the voluntary technological or operational changes implemented at the local level at a port that reduce emissions beyond regulatory requirements. Ports are not typically environmental regulatory agencies. As discussed in Guide No.1, various pollution control agencies (from international to local) are the primary entities for developing emissions standards and regulations. Ports, however, can use their unique position in the logistics chain to affect additional emissions controls. These are the issues covered in an ERS.

² See http://opusinspection.com/documents/def_pollution.htm. Accessed August 2018.

For ports in some regions of the world, existing regulations on port-related emissions sources are not enough to address the specific community and political pressures faced by the local port, so additional emissions reduction strategies **beyond** regulation need to be explored. As discussed in the Guide No.1, the reasons driving a port to consider an ERS can range from health effects studies showing significant impacts from port-related emissions, the threat of a proposed regulation to reduce port-related emissions from an environmental regulatory agency, or simply to meet the port's own corporate social responsibility goal. For the purposes of this document, an ERS plan will be defined as those goals and emissions control measures that go **beyond** regulatory requirements. The emissions reductions achieved by these strategies are 'surplus' to existing regulations. Emissions control measures in an ERS plan should be quantifiable – those measures that demonstrate emissions reductions through actions that go beyond baseline conditions (which includes all applicable regulatory requirements). While qualitative measures can be included in an ERS, since their benefits are difficult to measure, documenting success of emissions reductions is difficult.

Emissions control measures can target air pollutants such as particulate matter (PM), sulphur oxides (SO_x) and oxides of nitrogen (NO_x). They can also target GHGs, primarily carbon dioxide (CO₂). Emissions inventories are used to identify emissions reduction opportunities and to help quantify the benefits of those strategies.

2 Developing an emissions reduction strategies plan

There are several steps to follow when developing an ERS plan. These steps are illustrated in Figure 2.1 and further discussed in the following sections.

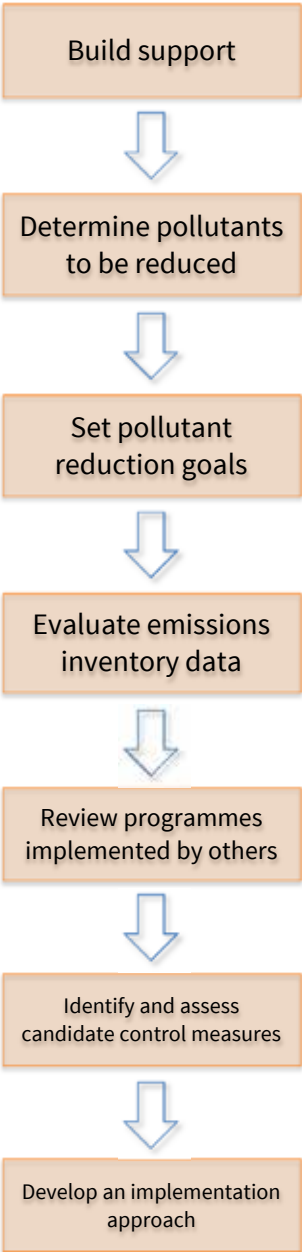


Figure 2.1: Steps for developing an emissions reduction strategies plan

Additional information on each of these steps is presented below.

2.1 Build support

All successful environmental projects and programmes have at least one thing in common: support from institutional leadership. Similarly, when undertaking an ERS plan, commitment from port management and its governing body are critical to ensure that the ERS is successful.

Development of an ERS plan will require port resources, including staff time across various departments and, depending on the scope, funding for external analytical and consulting work. Working with other stakeholders interested in reducing emissions, such as pollution control agencies, non-governmental organisations, community groups and trade organisations, is essential to build necessary support for the project. Engagement with privately owned companies that operate in the port area, in particular shipping lines and terminal operators, is critical, as most ports do not have direct control over these operations. Successful implementation of any ERS will likely rely on a strong partnership with privately owned companies to implement emissions reduction efforts, especially since the emissions control measures in the ERS go above and beyond existing regulations.

Within a port’s internal team, a project manager for the ERS should be appointed. This position should be fully supported by port management, including the provision of adequate funding and decision-making authority. The project manager will coordinate all stakeholder involvement in the development and implementation of the ERS plan. Developing an understanding of the objectives and concerns of each stakeholder group, as well as providing a structure for the stakeholders to discuss these matters in a neutral and constructive manner, are often overlooked elements necessary to build support for an ERS. Frequently, the project manager will be called upon to resolve conflicts within the stakeholder community and to find a compromise that addresses the issues raised while maintaining clear sight of the goals of the ERS. The project manager will also be responsible for reporting progress to port management and maintaining the overall ERS plan project schedule and budget.

2.2 Determine pollutants to be reduced

It is important to clearly identify the pollutants to be targeted by the ERS plan. The focus of the ERS could be one air pollutant or several. In cases where multiple pollutants are targeted, the development of a pollutant hierarchy will be helpful, as not all emissions reduction strategies will reduce all pollutants, and some strategies may reduce one pollutant while increasing another. Since ports are normally located near populated areas, reductions in air pollutants affecting human health, like PM, NO_x and SO_x, may be prioritised over reductions in GHG emissions, particularly until health-based air quality standards are met for the region. Pollutant hierarchies help in the development of an ERS plan by allowing for the elimination of potential emissions control measures that do not address emissions from the priority pollutants. Within the hierarchy, the pollutants are classified as ‘critical’ and ‘optional’. For a pollutant classified as critical, identified emissions control measures must reduce that specific pollutant in order to be considered. For a pollutant classified as optional, identified measures that would reduce critical pollutants as well as the optional pollutant would be given greater consideration.

An overview of common port-related pollutants, sources and their associated health and environmental effects is provided in Table 2.1.

Table 2.1: *Port-related pollutants, sources and health and environmental effects*

Air pollutant	Sources	Health and environmental effects
<p>Oxides of nitrogen (NO_x) is the generic term for a group of highly reactive gases; all of which contain nitrogen and oxygen in varying amounts. Most NO_x are colourless and odourless.</p>	<p>NO_x form when fuel is burned at high temperatures, as in a combustion process. The primary port-related NO_x sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel.</p>	<p>NO_x can react with other compounds in the air to form tiny particles adding to PM concentrations. NO_x can also bind with VOCs and sunlight to form ground level ozone or smog. NO_x and VOCs are ozone precursors. Ozone is linked to shortness of breath, coughing, sore throat, inflamed and damaged airways, and can aggravate lung diseases such as asthma, emphysema and chronic bronchitis.</p>

Air pollutant	Sources	Health and environmental effects
<p>Particulate matter (PM) refers to discrete solid or aerosol particles in the air. Dust, dirt, soot, smoke and exhaust particles are all considered PM. PM is typically categorised as Total PM (or just PM) or divided into two smaller size categories: PM₁₀, which consists of particles measuring up to 10 micrometres in diameter; and PM_{2.5}, which consists of particles measuring 2.5 micrometres in diameter or smaller. Diesel particulate matter (DPM) is a species of particulate matter important in some jurisdictions.</p>	<p>Airborne PM is a mixture of solid particles and liquid droplets generated in numerous ways. The primary port-related PM sources are from the exhaust of engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel. PM can also be generated from large open areas of exposed earth or dirt roads, where vehicles and equipment can disperse PM into the air.</p>	<p>Fine particles are a concern because their very tiny size allows them to travel more deeply into lungs and enter the blood stream, increasing the potential for health risks. Exposure to PM_{2.5} is linked with respiratory disease, decreased lung function, asthma attacks, heart attacks and premature death.</p>
<p>Oxides of sulphur (SO_x) is a group of colourless, corrosive gases produced by burning fuels containing sulphur.</p>	<p>SO_x (a group of gases) is released when fuels containing sulphur are burned in the combustion process. The primary port-related SO_x sources is exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fossil fuel.</p>	<p>SO_x is associated with a variety of respiratory diseases. Inhalation of SO_x can cause increased airway resistance by constricting lung passages. Some of the SO_x become sulphate particles in the atmosphere adding to measured PM levels. High concentrations of gaseous SO_x can lead to the formation of acid rain, which can harm trees and plants by damaging foliage and decreasing growth.</p>
<p>Volatile organic compounds (VOCs) are any compound of carbon (other than CO, CO₂, carbonic acid, metallic carbides or carbonates and ammonium carbonate) which participates in atmospheric photochemical reactions.</p>	<p>VOCs are generated when fuel is burned in the combustion process. The primary port-related VOCs sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel. In addition, liquids containing VOCs are used by numerous industrial and commercial applications, where they can volatilise into the air.</p>	<p>In addition to contributing to the formation of ozone, some VOCs are considered air toxics which can contribute to a wide range of adverse health effects. Some VOCs are also considered PM.</p>
<p>Carbon monoxide (CO) is a colourless, odourless, toxic gas commonly formed when carbon-containing fuel is not burned completely.</p>	<p>CO forms during incomplete combustion of fuels. The primary port-related CO sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel.</p>	<p>CO combines with haemoglobin in red blood cells and decreases the oxygen-carrying capacity of the blood. CO weakens heart contractions, reducing the amount of blood pumped through the body. It can affect brain and lung function.</p>
Climate change pollutant	Sources	Health and environmental effects
<p>Greenhouse gases (GHGs) that are typically emitted from port-related sources include carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). Additional gases that are not significantly emitted by maritime-related sources or included in this inventory also contribute to climate change.</p>	<p>GHGs come from both natural processes and human activities. The primary port-related GHG sources are from the exhaust from engines that power landside equipment and vehicles, marine vessels, non-renewable energy generation, other industrial and commercial sources that burn fuel.</p>	<p>Most climate scientists agree that the main cause of the current global warming trend is the human expansion of the 'greenhouse effect'. Warming results when the atmosphere traps heat radiating from Earth towards space. Certain gases in the atmosphere block heat from escaping, otherwise referred to as GHGs. Climate change results in extreme and unusual weather pattern shifts within the Earth's atmosphere.</p>

Some strategies that reduce air pollutants can also have a co-benefit of reducing greenhouse gases. These might be given higher consideration as meeting multiple goals.

