Developing Port Clean Air Programs

A 2012 update to the International Association of Ports and Harbor's Air Quality Toolbox

Prepared for:

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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Table of Contents

1. Introduction

The purpose of this guidance document is to provide an overview of technologies, policies and program examples that illustrate proven and effective approaches to reducing air emissions from port and maritime operations.

Balancing port operations and development with environmental considerations can be challenging, especially with issues like air quality and climate change that are complex and evolving. This document provides information on air quality issues and their relationship to port and maritime activities. Based on actual port experiences, it describes strategies to reduce emissions and guidance on how to develop a Clean Air Program (CAP). Strategies such as repowering older engines, applying effective technologies for efficiency and emission control, and using alternative and cleaner fuels in maritime operations will dramatically reduce air pollution and greenhouse gas emissions. Taking decisive action using these strategies will improve local air quality and ensure that your port can provide the economic benefits to the community while safeguarding public health.

Every port authority in every country has different needs, jurisdictions, and capabilities. The resources provided here are intended to help initiate, inspire, and inform discussions within port authorities and among their industry and regulatory partners about what course of action is regionally appropriate.

2. Background: A Call to Action

As international trade continues to increase each year, port cities are booming from the increase in industries supporting the transportation and distribution of these goods. However, the increase in international trade has also led to the increase in air emissions from port-related maritime activities as well as local and regional goods-transport. The potential health risk impacts associated with the goods movement sector have extended fully along the network between manufacturer and consumer.

Some of this impact can be seen in and adjacent to port marine terminals because all modes of transport (trucks, ships, cargo handling equipment, harbor craft, and rail locomotives) often meet at these intermodal hubs. When residential communities are located adjacent to port marine terminals, the residents are exposed to emissions from international, regional, and local freight movement sources. National and regional regulations control a subset of the source categories, with little overarching regulation. International regulations, as they stand now, likewise provide limited controls. Local programs and local controls can best ensure that responses to air quality concerns are tailored to the needs of the local community.

There is a special 'call to action' between ports around the world to address international port-related air quality issues. This work began with the International Association of Ports and Harbors (IAPH), a worldwide organization for ports that seeks to encourage important discussions between international ports and industries on how to address common issues like air quality. This facilitation resulted in the adoption of a resolution on Clean Air Programs for Ports at the 25th World Port Conference in Houston, Texas on 4 May 2007.

3. Overview of Air Quality Concerns and Mechanisms for Improvement

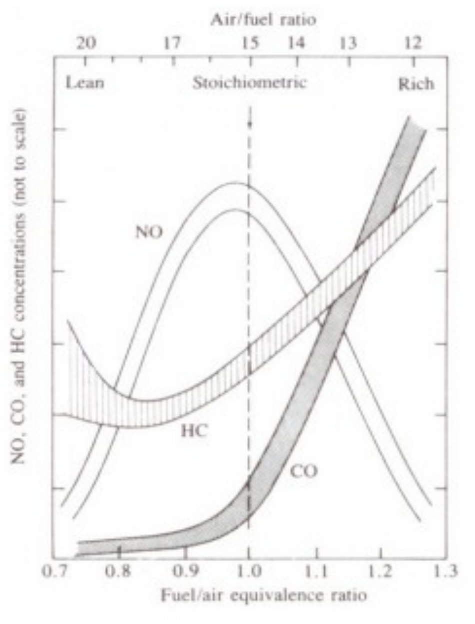
Key Air Pollutants for the Port and Maritime Sector and Their Sources

Most combustion-related emissions from the port and marine sector come from equipment using engines that burn diesel fuel. Reducing emissions from diesel engines is therefore one of the most important air quality challenges facing ports. Diesel engines are the most energy efficient internal combustion engines. This and other key characteristics such as reliability, longevity, and power make them the most common choice for the heavy-duty tasks of moving cargo. Understanding the basic principles of diesel fuel and how a diesel engine works, especially compared to other engines, helps to clarify why they produce the emissions they do and what specific control methods are applicable.

Of the main pollutants associated with diesel engines, only one is largely independent of the efficiency or effectiveness of the engine that it is being burned in. The levels of Sulfur Oxides (SO_x) emitted by diesel engines are directly proportional to the levels of sulfur in the fuel being used. Other pollutants associated with diesel engines are the result of the physics and chemistry of the diesel combustion process.

Diesel engines fundamentally differ from gas engines in how they ignite the fuel. Diesel fuel has a higher fuel density, meaning it can generate more energy per unit volume than gasoline. That also makes the fuel more viscous, requiring "compression ignition" (CI) instead of "spark ignition" (SI) as found in gasoline engines. This difference in ignition is fundamental to both the power profile and emission profile of their engines. Because diesel only needs a certain high level of pressure to ignite, it can be combusted in an environment that has more oxygen than is chemically needed for complete combustion of the hydrocarbons in the fuel. This is referred to as a "lean burning" engine and produces less CO_2 per unit energy compared to a gasoline engine that requires a "rich" fuel mixture. Lean versus rich burning has implications for many other air emissions, as shown in Figure 1.

Figure 1: Emissions from internal combustion engines with changing fuel/air ratios[1]



So the same reactions that lead to lower carbon dioxide (CO_2) emissions result in comparatively high formation of diesel particulate matter (PM) as well as oxides of nitrogen (NO_x), which is a function of the high temperature and pressure in the combustion chamber (usually in pre-combustion phase). The high temperature and pressure combustion, on the other hand, leads to a more complete combustion of the fuel and thus to lower hydrocarbon (HC) and carbon monoxide (CO) emissions.

Because of the physical and chemical properties involved, the main challenge of emission control for diesel engines is reducing PM and NO_x. The challenge becomes even more complex because the formation of PM and NO_x is inversely linked by the physical and chemical characteristics of the combustion process. Often, when one pollutant is reduced by engine process changes, (e.g. by lowering the combustion temperature) the other pollutant increases. This phenomenon is often referred to as the NO_x/PM trade-off. Therefore, NO_x and PM control using engine modifications alone is limited and future emission standards will require additional emission control technologies.

Currently, controlling NO_x, SO_x, and PM is the central focus for most port and maritime organizations throughout the world that have developed air quality programs.

Each of the pollutants introduced above is described more specifically in the following section:

Air Pollutants and Health Effects

Despite increasingly strict engine standards being put into place in Europe, the United States, and other countries and regions, diesel engines continue to produce emissions that contribute to serious health problems such as premature mortality, asthma attacks, millions of lost work days, and

[1] Heywood, Internal Combustion Engine Fundamentals, 1988,

numerous other health impacts. This section describes the specific physical and health effect attributes of each of the diesel-related pollutants described above.

Particulate Matter (PM)

"Particulate matter" (PM) is a general term used to describe aerosols that can have a wide range of physical and chemical properties. PM consists of mixtures of solid particles and liquid droplets found in the air. There are two forms of particle pollution that are regulated due to their potential impact to human health; inhalable coarse particles with diameters larger than 2.5 micrometers and smaller than 10 micrometers, and fine particles that are 2.5 micrometers and smaller. In comparison, the average human hair is about 70 micrometers in diameter.

Health Effects of PM: The effect of PM on public health is very direct – it causes acute respiratory stress and causes a range of chronic illnesses from long-term exposure. PM contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. The size of the particles determines how severe the impact on human health. Particulates that are smaller than 10 micrometers can penetrate deeper into the lungs and can even enter the blood stream. Several health authorities have listed particulate matter that specifically comes from diesel engines (diesel PM, or "DPM") as a "toxic air contaminant" indicating it has specific and demonstrated carcinogenic effects.

Nitrogen Oxides (NOx)

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

Health Effects of NO_x: NO_x does not have substantial direct human health impact. Instead, through a complex series of chemical reactions in the atmosphere, NO_x combines with volatile organic compounds (VOCs) to create ground level ozone (O_3), a very potent human respiratory irritant and short-term climate forcing gas. Ozone causes inflammation in the respiratory system that leads to coughing, choking, and reduced lung capacity over long periods of exposure. Increased hospital visits for respiratory problems such as asthma especially among children are common in urban areas with high ozone pollution. The effects of ground level ozone are more frequent during the warmer summer months. Children, elderly, and people who work or exercise outdoors are especially vulnerable to the impacts of ground level ozone. Today, there are millions of people who live in cities around the world that have levels of ozone that scientific consensus considers detrimental.

Sulfur Oxides (SOx)

SO_x describe the family of sulfur oxide gases that primarily includes SO_2 but also SO_3 and SO_4. Gases in this family can easily dissolve in water. Sulfur is found in raw materials such as crude oil, coal, and ore that contain common metals (aluminum, copper, zinc, lead, and iron). Fuel containing sulfur, such as coal and oil when burned can lead to the production of SO_x gases. SO_x emissions from ships are of great concern in the maritime industry, because of their potential to produce emissions that are harmful to human health.

Health Effects of SO_x: SO_x emissions negatively impact public health and the environment. SO_x interact with other substances in the air to create particulate matter. Exposure to elevated levels of particulate matter affect a wide variety of people but is particularly harmful to sensitive groups. These groups include people who have respiratory ailments such as asthma. They also include people with developing, decreasing, or hyperactive lung function such as children, elderly people, and active adults, respectively. SO_x also negatively impair visibility and can add to the formation of acid rain when emitted in large quantities.

Carbon Monoxide (CO)

CO is a colorless and odorless gas that is formed when carbon in fuel is not burned completely. It is a common component of diesel exhaust. In the United States, 56 percent of all CO emissions are related to motor vehicle exhaust while non-road engines contribute 22 percent of CO emissions. Highest levels of CO occur during the colder months of the year when inversion conditions are more frequent and air pollutants become trapped near the ground beneath a layer of warm air.

Health Effects of CO: The health effects of CO can result in the reduction of oxygen delivery to the body's organs (such as the heart and the brain) and tissues. Cardiovascular effects are the most serious effects of CO for those who suffer from heart disease. There are also effects on the central nervous system. Breathing in high levels of CO can result in blurred vision, reduced ability to work or learn, and reduced manual dexterity. CO also contributes to the formation of smog.

Approaches to Reducing Emissions from Port and Maritime Sources

Given that ports are a concentrated source of diesel emissions, usually in an already crowded urban environment, ports need to consider the environmental consequences of their operations.

Developing a comprehensive clean air program that considers emissions from both port land and waterside equipment will help to maximize potential emissions reductions and cost effectiveness of the program.

Technological improvements to equipment or infrastructure are central components of clean air programs, but they cannot be optimally successful or quickly implemented without deliberate planning steps, clear policy goals, and a firm commitment among stakeholders. Operational changes to reduce emissions may be more easily implemented but are best done in the context of a well-conceived plan to improve regional air quality.

Specific technologies and other emission reduction measures are highlighted in this section as a means to represent general approaches. This is not intended to be an exhaustive list of available technologies nor guidance on how to select technologies or other measures that are compatible with existing equipment or operations at any given port.

This section presents two approaches to identifying potential technological and operational measures. First, general conceptual approaches are presented for three distinct types of actions: technology, programmatic, and operational. This higher-level treatment of the measures highlights and discusses issues that are common across equipment types, noting whether they are applicable to all or specific categories of equipment. Second, specific measures from all applicable approach categories are discussed for each general category of equipment.

Common Principles for Emission Reduction Approaches

Approaches for all types of equipment will generally fall into a few broad categories that are fundamentally either technological or programmatic. This section describes these approaches in more detail, focusing on issues and considerations that may apply across equipment types.

Technology-oriented approaches:

- **Replace:** Entire vehicle or equipment with newer or less polluting models.

Concept:
Replacing an older, more polluting piece of equipment is the simplest technical approach to reducing emissions, but is also the most expensive. Equipment in normal service is often replaced on a regular schedule depending on its duty and longevity. Making equipment replacement a cost effect approach requires a careful consideration of normal turnover periods, expected remaining life and salvage value of existing equipment, and additional benefits provided by new equipment – both in terms of emissions reduced and other cost savings.

Barriers:
Technical barriers to equipment replacement are generally low. Normally, a newer version of the equipment with the same duty rating and engine format will simply replace the previous version. Some barriers may arise if maintenance or operation of new equipment is more complex than with previous versions, but this is usually easily overcome.

Cost Effectiveness:
Cost effectiveness is highly dependent on the application. Making equipment replacement a cost effective strategy depends on the potential to reduce emissions, the additional fuel efficiency, reduced maintenance costs, and improved reliability that comes with new equipment. Most operations will tend to replace equipment on a standard schedule, so incentive programs may best encourage either premature replacement or replacement that correlates the availability of equipment with improved emissions even if it means delay.

- **Repower:** Replace only the main engine and associated components that provide motive or auxiliary power

Concept:
Engine replacement involves completely removing either motive or auxiliary power systems on a given piece of equipment, and installing new engines that have been certified to have lower emissions. This is a potential strategy for any equipment with C1 and C2 class engines and is frequently undertaken at least once during the life of equipment with an expected life of 15-20 years or more. Motive engines on larger C2 and C3 engines are much less likely to be candidates for replacement because of the time and logistical difficulty involved in removal and replacement. Auxiliary engines may be more easily repowered on many vessels or equipment types because they are smaller. Repowering only auxiliary engines can be a good strategy on equipment (e.g. dredges) where conveyance is not the primary function.

Barriers:
The main downsides for engine replacement are operational downtime, capital and labor cost of replacing the engine, and the need to ensure that the engine continues to operate in the area where the emissions benefit is needed. Most industrial diesel equipment, including off-road equipment used on port terminals is designed so that its engines can be replaced at some point during the course of the equipment life, so the technical barriers are low. Some equipment may need alteration or accommodation for additional emission control equipment such as exhaust filters or urea tanks.

Cost Effectiveness:
Projects involving diesel engine replacement have been one of the favorites of US EPA diesel emission reduction grants. This is the combined result of the longevity of diesel engines and the recent availability of engines with technologies that substantially improve emissions compared to their predecessors. Even if a piece of equipment has an engine that is just a few years old, replacing the engine with a newer model that has 50-90% lower emissions means many tons of emissions reduced annually over the decades of remaining life in the engine. The window for making engine replacement most cost effective depends on the availability of new technology, the magnitude of emission reductions, and the remaining life of the equipment.

- **Rebuild:** Retain the same engines, but rebuild them to higher standards and less polluting

Concept:
Most heavy-duty equipment (including off-road equipment used on port terminals) has engines that are rebuilt every 5-10 years during the normal course of maintenance. Rebuilding engines retains most of the body of the engine and replaces only moving parts that gradually wear in the course of normal operation. Rebuilding returns the engine to near-new condition, and will improve both efficiency and reduce emissions to the original design levels. Some manufacturers offer rebuild "kits" that provide a "Tier upgrade." These will allow a given engine to improve its emission profile by one (EPA) Tier following a rebuild.

Barriers:
Generally speaking, rebuilding engines is a routine maintenance activity and the associated technical barriers are low. There may be some added barriers if "rebuild kits" are used that provide emission reducing "tier upgrades" for older engines. The process of rebuilding with an additional kit to achieve a tier upgrade will be more complicated. Engine manufactures are careful to specify which kits can be applied to their engines and provide detailed guidance for implementation.

Cost Effectiveness:
Rebuilding engines should be a routine part of equipment maintenance practices and can improve efficiency by 5-10%. Rebuilding more frequently diminishes the improvement while raising the cost significantly. Rebuilding will be a cost effective strategy in an environment where engines have been poorly maintained or where tier upgrade packages are available.

- **Refuel:** Select a compatible fuel that is cleaner burning or use electrification technologies

Concept:
In the U.S. and Europe, most non-road equipment is now required to use ultra-low sulfur fuel. This substantially reduces the amount of acidifying SOx emitted from the engine and the amount of particulate matter (PM) produced. Distillate fuels with reduced sulfur (S) are also required or

encouraged for many international vessels. In addition to reducing SOx emissions, cleaner burning low-S fuels are much cleaner burning than heavy fuel oils (aka "Bunker") and reduce the levels of other important pollutants like heavy metals.

Low-S fuel is the most mainstream option for a refueling strategy, but other fuels and energy sources are gaining popularity. Foremost among these is liquefied natural gas (LNG), which is widely seen as a desirable alternative for its clean-burning properties (compared to diesel fuels), its relatively low cost per unit of energy and price stability. Use of LNG requires special engines that are designed to burn it and dedicated storage tanks that are much larger than comparable diesel storage tanks.

Other alternative energy sources such as biodiesel, fuel cells, wind power, solar panel, and hydrogen have been deployed in limited applications and tend to have substantial cost, technical, supply, or logistic limitations that are likely to prevent their widespread deployment and use.

Barriers:
Changing to cleaner fuels is often the fastest and most straightforward approach to reducing emissions. Technical barriers are low insofar as technical requirements and potential problems have been well documented and should therefore be easy to plan for. However, switching to different fuels without knowing exactly what effect it will have on the fuel system and engine may lead to equipment failure.

Cost Effectiveness:
Fuel switching is often the fastest and most politically expedient option for reducing emissions, but may not necessarily be the most cost effective depending on the application. For instance, technologies that save fuel can be more cost effective because they save money while reducing emissions. Clean fuels are consistently more costly than their higher-emitting counterparts. The bunker fuel used by large ships is relatively cheap compared to the low-sulfur alternatives that can cost 40% more. Switching to lower-sulfur distillate diesel fuels substantially reduces SOx emissions. For non-road sources, this corresponds to a decrease of between 5-15% in overall PM emissions, depending on difference in S concentrations between the original and alternative fuel. For OGVs that use much higher sulfur fuel, switching to a much lower sulfur distillate can reduce PM emissions by up to 85%.

Program-oriented approaches

- **Repair:** Optimally maintained equipment is usually less polluting

Concept:
Most well managed fleets will have a maintenance program for the equipment in the fleet that ensures optimum life and operation. Smaller fleets and individual operators will often be less consistent in maintenance practices. A well-constructed "Inspection and Maintenance" (I&M) program instituted by an appropriate authority can improve both emissions and safety when there is a large population of smaller equipment operations in a region.

Barriers:
Equipment maintenance and repair should be a regular part of equipment management practices. While routine repair and improvement is normally part of a maintenance program, operations that are experiencing marginal profitability may choose to defer all but the most critical repairs.

Cost Effectiveness:
Because well-running equipment has many other operational benefits, including fuel efficiency and reliability, the practice should be cost effective even before emissions are considered.

- **Relocate:** Consider whether pieces of equipment that produce emissions can be relocated to an area less impacted by air quality

Concept:
Broadly speaking, larger port and maritime operations rely on activities that are partially concentrated in a centralized area and partially distributed more regionally. Health effects associated with emissions, especially diesel particulate matter (DPM) that dissipate beyond a localized area, can be addressed by moving operations to areas that are less populated. Depending on meteorology, this can also be a strategy for NOx/Ozone and other types of PM.

Barriers:
Relocating equipment from one service location to another requires that maintenance and other support and logistic facilities are equally available in the new location.

Cost Effectiveness:
This is entirely dependent on the application.

- **Repurpose:** Is all equipment being used optimally as a fleet?

Concept:
In a large fleet with diverse operations, management practices may not include optimizing the utility of individual equipment or the function of the fleet as a whole. Equipment will often be purchased and placed in service for a particular function but not change or evolve as the service function changes. Depending on the company objectives, the fleet can be re-optimized and tailored to improve the efficiency of the operation.

Barriers:
In a small operation, there is less flexibility to re-assign equipment to different purposes in a way that optimizes the efficiency of the fleet as a whole. In larger operations, this type of optimization requires somebody with in-depth understanding of the function and utility of fleet equipment, the trade-offs for using different equipment for the same operation, and an understanding of the "big-picture" of operational needs across the organization. These combined qualities can be difficult to find in an individual within any given organization.

Cost Effectiveness:
Similar to other strategies that do not inherently require capital costs, this can be a very cost effective option. The effect of this approach is to improve energy efficiency through active operational analysis. Implemented on an ongoing basis, a dynamic repurposing program will always be examining the utilization of the fleet as operational needs change.

- **Right Size:** Is equipment over-powered for its primary functions?

Concept:
Often as applicable to passenger vehicles as heavy-duty equipment, "right-sizing" equipment and vehicles refers to matching the duty and power of equipment to the task that is being performed the majority of the time. Frequently, equipment is sized to handle the maximum loads that could be encountered while the vast majority of the time it will only need a fraction of its installed power or capacity. Integrating vehicle purchase decisions with operations management can create a fleet that is better tuned to actual operational needs. This may even involve fielding a larger fleet of vehicles.

Barriers:
While having limited types of equipment may not be optimally efficient for all types of cargo movement or other applications, it is often much more efficient for operation and maintenance. Having a wider variety of equipment requires maintaining a larger stock of parts and supplies as well as a more substantial training burden for maintenance staff.

Cost Effectiveness:
This can be a very cost effective approach to emission reductions because its primary effect is to reduce fuel use by optimizing fleet-wide equipment utilization. Compared with repurposing, which implies a more active approach to fleet management that optimizes the existing fleet, right sizing is best implemented in combination with a purchasing strategy when new equipment is being ordered. Many times, larger or more powerful equipment is specified than really required in order to accommodate a broad range of unforeseen needs. This perceived future need might come at the expense of efficiency for the function that the equipment performs over the majority of its operating hours.

Operational or "in-use" approaches

- **Reduce:** Lower fuel consumption and lower speeds usually mean lower emissions

Concept:
Following the worldwide economic downturn in recent years and a general retardation of growth in the freight transport industry, most operations have identified and exploited quick and straightforward options for reducing fuel use as cost-saving measures. Such options include operational controls like idle and speed reduction. Some technology-focused options for reducing fuel use generally require longer term planning and great up-front investments. As the fuel costs increase with the use of cleaner fuels, these types of investments become more tenable.

Barriers:
This can vary widely and is partly dependent on the use of cleaner fuels and implementation of complementary strategies. If reducing fuel use requires adoption of new technologies, the barriers can be high. If it involves slow steaming, following an efficiency management plan, or engaging in other activities that are already commonly practiced (i.e. propeller polishing, hull cleaning), the barriers are much lower. Other barriers include spilt interest and commercial practice (i.e. short payback horizon).

Cost Effectiveness:
Fuel efficiency measures are normally the most cost effective approaches because they will often have neutral or net-negative costs associated with implementation. Even with net-positive costs, the value of reducing conventional pollutants can continue to drive overall cost-effectiveness of a given

measure. In the face of the SEEMP (see below) and emerging market-based mechanisms, fuel efficiency measures are likely to receive additional incentives.

- **Retrain:** Knowledgeable equipment operators and field personnel can reduce emissions with everyday decisions.

Concept:
In July 2011 the International Maritime Organization (IMO) passed a requirement that all vessels have a "Ship Energy Efficiency Management Plan (SEEMP)." This is a document that essentially describes the best practices for fuel-efficient operation of a specific ship. The regulation does not require or ensure that the measures spelled out in the SEEMP are implemented and only applies to large ships and fuel economy. Other equipment sectors could equally benefit from having individually oriented efficiency plans, plans that cover emission minimization in addition to fuel economy, and mandates for training on and adherence to plans.

Such deliberate planning and training is a key component of emissions and efficiency policies. Studies consistently show that emissions and efficiency can vary substantially for the same equipment depending on the operator. While external conditions (e.g. weather in the case of ships) will also contribute to varying efficiency, a well-conceived data collection and analysis program can distinguish where operator training could provide additional benefits.

Barriers:
While technical barriers are likely to be low in most circumstances, institutional and individual barriers may be substantial. Even though fuel costs concerns have risen over the past decade and especially in the last 5 years, the port and maritime industry and the companies that participate in it have been around much longer. Entrenched ways of thinking and operating may create resistance to adopting new procedures or training programs even if they are cost effective. Further compounding the issue is a shortage of qualified seafarers who can understand and adapt to a new paradigm of optimally efficient operations.

Cost Effectiveness:
This is likely to be substantial in the beginning but positive in the future. Reorienting individuals and organizations towards energy and emissions reduction will normally have a net negative cost overall once initial investments are realized.

- **Reward:** Incentivizing results for individuals and programs emphasizes and reinforces goals and reorients organizational behavior

Concept:
Once equipment-specific efficiency or emission-reduction plans are in place and operators are trained in appropriate practices, actually changing engrained behavior is often a substantial challenge. If it is possible to monitor specific performance of an operator, it may be straightforward to establish an incentive system that gradually motivates behavioral change.

In many cases, comprehensive operational data that would describe operator or even equipment-specific efficiency variation is not available or practical. It may be that gross operational metrics, such as amount of work done (containers moved per time) and total fuel used, are the only data available.

Matching such general information to a more general incentive program (e.g. sharing a portion of the realized savings) can still be an effective motivating tool.

Barriers:
Any new and unconventional incentive, especially monetary incentive, has the potential for unintended consequences as people may seek to game the system to take advantage of the new benefit. Maintaining equity and reducing the potential for unanticipated results requires careful design, planning, feedback, and tailoring.

Cost Effectiveness:
Because the goal is intended to encourage and hasten behavioral changes among people whose decisions strongly affect the efficiency of an operation, the cost effectiveness is likely to be high. Tailoring incentives to results can ensure optimal returns.

4. Technological Options for Improving Air Quality

Building on the previous introduction to air pollutants in the port and maritime sectors and the general concepts behind approaches to reducing them, this section presents specific technologies that are broadly applicable for reducing air pollutants followed by a discussion of measures that are appropriate for specific sectors and equipment.

General Emission Control Technologies

Diesel Oxidation Catalysts (DOCs)

Background

Diesel oxidation catalysts (DOCs) were one of the first retrofit emission reduction technologies to have widespread potential use throughout the world. Similar to the size and shape of the conventional muffler, a DOC is essentially a direct replacement with the muffler. There are no requirements to modify or adjust engine controls. Generally, DOCs are a little heavier than a conventional muffler and may require more robust mounting brackets. A DOC's performance is further enhanced with the use of ultra low sulfur diesel fuel (ULSD) with a sulfur content of < 30 ppm.

DOCs generally exhibit PM reduction efficiencies of 20 percent, which is modest compared to other, more advanced technologies. However the ease of installation, minimal modification to the vehicle structure or operational parameters (such as engine recalibration or low-sulfur fuel substitution), coupled with their low-cost, makes them an ideal PM retrofit technology when used in large-scale applications.

As the name suggests, the oxidation catalyst "oxidizes", or "adds oxygen" to hydrocarbons in the exhaust, to form carbon dioxide (CO_2) and water. Oxygen is present in diesel exhaust in large quantities, so oxidation occurs naturally; a DOC speeds up the reaction rate. The soluble organic fraction (SOF) is the hydrocarbon derivative organic carbon (so called "wet" carbon) portion of PM; DOCs oxidize the SOF fraction of PM and this reaction results in PM reductions.

"At A Glance"
Diesel Oxidation Catalyst

Benefits	Drawbacks
1. Moderate emission reductions in PM (20 – 30%), HC (50 – 90%) and CO (70 – 90%). 2. Comparatively a low cost. 3. Direct muffler replacement making it an easy installation. 4. More tolerant of higher sulfured fuels <500 ppm.	1. Low PM reduction and no NOx reduction. 2. Ineffective in reducing elemental carbon or soot. 3. May require more robust mounting brackets. 4. Potential for sulfate make.

Technical Considerations

"Sulfate Make"
A potential concern with DOCs is their ability to create "sulfate make." Under certain operational conditions along with the type of fuel use, DOCs can generate unwanted sulfate. This can outweigh any benefit in total PM reduction. Sulfate make is dependent primarily upon sulfur content in the diesel fuel, the operating conditions of the vehicle (and hence the resultant catalyst temperature) and the formulation of the metal on the catalyst itself.

The best defense against sulfate make is to use low-sulfur fuels. DOCs are attractive for retrofits since they are not poisoned by the use of higher sulfur fuels (300 ppm and above) the way many DPFs are. However, higher sulfur content can contribute to sulfate make, and their use with lower sulfur content fuel will ensure minimal sulfate production. Additionally, DOCs are becoming more sophisticated and coating formulations are selectively minimizing sulfate make. Finally, sulfur formation tends to decrease with increasing temperatures above a certain threshold point; there is a design trend for modern diesel, engines toward higher engine and exhaust temperatures.

Field Experience

DOCs have widespread use in on-highway applications and have become more prevalent for non-road construction, cargo handling equipment and marine applications.

Cost

On-Road
Trucks= $1,000 to $2,000

Non-Road
CHE (>750 hp= $1,000 to $2,000
Marine and CHE (<750 hp) = $3,000 to $4,000
Locomotives= Cost may vary (Currently in demonstration.)

Closed Crankcase Ventilation (CCV)

Background

Closed crankcase ventilation (CCV) systems prevent "blow by" gases from entering the atmosphere. Crankcase emissions result from a diesel combustion process in the engine. There are a certain percentage of engine exhaust gases that pass by the piston rings and valve seals and essentially make their way into the crankcase of the engine. Eventually, these "blow by" gases make it into the atmosphere. The gases contain harmful pollutants such as PM, NOx, HC and CO.

To effectively and safely perform this "recirculation" operation requires a vapor separator, filtering and re-circulating device, generically known as *closed crankcase ventilation* or *CCV*.

"At A Glance"
Closed Crankcase Ventilation (CCV) Systems

Benefits	Drawbacks
1. PM reduction of 15 – 20%. Added emissions benefit when combined with a DOC. 2. Low cost. 3. Minimal maintenance – filter replacement.	1. Negligible NOx, HC and CO reduction. Difficult to test. 2. Challenging installation on the first few retrofits. Becomes easier with installation experience.

Cost

On-Road
Truck= $700 for typical "on-highway" derivative engine.

Non-Road
CHE= $700 (engines >750hp)
Marine and Locomotives= NA

Cost for filter replacement=$48 to $50.

Diesel Particulate Filters (DPFs)

Background

Diesel particulate filters (DPFs) are one of the most effective emission control technologies to reduce particulate matter (PM) on appropriate equipment. When use in conjunction with a catalyst, DPFs are capable of reducing up to 90 percent of PM. This makes them a very attractive retrofit option. DPFs have been very successful across on-highway heavy-duty diesel vehicles. More and more, demonstration projects are testing the feasibility of DPFs on non-road applications such as marine, locomotives and CHE.

DPFs remove PM through a two-stage process. First, the DPF physically entraps the elemental carbon portion of PM. Then, through elevated exhaust temperatures, the DPF oxidizes particulates to form gaseous products, primarily CO_2. This process is termed "regeneration."

Passive DPFs vs. Active DPFs

Passive DPFs do not use an external source of heat to promote regeneration. Exhaust temperatures are elevated by the increased backpressure in the exhaust as the DPF fills with PM. As the PM level increases, the exhaust backpressure and hence the exhaust temperature increases to specific threshold values. When this threshold exhaust backpressure and temperature is reached, the PM is oxidized and removed, and the exhaust temperature subsequently reduces. The DPF starts to trap more PM and the process is repeated.

Active DPFs employ the same principal, but heat is added by one of a number of external means to promote regeneration – electric heating, injection of diesel fuel into the exhaust, or engine calibration to temporarily raise the exhaust temperature. Active DPFs are used when the engine exhaust temperatures are too low for the use of passive DPFs.

By combining a DPF with an oxidation catalyst (DOC), the SOF portion can also be removed, enhancing PM reduction up to 90 percent. Most DPF manufacturers have commercialized these dual-based systems into one container or "can", using a DPF in addition with a DOC or applying a catalytic coating to the DPF substrate itself, to facilitate retrofit installation.

"At A Glance"
Diesel Particulate Filters (DPFs)

Benefits	Drawbacks
1. Excellent PM reductions up to 90%. HC and CO reductions from 60 to 90%. 2. Comparatively easy installation – not as straightforward as the DOC, but replaces the muffler.	1. High cost. 2. Requires the use of ULSD. 3. Requires threshold exhaust temperatures to ensure regeneration. 4. Requires annual soot/ash removal.

Technical Considerations

Similar to the installation of DOCs, DPFs are generally designed as a direct replacement for the original muffler. However, DPFs tend to be larger and heavier than DOCs and require some engineering to fit properly. Special adaptations such as mounting brackets must be designed to sustain the increased weight and larger size of the DPF.

The requirements of certain threshold exhaust temperatures to promote regeneration can complicate the use of DPFs for some applications. To determine whether a specific application has the exhaust temperatures necessary for regeneration, it is important to conduct a thorough temperature analysis. Conducting exhaust temperature data logging can do this. Data logging instruments are installed to record the vehicle's exhaust temperature "history" prior to DPF retrofit installation. This approach ensures that the exhaust temperature, on average, is sufficiently high to promote timely and consistent regeneration of the DPF. Once a DPF is installed, an exhaust backpressure sensor and dashboard-mounted indicator light is installed to ensure consistent regeneration during use. Monitoring exhaust gas backpressure (EGBP) ensures that the DPF in not becoming plugged with soot due to insufficient regeneration. An increase in EGBP can result in an engine failure.

Field Experience

DPFs have proven successful with on-highway heavy-duty diesel vehicles. There are numerous demonstration projects testing the viability of DPFs on non-road applications.

Cost

On-Road
Trucks= $6 to $10K, depending upon engine displacement, for passive systems; active systems range up to $18K. Installation cost run around $4K. Annual cleaning can cost up to $500 per DPF.

Non-Road
CHE (>750 hp)= similar cost to an on-road application.
Marine and Locomotives= prices range and can go up to $40K. Currently under demonstration.

Selective Catalytic Reduction (SCR)

Background

SCR is one of three commercially available technologies that are proven to show significant reduction in NOx from diesel engines (emulsified diesel fuel and lean NOx catalysts are the others). SCR systems have a history of being used in stationary applications, such as diesel engines that power generator sets, compressors and pumps. They have also been successfully used in large power plant and other industrial applications. While SCRs are prevalent on stationary sources, there is less historical experience with SCR for on-highway and non-road applications. This is changing as stringent NOx requirements for vehicles come into effect.

Some of the challenges specific to mobile source application of SCR include transporting the requisite supply of ammonia, and ensuring that the engine operates within a rather narrow exhaust temperature band to ensure proper SCR operation. Nevertheless, SCRs are being more widely used on-highway. In addition, with the less transient duty-cycle of many marine applications, as well as central fuelling of vessels, typical of the ferry industry, SCR becomes an attractive NOx-reduction option.