2.3 Set pollutant reduction goals

An ERS plan should include emissions reduction objectives and targets. These are the goals the plan strives to achieve. These should be targets that can be tracked and measured. In cases where the goals are set based on the use of emerging and not yet proven technologies, it may be helpful to set interim targets to help measure the progress and status of the emerging technology.

A target may be set for one or more of the pollutants. For instance, a port might set itself a goal to reduce PM by 85% from a baseline within 10 years. This goal could be applied across all source categories. Emissions control measures would need to be developed that aimed to achieve significant reductions in PM from those source categories responsible for highest emissions of PM. Alternatively, a goal may be set for a particular emissions source category. For example, a port might set itself a target to convert all diesel-powered cargo handling equipment to electric. This kind of goal would be applied to a particular source category and may not necessarily include a specific pollutant reduction goal. This approach might result in several goals, one for each source category.

A key consideration in goal setting is the feasibility of technological and operational changes, as well as the availability of funding to make the required investments. Failure to properly consider these elements can impede successful implementation of the ERS. Often it is tempting to set over-ambitious goals with the intention of sending a signal to encourage private investment in technology development. This approach is usually only successful if the port has a dominant market position and provides significant funding for the development and demonstration of technologies. Another key consideration is the scope of operations the goals are meant to target. Most ports do not own or operate the majority of emissions sources, instead leasing facilities to private operators. Third parties almost always control seagoing vessels. A successful ERS should clearly delineate which scopes of operation (i.e. only emissions sources under direct port control vs. emissions sources under tenant or third-party control) are targeted, and should consider the challenges associated with setting emissions reduction goals for operations outside of the port's direct control.

2.4 Evaluate emissions inventory data

Understanding port-related emissions sources and their operational profiles is key to the evaluation of potential emissions control measures for inclusion in an ERS plan. A detailed emissions inventory is one of the best ways to gain understanding of both emissions sources and their operations. With the pollutants selected and a hierarchy set, review of the emissions inventory leads to the identification of the equipment and vessels that are significant contributors to either total or individual source category emissions.

Key information that should be reviewed from the emissions inventory include, but are not limited to: emissions source type, energy consumption (typically in kilowatt-hours or kWh), engine age, engine size (typically in kilowatts or kW), fuel type, population, owner/operator, residence time at the port, determination if the equipment or vessel is berthed at the port or just visits the port on a periodic basis, and associated emissions. A common metric used to assess emissions sources is *emissions per kWh* (e.g. tonnes PM/kWh, tonnes NO_x/kWh, etc.). Further information on these key data elements is provided below:

- Emissions source categories and types are important for aggregating emissions for further evaluation. Reduction strategies are typically applicable to only specific emissions source types. Port-related mobile emissions source categories include: seagoing vessels, domestic vessels, cargo handling equipment, on-road trucks, locomotives and terminal vehicles. Based on their operations within each of these source categories the mobile emissions sources can be further divided into following types:
 - **Seagoing vessels** – auto carrier, bulk (bulk self-load, bulk wood-chips, etc.), container, general cargo, liquid bulk (crude, product, asphalt, etc.), roll-on/roll-off, etc.
 - **Domestic vessels** – assist tugboats, tugboats, pushboats, pilot boats, tenders, police, fire, etc.
 - **Cargo handling equipment** – bulldozers, yard hostlers, cranes (rubber-tyred gantries, rail mounted gantries, quay, tracked, etc.), top picks, side picks, fork lifts, etc.

- **Trucks** – large trucks (that move loads or containers on-road), delivery trucks (smaller trucks delivering service goods), etc.
- **Locomotives** – switching, line-haul, etc.
- **Terminal vehicles** – pickup trucks, sedans, etc.
- Energy consumption identifies which emissions sources are working the most; pollutant emissions provide information on which emissions sources generate the most emissions; and emissions per energy consumption metric provides insight on relative emissions efficiency amongst emissions sources. It is also important to note the type of energy each equipment or vessel is using, since emissions reductions strategies may be limited to specific energy types.
- Engine age is typically an indicator of emissions level, since the older the engine, the more polluting it will be. Care should be taken to document both engine age and equipment age, since there are instances where these are not the same.
- Engine size and technology can be critical when identifying candidate strategies, as strategies may only be applicable within certain rated engine power bandwidths (typically expressed in kW ratings), stroke (e.g. 2-stroke, 4-stroke, etc.), and engine technologies (e.g. mechanical, electronic control, etc.). Engine size also determines the amount of work. Bigger engines are capable of producing more work.
- Fuel types (often diesel, but can include heavy fuel oil, kerosene, marine distillate oil, marine gas oil, natural gas, methanol, electricity, etc.) have different air pollutant and GHG emissions profiles. These may vary across and within source categories. For diesel fuels, sulphur content (expressed as per cent sulphur) is an important parameter as it has direct implications for sulphur and PM emissions.
- Population is important as it has direct ramifications on complexity, costs and effectiveness of an individual control measure. Equipment and vessels can be categorised by type or subtype, and population counts of each are useful. For seagoing vessels, it is also important to assess the number of calls by vessel to identify the frequent callers within the fleet (population) as there might be need to consider a distinction in the application of control measures between frequent and non-frequent callers.
- Data on the owner/operator of each emissions source is important as it will identify if the port has ownership/control over the targeted source or if it is the under control of a tenant or third party. This has implications on stakeholder outreach and the design and implementation of individual control measures.
- Residence time at port is an important consideration since equipment and vessels can be either home-ported or transient. There are cases where equipment or vessels are moved between terminals or to different ports over the course of a year or several years. It is not optimal to implement an emissions control measure on pieces of equipment that are likely to be moved from the port after the investment is made. This is one of the most significant challenges for ship-based control measures and can be a significant issue for the other source categories as well.

2.5 Review programmes implemented by others

Once the pollutant priorities are identified and goals are set, it is advantageous to evaluate the work of other ports, particularly those that have addressed similar pollution problems. In addition to reviewing other port emissions reduction programmes that are publicly available, it is strongly recommended that outreach be made to find other ports that may be undertaking an ERS that may not yet be public. These efforts can provide opportunities to learn about best practices in goal setting, evaluation of candidate strategies, lessons learned, and other key elements in the success or failure of the implementation of an ERS plan. This information both helps in the implementation of mobile source emissions control measures and helps avoid poor results. It is important to understand that not all emissions control measures implemented at ports have been successful in meeting the stated emissions reduction goals, and that best-practice sharing among ports can increase the rate of successful ERS implementation.

The following table provides a sample listing of the ports around the world that have been engaged in the development and implementation of emissions reduction strategies.

Table 2.2: Selected ports engaged in development and implementation of emissions reduction strategies

Port	ERS source categories	Started	Link
Port of Los Angeles	All	2001	https://www.portoflosangeles.org/idx_environment.asp http://www.cleanairactionplan.org/
Port of Long Beach	All	2001	http://www.polb.com/environment/default.asp http://www.cleanairactionplan.org/
Northwest Seaport Alliance	All	2007	https://www.nwseaportalliance.com/stats-stories/environmental-stewardship
Port of Vancouver	All	2007	https://www.portvancouver.com/environment/air-energy-climate-action/
Port of Rotterdam			https://www.portofrotterdam.com/en/the-port/sustainability
Port of Antwerp			http://www.portofantwerp.com/en/air-quality
Port of Amsterdam			https://www.portofamsterdam.com/en/port-amsterdam/sustainability-future-proof-port-customers-and-local-community
Port Authority of New York/ New Jersey	All	2009	https://www.panynj.gov/about/port-initiatives.html
Port of Oakland	All	2008	http://www.portofoakland.com/community/environmental-stewardship/maritime-air-quality-improvement-plan/
Port of San Diego	All	2007	https://www.portofsandiego.org/environment/clean-air.html
Port of Houston	All	2009	http://porthouston.com/environment/air-quality/
Hong Kong Maritime and Port Board	OGV	2013	http://www.enb.gov.hk/en/files/New_Air_Plan_en.pdf

2.6 Identify and assess candidate measures

Once the preceding steps have taken place, the identification and assessment of candidate emissions control measures can begin. This is where the specific control measures for the ERS plan are developed.

There are several other sources, in addition to those specified in Table 2.2 above, to review for potential candidate measures. The following table identifies several publications that include lists of potential candidate emissions control measures by source category.

Using the resources from Tables 2.2 and 2.3, as well as the examples provided in Section 3 below as a guide, candidate emissions control measures for the source category of focus can then be assessed.

Candidate measures should be assessed and ranked based on the priorities set by the port authority. This ranking of candidate measures is essential to ensure that the allocated resources achieve the ERS goals. Determining how to rank measures is port-specific. Considerations include: air pollutants targeted by the measure; co-benefit of reducing air pollutant and GHG emissions; proximity of the port to population centres; cost of implementing each strategy; commercial availability of the technology; equipment maintenance; acceptability by stakeholders; administrative burden; and implementation timeline. Once ranked, the port can then implement those candidate measures that best meet the emissions reduction goals of the ERS. This allows the port to establish a multi-year budget for funding selected measures and to ensure that finite resources are not wasted on efforts that will not meet the ERS goals.

Table 2.3: Potential candidate emissions control measures

Reference	ERS source categories	Link
IMO 2015. <i>Study of Emissions Controls and Energy Efficiency Measures for Ships in the Port Area</i> , International Maritime Organization (IMO), prepared by Starcrest Consulting Group, LLC, CE Delft, Civic Exchange, February 2015.	Seagoing Vessels	https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Port%20Area.pdf
ICCT 2012. <i>Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor's Air Quality Toolbox</i> , The International Council on Clean Transportation (ICCT), prepared by Starcrest Consulting Group, LLC, June 2012.	All	https://www.theicct.org/sites/default/files/ICCT_SCG_Developing-Clean-Air-Programs_June2012.pdf
IAPH 2008. <i>IAPH Toolbox for Port Clean Air Programs</i> , website, International Association of Ports and Harbors (IAPH), prepared by members of the World Ports Climate Initiative (WPCI) of IAPH, 2008.	All	http://wpci.iaphworldports.org/iaphtoolbox/

2.7 Develop an implementation approach

There are a number of implementation considerations to track when developing an ERS plan. There may be multiple ways to implement individual control measures, and an ERS will contain multiple measures. The port will need to evaluate the implementation approaches available to it, and will have to determine the best fit for each emissions control measure in the ERS. Issues to consider when developing the implementation approach for an individual emissions control measure include:

- Claims of technology vendors
- Administrative approach
- Coordination and collaboration with stakeholders
- Evaluating cost effectiveness
- Modelling, monitoring and reporting
- Review and adjustment cycles

Each of these is discussed in the subsections below.