SCR systems are inherently more complex than other NOx-reduction strategies, or than typical PM-reducing retrofit options such as DPFs and DOCS, in that they require an elaborate injection or "dosing" mechanism to provide the correct measure of ammonia into the exhaust stream to reduce engine-out NOx. As a result, the initial unit cost is higher, as are the installation costs. Furthermore, a constant ammonia/urea supply is needed, and care must be taken to ensure operators maintain ammonia/urea in the SCR fill tank.

SCR uses an outside agent, ammonia, to convert NOx to harmless nitrogen (N_2) and water. Because ammonia is quite toxic and corrosive in its pure form, a non-toxic substitute, urea, is used. The urea essentially "locks in" ammonia in a non-toxic, easy to handle and commercially available solution. When the injection or "dosing" unit releases the urea into the exhaust, the heat from the exhaust (minimum temperature of 160°C) releases the ammonia component of the urea stimulating the chemical reaction that converts NOx into N_2 and H_2O.

"At A Glance"
Selective Catalytic Reduction (SCR)

Benefits	Drawbacks
1. Excellent NOx reduction from 70 to 95%. 2. Does not require low sulfur diesel fuels. 3. No additional maintenance.	1. High cost. 2. Requires infrastructure for urea additive. 3. Requires on-board dosing unit. 4. Requires careful urea injection strategy to avoid "ammonia slip." 5. Requires strict monitoring of exhaust temperatures to avoid excessive NOx formation.

Technical Considerations

SCR units are large, heavy, complex and bulky systems. The system includes a catalyst (which is typically installed in series with the engine's muffler), a urea-holding tank, and a dosing injection unit. The dosing unit includes an injector and attendant electronic controls, and usually requires compressed air to aerate the injected urea. Compressed air is used for this purpose, either from on-board systems or as a stand-alone device consisting of the air compressor, accumulator, associated piping and pressure regulator. Due to the heavy weight of the SCR, extra brackets may be required as well as careful attention to weight influence on the vessel's maximum load rating.

SCR systems must maintain a careful balance of proper urea dosing. Not using the appropriate amount of urea results in poor (sometimes zero) NOx reduction. Additionally, excessive amounts of urea result in a phenomena known as "ammonia slip", where pure ammonia – a toxic substance – discharges from the exhaust.

Similarly, vessel operation and resultant exhaust temperatures that are too low (generally less than 200° C) can cause "secondary reactions" that can increase NOx formation. SCR, if improperly engineered, will contribute to NOx formation, rather than reducing it. These lower temperatures are often characteristic of light-load vessel duty cycles.

Field Experience

SCRs have been widely used on on-highway heavy-duty diesel vehicles. There has been reasonably extensive use of SCRs in small marine applications. Of all potential NOx-reduction strategies, SCR has become the most attractive in smaller vessels.

Costs

On-Road
Trucks= $30K for on-highway derivative engines. Installation cost is around $6K. There is also the additional fuel cost of urea.

Non-Road
CHE (>750hp)= Similar cost to on-highway trucks.
Marine= Cost range from $60K to $120K.
Locomotives= currently under demonstration.

Lean NOx Catalyst (LNC)

Background

Similar to an SCR, a lean NOx catalyst (LNC) selectively reduces NOx through the introduction of an enabling "outside agent." Instead of using urea as the fuel additive, a LNC injects a "shot of hydrocarbons" into the exhaust. This can be done in two ways, either through direct injection of fuel into the exhaust stream or through late injection of fuel, via the fuel injection equipment system, directly into the cylinder of the engine.

Oxides of Nitrogen + hydrocarbons (typically diesel fuel sprayed into the exhaust stream) =
atmospheric nitrogen + carbon dioxide + water

$\{HC\} + NOx = N_2 + CO_2 + H_20$

While there are challenges to using a LNC, the capability of the technology to employ an activation mechanism already on board the vehicle, diesel fuel – makes it far more attractive than the urea-infrastructure-intensive SCR system.

"At A Glance"
Lean NOx Catalyst (LNC)

Benefits	Drawbacks
1. Moderate NOx reductions. 2. Diesel fuel is used as the enabling fuel additive that is already on board the vehicle; diesel fuel infrastructure already in place. 3. Emission control technology combinations available to reduce PM – such as LNC in combination with a DPF.	1. High cost. 2. Lower NOx reduction that SCR. No reduction in PM, CO and HC. 3. Specific exhaust temperature required. 4. Must use ULSD. 5. Can create nitrous oxide, a greenhouse gas. 6. Fuel penalty 6 to 9%.

Technical Considerations

LNC units are typically designed and constructed in conjunction with some form of PM reduction device, usually a DOC or DPF. Size and weight become factors to consider when fitting the ECT in certain applications such as harbor craft.

Both diesel/HC injection strategies (in-cylinder injection or direct injection into the exhaust) enable the lean NOx catalyst to convert NOx to harmless nitrogen, carbon dioxide and water. However, both strategies bring about penalties in fuel economy.

Field Experience

Pilot programs in the on-highway sector are becoming more prevalent: a number of programs are underway in California using Carl Moyer Program funds. There is, at present, little marine activity, in large part because the cost, complexity and comparatively smaller NOx reductions from LNCs, which make SCR more attractive.

Cost

On-Road
Truck= $14,000 for on-highway derivative engines. Installation costs are similar to SCR around $6K.

Non-Road
Marine= Cost could cost up to $40,000, but applications are limited.

On-Engine Modifications

Exhaust Gas Recirculation (EGR)

Background

Exhaust gas recirculation systems (EGRs) reduce NOx by re-circulating a portion of the engine exhaust gases back into the engine. These essentially non-reactive exhaust gases reduce combustion temperatures and pressure in the engine, lowering NOx. There are two processes at work to reduce NOx.

Dilution of the intake air with non-reactive exhaust gases decreases oxygen content in the combustion process, reducing combustion temperatures and pressures.
Heat absorption by the EGR stream through the heat absorbing capacity of CO_2 (thermal effect) and dissociation of CO_2 (chemical effect) also leads to a reduction of engine combustion temperatures and pressures.

EGR systems work very well with DPFs. DPFs not only function to reduce PM but also are very important to the functionality and effectiveness of an EGR system. Since EGR systems require a clean exhaust supply before the exhaust gases are directed back to the engine, the use of a DPF fulfills this process while reducing PM at the same time.

"At A Glance"
Exhaust Gas Recirculation

Benefits	Drawbacks
1. Moderate NOx reduction 40 to 50%. 2. Packaged with a DPF reducing PM up to 70%. CO and HC are also reduced with DPF combination. 3. Widespread use in field.	1. Requires careful installation. 2. Slightly reduces engine power. 3. Exhaust cooling is required and may result in engine wear due to excess water vapor. 4. Requires ULSD. 5. Requires electronic control strategy to ensure operation.

Technical Considerations

EGR is already in widespread use as an OEM strategy for heavy-duty diesel engines. EGR use on marine and locomotives are under demonstration.

Cost

On-Road
Trucks= $12K including DPF, for on-highway derivative engines, more for larger engines. Installation cost around $6K.

Diesel Fuel Alternatives

ULTRA LOW SULFUR DIESEL (ULSD)

Fuel Background

Ultra low sulfur diesel fuel (ULSD) is a petroleum distillate product that undergoes hydro-desulfurization at the refining level to eliminate more than 99% sulfur content. Sulfur, a component of all petroleum based feedstocks and grades, serves the primary role of engine lubricant, though undesirably so because it creates corrosive combustion by products, releases sulfur oxides into the environment, and increases deposits on fuel injectors and combustion components[2].

October 2006 marked the widespread availability of ULSD in the United States. The movement was supported federally by an EPA final rulemaking that mandated that the fuel arrived at the retail and wholesale level for all on-road applications. Sulfur levels in ULSD are set at 15 ppm, allowing the facilitation of emission control technologies that require a lower sulfur fuel. This enables diesel engine manufacturers to meet more stringent diesel engine standards of 2007, which require a dramatic reduction in engine pollutants from heavy-duty diesel vehicles. By contrast, some non-road fuel grades contain sulfur in fuel levels of up to 3000 ppm. Even higher levels can be found in industrial

[2] http://www.techtransfer.anl.gov/techtour/desulfur.html.

boiler and marine applications. Non-road regulations in the U.S. brought down fuel sulfur content standards to match the on-road levels in June 2012

ULSD is an 'enabling technology' which allows the application of aggressive emission control technologies. Even without the use of ECTs, ULSD is used as a standalone technology primarily for minimal PM reduction and secondary emissions of sulfate particles (SO_4).

"At A Glance"
Ultra Low Sulfur Diesel (ULSD)

Benefits	Drawbacks
1. PM reduction 5 to 15% as a standalone technology. 2. Enables use of aggressive PM and NOx emission control technologies. 3. On road availability widespread in US. 4. Proven effective in maritime activities.	1. No impact on other criteria pollutants (HC, CO, etc.). 2. Reduced lubricity. 3. May have availability issues internationally in some geographic locations.

Technical Considerations

ULSD has had widespread use for both on-road and non-road applications on the West Coast, US and Canada.

Fuel Cost
Cost surcharge of 5.0 to 15.0 cents per gallon.

BIODIESEL FUEL (BXX)

Fuel Background

Biodiesel fuel (BXX) operates as a cleaner burning fuel and a fuel additive, if mixed in concentration with petroleum diesel that is biologically derived from domestic, renewable sources such as fats and vegetable oils[3]. **Biodiesel refers to the pure fuel ("neat") before blending with diesel fuel. Blends are denoted as "BXX", with "XX" representing the percentage of biodiesel contained in the blend; B20 is 20% biodiesel, 80% petroleum diesel.** Pure biodiesel (B100) is biodegradable, non-toxic, and virtually free of sulfur and aromatics.

Biodiesel fuels are produced from different types of feedstocks that include soybeans, rapeseeds, canola oil, grease, tallow and lard. Most biodiesel production in the US is soybean-based due to the abundant supply of this feedstock in the heartland states.

Used as an alternative to conventional diesel fuel, biodiesel achieves emission reductions of PM, CO, HC and poly-aromatic hydrocarbons (PAH). The emission reductions vary with BXX%, where the lowest figure applying to B20 and the highest to B100. Generally, there is a modest, application

[3] http://www.biodiesel.org/resources/biodiesel_basics/.

specific NOx penalty of between 2 and 10 percent associated with the use of biodiesel. Increasing the level of biodiesel in the fuel blend increases NOx with a proportionally greater reduction in PM. Reduction in CO and HC improves linearly with the addition of biodiesel, according to the literature. This is indicative of more complete combustion, thought to be promoted by the increased presence of oxygen in the fuel.

From an air quality and emissions control technology perspective, fueling with biodiesel will exceed the sulfur fuel standards for diesel because it does not contain native sulfur. It will also reduce the solid or carbonaceous fraction of the PM, which cannot be removed by an oxidation catalyst. Thus from a PM standpoint, the use of biodiesel in combination with a CCRT-SCR system (catalyzed, continuously regenerating trap and selective catalytic reduction) would serve to further remove the solid PM component from the exhaust, providing an opportunity to oxidize the soluble fraction stemming from engine lubricant and address NOx reductions[4].

"At A Glance"
Biodiesel (BXX)

Benefits	Drawbacks
1. PM, HC and CO emission reductions depending on the BXX ratio. (PM 15 to 70%, HC 10 to 40%, and CO 10 to 50%). 2. CO2 lifecycle emissions reductions potential of 70%, depending on source. 3. Lower sulfur content. 4. Renewable fuel. 5. Biodegradable. 6. Better lubricity.	1. Potential increase in NOx. 2. More corrosive. 3. Higher freezing temperature. Cold weather can cause operational issues. 4. Potential loss in engine power – about 2%. 5. Reduced fuel economy.

[4] Schumacher, L.G. et al (1995). 6V-92TA Detroit Diesel Corporation Engine Emissions Test Using Soybean Oil/Diesel Fuel Blends - B10, B20, B30, B40.

Figure 2: Biodiesel production process.

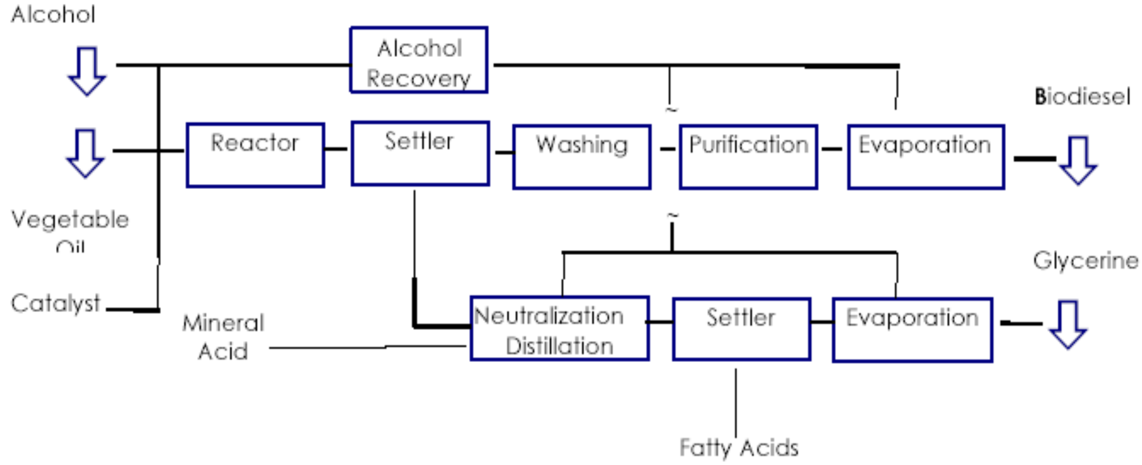


Table 2: Biodiesel Emissions Reduction Potential (EPA Verified), National Biodiesel Board.

AVERAGE BIODIESEL EMISSIONS COMPARED TO CONVENTIONAL DIESEL, ACCORDING TO EPA		
Emission Type	**B100**	**B20**
Regulated		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
Nox	+10%	+2%
Non-Regulated		
Sulfates	-100%	-20%*
PAH (Polycyclic Aromatic Hydrocarbons)**	-80%	-13%
nPAH (nitrated PAH's)**	-90%	-50%***
Ozone potential of speciated HC	-50%	-10%

* Estimated from B100 result
** Average reduction across all compounds measured
*** 2-nitroflourine results were within test method variability

Technical Considerations

Extensive on-road and off-road experience.

Fuel Cost

Projected cost surcharge of 25.0 to 40.0 cents per gallon.

EMULSIFIED DIESEL FUEL (EDF)

Fuel Background

Emulsified diesel fuel (EDF) is a petroleum distillate based fuel that undergoes emulsification, a process whereby one liquid is suspended within another, with a proprietary chemical additive agent to suspend water micro-droplets in the fuel, typically at the following ratio: 77% diesel, 20% water, and 3% emulsifying agent. Water content can range from 5 to 40%, depending on the production specification and end user application.

The practice of emulsifying fluids in diesel is not new, however the science of using additive chemistry and blending techniques to specifically address the air quality characteristics of diesel exhaust emissions is new and evolving, with a number of US based and international companies taking a lead role in its advancement. Key to this practice is the suspension of sub-micron sized water droplets in the fuel, a process accomplished by using additives that encapsulate and suspend the droplets during the blending process, thereby creating a secure, stabilized product ready for delivery, storage and combustion.

The principle effect of water in fuel is to lower the combustion temperature, i.e. reduce the peak flame temperature within the combustion chamber to modify the combustion process itself and mitigate the formation of NOx emissions. NOx formation in the diesel combustion engine is influenced by N_2, O_2, the temperature of combustion ($T_{combust}$), and the residency time (t_{res}). Water emulsions work by lowering the overall $T_{combust}$ to rate limit NOx formation and lower downstream engine out NOx emissions. Water also serves to alter fuel flow properties and injection characteristics, thus resulting in a PM (particulate matter) benefit. This benefit is realized due to:

- Increased liquid column penetration during pre-mixed combustion, resulting in more entrainment and less PM formation; and
- Larger flame light off length, resulting in a less rich combustion process and lower PM (especially at higher loads).

Actual emission reductions achievable using EDF is highly variable depend on the engine, test cycle, emulsification process, water content, baseline diesel fuel properties, and peak torque vs. torque loss comparison (less work per composite duty cycle). There is conflicting data in the literature concerning PM mitigation/production; CO, HC, and toxic air contaminants have propensity to increase w/emulsion, some by factor of 2 or more though not in quantities above regulatory standards, due to inherently low emissions output.

From an operational perspective, significant losses in fuel economy have been experienced with EDF, on the order of 10-30%. This is due to the water in fuel %, on-road vs. off-road engine application, and age of the engine (mechanically vs. electronically controlled). In some engines, longer flame length may lead to excess PM due to EDF "splashing" on the combustion bowl during incomplete combustion. Higher PM is then expelled during the exhaust stroke.

The market for EDF in the United States is supported by counties in non-attainment that have an immediate need for an alternative to diesel that addresses both NOx and PM reductions simultaneously, by demonstration projects in those areas and others throughout the country, and by the EPA ETV program, which verified and approved EDF for use in diesel engines.

"At A Glance"
Emulsified Diesel Fuel (EDF)

Benefits	Drawbacks
1. Emission reduction benefits of both NOx and PM (NOx 10 to 20% and PM 15 to 60%). 2. No major engine modifications required. 3. No new fuel infrastructure needed. 4. No increase in other pollutants.	1. Incremental cost differential on the order of 25-40 cents per gallon. 2. Potential engine durability issues with older pre-1994 engines (corrosion). 3. Fuel stability – balanced mixture. 4. Reduction in engine power – potential 5 to 10 %. 5. Reduced fuel economy.

Technical Considerations

Emulsified diesel fuel may have a fuel penalty of 10 to 30% and peak torque loss of 6 to 7% peak torque loss. The engine will do less work per unit fuel consumption vs. No. 2 diesel over comparable duty cycle.

On-road and off-road application experience; Port of Houston, TX, Big Dig Project, Boston, MA; Texas Fuels Project – TX DOT, Houston and Dallas, TX; Marine application experience; MV Golden Gate, WTA (Water Transit Authority) San Francisco, CA.

Fuel Cost
Projected cost surcharge of 25.0 to 40.0 cents per gallon

Emission Control Options for Specific Sectors

The following section presents additional technology and operational strategies, as they are suited specifically to Ocean Going Vessels, Harbor Craft and Cargo Handling Equipment. There are other areas where emissions reduction strategies could be applied (HDVs, LDVs, locomotives, construction equipment), but they are outside the scope of this document and so are not discussed here.

Strategies to Reduce Emissions From Ocean-Going Vessels

Vessel Speed Reduction (VSR)

Strategy – Slower vessels have lower emissions per mile than faster moving vessels. A VSR program is aimed to reduce emissions from OGVs by slowing vessels when they are in the vicinity of populated areas around ports. This would include a speed reduction down to 12 knots or lower when OGVs are within the coastal waters of a port or within the port area.

Technical Consideration – No operational changes are required of the engine 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 centers. Vessel speed at which net emissions are lowest is still based on limited data and likely to vary with engine.

Options for Implementation – Assure compliance through tariff reduction incentives, lease requirements for renewed lease agreements, or voluntary programs. Create a memorandum of understanding with shipping companies, ports and regulatory agencies.

Costs and other considerations – Overall reductions in fuel consumption brings net reductions in NOx, PM, and other air pollutants. These can be implemented with net negative cost 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 programs have been put in place on the East Coast of the United States to protect endangered whale species. Voluntary and incentivized programs are increasingly being used around busy ports to reduce ship emissions.

Landside Operational Improvements

Strategy - Reconfigure existing terminals, deepen channels and berths and improve inland access by rail and barge; install infrastructure to support electric-regenerative cranes; significantly 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.

Options for Implementation – Appropriate design will support a business case, and thus, voluntary action.

Pros and Cons – If designed properly to support the business case, the result is higher efficiency and lower emissions, a win-win scenario.

Clean Fuels

Strategy – Require the use of lower sulfur distillate fuels in auxiliary and/or propulsion engines of OGVs within the coastal waters of a port. A substantial reduction in DPM can be achieved if OGVs use distillate fuels that have a sulfur content of < 0.2 S. See the extensive discussion of fuels in the previous section for more information.

Technical Considerations – Consider an on-board fuel tank for lower sulfur fuels. Work with ports, fuel suppliers, shipping lines, and others to ensure low sulfur fuel availability.

Options for Implementation – Implementation strategies may include the use of lease requirements and tariff changes.

Pros and Cons – Positive emission reduction benefits for NOx, PM and other pollutants. Challenges may arise with low sulfur fuel availability and putting in place an on-board tank/fueling station. Fuel contamination may be another drawback. Fuel tank cleaning may be required for ultra-low sulfur diesel fuels.

Emission Control Technologies (ECTs)

Strategy – Improvements to main and auxiliary engines help reduce DPM, NOx and SOx emissions. Measures for main engine improvements may include; slide valves, seawater scrubbing as well and engine upgrades. Measures for auxiliary engines include; Selective Catalytic Reduction (SCR) and engine upgrades or repowers.

Technical Considerations – Operational and feasibility testing is required to ensure the function and appropriateness of an emissions control technology on marine applications. 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. Emission control technologies that have been certified or verified by regulatory agencies (such as those programs at the US Environmental Protection Agency and the California Air Resources Board) are most likely to deliver the claimed benefits

Options for Implementation – Implement strategy through lease requirements, tariff charges, and incentives. Design a "Technology Advancement Program" that would demonstrate the feasibility of ECTs on marine applications.

Pros and Cons – Positive emission reduction benefits. Challenges may occur with technology feasibility. Costs vary widely as many of the technologies for OGV, especially as retrofits, are still experimental.

Cold Ironing

Strategy – Shore Power for ships commonly referred to as "cold ironing" in the maritime world, focuses on reducing dwelling (hoteling) emissions from OGVs while at berth. This strategy has two approaches 1) shore-power (transferring the electrical generation needs for OGVs while at berth – power generated by regulated/controlled stationary sources) and 2) hoteling emissions reduction requirements through alternative technologies for ships that do not fit the shore power model. Cold ironing is best for OGVs that make multiple calls at a particular terminal for multiple years. The best candidates for cold ironing are container ships, reefer ships, and cruise ships because they tend to operate in these types of regular services and require substantial electricity while at berth.

Technical Considerations – Provide cold ironing infrastructure on-dock and on-board vessels. Determine necessary power needed and ensure adaptability. It is important to consider the local power company that is providing the electrical power to the terminal. Some power companies operate coal-burning power plants without the use of scrubbers and other types of emission control technologies. A local power company that uses a cleaner source of energy with use of emission control technologies will optimize the overall benefits of shore power.

Options for Implementation – Implementation strategies include lease requirements, incentives, tariff changes and capital funding.

Costs and other considerations - Shore power is one of many emissions control strategies that ports and shipping lines can utilize to reduce at-berth emissions from ships. Cold ironing is ***not*** universally effective for all ships and ship types. 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. Liner-type services typically include cruise ships, containership, some bulk liquid and chemical/product tanker operations, LPG tankers, and some general cargo operations.

In addition to frequency of calls by the same ships to the same terminal, another key factor is the amount of energy the 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.

Liner type services are critical in a cold iron strategy because the costs of vessel and terminal infrastructure need to be diluted by frequent calls by 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 optimizes cost spent per ton of emissions reduced.

The most expensive component to cold ironing is shore-side infrastructure. Typical infrastructure needed includes power connection to utility, underground vaults, power converter/transformer/switching equipment and land for these facilities, receptacle pits, receptacles, cabling, synchronization 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 be significant and the cost varies by each terminal. One of the most expensive container terminal retrofit projects actually built was the China Shipping berth at Port of Los Angeles which cost ~$7 million. Based on the range of feasibility studies done by ports in the US and Canada, a normal range of costs to provide shore power at a berth can be between

~$1 - $15 million. These costs vary significantly depending on the extent of terminal rebuilding, the proximity to adequate electricity supplies, and the ability to locate the shore-side infrastructure.

There are also less expensive temporary approaches that use large, portable LNG generators placed on the dock near the front of the ship and connect to a ship's bow thruster electrical circuit. These systems require ~$200,000 to refit each ship and approximately $1,000 per hour for the generator. The Port of Oakland, whose shore-side infrastructure for standard cold ironing was estimated at $90 million, has successfully demonstrated this system and intends to make it available to all of its customers in the near future.

For standard cold ironing, shipside infrastructure is the second largest capital cost and can range from $400,000 to $2 million per ship due to the wide variety of ship designs. These costs have been coming down as more retrofits have lead to more streamlined and standardized designs. Many new ships currently being built are including cold ironing systems or implementing designs that would make future retrofits less costly.

The cost of grid power is another key factor when estimating cost effectiveness. Currently, the high prices of bunker fuel have nearly offset the electrical costs on the west coast. In New York, their implementation of shore power for cruise vessels is now solely hinged on the cost of power from their regional supplier.

Shore power projects in California have been awarded grants under the Carl Moyer Grant Program. The first was to the Port of San Francisco and the second was to the Port of San Diego. These awards demonstrate that cold ironing can be a cost effective strategy under the right conditions. Cost effectiveness estimates vary significantly by terminal, by port, and by region. A detailed cost effectiveness analysis needs to be completed on a project-by-project basis to determine what the real cost impacts would be.

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

For the first estimate, energy costs, a common assumption is that it is approximately the same price to generate power on board, as it is to provide that same amount of power from on shore. This may be accurate when ships use inexpensive bunker fuels for their auxiliary generators. For more expensive low-sulfur fuels, such as Marine Gas Oil (MGO), that are increasingly being required by ports for ships at or near berth, the cost of generating power on board quickly becomes more expensive than on-shore electricity. Figure 2 illustrates the cost savings per hour for a ship using 1.5 megawatts of power for a range of bunker prices. This assumes that on-shore electricity costs an average 10 cents per kilowatt-hr (kWh) and that a ship's auxiliary engine uses 0.22 kg MGO per kWh. It also neglects costs associated with operating and maintaining on-board generators.

Figure 2: Effective Electricity Costs and Energy Savings from Cold Ironing (Assuming 1.5 MW Shorepower Load & 10-cent/kWh Landside Electric Cost), only considering variable cost

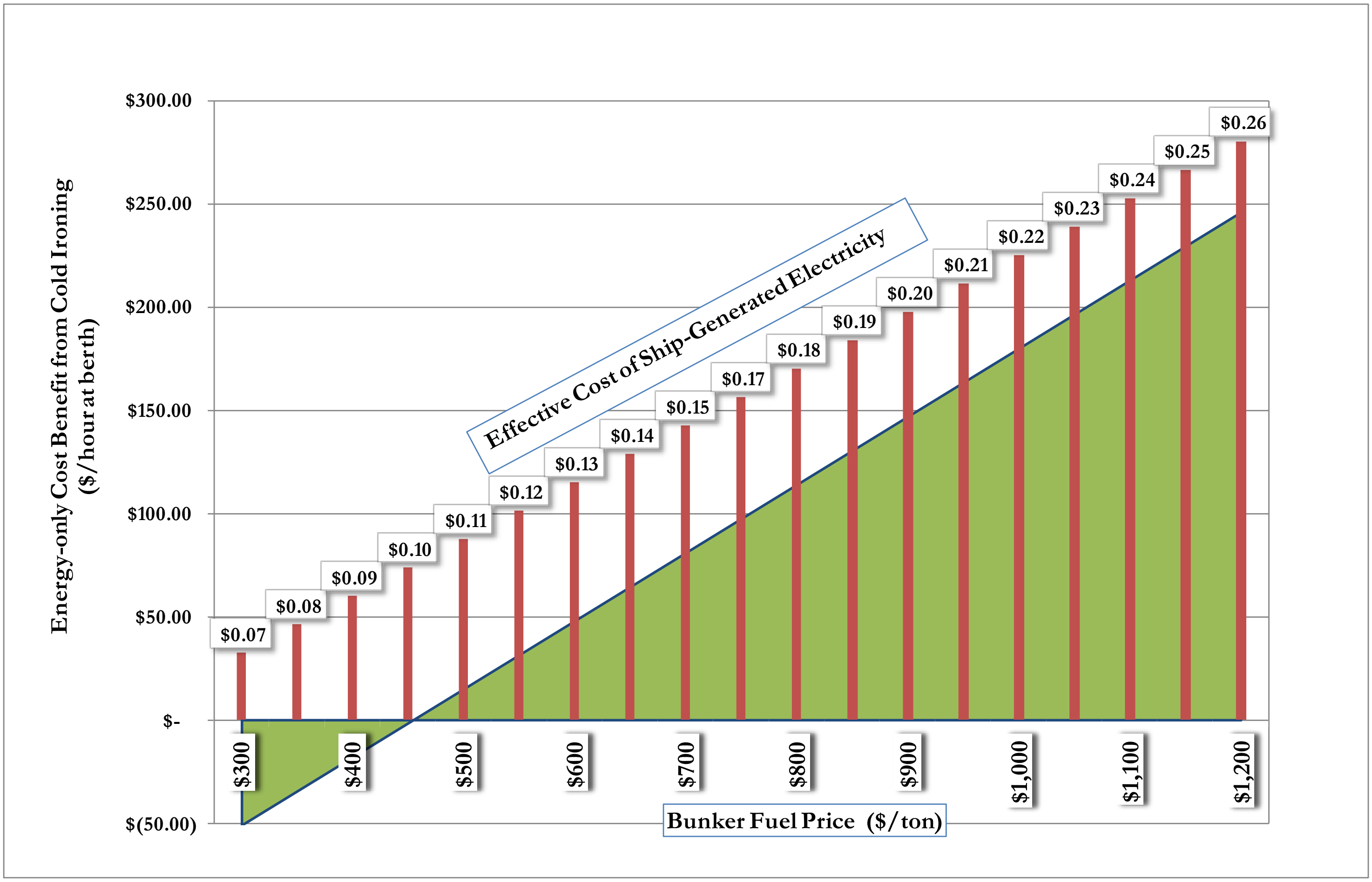


Figure 2 shows bunker fuel prices up to $1,200 even though the price of MGO peaked at about $1,000 during the summer of 2008. Prices over the life span of a shore power system are likely to exceed both of these values and should be considered in estimates. Based on the above comparison, a cold ironed ship call that draws 1.5 MW for 36 hours may save $2,322 in net energy costs at today's MGO price of $650 but just break even at today's bunker price of $460. If capital costs for terminal and ship retrofits were not an issue, this comparison would make the economic model for cold ironing very attractive. Unfortunately, with the high capital costs shown above, the annual amortized cost to ports (30 years at 4%) would be between $57,000 and $857,000. Table 1 shows the amortized prices of a range of capital investments compared to the number of the previously described ship calls needed to balance those cost.

Table 3: Amortized Capital Costs of Cold Ironing Projects and Projected Annual Ship Calls Needed to Break Even Based on Energy Savings Alone

Cold Ironing Capital Costs	Annual Cost: 30-yr Amort.	Ship Calls @ $650/ton MGO	$1,200/ton MGO
$ 1,000,000	$ 57,830	25	7
$ 3,000,000	$ 173,490	75	20
$ 5,000,000	$ 289,150	125	33
$ 7,000,000	$ 404,811	174	46
$ 9,000,000	$ 520,471	224	59
$ 11,000,000	$ 636,131	274	72
$ 13,000,000	$ 751,791	324	85
$ 15,000,000	$ 867,451	374	98

It is clear from estimates in Table 3 that energy savings alone are not likely to make up for high capital costs of cold ironing projects unless the up-front costs are low and bunker prices are high. Many cold ironing projects are still justified, though, based on reductions in tons of NOx and particulate matter (PM) emissions that result from shutting down a ship's auxiliary engines. If a ship hotels at berth for 36 hours, it could emit approximately 2.8 tons of NOx and 47 kg of PM. At this rate, if NOx emissions are worth $3,000 per ton, a Cold Ironing facility with $5 million in capital costs could be justified with only 34 ship calls per year without any energy cost benefits.

Strategies to Reduce Emissions From Harbor Craft

Strategies that can be applied to address emissions from Harbor Craft (HC) are often adapted from technologies or strategies that have been developed for on-road and non-road equipment. Some of the strategies can also apply to dredging equipment and will generally vary in applicability by equipment size and function.

Engine Replacement

Strategy – Repower HC main and auxiliary engine with cleaner engines that meet newest national air quality standards. For example, the United States has diesel engines that meet U.S. EPA Tier II and Tier III engine standards. Replacing a Tier 0 engine with a Tier II engine will reduce NOx up to 47%. Tier III engines will reduce NOx and PM up to 90%. The European Commission has an equivalent engine that meets Stage IIIA engine standards.

Technical Considerations – Ensure technical feasibility. Strategy will involve the careful removal of the original engine and replacing it with a newer, cleaner engine. As described in the "replace" section of the general measures overview, compatibility, even among similar models of different years, is not always guaranteed. Many new models add emissions controls or other equipment that may need additional space accommodation in the already carefully planned spaces of harbor craft. Technology availability is likely to be a concern.

Options for Implementation – Implementation through voluntary programs, incentives, and/or lease renewals/renegotiations.

Pros and Cons – Replacing main-propulsion engines with cleaner engines will provide great emission benefits that compound over the remaining life of the equipment. For HC, this can be significant because the total operating life can be up to 30-40 years. Cleaner engines are costly and capital costs may cause an economic burden. For a mid-sized HC, total cost of engine replacement can be between 0.5 and 1.5 million dollars, 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.

Clean Fuels

Strategy – As described in the alternative fuels section, the use of cleaner fuels with low sulfur content is the most common emission reduction approach for HC. Cleaner fuels for HC may include; low and ultra-low sulfur 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 – Work with ports and fuel suppliers on the availability and supply of clean fuels. 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 – Implementation strategies may include the use of lease requirements and tariff changes.

Pros and Cons – As with other equipment, positive emission reduction benefits for NOx, PM, and other pollutants. The use of biodiesel may present a slight increase in NOx. Challenges may arise with fuel availability.