2.7.1 Claims of technology vendors

As ports develop programmes to implement emissions control measures, technology vendors will contact the ports to consider their technologies for inclusion as ERS measures. Ports should endeavour to verify vendor claims regarding their technology capabilities as well as the company's capability to fulfill commitments. It is highly recommended to request emissions testing data from independent third-party testing companies to document emissions reduction claims from vendors.

Another consideration is that ports should not place themselves in a position to be perceived as endorsing specific manufacturers or vendors. Maintaining a technology-neutral perspective and setting performance standards as opposed to specifying a certain company or product will ensure that the port not be held responsible by the equipment operators if the technology does not meet expectations.

2.7.2 Administrative approach

The ERS plan should address both the technical and administrative approaches necessary to reduce emissions from port operations. The technical approaches are the various emissions control measures that can be applied to equipment or operations, which are identified and evaluated as discussed in section 2.6. The administrative approaches are the various ways that the emissions control measures in the ERS plan are implemented.

Ports around the world have different administrative organisations. Some are privately operated businesses. Some ports are government run, with or without regulatory powers. Others are public-private partnerships. Some generate revenue that they then control to be used for operational or environmental programmes, while others generate revenue that is transferred to the state, which then controls allocation of funding for operations. Each of these different business models requires a different administrative approach.

Some of the implementation approaches employed by other ports around the world include:

- Terminal lease/agreement modifications
- Tariff changes
- Incentives/disincentives
- Voluntary adoption

Each port will determine the most effective administrative approaches for the implementation of the individual emissions control measures. These different implementation approaches should be assessed early on and discussed in the ERS plan. A combination of approaches will probably be necessary to implement the various measures in the plan, particularly if multiple source categories are involved.

The Port of Los Angeles and the Port of Long Beach have stated in their Clean Air Action Plan “that the most effective combination of implementation strategies includes a mix of lease requirements, tariff changes, incentives, grants, and voluntary efforts with an ultimate backstop of regulatory requirements. This combination provides redundancy in implementing the [goals] should any one of the other specific strategies fail to be applied.”³

If the ERS plan has been developed in sufficient detail, implementation of the emissions reduction strategy is a straightforward process. That is not to say that it is easy. Implementing emissions control measures will take substantial time and effort involving staff, customers, equipment manufacturers and owners. It is important to understand that a significant amount of work will be needed, in both the short and long term, to ensure that plan goals are met and maintained. These challenges drive the need for periodic evaluation, adjustment, and updates of the ERS plan.

2.7.3 Coordination and collaboration with stakeholders

A communication plan will specify how the ERS plan is to be explained to various audiences and will determine key messaging. Depending on how the port is organised, the message may need to be adapted to different groups within the organisation. The same applies to communicating with stakeholders outside of the port administration – customers, tenants, business partners, local residents and the port community.

2.7.4 Evaluating cost effectiveness

Cost-effectiveness analysis (CEA) is an evaluation approach that provides port, government and environmental pollution control agencies with a tool to compare the relative costs of two or more emissions control measures and their effects, or outcomes. CEA is particularly helpful when comparing control measures associated with an individual source category.

³ SPBP 2010. *San Pedro Bay Ports Clean Air Action Plan, 2010 Update*; jointly prepared by the Port of Los Angeles and Port of Long Beach, October 2010.

The effects of a control measure are quantified in terms of the amount of pollutants reduced, in units of grams, kilograms, pounds, tons, metric tonnes, etc. Cost effectiveness is usually evaluated in ratio of monetary unit/pollutant mass (\$/ton, €/tonne, £/tonne), but some agencies prefer to compare measures using a pollutant mass/monetary unit ratio (pound/\$, kilogram/€) or other variations including \$/metric tonne for greenhouse gas reductions. Cost-effectiveness analysis allows competing measures to be ranked by the amount of emissions reduction relative to the funding investment. The most cost-effective measures are ranked as the best choice.

Important in this decision-making process, however, is the acknowledgement that while a measure might rank below other measures because it is not the most cost-effective, the impact of the measure still must be considered when the measure stands on its own. If one measure out of a group of measures has a cost effectiveness of \$1,000,000/ton (in other words, the cost is \$1 million for every ton of emissions reduced), it would not normally be implemented without significant qualitative justification, since there are other measures that have cost effectiveness far below this level. However, if this is the only control measure available and feasible to address a significant acute health risk affecting a substantial population, it might be considered anyway.

Note that CEA as discussed herein is considered to be “prospective”, or an analysis that is undertaken in advance of selecting and implementing a measure. An evaluation approach that returns to the measure at its conclusion to assess actual measure results would prove useful to check measure results against original assumptions and expectations. If substantively different, lessons learned can be applied in future implementation efforts.

Refer to Annex 2 for a detailed discussion and sample calculations for CEA.

2.7.5 Modelling, monitoring and reporting

It can be helpful to model the potential emissions benefits expected from the ERS plan. Using the baseline emissions inventory and applying control measure assumptions based on the specific measures and identified timeframes, one can produce an estimate of expected benefits from programme implementation. This will serve as additional benchmarking for the programme.

In order to monitor the success of the various measures that are ultimately implemented, a system that is designed to track progress is essential. A tracking system that manages the ERS plan measure implementation will help ensure that the ERS plan targets are achieved over the assigned timeframe. As measures are implemented their effectiveness can be evaluated against predictions and expectations and, if necessary, modifications can be made to improve the effectiveness of the measures. The ability to feed real-world results back into the ERS plan will enhance its chance for success.

Reporting is also helpful to document programme ERS plan progress and effectiveness for stakeholders. Reports on ERS plan implementation efforts, including both successful strategies and lessons learned are particularly important so that other ports can learn about the strategies and assess if they can be replicated at their port with the same effectiveness.

2.7.6 Review and adjustment cycles

During implementation of the ERS plan, challenges will be encountered, and inevitably one or more measures will be delayed or only be partially implemented. These challenges should be documented, and a process should be developed to identify other ways to achieve the underlying goals of the ERS plan. The following steps generally take place:

- Use a tracking system to monitor the progress of the ERS plan.
- Evaluate how well the ERS plan is operating under the measures that have been established.
- Measure the results of the emissions control measures.
- Quantify the emissions that have been reduced and where operational performances have improved.

Information from the tracking system should be analysed at regular intervals. These intervals should be set up on a reasonable schedule. Committing to an overly aggressive schedule of updates may be counter-productive

in that they will require staff resources. Milestones and interim goals should be set to assess progress and effectiveness of each emissions control measure. Fine-tuning or major changes can then be introduced as needed to further improve the ERS plan. As measures are implemented, targets may need to be adjusted (e.g. once all trucks meet newer, stricter emissions standards, a new target could be implemented that focuses on advanced technologies, such as zero-emissions vehicles).

More broadly, periodic updates to the emissions inventory (for example, on an annual or biennial basis) provides the ability to objectively review progress and highlight the most effective emissions control measures for the ERS plan.

3 Overview of emissions control measures

Building off the emissions control strategy frameworks developed in the IMO's Air Pollution and Energy Efficiency Studies, Volume 2, Study of Emissions Control and Energy Efficiency Measures for Ships in the Port Area,⁴ the IAPH Environmental Ship Index (ESI),⁵ the Port of Long Beach (POLB) and Port of Los Angeles (POLA) San Pedro Bay Ports (SPBP) Clean Air Action Plan (CAAP),⁶ and other port-related emissions reduction strategies implemented by IAPH member ports, emissions control measures can be grouped into the following categories:

- **Equipment** – physical changes to existing machinery and equipment or the replacement of older, dirtier equipment with newer, cleaner and more efficient equipment, including:
 - Engine technologies
 - Boiler technologies
 - Emissions reduction technologies (pre- and after-treatment)
 - Equipment/engine replacement
- **Energy** – measures related to the energy sources used by vessels and port equipment:
 - Energy sources and fuel types
 - Alternative power supply
 - Hybridisation
- **Operational** – measures related to operational efficiency improvements:
 - Emissions source operational efficiencies
 - Terminal operational efficiencies
 - Port wide operational efficiencies

Measures can be implemented in different ways, including new purchase, replacement, repower and retrofit.

- **New purchase:** A new ship, piece of equipment, or terminal infrastructure is designed with cleaner emissions and/or energy efficiencies in mind. Additions to a fleet are made such that the cleanest available design is selected for the new purchase. A new purchase is sometimes referred to as a “new build”, and depending on the equipment type can sometimes be a lower cost approach, compared to repower or retrofit to reduce emissions. The usefulness of the new purchase approach is that availability is limited by manufacturer schedules and the long lead-time necessary to place a new unit in service.

⁴ IMO 2015. *Study of Emissions Controls and Energy Efficiency Measures for Ships in the Port Area*; International Maritime Organization (IMO), prepared by Starcrest Consulting Group, LLC, CE Delft, Civic Exchange, February 2015, See <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Port%20Area.pdf>, cited February 2018.

⁵ IAPH 2018. *Environmental Ship Index*; website, International Association of Ports and Harbors (IAPH), prepared by members of the World Ports Sustainability Program (WPSP) of IAPH, 2018. See <http://www.esi.wpci.nl/Public/Home>, cited February 2018.

⁶ SPBP 2017. *2017 San Pedro Bay Ports Clean Air Action Plan Update*; jointly prepared by the Port of Los Angeles and the Port of Long Beach, November 2017. See <http://www.cleanairactionplan.org/>, cited February 2018.