Emission Control Technologies

Strategy – Retrofit HC with the best available engine controls, fuel additives and after-treatment emission control technologies (ECTs). Depending on the appropriate application of ECT, ECTs can include exhaust after-treatment devices such as diesel oxidation catalyst (DOC), diesel particulate filter (DPF), selective catalytic reduction (SCR), or engine and fuel efficiency technologies such as modern injectors, computer controls and software upgrades, which result in more efficient engine air fuel mixtures and fuel savings. The engine manufacturers and distributors of emission control technologies can provide technical guidance to HC owners and operators in the selection of appropriate ETCs for their vessel. While evaluating different emission control technologies, consider ECTs that have had proven success with HC similar to the HC under evaluation. To further improve emission reductions from auxiliary engines, retrofit cleaner engines with ECTs.

Technical Considerations – Operational and feasibility testing is required to ensure the function and applicability of an emissions control technology on marine applications. 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. Emission control technologies, which have been certified or verified by regulatory agencies (such as those programs at the US Environmental Protection Agency and the California Air Resources Board), are most likely to deliver the claimed benefits

Options for Implementation – Implement strategy through lease requirements, tariff charges, and incentives. Design a Technology Advancement Program that would demonstrate feasibility and effectiveness (this comment should be included in all of the sections which discuss emission control technologies) of ECTs on marine applications. The Technology Advancement Program would consider use of newer technologies.

Pros and Cons – Applying ECTs proves to have positive emission benefits in reducing particulate matter (PM), Oxides of Nitrogen (NOx), carbon monoxide (CO) and hydrocarbon (HC). Not all ECTs reduce all pollutants. Retrofitting HC with ECTs can be challenging, careful evaluation and analysis is a must.

Electrification (including Shore Power and Hybridization)

Strategy – Reduce harbor craft hotelling emissions by hybridization and/or providing shore power connection. Similar to OGV, shore power provided through an electrical connection at berth can replace the HC vessel's on-board electrical generation for hoteling functions. Hybridization is best for HC when they are away from the berth and have fluctuating energy demands.

Technical Considerations – Provide shore power infrastructure on-dock and on-board HC. Determine necessary power needed and ensure adaptability. Again, it is important to consider the local power company that is providing the electrical power to the terminal. Some power companies operate coal-burning power plants without the use of scrubbers and other types of emission control technologies. Ensure that the local power company is using a cleaner source of energy along with emission control technologies. In some cases, it is better not to use shore power if the local power company has dirty polluting power plants. Evaluate the HC engine and duty cycles to determine whether the vessel is a good candidate for hybridization, which is currently being developed and used on tugboats and ferries. Substantial fuel savings can be realized in addition to lowering emissions by use of hybrid technology.

Options for Implementation – Implementation strategies include lease requirements, incentives, tariff changes and capital funding.

Pros and Cons – Positive emission reduction benefits while at port with shore power. Challenges 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 OGV shore power.

Hybridizing HC has become much more feasible in the past several years as several demonstration projects have illustrated the feasibility and benefits of the technology. In Long Beach, Foss tugboats retrofitted an existing tug with lithium ion batteries and advanced drives for a total project cost of $2.1M, which included design costs. Future applications and lighter-duty projects are likely to be much less.

Strategies to Reduce Emissions From Cargo Handling Equipment

Strategies

Strategies that can be applied to address diesel emissions from Cargo Handling Equipment (CHE) are much more common and feasible as they often derive directly from strategies that have been developed for the on-road fleet.

Equipment Replacement with Engines Meeting Cleaner Standards

In some cases, cargo handling equipment (CHE) fleet managers prefer to buy new equipment with new engines rather than repower old cargo handling equipment with new engines. The cost of the CHE is a small fraction of the overall life cycle costs relative to operations and maintenance costs. The labor 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. The emissions benefits would be similar whether equipment is replaced or repowered.

Strategy – Replace older off-road yard tractors, top picks, forklifts, reach stackers, RTGs, and straddle carriers <750 hp with new equipment that meets cleaner on-road and off-road engine standards. Replace CHE with >750 hp with new equipment that meet cleaner off-road engine standards.

For example, the San Pedro Bay Ports Clean Air Action Plan will require the replacement of older CHE with new clean engines over a specific time period. The Ports aim to implement the cleanest available NOx alternative-fueled engine or the cleanest available NOx diesel-fueled engine that will meet 0.01 g/bhp-hr for particulate matter (PM). If there are no engines that meet the 0.01 g/bhp-hr for PM, then the CAAP recommends the purchase of the cleanest available engine along with the best available emissions control technology that would meet the 0.01 g/bhp-hr for PM. The European Commission has similar clean engine standards, Euro III, IV, and V.

In the Port of New York and New Jersey, the major container terminal operators are systematically replacing yard tractors, at the end of their five to ten-year duty cycle, with brand-new equipment that come 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.

Technical Considerations – Ensure technical feasibility. Strategy will involve the careful removal of original engine and replacing it with newer-cleaner engine. Equipment that includes regenerative electric capabilities (e.g. some of the new Rubber Tire Gantry (RTG) and Rail Mounted Gantry Cranes) will increase fuel efficiency and further reduce emissions.

Options for Implementation – Implementation through voluntary programs, incentives, and/or lease renewals/renegotiations.

Pros and Cons – The purchase of newer cargo handling equipment that meet cleaner on-road or off-road engine standards will demonstrate great emission reduction benefits and, under the right conditions, make a good business case. The challenge may be the availability of cleaner engines internationally.

Clean Fuels

Strategy – Implement the use of cleaner fuels with low sulfur content. Cleaner fuels include; low to ultra low sulfur diesel fuel, emulsified diesel fuels, and biodiesel. Additional clean fuel options for CHE include LNG and CNG.

Technical Considerations – Work with ports and fuel suppliers on the availability and supply of clean fuels. 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 – Implementation strategies may include the use of lease requirements and tariff changes.

Pros and Cons – Positive emission reduction benefits for NOx, PM and GHGs. The use of biodiesel may present a slight increase in NOx. Challenges may arise with fuel availability. Cleaner fuels often cost more than standard ones.

Emission Control Technologies

Strategy – Retrofit CHE with the best available emission control technologies (ECTs). Depending on the appropriate application of ECT, ECTs can include: diesel oxidation catalyst (DOC), diesel particulate filter (DPF), or selective catalytic reduction (SCR). While evaluating different emission control technologies, consider ECTs that have had proven success with CHE similar to the CHE under evaluation. To further improve emission reductions, retrofit cleaner 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. Emission control technologies that have been certified or verified by regulatory agencies (such as those programs at the US Environmental Protection Agency and the California Air Resources Board) are most likely to deliver the claimed benefits.

Options for Implementation – Implement strategy through lease requirements, tariff charges, and incentives. Design a Technology Advancement Program that would demonstrate feasibility of ECTs on CHE. The Technology Advancement Program would consider use of newer technologies.

Pros and Cons – Applying ECTs has proved to have positive emission benefits in reducing particulate matter (PM), Oxides of Nitrogen (NOx), carbon monoxide (CO) and hydrocarbon (HC). Retrofitting CHE with ECTs can be challenging, careful evaluation and analysis is a must.

5. CREATING AND IMPLEMENTING A CLEAN AIR PROGRAM

While the economic benefits of the global trade affect an entire nation, the environmental impacts of trade are more locally concentrated. Major trade corridors concentrate at ports, which are typically located in urban areas where the large population (with all its associated emission sources) contribute to the formation of air pollution. Port activities only exacerbate this situation. By virtue of the international nature of shipping, port-related sources of air pollution have been relatively immune to air pollution regulation until recently. Port authorities or government agencies in charge of managing the ports need to recognize that their ability to continue to accommodate growth in global trade will depend upon their ability to address adverse environmental impacts (and, in particular, air quality impacts) that result from such trade. Dealing with these issues in a comprehensive, sustainable way is the subject of this section.

This section will describe the process for creating a comprehensive Clean Air Program for a port.

COMMITTING TO CLEAN AIR

It is important to make a specific commitment to clean air before undertaking development of a Clean Air Program. By making a commitment, either to stakeholders or to upper level officials, there is a promise to fully carry out the actions necessary to ensure that the Clean Air Program is a success. In addition, the commitment starts the process of developing the support and dedication from people within the organization to participate in reducing emissions. The size or type of organization does not make a difference; the most important element of a successful Clean Air Program is commitment.

The statement of commitment does not have to be long or complex. In fact, sometimes simple is best. As an example, here is a straight forward commitment statement, modified from an adopted plan at a U.S. Port: "The Port is committed to expeditiously and constantly reduce the air emissions from port-related mobile sources, and implement a program within five years that will achieve this goal. The Port is committed to facilitate growth in trade while reducing air emissions."

Once this commitment is made, several additional steps are recommended to prepare for the development of the Clean Air Program.

Appoint a Clean Air Director

Appoint person in charge of the Clean Air Program. The Clean Air Director would be responsible for setting goals, tracking progress and promoting the Clean Air Program. This individual would be someone that is capable of effectively overseeing the creation, management and implementation of a major administrative and operational program.

For a port operated by a government agency (Port Authority), the Clean Air Director might be an existing staff person already in charge of environmental programs or environmental compliance. It probably needs to be someone dedicated to the task, since it is a large task.

For a port operated by a private company, but overseen by a government agency, the Clean Air Director might be a pair of individuals one from the operator and another from the government agency. The specific port operator/government oversight arrangement of a particular port would suggest the appropriate approach. It is important that the Clean Air Director have the ability to impact day-to-day port operations.

Establish a Clean Air Team

The Clean Air Team develops the Clean Air Program and oversees its implementation. The Team executes clean air management strategies ensuring integration of best practices into maritime operations.

The Clean Air Team monitors and tracks progress of the Clean Air Program. Regular reporting is made to the Clean Air Director on program progress.

Clean Air Team members may include staff involved in engineering, operations and maintenance, building/facilities management, environmental health and safety, construction management, and contractors and suppliers.

Coordinate with Stakeholders and Regulatory Agencies

Developing a Clean Air Program with the support of customers, tenants, business partners, stakeholders and regulatory agencies will ensure the Program's sustainability. In addition, involving customers, tenants, business partners, stakeholders and regulators in the decision and goal-setting process brings in different perspectives that will give the Clean Air Program more diversity.

Undertaking coordination with stakeholders and regulatory agencies has the potential to complicate development of the plan. However, failure to do at least some level of coordination may complicate Plan implementation as stakeholders or regulatory agencies may introduce administrative, technical or legal roadblocks not considered during Plan development. In particular, a port may benefit from coordinated emission control strategy when including appropriate Regulatory Agencies in Plan development. As an example, in developing their Clean Air Action Plan, the Port of Los Angeles and the Port of Long Beach coordinated with the California Air Resources Board and the US EPA, the agencies responsible for statewide and national air quality regulations. This coordination led to complementary regulations at the state and national level to the Clean Air Action Plan.

The Plan-Do-Check-Act Cycle for Continuous Improvement

A comprehensive, sustainable clean air program will follow the systematic process that promotes continual improvement. Environmental Management Systems following ISO 14000 already use one such approach, the ‘Plan, Do, Check and Act' (PDCA) cycle.

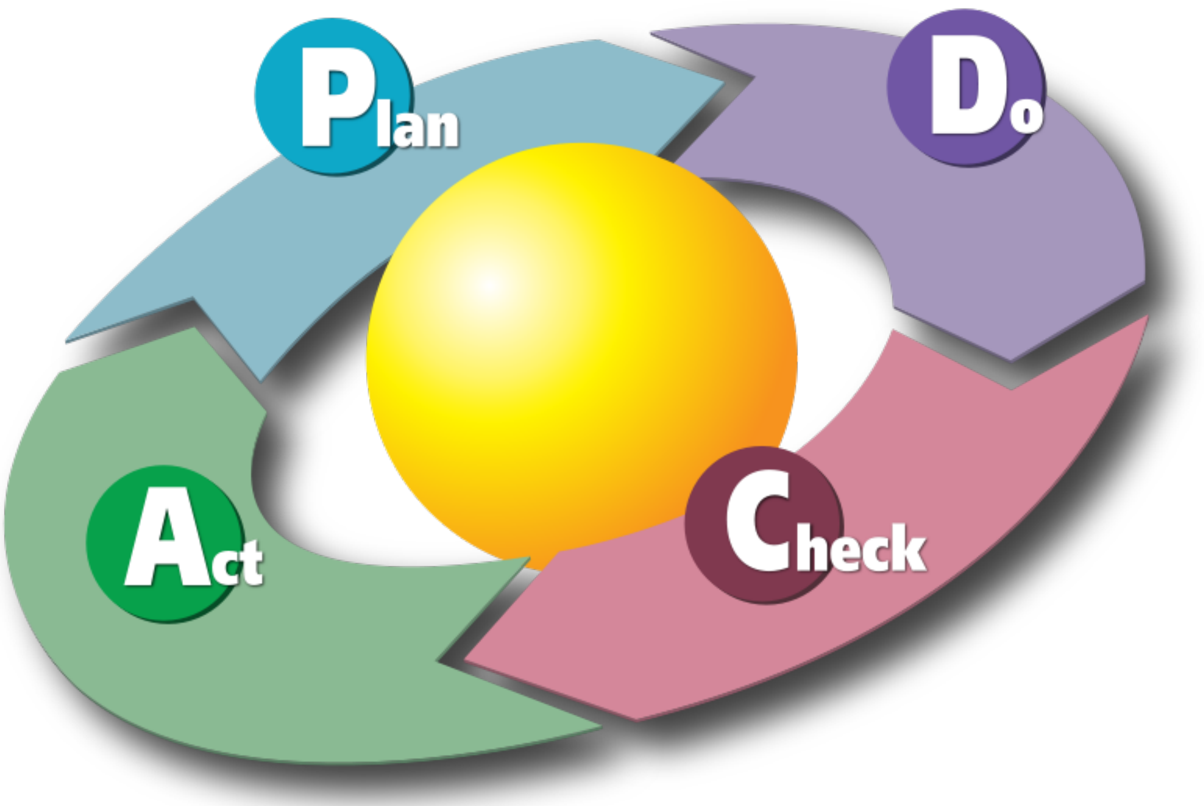
The PDCA Cycle is an approach to change. Where the consequences of getting things wrong are significant, it makes sense to have a process that you follow when you need to make a change or solve a problem that will ensure that you plan, test and incorporate feedback as you move forward.

The PDCA cycle breaks down thus:

- PLAN – establish objectives and processes required
- DO – implement the processes
- CHECK – measure and monitor the processes and report results
- ACT – take action to improve performance of PLAN based on results

Figure 3 provides a graphic representation of the cycle.

Figure 3. The PDCA Cycle for Continuous Improvement



For Ports that have or plan to implement an Environmental Management System (EMS) following ISO 14000, this approach can be used to make the Clean Air Program compatible with the Port's overall environmental management program.

Of the steps within the PDCA cycle, the two steps that are most extensive and require the most time and thought are probably the PLAN and DO steps. The following sections detail these steps in preparing a Clean Air Program.

PLAN – Planning A Clean Air Program

With a commitment to clean air and a Clean Air Team in place, planning a Clean Air Program can begin. This section generally describes the steps for development of a Clean Air Program document.

The Program establishes the path by which the targeted control measures will be implemented in the short-term and provides for budget planning over defined time period.

Evaluate Programs Prepared by Others

Prior to starting on the development of a program plan, it may be advantageous to evaluate the work prepared by others, particularly by those who have had to address similar problems.

• *Evaluate clean air programs currently in-place.*

At the start of this process, it may be helpful to evaluate clean air programs developed by other ports around the world. Several of these are described in the Case Studies section below. Attention should focus on the similarities/differences of the issues/challenges faced by these other ports and the measures they take to address the problems.

• *Design the Clean Air Program to follow approaches that have demonstrated success in other clean air programs.*

In addressing the air pollution issues faced by other ports around the world, these other ports have already evaluated many of the technical issues that will be faced in developing the Clean Air Program. Some Clean Air Programs at other ports have been in place sufficiently long enough to determine whether particular strategies have been successful. Additionally, in some cases there may even be measures of success available to determine cost/benefit for a particular method or approach.

• *Create a Clean Air Program that is most suitable to meet business needs.*

Ports around the world have different types of organization. Some of them are privately operated businesses. Some are government run, with or without regulatory powers. Some are independently run but with government taking controlling stakes. Still others are public-private partnerships. Some generate revenue that they then control to be used for operational or environmental programs, while others generate revenue that transfers to the state, which then controls allocation of funding for operations. Each of these different business modes will need to be addressed by different implementation strategies.

Determine Emissions Baseline and Pollutant Prioritization

In order to determine the magnitude of the problem and to assist the development of goals, performance targets, and control strategies, it is important to take a measure of emissions from port operations. If a baseline inventory has not already been done, one should be undertaken.

Prior to starting the actual inventory process, there are several key questions that ports should address first. The answers to these questions will help frame the approach, determine what information is needed, define geographical boundaries, and establish the level of detail of the inventory. The key questions are:

- What are the drivers behind developing an inventory?
- What uses will be made of the information?
- Will change over time be tracked and to what resolution?
- What source categories will be covered?
- What are the geographical boundaries of the inventory?
- What level of information detail will be needed?

There are several types of emission inventories, from simple to complex.

- Activity-Based
    - Incorporates Locally Generated Activity Data
    - Incorporates Actual Equipment Counts & Parameters
    - Minimizes Assumptions
    - Most Accurate
    - Most Expensive Initial Option
- Surrogate-Based
    - Incorporates Other Published Port Data
    - Scales Emissions from Surrogate Port and/or Surrogate Equipment
    - Maximizes Assumptions
    - Least Accurate
    - Least Expensive Option
- Hybrid
    - Incorporates Local & Surrogate Data
    - Limits Some Assumptions
    - More Accurate than Surrogate
    - More Expensive than Surrogate

Evaluating the type of baseline emissions inventory to be undertaken, and the actual process to follow in preparing the inventory, are beyond the scope of this document. Suffice it to say, the more detailed the inventory, the more confidence in its findings. This upfront investment in a baseline emissions inventory will yield more confidence in the goals and objectives of the Program, and help to assure that the emission control measures targeting the particular source categories are properly focused and technically sound.

The inventory should be detailed enough to allow comparison of emissions from various equipment categories (such as ocean-going vessels, harbor craft, terminal equipment, etc.).

The inventory should define the geographic extent of the study, and the inventory should use a geographic extent consistent with the area of influence to be included in the Clean Air Program.

In most ports, the inventory should address the following pollutants:

- NOx – Oxides of Nitrogen
- SOx – Oxides of Sulfur
- PM – Particulate Matter (Total, 10, 2.5)
- HC – Hydrocarbons
- CO – Carbon Monoxide

In addition to the criteria air contaminants, it is a trivial addition to analyze greenhouse gases. Unless there is a compelling reason against, it is recommended that the following be included:

- GHGs – Methane, Carbon Dioxide (& Equivalent), & Nitrous Oxide[5]

• *Determine pollutant types to be included.*

The baseline emissions inventory will usually provide the detail necessary to determine which equipment categories predominate for a particular pollutant. Armed with the pollutants of concern in a particular locale, this will provide direction on where attention should be focused for the Clean Air Program policy and goal setting, and development of emission control strategies.

Both China and the U.S. consider the following pollutants as 'criteria air contaminants' that can harm health and the environment, and for which national standards have been developed:

- Ozone
- Particulate Matter (10 micron)
- Particulate Matter (2.5 micron)
- Sulfur Dioxide
- Nitrogen Dioxide
- Carbon Monoxide
- Lead

Table 4 provides a comparison of health standards for the criteria air contaminants from around the world.

[5] CO_2, CH_4, and N_2O are by far the most significant GHGs for port emissions inventories. They are produced during the combustion of fossil fuel. Greenhouse gas emissions from fuel combustion are dominated by the CO_2 fraction because virtually all fuels are composed primarily of carbon while CH_4 and N_2O are formed as minor byproducts of combustion. CO_2 typically constitutes over 99% of combustion related greenhouse gas emissions.

Table 4. Air Pollution Health Standards Comparison

Pollutant	Averaging Time	China[1] Grade I	China[1] Grade II	USA[2]	WHO[3]	EU[4]
PM_{10}	Day	50	150	150	50	50
	Year	40	70	-	20	40
$PM_{2.5}$	Day	35	75	35	25	-
	Year	15	35	15	10	255
Sulfur Dioxide	Hour	150	500	-	500	350
	Day	50	150	364	20	125
	Year	20	60	78	-	-
Nitrogen Dioxide	Hour	200	200	-	200	200
	Day	80	80	-	-	-
	Year	40	40	100	40	40
Carbon Monoxide	1-Hour	10	10	40	-	-
	8-Hour	-	-	10	-	10
	Day	4	4	-	-	-
Ozone	1-Hour	160	200	220	-	-
	8-Hour	100	160	147	100	120
Lead	Rolling 3-mod average			0.15	-	-
	Quarterly average	1.5	1.5	1.5	-	-
	Year	1	1	-	-	0.56

With the exception of carbon monoxide, all units are μg/m³. Figures for CO are given in mg/m³.

Notes:

1. The figures for Chinese air pollution standards come from GB3095-2012. Grade I is for natural protection area and other areas which need special protection *Grade II is for residential, commercial, industrial and rural area
2. EPA National Ambient Air Quality Standards (NAAQS) (http://www.epa.gov/air/criteria.html#1).
3. WHO air quality guidelines, last updated in 2005, can be found at http://www.who.int/phe/health_topics/outdoorair_aqg/en. According to the WHO, the "air quality guidelines (AQGs) are intended for worldwide use but have been developed to support actions to achieve air quality that protects public health in different contexts."
4. The EU's health standards for air quality can be found at http://ec.europa.eu/environment/air/quality/standards.htm. Several pollutant limits have not yet entered into force. A number entered into force in 2005, but several are due to be effective in 2010 and beyond.
   ◊ Limit value enters into force January 1, 2005
   † Target or limit value enters into force January 1, 2010
5. For PM2.5 in the EU: Target value enters into force January 1, 2010 Limit value enters into force January 1, 2015
6. For lead in the EU: Limit value enters into force January 1, 2005 (or January 1, 2010 in the immediate vicinity of specific, notified industrial sources; and a 1.0 μg/m3 limit value applies from January 1, 2005 to December 31, 2009)

Source: Updated from AMENDING CHINA'S AIR POLLUTION PREVENTION AND CONTROL LAW: RECOMMENDATIONS FROM THE INTERNATIONAL EXPERIENCE, July 2009, Natural Resources Defense Council, the Regulatory Assistance Project, and the Energy Foundation's China Sustainable Energy Program.

Ocean going vessels are a significant source of sulfur dioxide, given the fuels typically used in this equipment. If exceedances of the national sulfur dioxide standard are at issue in a particular locale, focus of the plan will be required on sulfur dioxide and OGV. Much of the cargo handling equipment and heavy duty vehicles at ports are diesel powered, and particulate matter is usually therefore of substantial concern as well.

If it is possible to compare the baseline port emission inventory with a regional inventory, trying to isolate the contribution of port sources to the regional inventory will provide some guidance as well.

For instance, in Southern California, the Ports of Los Angeles and Long Beach found when comparing the port emission inventories to the regional inventory, that the Ports were responsible for almost half the sulfur dioxide emissions for the region. Without addressing port sources of sulfur emissions, the region would not be able to meet its requirements. Therefore the Clean Air Action Plan had to focus on ocean-going vessels and their fuels.

In addition to the focus on criteria air contaminants, it is important to recognize that GHGs are also a consideration when evaluating emissions from mobile sources, due to their potential global effect. It should be made clear whether GHG elements are included in the Program, and whether there is a hierarchy of pollutants being considered. The implementation of some of control measures for criteria air contaminants will result in GHG co-benefits, while others will increase GHG emissions. This may be acceptable for a time in order to reduce the immediate impacts caused by criteria air contaminants.

• *Give special attention to diesel particulate matter.*

Exposure to diesel exhaust particulates is reasonably anticipated to be a human carcinogen[6], and is widely accepted to cause health effects from both short term and long-term exposures. The type and severity of health effects depends upon several factors including the amount of exposure and the length of time exposed. Exposure to particulate matter pollution is linked to increased frequency and severity of asthma attacks. Exposure to particulate matter can also trigger heart attacks and cause premature death in people with pre-existing cardiac or respiratory disease. People most sensitive to particulate matter pollution include infants and children, the elderly, and persons with existing heart and lung disease.

In 1998, the California Air Resources Board (CARB) designated the exhaust from diesel-fueled engines as a toxic air contaminant, with diesel particulate matter (DPM) as a surrogate for total emissions. The US EPA also lists diesel exhaust as a mobile source air toxic. According to CARB, about 70 percent of the potential cancer risk from toxic air contaminants in California can be attributed to DPM. This designation of diesel exhaust as a carcinogen has made operation of Ports and large transportation centers a major public health concern.

On 12 June 2012, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), classified diesel engine exhaust as carcinogenic to humans, based on sufficient evidence that exposure is associated with an increased risk for lung cancer.

If diesel-fueled equipment is a significant part of a port inventory, special consideration should be given to DPM in a Clean Air Program. Issues related to cancer health risk will need to be addressed.

• *Evaluate the implementation strategies needed to bring about emission reductions.*

The Program plan should address both the technical and administrative approaches necessary to reduce emissions from operations. The technical approaches are the various control measures that can be applied to equipment or operations. The administrative approaches are the various ways that the technical measures get implemented. Some of the implementation strategies employed by other ports around the world include:

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[6] Source: Page 153, Report on Carcinogens, Twelfth Edition (2011), National Toxicology Program, National Institute of Environmental Health Sciences, National Institute of Health, U.S.

- Terminal Lease/Agreement Modifications
- Tariff Changes
- Incentives/Disincentives
- Agency Regulation
- Voluntary Adoption

• *Design a benchmarking process to measure emission reduction progress.*

The Program plan should detail a process that will be followed to track progress of the completed Program. Again, the commitment does not have to overly detailed or complex. A simple statement such as: 'To track, monitor, and demonstrate the progress of the Clean Air Program, the Port will develop monitoring programs to encompass the breadth of actions proposed in the Program.'

This can be followed by more detailed specifics outlining the steps that will be taken to monitor and report on progress (such as doing new emissions inventories on a regular basis, or expanding a real-time air quality monitoring network).

Define Goals

Every program needs objectives and targets. These are the goals the program strives to achieve. These should be goals that can be tracked and measured. The objectives and targets should also be related to port operations, rather than as regional goals, given the difficulty of using regional indicators to track port related emissions in a large urban environment.

• *Set emission reduction targets.*

It may be advantageous to set objectives and targets by pollutant and by source category, rather than using a single or composite objective/target. Depending on the particular situation in any given locale, one source category or another may predominate. In another locale, the problem may be related to one or another pollutant category. When objectives and targets are tailored to the particular issue or locale, appropriate control strategies can likewise be tailored.

Emissions reduction targets can also be set for the various equipment operating modes if applicable. For instance, it is perfectly acceptable to set a target focusing on vessels while at berth (hoteling mode) and another for vessels in transit.

The target can also follow national target, if applicable. For example, Port operators are also required to cut CO2 emissions per throughput by 10% and energy use per throughput by 8%. Meeting these targets is the prerequisite of exploring further reductions.

• *Define limits of the geographic extent and/or activity of program.*

It is important to define the geographic extent or boundary of the program for monitoring and reporting purposes.

Given the nature of international goods movement, port activity reaches great distances. However, the impact of emissions from operations at any particular port diminishes with distance, to a point that it becomes difficult to isolate port-related impacts from regional impacts. The geographic extent or boundary should be set to a location where port-related impacts are still measurable.

For a particular locale, there may be geographic features that define the region of influence, and that may make sense as the geographic extent for the Program. It may be necessary to make a more arbitrary decision.

The geographic region may vary by type of source. For instance, the emissions from Heavy Duty Trucks may be tracked a few miles inland based on origin of the last place a truck has visited, to several hundred miles for rail movements to or from a port. Likewise the geographic extent for tracking emissions from vessels may be limited to the local port area for some jurisdictions to many miles out to sea for others.

- *Identify the number and types of equipment to be improved.*

Knowing the type, number, and operating profile of equipment used in port operations is critical to success. This information should be gathered as part of the baseline inventory carried out for the plan.

Equipment source categories routinely considered as port-related:

- Ocean-going Vessels - Ocean-going vessels are large ships capable of trans-oceanic cargo shipment, many times foreign flagged. These vessels are often further categorized by vessel type (such as auto carrier, containership, tanker, etc.).
- Coastal/River Vessels – Ships varying in size used for movement of cargo from inland locations to coastal ports by river, or along the coast.
- Harbor Craft - Harbor craft are commercial vessels that spend the majority of their time within or near the port/harbor.
- Cargo Handling Equipment - This includes equipment that moves cargo (including containers, general cargo, and bulk cargo) to and from marine vessels, railcars, and on-road trucks. The equipment typically operates at marine terminals or at rail yards and not on public roadways.
- Rail – Railroad operations are typically described in terms of two different types of operation, line haul and switching. Line haul refers to the movement of cargo over long distances (e.g., cross-country) and occurs within the Port as the initiation or termination of a line haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas. Switching refers to short movements of rail cars, such as in the assembling and disassembling of trains at various locations in and around the Port, sorting of the cars of inbound cargo trains into contiguous "fragments" for subsequent delivery to terminals, and the short distance hauling of rail cargo within the Port.
- Heavy-Duty Vehicles – This typically is used to describe the on-road trucks, which are used extensively to move cargo, particularly containerized cargo, to and from the terminals that serve as the bridge between land and sea transportation. Trucks deliver cargo to local and national destinations, and they also transfer containers between terminals and off-port railcar loading facilities, an activity known as draying.

• *Determine the timeline that the Clean Air Program will be carried out.*

The goals need to be placed in the context of time. For a particular goal, how long will given for the reductions to be implemented? It may be necessary to provide different time frames for different goals or to create separate short- and long-term goals

Determine Technical Approach

This is where the specific control measures for the Program are identified. Once the preceding activities have taken place (estimating reduction potential and defining goals), detailing the specific strategies can begin.

• *Identify the technical steps to reduce emissions from the selected maritime activity.*

Using the Technological Options for Improving Air Quality section of this document as a guide, evaluate the strategies recommended for the source category of focus. For example, refer to the strategies recommended for cargo handling equipment (CHE).

Depending on the strategy, research the various options available that will work best with the identified equipment. For example, research the different emission control technology companies that provide diesel particulate filters (DPFs) for non-road applications such as CHE. There are differences in operational measures, effectiveness, maintenance and cost.

Identify where to improve operational efficiency either through idle-reduction strategies, gate efficiencies and/or better maintenance programs.

For example, here are the types of questions that will help identify what technical steps are needed. The maritime source in this example is cargo-handling equipment (CHE).

- How will operational staff schedule selected CHE to be retrofitted with emission control technologies without creating operational and schedule conflicts?
- What equipment will be retrofitted first?
- What training is required to educate maintenance/operational staff on technical implementation?
- What are the steps needed to retrofit a piece of equipment with a particular technology?
- Once CHE is retrofitted, what maintenance is involved?

After researching the various control options for your selected maritime operation, determine the control option(s) that is technically feasible and provides the most environmental benefits. Carry out a pilot test to ensure feasibility.

Determine Performance Targets

Control measures lay out particular strategies to attain the ultimate Program goals. The control strategies should include source specific performance standards/targets to assist in Program implementation. The performance standard/target should:

- Set the emissions to be reduced from a particular source or specify how the equipment should be changed.
- Set specific timelines for defined actions in the Clean Air Program.

Timelines may include: the number of equipment retrofitted over a period of time; meetings to discuss goals and evaluate progress; and dates when certain actions would be completed.

As an example, here are several performance standard/target from a US port:

- By the end of 2010, all yard tractors operating at the Port will meet at a minimum the EPA 2007 on-road or Tier IV engine standards.
- The use of ≤0.2% sulfur MGO fuel in vessel auxiliary and main engines at berth and during transit out to a distance of 20 nm from Port starting 1st quarter 2008.

Another example from a Chinese Port:

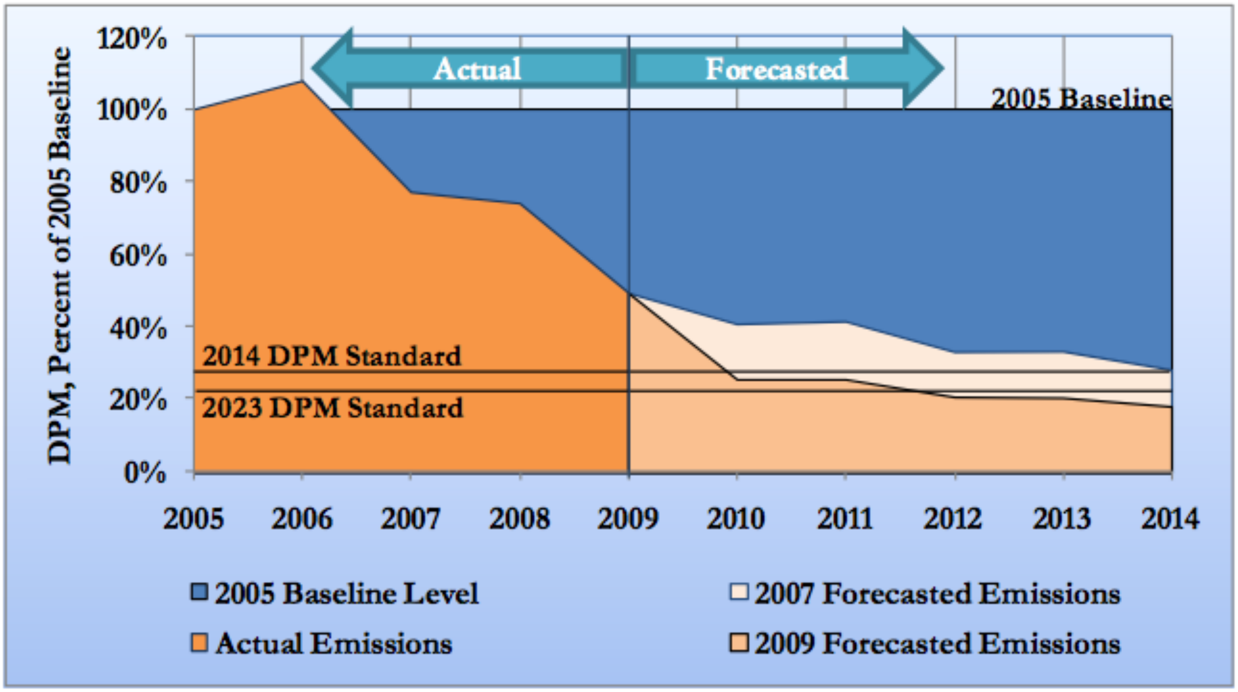
- Port CO_2 emission: by 2015, emission reduce by 10% from 2005 level; RTG retrofit rate for energy saving and emission reduction is 100% by 2015; Port particulate control/mitigation rate reach 70%; vessel bilge water and trash collection rate is 100%.