- **Replacement:** Replacement expands the new purchase approach to include the removal of a similar vehicle or equipment from the fleet (i.e. the old unit is relocated, retired or scrapped), in addition to the purchase of the cleaner replacement unit.
- **Repower:** For a repower, the older, existing engine in a piece of equipment or vessel is removed from the unit and is replaced by a newer, cleaner engine or power plant that has reduced emissions.
- **Retrofit:** Retrofit means that emissions reduction and energy efficiency technologies are added on to existing pieces of equipment, ships, etc. to reduce emissions. Retrofits do not involve removal of the engine as is done in a repower. For vessels, retrofits may be more expensive than new builds since it is difficult to modify existing vessels to reduce emissions (very limited engine room space, compatibility issues, etc.). However, for applications where retrofits are feasible (such as on-road equipment and some non-road equipment), the approach can be faster and provide similar benefits as new builds.

In order to increase availability of technologies that can be used with the above approaches, some ports implement technology advancement programmes to accelerate the development and commercialisation of clean technologies. These programmes provide grant funding to share the cost to design, demonstrate, evaluate and commercialise clean technology. Since ports need assurance that emissions reductions are quantifiable, some pollution control agencies undertake verification of emissions control technologies. Verification of emissions reductions provides a mechanism for clean technologies to gain approval from regulatory authorities for use in certain applications. This verification will detail the specific reductions that can be claimed when implementing a verified technology. These emissions reductions values from technology verification can then be used during emissions assessments to document the emissions changes from application of these technologies. The following recommended resources are provided as a place to begin research of port-related emissions reduction strategies and measures:

Table 3.1: *Environmental technology verification resources*

Resource	Organisation	Notes	Link
World Ports Sustainability Program	IAPH	Reference website for port-related emissions control strategies and best practices	http://wpci.iaphworldports.org/
Technology Advancement Program	Port of Long Beach Port of Los Angeles	Annual reports on numerous port-based emissions reduction technology evaluations and demonstration projects	http://www.cleanairactionplan.org/technology-advancement-program/
Verified Emissions Reduction Technologies	California Air Resources Board	Site lists currently verified emissions reduction technologies, reduction levels and associated applications	https://www.arb.ca.gov/diesel/verdev/vt/cvt.htm
Environmental Technology Verification Program	United States Environmental Protection Agency	Site lists currently verified emissions reduction technologies, reduction levels and associated applications	https://www.epa.gov/verified-diesel-tech/verified-technologies-list-clean-diesel
European Union (EU) Environmental Technology Verification	EU Environmental Technology Verification	Site lists currently verified emissions reduction technologies, reduction levels and associated applications	https://ec.europa.eu/environment/ecoap/etv_en
DANETV	Danish Center for Verification of Climate and Environmental Technologies	Site lists currently verified emissions reduction technologies, reduction levels and associated applications	http://www.etv-denmark.com/
ETV Canada	Environmental Technology Verification Canada	Site lists currently verified emissions reduction technologies, reduction levels and associated applications	http://etvcanada.ca/
Environmental Technology Verification Program	Ministry of the Environment		http://www.env.go.jp/policy/etv/en/
New Excellent Technology	Korea Environmental Industry Technology Institute		https://www.koetv.or.kr/eng/home/default.jsp

3.1 Equipment measures

Due to the dominance of diesel fuelled equipment usage in port-related operations, port-related equipment emissions reduction measures commonly focus on reducing emissions from diesel fuel oil and diesel fuelled engines and boilers through improvements in engine and boiler technologies, installation of pre- and after-treatment engine emissions reduction technologies, and the replacement of older, dirtier engines with newer, cleaner engines. Note that equipment measures can sometimes lead to significant reductions in certain targeted pollutant emissions while potentially increasing other pollutant emissions. For instance, selective catalytic reduction units can significantly reduce NO_x emissions at the expense of energy consumption and increased GHG emissions. In addition, some technologies are only effective under certain operating conditions/duty cycles; therefore, it is important to ensure compatibility not only between the technology and the equipment, but also between the technology and the duty cycles under which the equipment operates (i.e. load, engine temperature, etc.).

Equipment measures are usually developed for a specific type of equipment within an emissions source category and they target specific pollutant emissions. Engine measures are often initially designed for a specific emissions source category and are then adapted and transferred to other emissions source categories. For example, diesel particulate filters, which are an after-treatment technology, were developed for smaller diesel-powered cargo handling equipment and then re-engineered to work on larger cargo handling equipment, on-road trucks, and locomotive diesel engines, all having a wide range of engine power ratings and duty cycles.

Below is a selection of examples, by emissions source category, of equipment control measures that have been successfully implemented at ports:

3.1.1 Seagoing vessels

Numerous and diverse emissions control measures are available to effectively reduce emissions and improve energy efficiency for seagoing vessels. The IMO has delved deeply into this subject with its Study of Emissions Control and Energy Efficiency Measures for Ships in the Port Area.⁷ There is no common, cost-effective solution for reducing PM and NO_x on ships at this time nor in the foreseeable future, 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).

Measure	Engine improvements
Description	Improvements to main and auxiliary engines help reduce PM, NO _x and SO _x emissions. Measures for reducing emissions from main engines may include: slide valves, seawater scrubbing, as well as engine upgrades. Measures for auxiliary engines include: selective catalytic reduction (SCR) (for NO _x only), and engine upgrades or equipment repower with cleaner engines.
Technical considerations	Operational and feasibility testing is required to ensure the function and appropriateness of an emissions control technology (ECT) for marine applications. In particular, many ECTs require exhaust gas temperature analysis based on exhaust gas temperature data logging to measure exhaust gas temperatures. Many ECTs are not effective at low operating temperatures, since many have minimum exhaust temperature thresholds that are required for the operation and effectiveness of the technology. Emissions control technologies that have been certified or verified by regulatory agencies (such as those programmes at the US Environmental Protection Agency and the California Air Resources Board) are most likely to deliver the claimed benefits.
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • addition of port tariff charges/fees • financial incentives to vessel or terminal operators (to help reduce the cost of a measure) <p>An approach successfully used at US ports is to design and implement a “Technology Advancement Program” that would demonstrate the feasibility of ECTs on marine applications.</p>

⁷ IMO 2015. *Study of Emissions Controls and Energy Efficiency Measures for Ships in the Port Area*; International Maritime Organization (IMO), prepared by Starcrest Consulting Group, LLC, CE Delft, Civic Exchange, February 2015. See <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Port%20Area.pdf>, cited August 2018.

Measure	Engine improvements
Other considerations	While equipment ECT measures yield emissions reduction benefits, challenges may be encountered with technology feasibility. Costs vary widely as many of the technologies for seagoing vessels, especially as retrofits, are still experimental.

3.1.2 Domestic vessels, harbour craft and inland waterway vessels

Equipment measures that can be applied to address emissions from domestic vessels are often adapted from technologies or strategies that have been developed for on-road and non-road equipment because engine sizes are similar, and the modifications required to allow for their use in the marine environment are less significant than for seagoing vessels. Some of the measures can also apply to dredging equipment. Some measures will generally vary in applicability by equipment size and function.

Measure	Engine repower
Description	Replacing existing main and auxiliary engines of domestic vessels with cleaner engines that meet the newest and most strict national air quality standards. For example, the US has diesel engines that meet US EPA Tier II and Tier III engine standards. Replacing a Tier 0 engine with a Tier II engine will reduce NO _x up to 47%. Tier III engines will reduce NO _x and PM up to 90% compared to their Tier 0 counterparts. EU has similar clean engine standards for inland waterway vessels, Stage III (currently in place) and Stage V (starting 2019).
Technical considerations	A domestic vessel engine replacement strategy will involve the removal of the original engine and replacing it with a newer, cleaner engine. The compatibility of a replacement engine with the vessel, even among similar models of different years, is not always guaranteed. Further, new engine models may have emissions controls or other equipment that may not fit within the existing engine room space. Replacing main-propulsion engines with cleaner engines will provide significant emissions benefits that compound over the remaining life of the equipment. For domestic vessels, this is important because the total operating life of an engine can be up to 30 to 40 years.
Other considerations	Cleaner engines are costly and capital costs may cause an economic burden. For a mid-sized domestic vessel, the total cost of engine repower can be between \$0.5 and \$1.5 million, varying widely with the engine type, access, yard costs, opportunity costs and other factors. Destroying old engines may also increase costs. Ideally, old engines should be rendered inoperable so they are not able to continue to pollute.

Measure	Emissions control technologies
Description	Additional ECTs applicable to domestic vessels include equipping vessels with the best available engine pollution controls, using fuel additives and after-treatment emissions control technologies. ECTs can include exhaust after-treatment devices, such as diesel oxidation catalyst (DOC), diesel particulate filter (DPF) and selective catalytic reduction (SCR), or engine and fuel efficiency technologies, such as modern fuel injectors, computer controls and software upgrades, which result in more efficient engine air fuel mixtures and fuel savings. The engine manufacturers and distributors of emissions control technologies can provide technical guidance to vessel owners and operators in the selection of appropriate ECTs for their vessel. While evaluating different emissions control technologies, consider ECTs that have had proven success with vessels similar to the vessel under evaluation.
Technical considerations	Similar to seagoing vessels (section 3.2.1), operational and feasibility testing is required to ensure the function and applicability of an emissions control technology on marine applications.
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • addition of port tariff charges/fees • financial incentives to vessel or terminal operators (to help reduce the cost of a measure) • design a Technology Advancement Programme that would demonstrate feasibility and effectiveness of ECTs on marine applications. The Technology Advancement Programme would consider use of newer technologies.
Other considerations	Cost varies widely based on the both the type of ECT and the vessel it is applied on. The use of ECTs proves to have positive emissions benefits in reducing PM, NO _x , CO and hydrocarbon (HC). Not all ECTs reduce all pollutants. Retrofitting domestic vessels with ECTs can be challenging; careful evaluation and analysis is very important to ensure the maximum benefits possible with a particular ECT are achieved.