Performance targets should be aggressive, but achievable. What this means will vary from port to port. While an exhaustive review of goals/targets is beyond the scope of this report, an example can be provided. In the San Pedro Bay Ports Clean Air Action Plan prepared in 2006 and updated in 2010 by the Port of Los Angeles and the Port of Long Beach set targets that went significantly beyond regulatory requirements. Many of the goals were based on what could be expected to be technically achievable with little regard to cost. The ports set the following as one of their goals:

- By2014, reduce emissions by 22% for NOx, 93% for sulfur oxides (SOx), and 72% for DPM to support attainment of the federal fine particulate matter ($PM_{2.5}$) standards.
- By 2023, reduce emissions by 59% for NOx to support attainment of the federal 8-hour ozone standard. The corresponding SOx and DPM reductions in 2023 are 93% and 77%, respectively.

The ports then go on to show progress on this standard in their 2010 update to the CAAP in the following figure (just for DPM).

Figure 4. Example to Show Progress on Meeting Targets



The figure above shows both progress on meeting the goals through publication of the 2010 update to the CAAP and the forecast for meeting the goals into the future.

Establish a Tracking System to Help Monitor Progress

In order to measure the success of the Clean Air Program, design a tracking system that will help monitor progress. A tracking system will ensure that actions laid out in the Program are achieved over the assigned time frame.

It may also be helpful to model the potential emission benefits expected from the control measures detailed in the Program. Using the baseline emissions inventory, and applying control measure assumptions based on the specific measures and identified time frames, one can produce an estimate of expected benefits from program implementation. This will serve as additional benchmarking during the 'DO' phase.

DO – Implementing Strategies

There are two equally important aspects to the "DO" process of the 'Plan, Do, Check Act' cycle: Communication Approach, and Technical Approach.

Coordination Approach

Coordinating the Program

Sometimes, the management and regulation of port operations are fragmented within different departments. The point person in charge of the Clean Air Program should be competent and have appropriate authority to coordinate port, environmental bureaus, and transportation departments.

Communication Approach

Communicating The Program

A communication plan will direct how the Program is explained to the various audiences. Depending on how the port is organized, the message may need to be adapted to the different groups of people within the organization. The same applies to communicating to people outside of the port – customers, tenants, business partners, stakeholders and the port community.

Raise Awareness (Internal and External)

Identify the different mediums on how to communicate the Clean Air Program. Mediums may include: meetings, workshops, written materials, campaigns, and the internet (include a program link on the port's webpage).

Capacity Building

Open up opportunities for employees to learn and share ideas. Training allows for the exchange of helpful information on best practices. Capacity building will help sustain the success of the program. The more people are aware of and understand the purpose and benefits of the Clean Air Program, the higher the likelihood that people will support it.

Motivating The Clean Air Team

Motivate the team through incentives. It is very important that people feel like they are a part of something that is special and important. Recognize staff that has worked hard on the program and staff who have made achievements while supporting the goals of the Clean Air Program.

Technical Approach

Implement The Control Measures

If the Program has provided sufficient detail, control measure implementation is a straightforward process. That is not to say that it is easy. Implementing 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 continued re-evaluation, adjustment, and updates of the Program.

• *Apply control strategies to maritime operation.*

Each port will determine the most effective administrative strategies for implementing the technical control measures in the Program. As described in the "PLAN" section above, these different implementation strategies should be evaluated early on and included in the Program. A combination of strategies will probably be necessary.

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 Source Specific Performance Standards should any one of the other specific strategies fail to be applied."

The specific combination of control strategies necessary to implement a particular plan will vary from port to port.

• *Follow implementation schedule.*

Priority for limited resources should be made toward implementing measures that will provide the greatest or most immediate benefit.

CHECK – Measuring Results

Study the actual results of the Program (measured and collected in "DO" above) and compare against the expected results (targets or goals from the "PLAN" above) to ascertain any differences. Look for deviation in implementation from the Program and also look for the appropriateness/completeness of the Program to enable the execution.

Monitor and Evaluate Progress

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

- Use the tracking system described in the Program to monitor the progress of the Clean Air Program.
- Evaluate how well the Program is operating under the measures that have been established.
- Measure the results of the control strategy.
- Determine how much emissions have been reduced and where operational performances have improved.

The lessons learned from problems encountered during implementation lead directly to the next phase of the process.

ACT – Review The Clean Air Program and Update Regularly

It is important to continuously update and improve upon Program, to monitor progress, plan for the future, and maximize success in controlling air pollution from port operations. At this point in the process, implementation of the Program should be well underway, and some level of monitoring and evaluation of how well program elements are working should have taken place.

Make Improvements to The Clean Air Program

With the knowledge gained from initial attempts at Program implementation, and following upon steps taken in 'CHECK' above, there should be sufficient information available to make necessary adjustments to the Program. Adopting these changes to the Program will assure that the emissions benefits continue and will provide additional effort toward achievement of the goals.

Make the Program updates on a reasonable schedule. Committing to an overly aggressive schedule of updates may be counter-productive. It takes time to determine what is working and what is not.

When the Ports of Los Angele and the Port of Long Beach originally developed their Clean Air Action Plan, they developed a five-year plan laying out goals, targets, control measures and implementation strategies to significantly reduce emissions from port related sources in southern California in the US. In the original plan, they committed to completing updates to their plan every year. This commitment was found to be overly aggressive given the time it takes to begin implementation of control measures. In fact, the first update to the Clean Air Action Plan did not occur for four years.

Celebrate Program Achievement

Recognize and commend the achievements of staff that have helped make the Clean Air Program a success. It is very important to recognize the efforts of the clean air team and the hard work they have put forward to bring the Clean Air Program into reality.

Communicate the success of the Clean Air Program to the port community and stakeholders. Share the benefits of the Program with the public. A great way to share success and receive recognition is to apply for achievement or environmental awards. This will help build positive public awareness and support.

6. Case Studies

Overview:

San Pedro Bay Ports Clean Air Action Plan
In southern California on the Pacific Coast of the United States, the Port of Los Angeles partnered with its sister port, the Port of Long Beach, and engaged the United States Environmental Protection Agency, California Air Resources Board and the South Coast Air Quality Management District in a partnership to develop the world's first multi-port, comprehensive port-related air management plan – the San Pedro Bay Ports Clean Air Action Plan.

Northwest Ports Clean Air Strategy
The ports of Seattle and Tacoma in the Pacific Northwest of the United States and the Port Metro Vancouver in British Columbia, Canada have been working closely with federal, state and local air agencies for years on successful voluntary collaborative approaches to reduce air emissions from maritime-related sources in the region. In 2007, they developed the Northwest Ports Clean Air Strategy to establish common performance goals and further reduce emissions to protect public health and the environment.

Port Authority of New York and New Jersey Clean Air Strategy
The Port Commerce Department of the Port Authority of New York and New Jersey in the Atlantic Northeast of the United States, along with its tenants, public agencies and private partners, collaborate on voluntary efforts to field test new off road technologies and develop clean equipment prototypes. Collaborative efforts are conducted under the Department's participation with the Regional Air Team on the Harbor Air Management Plan, the Northeast Diesel Collaborative and through U.S. EPA's Clean Ports Program.

Rijnmond Regional Air Quality Action Program
ROM Rijnmond Executive Council commissioned the DCMR Rijnmond Environmental Agency to draw up a regional plan through the Top Management Steering Committee on Air, which comprise of leaders from Ministries of Housing, Spatial Planning and the Environment; Transport, Public Works and Water Management; Economic Affairs; Agriculture; Nature and Food Quality; the Province of Zuid-Holland, the city of Rotterdam, Rotterdam Metropolitan Region; and Rotterdam Port Authority. The Rijnmond Regional Air Quality Action Program draws up existing air quality programs and creates a great uniformity of air quality control measures.

CASE STUDY: SAN PEDRO BAY PORTS CLEAN AIR ACTION PLAN

Located in the South Coast Air Basin (SoCAB) in the state of California, the second largest urban area in the United States of America, the Ports of Los Angeles and Long Beach (collectively, the San Pedro Bay Ports) are situated in an area with the worst air quality in the nation. US regulatory agencies have identified ozone and particulate matter less than 2.5 microns (PM2.5) to be of particular concern with diesel particulate matter (DPM) as a surrogate for total emissions. This poses a serious risk to Southern California residents who live near the Ports, transportation corridors and other areas with high levels of diesel-related activity. The California Air Resources Board predicts that 70 percent of the potential cancer risk from toxic air contaminants in California can be attributed to DPM.

With the need to accommodate the rapid growth in trade and the increased demands of goods movement, the San Pedro Bay Ports recognize the necessity to reduce their "fair share" with respect to other sources in the South Coast Air Basin. In doing so, the Ports would have to address all maritime operations by implementing strategies that would substantially reduce diesel emissions from ocean going vessels, harbor craft, cargo handling equipment, trucks and locomotives.

In March 2006, an important partnership was formed between the Port of Los Angeles and the Port of Long Beach along with the South Coast Air Quality Management District, California Air Resources Board and the United States Environmental Protection Agency Region 9 to work jointly toward solutions to enhance air quality and the quality of life for the residents of Southern California. Collaborating as team, the partnership developed the San Pedro Bay Clean Air Action Plan (CAAP).

The Clean Air Action Plan sets forth an array of control measures and implementation strategies that the Ports will use to reduce public health risk from port/maritime operations. The five-year Action Plan includes performance driven goals, emission reductions, and budgetary needs. In addition, the Ports have created a Technology Advancement Program that will evaluate promising projects and technologies that will demonstrate effectiveness in port-related emission reductions. The Plan also includes a program to evaluate infrastructure and operational efficiencies.

Tenants, railroads, and the trucking industry will be expected to 'sign on' and participate in the CAAP starting in 2007. The Ports will work with tenants and the railroads to assist them in developing their own programs to meet CAAP standards. To substantially address diesel emissions from trucks, the Ports are adopting a goal to eliminate "dirty" trucks from the San Pedro Bay terminals within 5 years of CAAP adoption. The Ports are working with all concerned parties to establish new relationships and business paradigms to secure adequate funding to make this program successful.

One of the most valuable aspects of the CAAP is that both Ports will combine resources and expertise to supplement the actions of the federal, state, and local regulators as necessary to implement cleaner technologies for various source categories. This coalition also provides the two Ports with similar requirements related to environmental measures that might otherwise hurt their competitive positions.

Since its release in 2006, the implementation actions undertaken by the Ports have had a profound effect on emissions from port operations. In 2010, the Ports released an update to the CAAP that evaluated progress to date and made several major enhancements to the Plan that sets new goals for future years.

CASE STUDY: NORTHWEST PORTS CLEAN AIR STRATEGY

The Ports of Seattle and Tacoma in the Pacific Northwest of the United States and the Port Metro Vancouver in British Columbia, Canada are located in areas that meet federal, state, and local ambient air quality standards. Some areas in the region are expected to have difficulties in the future meeting stricter United States standards for fine particulate matter. Recognizing that port operations contribute air emissions in local and regional air sheds, Port Metro Vancouver, the Port of Seattle, and the Port of Tacoma ('the Ports') have partnered with regulatory agencies to identify ways to reduce air emissions from all aspects of port operations. The Northwest Ports Clean Air Strategy ("the Strategy") was developed in 2007 as collaboration between the Ports and regulatory agencies including Environment Canada, the Puget Sound Clean Air Agency, the Washington State Department of Ecology, and the United States Environmental Protection Agency.

The Northwest Ports Clean Air Strategy has three primary emissions reduction objectives:

- Reduce maritime and port-related air quality impacts on human health, the environment, and the economy,
- Reduce contribution to climate change through co-benefits associated with reducing air quality impacts, and
- Help the Georgia Basin – Puget Sound air shed continue to meet air quality standards and objectives.

The Strategy defines specific targets, or 'performance measures' for the reduction of port-related air quality impacts on human health, the environment, climate change, and the economy. The focus of the Strategy is on emission reductions in six sectors of port operations. Performance measures are quantitative or qualitative, depending on the sector of port operations. The Strategy includes two milestones: a set of near-term performance measures to be met by 2010, and a set of longer-term performance measures for 2015.

The performance measures for ocean-going vessels are included here as an example of the goals for one sector of port operations:

2010 OGV Performance Measure

- Reach the equivalent PM reduction of using distillate fuels with a maximum sulfur content of 0.5% for all hotelling auxiliary engine operations.
- Use of fuels with a maximum sulfur content of 1.5%, or use of equivalent PM reduction measures, for all hotelling main or diesel electric engine operations (except during active docking and departure, during which non-hotelling engine operations are running).

2015 OGV Performance Measure

- For all ships, compliance with performance measures that the International Maritime Organization (IMO) adopts and in accordance with the IMO schedule.2

Progress has been made towards achieving the 2010 performance measures. However, not all performance measures have been met. The Ports are continuing to work to achieve 2010 performance measures while also pursuing progress towards 2015 performance measures[7].

CASE STUDY: PORT OF NEW YORK AND NEW JERSEY CLEAN AIR STRATEGY

The Port of New York and New Jersey, the largest port complex on the East Coast of North America, is located in the Atlantic Northeast of the United States within the USEPA-designated New York/New Jersey/Long Island Non-Attainment Area (NYNJLINA) for Nitrogen Oxides (NOx). Portions of the NYNJLINA are unlikely to meet federal ambient air quality standards for fine particulate matter as new stricter US standards come into place.

The Port Commerce Department of the Port Authority of New York and New Jersey (PANYNJ) is a landlord for six marine cargo terminals. Dedicated to Environmental Stewardship as one of its key business objectives, the Port Commerce Department is committed to promoting air quality enhancement efforts as it accommodates growing cargo volumes to satisfy the needs of the largest consumer demand region in the United States. In order to be successful, the Port aims to be a sustainable port, by promoting regional prosperity, financial return and the dual imperatives of security and the environment.

PANYNJ has adopted a proactive strategy to improve air quality that involves compliance with existing regulations, exceeding all mitigation requirements and undertaking voluntary initiatives to reduce air emissions. The Port Commerce Department has implemented an Environmental Management System to ensure compliance with air quality laws and regulations. In addition, there are initiatives underway to offset NOx emissions generated during channel-deepening construction that will exceed regulatory requirements. The Port Commerce Department also has several on-going voluntary, collaborative efforts that are evaluated for their ability to reduce air emissions and cost effectiveness.

For example, a cargo handling equipment (CHE) emissions inventory undertaken to assess the impact of our container terminal tenants' voluntary modernization of CHE and use of cleaner burning fuels showed a greater emission reductions across the full spectrum of pollutants despite a 25% increase in cargo handled. A subsequent emission inventory of vessels dwelling at these same facilities showed that they contributed a small percentage of overall pollutants in the non-attainment area.

In order to meet growing cargo demands, the Port Commerce Department is investing nearly two billion dollars over the next decade to reconfigure existing terminals, deepen the harbor's channels and berths and improve inland access by rail and barge. This investment will create an efficient and cost-effective port, while also reducing local congestion, enhancing air quality and conserving energy. Improvements include installing infrastructure to support electric-regenerative cranes, and significantly enhancing on-dock and regional rail capabilities. In addition, our marine tenants are investing heavily in gate improvements, electric cranes, yard equipment modernization and use of cleaner fuels, all of which enhance air quality. The Port Commerce Department, along with its tenants, public agencies and private partners collaborate on voluntary efforts to field test new off road technologies and develop clean equipment prototypes, such as active diesel particulate filters and hybrid yard tractors. Collaborative efforts that go beyond the immediate port area include working

[7] Northwest Ports Clean Air Strategy 2011 Implementation Report, July 2012.

with the EPA, state regulators and port members of the Northeast Diesel Collaborative to develop voluntary regional strategies and USEPA's Clean Ports Program to help develop voluntary industry wide initiatives.

The Ocean-Going Vessel Low-Sulfur Fuel Program (LSF) is a program that provides financial incentives to encourage operators of ocean-going vessels calling at certain Port Authority marine terminals to utilize low-sulfur fuel in their main (propulsion) and auxiliary engines instead of the Intermediate Fuel Oil 380. As an important component of the Clean Air Strategy for the Port of New York & New Jersey the OGV low-sulfur fuel program aims to provide incentives to vessels operators to switch from highly polluting bunker fuel. This heavy fuel generates the majority of sulfur oxide emissions and makes these vessels the single largest source of air pollution, accounting for roughly half of the port-relation pollution. Switching to low-sulfur fuels reduces emissions of fine particles, including black carbon, as well as carbon dioxide, nitrogen oxides and nitrous oxide. Perhaps the most significant benefit from participation in this program is the contribution to improving public health.