3.1.3 Cargo handling equipment

Measures to reduce emissions from CHE are more commonly available and feasible than the vessel categories as they often derive directly from measures that have been developed for the on-road fleet. The following are examples of strategies and ECTs that have been successfully implemented to reduce emissions from CHE.

Measure	Equipment replacement meeting cleaner standards
Description	<p>In some cases, CHE fleet managers prefer to buy new equipment with new engines rather than repower or retrofit old cargo handling equipment with new replacement engines. The emissions benefits would be similar whether equipment is replaced or the engines are repowered.</p> <p>Various countries have adopted clean diesel engine emissions standards for off-road equipment, which are applicable to CHE used at ports. These emissions standards are phased in over time. As an example, US EPA has Tier I to Tier IV standards and the EU has similar clean engine standards, Euro III, IV and V.</p> <p>In the Port of New York and New Jersey, the major container terminal operators are systematically replacing yard tractors, at the end of their 5 to 10 year duty cycle, with brand-new equipment that comes equipped with the cleanest available on-road engines, and are doing this voluntarily because there is a business case to do so. These terminal operators are also investing heavily to replace older diesel-powered gantry cranes with pieces that feature regenerative electric capabilities, which likewise is supported by a strong business case.</p>
Technical considerations	This strategy involves replacing fleets of CHE with newer, less polluting and more fuel-efficient equipment. The only technical considerations are that replacement equipment has similar utility to the equipment replaced.
Options for implementation	<ul style="list-style-type: none"> • voluntary programmes • incentives • lease renewals/re negotiations • stakeholder education
Other considerations	<p>The cost of the CHE is a small fraction of the overall life cycle costs relative to operations and maintenance costs. The labour costs for terminal maintenance shops to repower CHE also need to be factored into the decision-making process. New CHE would come with warranties, which could lower maintenance costs. Each fleet manager will need to consider the relative costs and benefits for their operation.</p> <p>The purchase of newer cargo handling equipment that meet cleaner on-road or off-road engine standards will lead to emissions reduction benefits and, under the right conditions, make a good business case. The challenge may be the availability of cleaner engines internationally and the cost of replacement earlier than the intended useful life of the equipment.</p>

Measure	Emissions control technologies
Description	Retrofit CHE with the best available ECTs. ECTs can include: diesel oxidation catalyst (DOC), diesel particulate filter (DPF), or selective catalytic reduction (SCR). While evaluating different emissions control technologies, consider ECTs that have had proven success with CHE similar to the CHE under evaluation. To further improve emissions reductions, retrofit CHE engines with ECTs.
Technical considerations	Operational and feasibility testing is required to ensure the function and applicability of an emissions control technology on CHE. In particular, many ECTs require exhaust gas temperature analysis by conducting exhaust gas temperature data logging to measure exhaust gas temperatures. Many ECTs have exhaust temperature thresholds that are required for the operation and effectiveness of the technology. Emissions control technologies that have been certified or verified by regulatory agencies (such as those programmes at the US Environmental Protection Agency and the California Air Resources Board) are most likely to deliver the claimed benefits.
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • tariff charges • incentives • design a Technology Advancement Programme that would demonstrate feasibility of ECTs on CHE. The Technology Advancement Programme would consider use of new technologies.
Other considerations	<p>Consider retrofitting existing rubber-tyred gantry (RTG) cranes with hybrid technology. Retrofitting the RTG cranes to hybrid is cheaper than buying new RTG crane and the smaller engine would reduce fuel consumption and emissions.</p> <p>Applying ECTs has proven to have positive emissions benefits in reducing PM, NO_x, CO and HC. Retrofitting CHE with ECTs can be challenging; careful evaluation and analysis is a must. Some retrofit technologies have negative impact on fuel consumption.</p>

3.1.4 On-road trucks

Measure	Equipment replacement meeting cleaner standards
Description	<p>The most effective strategy for reducing air pollutant emissions from on-road trucks is to replace the oldest trucks with new vehicles equipped with engines meeting stringent emissions standards and factory-equipped with ECTs, including DPF, SCR, exhaust gas regeneration (EGR), etc. Engines with SCR require the use of low sulphur fuel as well as a urea-based additive, commonly known as diesel exhaust fluid (DEF), for the SCR to properly function and avoid damaging the catalytic materials. In order to get maximum benefit from vehicle replacement, programmes should be set up to ensure that the replaced vehicle is not used elsewhere.</p> <p>If replacing the entire vehicle exceeds available budget resources, engine replacement with a newer, lower-emitting engine is often a lower cost option. However, it is critical to ensure that the replacement engine is compatible with the other vehicle components as well as the available engine compartment envelope. Compatibility with the remainder of the vehicle driveline and fluid and electrical interfaces must be verified.</p> <p>On-road vehicles can also be retrofitted with ECTs to lower emissions. Diesel engines not equipped with DPFs can be retrofitted; however, as with off-road vehicles, many ECTs require exhaust gas temperature analysis. While DPFs are very effective in the control of PM, control of NO_x emissions requires the installation of an SCR. As noted above, after-treatment ECTs typically require the use of low sulphur diesel fuel and, in the case of SCR, require dosing componentry and consumable DEF fluid in addition to the SCR unit.</p>
Technical considerations	<p>This strategy involves replacing fleets of on-road trucks with newer, less polluting and more fuel-efficient equipment. The only technical considerations are that replacement equipment has similar utility to the equipment replaced. If engine retrofit is chosen instead, compatibility with other vehicle components must be verified.</p>
Options for implementation	<p>Port authorities can implement this strategy with a truck replacement programme that offers incentives to those owner-operators that replace their older trucks, such as offering a grant programme. Some entities have banned older trucks from calling their terminals/ports.</p>

3.1.5 Locomotives

Measure	Engine replacement
Description	<p>Diesel locomotives typically have a long useful life and are an integral component of the cargo transport infrastructure. Very few ECT retrofits are currently available for locomotives, although demonstrations of retrofit DPF⁸ and SCR⁹ systems have been conducted with varying degrees of success.</p> <p>This measure would be diesel engine replacement with a higher tier (i.e. lower emitting) rated engine and locomotive remanufacture.</p>
Technical considerations	<p>A locomotive should be remanufactured properly. If a country does not have regulations in place, US EPA or EU standards should be followed.</p>
Other considerations	<p>The cost of locomotive diesel engine replacement is expensive, but the emissions benefits have increased due to the newer engine standards (Tier 4 in the US and Stage IV EU Standards) that are available. Locomotive remanufacturing is a less expensive alternative to engine replacement. Seek out grants from the government to help pay for the cost.</p>

3.2 Energy measures

Port-related energy strategies focus on energy sources used by vessel or port equipment, whether they are physically located on board or on land (e.g. shore power). Energy strategies include cleaner or alternative fuels and alternative power systems. Below is a selection of examples, by source category, of energy strategies that have been successfully implemented at ports.

⁸ See https://www.arb.ca.gov/railyard/rsubmittal/dpf_sum.pdf

⁹ See <https://www.epa.gov/sites/production/files/2016-11/documents/cat-loco-sc-verification-ltr-2016-08-08.pdf>

3.2.1 Seagoing vessels

Measure	Cleaner fuels
Description	Require the use of lower-sulphur distillate fuels in auxiliary or propulsion engines of seagoing vessels within the coastal waters of a port. A substantial reduction in PM can be achieved if seagoing vessels use distillate fuels or alternative fuel such as LNG and biofuels instead of heavy fuel oil (HFO).
Technical considerations	There may be a need for a separate on-board fuel tank for the lower sulphur fuel. It may be necessary to coordinate with fuel suppliers, shipping lines, and others to ensure low sulphur fuel availability. Similarly, availability of LNG or biodiesel throughout the voyage of the vessel or just near the ports would need to be secured if this approach is chosen.
Options for implementation	<ul style="list-style-type: none"> • lease requirements • tariff changes • incentive programmes, such as ESI
Pros and cons	Positive emissions reduction benefits for NO _x , PM and other pollutants. Challenges may arise with low sulphur fuel availability and putting in place an on-board tank/fuelling station. Fuel contamination may be another drawback. Fuel tank cleaning may be required for ultra-low sulphur diesel fuels. When it comes to LNG or biodiesel, careful evaluation of the potential negative impact on GHG emissions will need to be undertaken. For example, using LNG fuels may result in methane leaks, which have a global warming potential greater than CO ₂ .

Measure	Shore power/hotelling emissions reductions
Description	<p>Shore power for ships, also referred to as “cold ironing”, focuses on reducing dwelling (hotelling) emissions from seagoing vessels while at berth. This strategy has two approaches: 1) shore-power (supplying electricity to seagoing vessels while at berth, where the power is generated by regulated stationary sources) and 2) hotelling emissions reduction requirements through alternative technologies, such as barge-based emissions control systems for ships that do not fit the shore power model.</p> <p>Operational and infrastructure conditions might not provide 100% shore power connection capabilities or an infrequent calling vessel may not be shore power ready. In these conditions an alternative technology such as barge-based exhaust scrubber system may be warranted. In California, there are two competing barge-based systems in operation that affix to the vessel’s exhaust stacks to filter pollutants from auxiliary engines while the vessel is at berth.</p>
Technical considerations	Substantial electrical power and transformer/connection infrastructure is required, both on-dock, and on-board any vessel that will connect to shore power. It is necessary to determine the appropriate power needs for each terminal and ensure adaptability. Upgraded regional electrical infrastructure may be required to handle the potential loads. The energy profile of the power company that is providing the electrical power to the terminal needs to be considered in order to assess the air pollutant and GHG emissions generated by the use of shore power. Some power companies operate coal-burning power plants without the use of scrubbers and other types of emissions control technologies. A local power company that uses a relatively cleaner source of fuel and uses emissions control technologies will optimise the overall benefits of shore power. If barge-based exhaust scrubber systems are considered, limitations on berth space could limit the number of barge-based systems that can be deployed, as there may be little available space for these units to tie up when not in use. Additionally, each terminal in a port may require its own unique barge-based solution, potentially limiting sharing barge-based systems between terminals.
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • incentives • tariff changes • capital funding
Other considerations	<p>Shore power is one of a few emissions control strategies that ports and shipping lines can utilise to reduce at-berth emissions from ships. Cold ironing is not universally effective for all ships and ship types.</p> <p>Cold ironing works best when ships operate in liner-type services that have the same vessels calling in a frequent rotation over a number of years to the same terminals, due to the infrastructure required for on-board equipment and the need to upgrade a terminal to support provisioning of shore power. Liner-type services typically include cruise ships, containerships, some bulk liquid and chemical/product tanker operations, LPG tankers and some general cargo operations.</p>

Measure	Shore power/hotelling emissions reductions
Other considerations (Cont.)	<p>In addition to frequency of calls by the same ships to the same terminal, another key factor is the amount of energy the ships use while at berth. Energy is the combination of ship power demand while at berth and duration at berth. Cruise ships represent one extreme as they have very short times at berth; however, their power demand at berth is high, as are their berthing frequencies. Other vessel classes have lower power demand at berth; however, they are at berth longer.</p> <p>Liner type services are critical in a shore-power strategy because the costs of vessel and terminal infrastructure need to be amortised by frequent calls of those ships that have been retrofitted to terminals that have been upgraded. In addition to frequent calls per year, it is important to note that these same vessels need to continue to call for several years in a row to make this strategy cost effective. This approach optimises cost spent per ton of emissions reduced.</p> <p>The most expensive component to cold ironing is the related shore-side infrastructure. Typical infrastructure needs include: power connection to the utility grid, underground electrical vaults, power converter/transformer/switching equipment and land for these facilities, receptacle pits, receptacles, cabling, synchronisation equipment and wharf infrastructure. These costs can be significantly reduced if the terminal is designed with cold ironing infrastructure prior to being built. Converting an existing terminal to cold ironing capabilities can require significant modifications, and the cost varies by complexity. One of the most expensive container terminal retrofit projects built was the China Shipping berth at the Port of Los Angeles which cost ~\$7 million in 2004. Based on several feasibility studies done by ports in the US and Canada, costs to provide shore power at a berth range between ~\$1 - \$15 million.^{10,11,12,13} These costs vary significantly depending on the extent of terminal rebuilding, the proximity to adequate electricity supplies, and the ability to locate the shore-side infrastructure.</p> <p>Alternative barge based scrubber systems technology is still new, so accurate cost information is difficult to estimate. Initial system costs will likely decrease as the designs are streamlined and multiple systems are built. One manufacturer estimates that when dozens of systems are built they will sell for \$8 million each.¹⁴</p>

3.2.2 Domestic vessels, harbour craft and inland waterway vessels

Measure	Cleaner fuels
Description	The use of fuels with low sulphur content is the most common emissions reduction approach for domestic vessels. Cleaner fuels for vessels may include: low and ultra-low sulphur diesel fuel, emulsified diesel fuels and biodiesel. More options are also becoming available for mid-sized LNG powered vessels, but this most likely requires equipment replacement rather than fuel switching.
Technical considerations	It may be necessary to coordinate with fuel suppliers, vessel operators and others to ensure low sulphur fuel availability and supply. Depending on the type of clean fuel used, cleaning of the fuel tank may be required in order to avoid fuel contamination.
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • tariff changes
Other considerations	As with other equipment, positive emissions reduction benefits for NO _x , PM and other pollutants accrue with cleaner fuels. The use of biodiesel may present a slight increase in NO _x . Challenges may arise with fuel availability in some locales.

¹⁰ ENVIRON 2004. *Cold Ironing Cost Effectiveness Study: Volume I – Report*; prepared for Port of Long Beach by ENVIRON International Corporation Los Angeles, California, March 2004. See <http://www.polb.com/civica/filebank/blobdload.asp?BlobID=7718>

¹¹ Yorke 2007. *Port of San Diego: Cold Ironing Study*; prepared for the Port of San Diego by Yorke Engineering, May 2007.

¹² Westmar 2007. *Deltaport Third Berth Container Terminal Cold Ironing Feasibility Study*; prepared for TSI Terminal Systems, Inc. by Westmar Consultants, Inc., May 2007.

¹³ US EPA 2017. *Shore Power Technology Assessment at U.S. Ports*; prepared for EPA by Eastern Research Group, Inc. and Energy & Environmental Research Associates, LLC, March 2017.

¹⁴ CARB 2018. *Draft Technology Assessment: Ocean-Going Vessels*; California Air Resources Board, May 2018. See https://www.arb.ca.gov/msprog/tech/techreport/ogv_tech_report.pdf

Measure	Electrification (including shore power and hybridisation)
Description	<p>Reduce domestic vessel hotelling emissions by hybridisation or providing shore power connection. Similar to seagoing vessels, shore power provided through an electrical connection at berth can replace the domestic vessel's on-board electrical generation for hotelling functions.</p> <p>Hybridisation is best for vessels when they are operating away from the berth and have fluctuating energy demands. For example, tugs spend much of their time away from berth operating in low power mode, with occasional periods using high power. A hybrid, in this case, could potentially use battery power while in low power mode (moving around port), switching to engine power during time of high load (ship assist).</p>
Technical considerations	<p>Provide shore power infrastructure on-dock and on-board the domestic vessel. Determine necessary power needed and ensure adaptability. Again, it is important to consider the fuel source of local power company that is providing the electrical power to the terminal.</p> <p>Currently, Norway has 2 fully operational electric-powered ferries and converted a supply vessel to operate on batteries, diesel and liquefied natural gas. Other countries that have launched electric car ferries include Finland, and soon, Sweden and Denmark. Ferries, with their fixed routes, short trips and known berths are ideal for operating in full electric capacity.</p> <p>With respect to hybridisation, evaluate the domestic vessel engine and duty cycles to determine whether the vessel is a good candidate for hybridisation, which is currently being developed and used on tugboats and ferries. Substantial fuel savings can be realised in addition to lowering emissions by use of hybrid technology.</p>
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • incentives • tariff changes • capital funding
Other considerations	<p>Positive emissions reduction benefits accrue while at port with shore power. Challenges can occur with infrastructure cost and shore power hook up. Shore power requires extensive infrastructure improvements. On the other hand, because of the power characteristics required, adequate shore power may already be available at or near many terminals without the substantial capital expenses required for seagoing vessel shore power.</p> <p>Hybridising domestic vessels has become much more feasible in the past several years as several demonstration projects have illustrated the feasibility and benefits of the technology. In Long Beach, Foss tugboats retrofitted an existing tug with lithium ion batteries and advanced drives for a total project cost of US\$2.1 million, which included design costs.</p>

3.2.3 Cargo handling equipment

Measure	Cleaner fuels
Description	<p>Implement the use of fuels with low sulphur content. Cleaner fuels include: low to ultra-low sulphur diesel fuel, emulsified diesel fuels and biodiesel. Additional cleaner fuel options for CHE include LNG and CNG.</p>
Technical considerations	<p>It may be necessary to coordinate with fuel suppliers, vessel operators and others to ensure low sulphur fuel availability and supply. Depending on the type of clean fuel used, cleaning of the fuel tank may be required in order to avoid fuel contamination.</p>
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • tariff changes
Other considerations	<p>Positive emissions reduction benefits accrue for NO_x, PM and GHGs. The use of biodiesel may present a slight increase in NO_x. Challenges may arise with fuel availability. Cleaner fuels often cost more than standard ones.</p>

3.2.4 On-road trucks

Measure	Cleaner fuels
Description	Implement the use of cleaner fuels with low sulphur content. Cleaner fuels include: low to ultra-low sulphur diesel fuel, emulsified diesel fuels and biodiesel. Additional clean fuel options for on-road trucks include natural gas, both compressed (CNG) and liquefied (LNG), and liquefied petroleum gas (LPG, propane).
Technical considerations	Alternative fuels such as CNG and LNG require substantial modifications to on-road truck engines and fuel systems as well as infrastructure required to store, condition, and dispense the fuel.
Options for implementation	<ul style="list-style-type: none"> • lease requirements on terminal operators • tariff changes
Other considerations	Positive emissions reduction benefits accrue for NO _x , PM and GHGs. The use of biodiesel may present a slight increase in NO _x . Challenges may arise with fuel availability. Cleaner fuels often cost more than standard ones.

3.3 Operational measures

Operational measures primarily affect and focus on reducing emissions from the operation of the vessel, terminal or port. 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 and port/terminal operational efficiencies. The following section presents operational measures, as they are suited specifically to seagoing vessels and landside operations.

3.3.1 Seagoing vessels

Measure	Vessel speed reduction (VSR)
Description	Slower vessels have lower emissions per mile than faster moving vessels. A VSR programme is aimed at reducing emissions from seagoing vessels by slowing vessels when they are in the vicinity of populated areas around ports. This would include a speed reduction down to 10-12 knots when OGVs are within the coastal waters and approaches to a port area.
Technical considerations	No operational changes are required of the vessel engine(s) as low speeds are already frequently used for navigation and operational purposes. Technical considerations may include updating existing radars and communication devices to communicate with local navigation and communication centres. There is limited data on the vessel speed at which net emissions are lowest. However, at least one study ¹⁵ concluded that there was approximately 61% reduction in CO ₂ , 56% reduction in NO _x and 69% reduction in PM _{2.5} by reducing vessel speeds from cruise to 12 knots or less. The particular VSR benefits are likely to vary with engine type.
Options for implementation	<ul style="list-style-type: none"> • tariff reduction incentives • lease requirements for renewed lease agreements • voluntary programmes
Other considerations	Overall reductions in fuel consumption bring net reductions in NO _x , PM and other air quality pollutants. These can be implemented with net negative costs over time if structured correctly. VSR savings are balanced by a range of additional operational costs and have to be managed for broader supply chain effects if there is any increase in transportation times. Following the economic downturn in 2008, many carriers used VSR as a means of reducing operational costs. Mandatory VSR programmes have been put in place on the East Coast of the United States to protect endangered whale species. Voluntary and incentivised programmes are increasingly being used around busy ports to reduce ship emissions.