The LSF Program reimburses vessel operators for 50% of the cost difference between using Low Sulfur Marine Fuel in their main engines while operating within 20 nautical miles of the Port of New York & New Jersey. The Program also reimburses vessel operators for 50% of the cost difference between using Low Sulfur Marine Fuel and IFO 380 in their auxiliary engines while at a Port Authority marine terminal facility berth.

The Truck Replacement Program (TRP) is a program to provide grants and financing to eligible truck owners to help them purchase newer, cleaner and more environmentally friendly trucks. As an important component of the Clean Air Strategy for the Port of New York and New Jersey the TRP aims to replace trucks that have engines Model Year 2003 or older with newer trucks equipped with Model Year 2004 or newer EPA emissions-compliant engines. The purpose of the TRP is to reduce diesel emissions from older trucks and improve local and regional air quality while also improving public health.

As of January 1, 2011, port drayage trucks equipped with engines Model Year 1993 and older were not allowed to access the Port Authority’s marine terminals. In addition, starting January 1, 2017, only trucks equipped with engines that meet or exceed engine Model Year 2007 federal emission standards will be allowed access to these same facilities.

Eligible applicants will receive a grant that covers up to 25 percent of the purchase price of a newer truck. They may also qualify for low-interest financing on the remaining 75 percent.

CASE STUDY: RIJNMOND REGIONAL AIR QUALITY ACTION PROGRAM

Air quality in Rijnmond among other regions in the Netherlands, has improved over the last 30 years. However, according to recent figures, emissions have increased beyond their limit values. The increase in emissions poses a serious risk to spatial and economic development and can adversely affect public health. Projections show that emissions for particulate matter (PM) and oxides of nitrogen (NOx) in the Rijnmond region will exceed European air quality standards set for 2010 if actions are not taken to reduce air pollution.

To address Rijnmond's growing air quality problems, the ROM Rijnmond Executive Council (BOR) has united in a partnership with administrative authorities to develop a package of measures to mitigate air pollution in the Rijnmond region. Better known as the Rijnmond Regional Air Quality Action Program, the program builds upon existing clean air programs. The combination of air quality programs include; Rotterdam's Approach to Air Quality, the Air Quality Master Plan developed by BOR, the Air Quality Plan of Approach by the Rotterdam Metropolitan Region, and the Plan of Approach to Air by the Rotterdam Port Authority.

Through the Top Management Steering Committee on Air, a committee comprised of leaders from all participating parties under BOR, commissioned the DCMR Rijnmond Environmental Agency to develop the Rijnmond Regional Air Quality Action Program. The program is carried out in close coordination with the participating administrative authorities and other parties such as members from the business community. In order to establish greater uniformity for measuring and calculating control measures, the Top Management Steering Committee on Air organized five task groups to focus on different source categories. The five task groups were divided into the following groups: road traffic, shipping, railway, industry and households. Each of the sources identified by the Committee, account for 90% of the emissions in the region.

Clean air strategies were evaluated by the impact on air quality, costs, feasibility, side effects, and time frame. Efforts from the five task groups resulted in 100 different strategies of which 34 were selected as most promising. The proposed strategies aim to impact air quality both in a local and regional manner. Local measures included strategies such as shore side power for ocean-going vessels and low emission zones in urban centers. Regional measures included pushing for stronger EU regulations. The 34 promising strategies are prioritized for implementation through a phased approach, which include: immediate, near-term and long-term implementation.

7. GLOSSARY OF TERMs

Air quality monitoring – Method used to measure ambient air quality.

Air toxics – Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious, chronic health effects, such as reproductive effects or birth defects, or adverse environmental effects.

Alternative fuel – Also known as "non-conventional fuels," is any material or substance that can be used as a fuel, other than fossil fuels, or conventional fuels of petroleum (oil), coal, propane, and natural gas. The term "alternative fuels" usually refers to a source of which energy is renewable (See "renewable fuel").

Area source – A general term for a source that is an aggregate of all emission sources within a defined spatial boundary. Though emissions from individual sources in an area are relatively small, collectively their emissions can be of concern - particularly where large numbers of sources are located in heavily populated areas.

Auxiliary engine – A small engine often used when a ship is hotelling.

Baseline Air Emissions Inventory – For a given air emission source category, a baseline inventory establishes a reference point with more detailed emission data than previously existed. An established baseline allows comparison with future inventories of similar precision to describe changes to the characteristics of the source category and intensity of the emissions.

Brake-Specific Fuel Consumption – A way to measure the efficiency of an engine by dividing rate of fuel consumption by the rate of power production.

Bunker Fuel – See "Fuel Oil"

Cargo Handling Equipment (CHE) – Equipment used to move cargo to and from marine vessels, railcars and trucks. This includes equipment such as cranes, rubber tired gantry cranes, terminal trucks, container handlers, bulk loaders, and forklifts.

Cold Ironing – Also called "Alternative Maritime Power" and more generally referred to as "Shore Power." This specifically refers to an electrical connection made between the vessel and the terminal to provide full or partial operational power during hoteling periods. The primary motivation for cold ironing has been as a method to reduce emissions from the exhausts of auxiliary engines that would normally operate during hoteling. "Cold iron" is a reference to when ships mainly used boilers to produce steam for propulsion, heat, and power. When the steam production was shut down, the iron in the boiler housing would go cold.

Commercial vessel – Any vessel involved in commercial trade or business.

Criteria pollutants – A regulatory term that refers specifically to six outdoor air pollutants for which EPA is required to develop National Ambient Air Quality Standards (NAAQS), as codified in the federal Clean Air Act. These six are carbon monoxide (CO), lead, nitrogen dioxide (NO_2), particulate matter (PMx), ozone, and sulfur oxides (SOx).

Deadweight tonnage – Refers to the total amount of weight that a vessel is carrying, minus the actual weight of the vessel. Historically, tonnage was the tax on tons (casks) of wine that held approximately 252 gallons of wine and weighed approximately 2,240 pounds. This suggests that the unit of weight measurement, long tons (also 2,240 lb) and tonnage both share the same etymology. The confusion between weights based terms (deadweight and displacement) stems from this common source and the eventual decision to assess dues based on a ship's deadweight rather than counting the tons of wine.

Deterioration factor – For use in emission or performance calculation, this number accounts for the effect of gradual wear in the internal engine components in the course of normal operation.

Diesel – In standard use, this refers to a specific fractional distillate of fuel oil that is used as fuel in a compression-ignition (CI) engine. Practically, diesel can refer generally to any hydrocarbon-dense oil with relatively low volatility that can be used as a combustion fuel. In common maritime use, diesel can refer to several varieties of distillate fuels including "Marine Diesel Oil" (MDO, aka DMB or DMC) and "Marine Gas Oil" (MGO, aka DMA or DMX) as specified by ISO 8217. Diesel can also be referred to by its sulfur content, such as the case of LSD (low sulfur diesel with less than 500 ppm sulfur) or ULSD (ultra low sulfur diesel with less than 15 ppm sulfur).

Diesel electric – Refers to equipment that uses electric motive systems that rely on electricity from diesel generators.

Diesel Oxidation Catalyst (DOC) – A flow-through canister, fit to an engine exhaust pipe, containing a honeycomb-like structure or substrate. The substrate has a large surface area that is coated with an active catalyst layer. This layer contains a small, well-dispersed amount of precious metals such as platinum or palladium. As exhaust gases pass over the catalyst, carbon monoxide, gaseous hydrocarbons and liquid hydrocarbon particles (unburned fuel and oil) are oxidized, thereby reducing harmful emissions.

Diesel Particulate Matter (DPM) – Refers to particulate components of combustion products that are directly emitted from diesel engines. These include soot ("elemental" or "black" carbon) and other aerosols that are complex aggregates of hydrocarbons, metals, silicates, and other chemicals. In recent years, DPM has been singled out as posing a carcinogenic risk to people who regularly work in proximity to diesel equipment over the course of many years.

Diesel Particulate Filter (DPF) – A filter installed on the exhaust pipe of diesel engine to physically separate particulate matter from the exhaust stream. Some filters are single use (disposable), while others are designed to burn off the accumulated particulate, either through the use of a catalyst (passive), or through an active technology, such as a fuel burner which heats the filter to soot combustion temperatures

Economizer – A heat exchanger that transfers heat from the exhaust stream to a water circulation system to produce steam. Often used when a vessel is in transit, an economizer can allow the regular diesel powered boiler to be shut off.

Emission factor – A number specific to an engine or system that describes the amount of a pollutant that is generated per unit of activity, e.g. mg/mile or g/hr

Emulsified fuel – A homogenized blend of water into diesel fuel that changes the fuel combustion characteristics and resulting emissions. This strategy is mainly employed to reduce NOx emissions but may also reduce PM and improve fuel economy.

Environmental Protection Agency (EPA) – A US federal or state agency responsible for standard setting in the environmental field

EPA NONROAD model – NONROAD is a computer modeling program created and regularly updated by EPA that calculates past, present, and future emission inventories (i.e., tons of pollutant) for all off-road equipment categories except commercial marine, locomotives, and aircraft. For a specified geographic area, time period, and fuel type, the model estimates exhaust and evaporative hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2).

Exhaust gas recirculation (EGR) – A technique used in most gasoline and diesel powered engines to control emissions. Engine exhaust is mixed with engine intake air and recirculates through the combustion process. The result is a reduction in NOx emissions due to lower combustion temperatures and reduction of excess oxygen.

Fine particulate matter – See Particulate Matter

Four-stroke engines – The most common type of engine for cars and trucks. This engine uses the 'Otto cycle' and consists of four strokes: 1. in-take stroke, 2. compression stroke, 3. power (ignition) stroke, and 4. exhaust stroke.

Fuel correction factor (FCF) – A number used in emission inventory models to reflect the impact on emissions of commercially dispensed fuel compared to fuel used during the certification process. These factors are derived as the ratio of the impact of the dispensed fuel to the impact of the certification fuel.

Fuel Oil – A general term for viscous liquid fuels used for powering engines. In the maritime industry the following classifications are used.

- ***MGO (Marine gas oil) –*** A purely distillate fuel (see "diesel")
- ***MDO (Marine diesel oil) -*** A blend of gas oil and heavy fuel oil
- ***IFO (Intermediate fuel oil)*** A blend of gas oil and heavy fuel oil, with less gas oil than marine diesel oil
- ***MFO (Medium fuel oil) -*** A blend of gas oil and heavy fuel oil, with less gas oil than intermediate fuel oil
- ***HFO (Heavy fuel oil) -*** Pure or nearly pure residual oil (bunker fuel)

Fugitive emissions – Emissions not created through a defined process or controlled by a dedicated system. These can be due to equipment leaks, evaporative processes, materials processing, and windblown disturbances

GHG equivalent – Similar to "carbon equivalent" this refers to a method by which air emissions are standardized for comparison based on their "global warming potential" (GWP) as greenhouse gases. Each greenhouse gas differs in its ability to absorb heat in the atmosphere so will be presented in units of carbon equivalents, which weighs each gas by its GWP relative to carbon dioxide. For example, methane traps over 21 times more heat per molecule than carbon dioxide, and nitrous oxide absorbs 310 times more heat per molecule than carbon dioxide.

Greenhouse Gas (GHG) – Substances in the atmosphere that absorb radiated heat form the earth's surface and also radiate heat back to the surface, causing a net retention of heat energy. Carbon dioxide, methane, and nitrous oxide are common examples.

Gross vehicle weight rating – The estimated total weight of a road vehicle that is loaded to capacity, including the weight of the vehicle, the passengers, fuel, cargo, and miscellaneous items. The rating allows the vehicle driver to know what routes are acceptable, depending on whether the roadways can accommodate a vehicle of the estimated weight.

Harbor craft – A term that generally refers to vessels that do not make regular ocean passage. These include fishing boats, tugboats, ferries, and other commercial workboats. For the purpose of this report, any craft that is not an ocean-going vessel, recreational vessel, or tank barge, has been categorized as a harbor craft.

Hoteling **–** The period during which a vessel is secured at berth

Hydrocarbon – A chemical term referring to compounds that consists of carbon and hydrogen in various structures. Most common liquid fuels are primarily comprised of some form of hydrocarbon.

Integrated tug/barge – Any tug and barge combination with a specially designed connection system joining the two together. The combination allows the vessel to have increased sea-keeping capabilities when compared to a separated tug and barge.

Intermediate fuel oil (IFO) **–** See Fuel Oil

Intermodal Container Transfer Facility – A rail yard that is located close to a port facility and is where a cargo transition between two different transportation modes (e.g. trucks, trains, or ships) occurs.

Liquefied Natural Gas (LNG) – Natural gas that has been processed to remove impurities and heavy hydrocarbons and is then condensed into a liquid using extremely low temperature or high pressure.

Liquefied Petroleum Gas (LPG) – A mixture of hydrocarbon gases that are commonly used to fuel heating appliances and vehicles. The two most common forms of liquefied petroleum gas are propane and butane.

Load Factor (LF) – A ratio of an engine's average actual power used to its maximum power rating.

Low Sulfur Diesel (LSD) **–** See "Diesel"

Main line locomotives – Also called "line-haul," these are the largest class of locomotives and are designed for the heaviest loads, longest distances, and steepest grades.

Main propulsion engine **–** The engines on a vessel that are dedicated to movement of a ship over long distances.

Marine Diesel Oil (MDO) – See "Fuel Oil"

Maximum continuous rating – A value assigned to a piece of equipment by its manufacturer that sets a guideline for which the equipment can be operated for an unlimited period of time without damage.

Non-Methane Organic Gas (NMOG) – Organic gases that exclude methane but account for all other organic pollutants that form a foundation for the formation of ozone.

Ocean-going vessel (OGV) – Vessels that operate in open oceanic waters.

Particulate Matter (PM) – A general term for any substance, except pure water, that exists as a liquid or solid in the atmosphere under normal conditions and is of microscopic or sub-microscopic size but larger than molecular dimensions. Airborne PM can result from direct emissions of particles (primary PM) or from condensation of certain gases that have them been directly emitted or chemically transformed in the atmosphere (secondary PM). PM is often classified by size:

- ***$PM_{2.5}$*** – Also known as "fine" particulate matter, $PM_{2.5}$ refers to the fraction of PM in a sample that is 2.5 microns in diameter or less. This size of PM is commonly associated with combustion and secondary PM.
- ***PM_{10}*** – Also known as "coarse" particulate matter, PM_{10} refers to the fraction of PM in a sample that is 10 microns in diameter or less.

Polycyclic Aromatic Hydrocarbon (PAH) – One of the first atmospheric species to be identified as carcinogenic. PAH's are formed during the incomplete combustion of organic matter, e.g. coal, oil, wood, and petroleum. PAH's consist of two or more fused benzene rings in various configurations that, by definition, contain only carbon and hydrogen.

Polycyclic organic material – Compounds containing polycyclic aromatic hydrocarbons and derivatives.

Renewable Fuels – Fuels derived from sources that are regenerative or for all practical purposes cannot be depleted.

Residual oil – "Residual Fuel Oil" or "Bunker Fuel" – See "Fuel Oil"**.**

Roll-on/Roll-off (RoRo) – A vessel featuring a built-in ramp for wheeled cargo to be 'rolled-on' and 'rolled-off" of the vessel.

Rubber Tired Gantry (RTG) Crane – A common piece of cargo handling equipment at marine terminals used to transfer containers from stacked storage to a vehicle.

Selective Catalytic Reduction (SCR) – A process where a gaseous or liquid reductant (most commonly ammonia or urea) is added to the flue or exhaust gas stream and absorbed onto a catalyst. The reductant reacts with NO_X in the exhaust gas to form H_2O (water vapor) and N_2 (nitrogen gas).

Seawater scrubbing – An exhaust treatment technique used on ships to reduce emissions by through physical and chemical interaction with seawater. When the exhaust comes in contact with the seawater, the SO_X reacts with calcium carbonate to form a solid calcium sulfate and CO_2. Scrubbers also function by physically scavenging particles and gases from the air.

Shaft generators – Provides electric power to a moving vessel by generating current from the rotation of the vessel's drive shaft.

Shore power – See "Cold Ironing"

Point source – A single, stationary point source of emissions that is immoveable for all practical purposes.

Total organic gases – The sum of reactive and non-reactive organic gases in the air.

Two-stroke engines – A type of internal combustion engine that completes the same four processes as a four-stroke engine (intake, compression, power, and exhaust) in only two strokes of the piston rather than four. This is accomplished by using the space below the piston for air intake and compression, thus allowing the chamber above the piston to be used for just the power and exhaust strokes. This results in a power stroke with every revolution of the crank, instead of every second revolution as in a four-stroke engine. For this reason, two-stroke engines provide high specific power, so they are valued for use in portable, lightweight applications. Two stoke diesel engines are common in large marine vessels.

Ultra Low Sulfur Diesel (ULSD) – See "Diesel."

Volatile Organic Compound (VOC) – A very board term used to describe the entire set of vapor-phase atmospheric organic chemicals except CO and CO_2.