¹⁵ CARB 2012. *In-use Emissions Test Program at VSR Speeds for Oceangoing Container Ship*; prepared by University of California, Riverside, College of Engineering-Center for Environmental Research and Technology for the California Air Resources Board, June 2012.

3.3.2 Landside operational improvements

Measure	Terminal efficiency improvements
Description	Reconfigure existing terminals, deepen channels and berths and improve inland access by rail and barge; install infrastructure to support electric-regenerative cranes; enhance on-dock and regional rail capabilities; invest in gate improvements; and speed up vessel loading and unloading time. The latter further enhances air quality by reducing vessel dwelling time.
Technical considerations	Most ports can take advantage of new technologies and designs in some form. Every terminal is different, so new designs have to be implemented in a way that also provides a reasonable return on investment through operational efficiencies.
Other considerations	Appropriate design will support a business case, and thus, voluntary action. If designed properly to support the business case, the result is higher efficiency and lower emissions, a win-win scenario.

The following table provides a summary of the different emissions reduction measures described above.

	Seagoing vessels	Domestic vessels, harbour craft, and inland waterway vessels	Cargo handling equipment	On-road trucks	Locomotives	Landside improvements
Equipment measures	Engine improvements (via)	Engine repower	Equipment replacing		Engine replacement	
	Emissions control technologies (ECTs)					
Energy measures	Cleaner fuels					
	Electrification/onshore power					
Operational measures	Vessel speed reduction (VSR)					Terminal efficiency improvements

3.4 Conclusion

Emissions control measures are the heart of an ERS plan. Using the example control measures included above, and evaluating others from the other sources provided in this section and the next, a set of measures can be customised to the needs of a particular port. Taking the time to develop the individual control measures, identifying the particulars of how each measure will be applied and implemented with as much detail as practical, will help to ease the rollout of the ERS once completed.

Providing for industry and community stakeholder involvement in development of the control measures and the ERS plan will help the port identify issues important to both stakeholder groups and allow the port to acknowledge and potentially address these issues in the ERS plan. In particular, reviewing candidate control measures with industry stakeholders will help to identify technical issues with the implementation of candidate equipment and operational measures so that these issues can be considered prior to inclusion in the ERS plan.

The Resources section below provides a list of references. Annex 1 provides a checklist of items to consider while developing an ERS.

4 Resources

This section provides a list of resources that were used in the writing of this guide.

- CARB 2018. *Draft Technology Assessment: Ocean-Going Vessels*; California Air Resources Board, May 2018.¹⁶
- CARB 2012. *In-use Emissions Test Program at VSR Speeds for Oceangoing Container Ship*; prepared by University of California, Riverside, College of Engineering-Center for Environmental Research and Technology for the California Air Resources Board, June 2012.
- ENVIRON 2004. *Cold Ironing Cost Effectiveness Study: Volume I – Report*; prepared for Port of Long Beach by ENVIRON International Corporation Los Angeles, California, March 2004.¹⁷
- IAPH 2018. *IAPH Toolbox for Port Clean Air Programs*; website, International Association of Ports and Harbors (IAPH), prepared by members of the World Ports Climate Initiative (WPCI) of IAPH, 2018.¹⁸
- ICCT 2012. *Developing Port Clean Air Programs: A 2012 update to the International Association of Ports and Harbor’s Air Quality Toolbox*; The International Council on Clean Transportation (ICCT), prepared by Starcrest Consulting Group, LLC, June 2012.¹⁹
- SPBP 2006. *2006 San Pedro Bay Ports Clean Air Action Plan – Technical Report*; jointly prepared by the Port of Los Angeles and the Port of Long Beach, November 2006.²⁰
- SPBP 2010. *2010 San Pedro Bay Ports Clean Air Action Plan Update*; jointly prepared by the Port of Los Angeles and the Port of Long Beach, October 2010.²¹
- SPBP 2017. *2017 San Pedro Bay Ports Clean Air Action Plan Update*; jointly prepared by the Port of Los Angeles and the Port of Long Beach, November 2017.²²
- PANYNJ 2014. *A Clean Air Strategy for the Port of New York & New Jersey – 2014 Update*; the Port of NY & NJ, 2014.²³
- IMO 2015. *Study of Emissions Controls and Energy Efficiency Measures for Ships in the Port Area*; International Maritime Organization (IMO), prepared by Starcrest Consulting Group, LLC, CE Delft, Civic Exchange, February 2015.²⁴
- Sharma DC. *Ports in a Storm*; Environmental Health Perspectives. 2006; 114(4):A222-A231.
- US EPA 2017. *Shore Power Technology Assessment at U.S. Ports*; prepared for EPA by Eastern Research Group, Inc. and Energy & Environmental Research Associates, LLC, March 2017.
- Westmar 2007. *Deltaport Third Berth Container Terminal Cold Ironing Feasibility Study*; prepared for TSI Terminal Systems, Inc. by Westmar Consultants, Inc., May 2007.
- Yorke 2007. *Port of San Diego: Cold Ironing Study*; prepared for the Port of San Diego by Yorke Engineering, May 2007.

¹⁶ See https://www.arb.ca.gov/msprog/tech/techreport/ogv_tech_report.pdf

¹⁷ See <http://www.polb.com/civica/filebank/blobload.asp?BlobID=7718>

¹⁸ See <http://wpci.iaphworldports.org/iaphtoolbox/>, cited April 2018

¹⁹ See https://www.theicct.org/sites/default/files/ICCT_SCG_Developing-Clean-Air-Programs_June2012.pdf, cited April 2018.

²⁰ See <https://www.cleanairactionplan.org/documents/2006-clean-air-action-plan-update-tech-report.pdf>, cited April 2018.

²¹ See <https://www.cleanairactionplan.org/documents/2010-final-clean-air-action-plan-update.pdf>, cited March 2018.

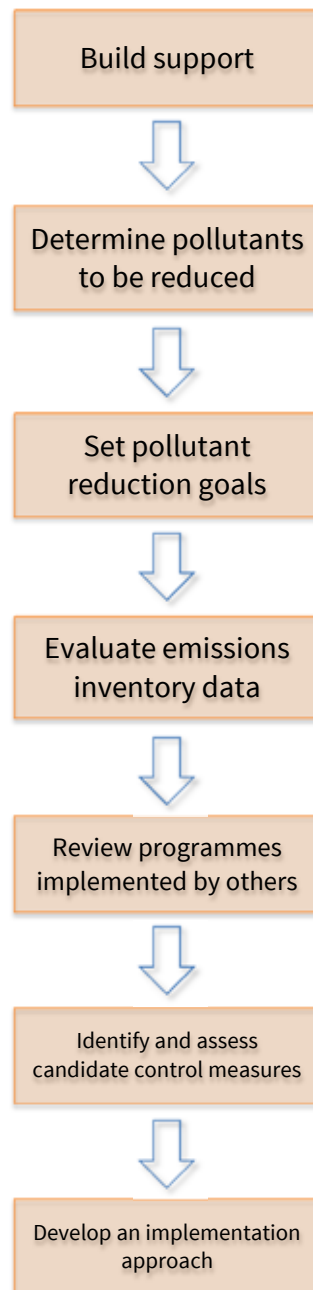
²² See <https://www.cleanairactionplan.org/documents/final-2017-clean-air-action-plan-update.pdf>, cited April 2018.

²³ See https://www.panynj.gov/about/pdf/PANYNJ_CAS_2014_FINAL2.pdf, cited April 2018.

²⁴ See <https://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Port%20Area.pdf>, cited March 2018.

Annex 1

Port emissions reduction strategy plan checklist



Build support

- Port leadership support List: _____
- Budget for ERS planning List: _____
- Project leader assigned List: _____
- Project team assigned List: _____

Determine pollutants to be reduced

Air quality pollutants:

- Oxides of nitrogen (NO_x)
- Particulate matter (PM)
 - PM <10-microns (PM₁₀) and
 - PM fines <2.5-microns (PM_{2.5})
 - Diesel PM (DPM)
- Oxides of sulphur (SO_x)

Greenhouse gases/climate change pollutants:

- Carbon dioxide (CO₂)
- Carbon dioxide equivalents (CO₂e)

Set pollutant reduction goals

- Project goal(s) List: _____
- Source category goal(s) List: _____

Scopes of operation

- Direct port control List: _____
- Tenant control List: _____
- Third party control List: _____

Evaluate emissions inventory data

- Highest emitting source category List: _____
- Highest emitting class within source category List: _____
- Population for above List: _____
- Engine details for above List: _____
- Fuel details for above List: _____
- Owner/operator details for above List: _____

Review programmes implemented by others

- Similar port with ERS in place List: _____
- Review ERS plan List: _____
- Contact port List: _____

Identify and assess candidate control measures

- Review strategy references List: _____
- Select candidate measures List: _____
- Develop ranking scheme List: _____
- Rank candidate measures List: _____

Implementation considerations: claims of technology vendors

- Verify vendor claims
- Remain technology-neutral

Implementation considerations: administrative approach

- Terminal lease modifications List: _____
- Tariff changes List: _____
- Incentives/disincentives List: _____
- Agency regulation List: _____
- Voluntary adoption List: _____

Implementation considerations: coordination and collaboration with stakeholders

Coordination with:

- Pollution control agency List: _____
- Terminal operators List: _____
- Vessel operators List: _____
- Other stakeholders List: _____

Implementation considerations: evaluating cost effectiveness

- Strategy cost effectiveness List: _____

Implementation considerations: monitoring and reporting

Monitoring/Tracking:

- System developed List: _____
- Frequency List: _____

Reporting:

- Internal List: _____
- External List: _____
- Frequency List: _____

Implementation considerations: review and adjustment cycles

- Frequency List: _____

Annex 2

Cost-effectiveness analysis

As discussed in section 2.7.4, cost-effectiveness analysis (CEA) is an evaluation approach that provides port, government and environmental pollution control agencies with a tool to compare the relative costs of two or more emissions control measures and their effects, or outcomes. CEA is particularly helpful when comparing control measures associated with an individual source category.

The effects of a control measure are quantified in terms of the amount of pollutants reduced, in units of grams, kilograms, pounds, tons, metric tonnes, etc. Cost effectiveness is usually evaluated in ratio of monetary unit/pollutant mass (\$/ton, €/tonne, £/tonne), but some agencies prefer to compare measures using a pollutant mass/monetary unit ratio (pound/\$, kilogram/€) or other variations including \$/metric tonne for greenhouse gas reductions. Cost-effectiveness analysis allows competing measures to be ranked by the amount of emissions reduction relative to the funding investment. The most cost-effective measures are ranked as the best choice.

Important in this decision-making process, however, is the acknowledgement that while a measure might rank below other measures because it is not the most cost effective, the impact of the measure still must be considered when the measure stands on its own. If one measure out of a group of measures has a cost effectiveness of \$1,000,000/ton (in other words, the cost is \$1 million for every ton of emissions reduced), it would not normally be implemented without significant qualitative justification, since there are other measures that have cost effectiveness far below this level. However, if this is the only control measure available and feasible to address a significant acute health risk affecting a substantial population, it might be considered anyway.

Note that CEA as discussed herein is considered to be “prospective”, or an analysis that is undertaken in advance of selecting and implementing a measure. An evaluation approach that returns to the measure at its conclusion to assess actual measure results would prove useful to check measure results against original assumptions and expectations. If substantively different, lessons learned can be applied in future implementation efforts.

A note about lifecycle cost analysis

As discussed above, CEA is most often used to compare emissions control measures when deciding how to allocate financial resources. CEA is a simplified approach to compare measures, considering initial capital costs and associated emissions reduction benefits. A more detailed comparison approach to select the emissions reduction strategies is often used by regulators when assessing a new regulation or requirement. This deeper analysis often includes an assessment of a proposed regulation’s lifecycle emissions and economic impacts, environmental justice considerations as well as an evaluation of alternatives. Lifecycle cost analysis considers all benefits and costs over a measure’s lifetime. It applies a discount rate to all measure benefits and costs to bring them to a present value for “apples-to-apples” comparison. Lifecycle is a complete evaluation approach, but it is much more complex than the simple CEA methodology summarised below. Basic CEA provides a good basis to compare similar emissions reduction measures to each other for the purpose of ranking them in priority order.

CEA methodology examples

Below are highlights of programmes that utilise CEA as a key selection criterion. Not every detail of each programme is summarised, but links are provided if additional information is of interest.

California – Carl Moyer Program

A well-established emissions reduction grant programme is the California Air Resources Board’s (CARB’s) Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program). This programme is currently in its 20th year of funding, having allocated over \$950 million from the state to clean up over 50,000 engines, resulting in a reduction of NO_x and ROG emissions by 178,000 tons and PM emissions by 6,500 tons. The Moyer Program has served as the forerunner of a number of different grant programmes in California, and its CEA approach forms the basis of many programmes to reduce emissions throughout California and the US. Even though the Moyer Program CEA methodology was developed as a means to make project selection in a government grant programme, the Moyer approach is also a useful approach when comparing measures for ERS plans.

The Moyer Program CEA methodology annualises the cost and divides this by the measure’s total tons of air pollutants reduced per year. The Moyer Program defines the cost as a portion of a total project cost (such as the incremental cost to implement the new, more expensive technology) but for the purpose of comparing different control measures, the total cost of the measure is used. A detailed explanation of the Moyer Program CE Calculation Methodology is available online at: <https://www.arb.ca.gov/msprog/moyer/moyer.htm>

The Moyer CEA methodology is best illustrated with the programme’s key equations, which are summarised below:

Calculate Cost Effectiveness using the following equations:

$$CE (\$/ton) = \frac{\text{Annualised cost (\$/year)}}{\text{Annual weighted surplus emissions reductions (tons/year)}}$$

$$\text{Annualised cost (\$)} = CRF * \text{Incremental measure cost (\$)}$$

The CRF, or capital recovery factor, is calculated based on the life of the control measure (i.e. how long the measure will provide annual emissions reductions) and the interest rate. Essentially, the use of annualised cost allows the “time value of money” to be accounted for over the life of the measure.

$$\text{Annual weighted surplus emissions reductions (tons/year)} = (\text{NO}_x \text{ reductions}) + (\text{ROG reductions}) + (20 * \text{PM reductions})$$

Note that PM is weighted by a factor of 20 to reflect the toxicity of PM, compared to other pollutants. This is a way of acknowledging the extra importance of reducing toxic PM compared to NO_x and ROG. The Moyer Program established priorities for NO_x, ROG and PM, but this approach could consider any combination of air pollutants.

Once a set of measures is evaluated using this CEA methodology, the measures can be compared for selection. To provide context for measures being implemented under the Moyer Program, at inception the highest cost effectiveness was \$12,000 per weighted ton of emissions reduced. Today, measures are eligible for funding up to a limit of \$30,000 per ton to bring technology up to current standards, and measures that further apply advanced and zero emissions technology are eligible for funding at a \$100,000 per ton CE limit for the increment between current technology and surplus technology. The cost effectiveness of measures increases as the amount of emissions to be reduced shrinks. In regions of the world that have not yet implemented control measures, it should be possible to achieve cost-effective reductions, but as the dirtiest equipment is replaced, repowered or retrofit with clean technology, the cost effectiveness of additional control will increase. Under this two-tiered approach, the gap between current technology and advanced technology would be supported at a much higher cost-effectiveness limit than a basic measure to bring old engines and equipment to current standards.

California – Alternative and Renewable Fuel and Vehicle and Technology Program (ARFVTP)

The California Energy Commission (CEC) implements the ARFVTP, a programme “to develop and deploy alternative and renewable fuels and advanced transportation technologies to help meet the state’s goals for reducing greenhouse gas emissions and petroleum dependence in the transportation sector”. Unlike the above programme, which is focused on the reduction of air pollutants, the ARFVTP is focused on the reduction

of greenhouse gas emissions (usually using CO₂ equivalent, or CO₂e) and petroleum fuel consumption (diesel or gasoline gallons) as key metrics. Thus, cost-effectiveness evaluation for the ARFVTP differs slightly in the metrics used to compare measures, though the basic approach is similar in concept to that described above. Below are the various ways the ARFVTP uses cost effectiveness as a decision tool, often requesting all of the below metrics to select measures.

- CEC’s Benefit/Cost score is defined as the amount of lifecycle GHG emissions reduced over the measure duration per dollar of CEC funding expressed in grams CO₂e reduction per \$1.00 ARFVTP.
- CEC also employs a more typical cost effectiveness, defined as dollars per ton of Weighted Emissions Reductions (WER), where WER = NO_x reductions + Reactive Organic Gas (ROG) reductions + 20*Particulate Matter (PM) reductions, expressed in tons reduced over the full life of the measure’s implementation. Note that unlike the Moyer Program, these dollars (and emissions reductions) are not annualised, but instead divide the total ARFVTP dollars by the total tons reduced over the measure term.

United State Environmental Protection Agency

US EPA defines cost effectiveness as an evaluation to identify measure benefits, outputs or outcomes and compare them with the internal and external costs of the measure. US EPA’s Diesel Emissions Reduction Act (DERA) Program provides its Diesel Emissions Quantifier (DEQ) tool online at: <https://www.epa.gov/cleandiesel/diesel-emissions-quantifier-deq>. This tool is helpful in evaluating measures to reduce emissions from diesel engines. The DEQ calculates emissions reductions for four air pollutants, NO_x, PM_{2.5}, HC, CO, as well as CO₂, when a measure includes a reduction in fuel consumption. The tool calculates the capital cost effectiveness for a measure by adding together the unit and installation costs for each vehicle/technology and dividing the resultant sum by the total lifetime tons reduced for all of the five pollutants; note that there are no weighting factors applied.

Environmental Ship Index

The Environmental Ship Index (ESI) is a measure within the IAPH World Ports Climate Initiative (WPCI). While not a CEA tool, per se, the ESI provides a mechanism to identify ocean-going vessels with lower air emissions than are required by the current IMO emissions standards. The ESI considers OGV emissions of NO_x and SO_x, each assigned a score from 0-100, with a bonus for reporting on energy efficiency (the CO₂ term, worth 5-15 points) and the existence of an onshore power supply (OPS), fixed at 10 points. For the purposes of this paper, the details of deriving the specific ESI is less important than noting the relative weighting of the scores’ inputs. NO_x is weighted twice that of SO_x, which indicates the relative “average environmental damage from NO_x in ship air emissions is approximately twice the damage from SO_x.”²⁵ The ESI is considered a good indication of the environmental performance of ocean-going vessels and provides a general way to identify clean ships. The ESI formula is presented below to illustrate the relative weighting of each term.

ESI formula for an OGV’s ESI Score:²⁶

$$\text{ESI score} = \frac{2 \times \text{ESI}_{\text{NO}_x}}{3} + \frac{\text{ESI}_{\text{SO}_x}}{3} + \text{ESI}_{\text{CO}_2} + \text{OPS}$$

The ESI score assigns a weighting factor of two to NO_x, compared to SO_x, providing good insight into the WPCI value of NO_x reductions compared to SO_x reductions. The ESI score could be used as a means to assess the value of a port investment/priority in attracting vessels with the best ESI scores.

Qualification of cost effectiveness rankings

The above discussion provides example CEA methodologies that may be used to rank a set of measures based on the cost to implement emissions reduction strategies. Each port may establish a CEA methodology that best fits their ERS plan. An important final step before proceeding with a measure or set of measures on a ranked list

²⁵ See <http://www.environmentalshipindex.org/Public/Home/ESIFormulas>, accessed March 27, 2017.

²⁶ Ibid.

is to qualify those measures in terms of the efficacy of the investment. It is possible that a set of measures can be ranked, but even the best-ranked measure may not be a cost-efficient investment to affect the most benefit. Proceeding with such a measure might still be undertaken, however, if the health concerns or non-monetary considerations, such as local policy/politics, job creation initiatives or other qualifiers support moving forward at all costs.



MORE INFORMATION?

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