

Marine Vessel Emissions, Strategies for Abatement

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In March 2008, The Glostén Associates compiled a study to ascertain the regulatory environment and industry approaches for emissions abatement from a marine engineering/ naval architecture perspective. This is a white paper based on our 2008 study, which we hope will be of use to others looking for emissions abatement solutions. All information presented here is based on our data as of March 2008, is not peer-reviewed, and should not be referenced by others.

Corrections and additions sent to email@glosten.com would be sincerely appreciated. Updates will be performed periodically.



THE GLOSTEN ASSOCIATES
Consulting Engineers Serving the Marine Community

TABLE OF CONTENTS

1.	EXECUTIVE SUMMARY	1
2.	INTRODUCTION.....	4
3.	MARITIME SHIPPING (NATURE OF BUSINESS AND ENVIRONMENTAL FOCUS).....	5
3.1	BLUE WATER SHIPPING.....	5
3.2	OTHER MARINE VESSELS	9
4.	VESSEL GROUPING (MATCHING WITH EMISSIONS REDUCTION STRATEGY).....	10
5.	MARINE FUELS (OVERVIEW)	12
6.	REGULATORY PRACTICES (CURRENT AND PROPOSED EFFORTS).....	15
6.1	INTERNATIONAL MARITIME ORGANIZATION (IMO) ANNEX VI	16
6.2	MARINE ENVIRONMENTAL PROTECTION COMMITTEE (MEPC)	16
6.3	INTERTANKO “DISTILLATES OPTION” PROPOSAL TO MEPC 57	16
6.4	EPA PROPOSALS TO MEPC 57.....	17
6.5	UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (EPA)	19
6.6	CALIFORNIA AIR RESOURCES BOARD (CARB).....	22
7.	LEVERAGING OPPORTUNITIES (STACKING THE DECK TO MINIMIZE EMISSIONS).....	23
8.	VESSEL DESIGN (REDUCING CARBON EMISSIONS BEFORE BUILDING)	25
8.1	HULL/PROPELLER OPTIMIZATION	26
8.2	ENERGY EFFICIENT AUXILIARY SYSTEMS.....	26
8.3	ENGINE HEAT RECOVERY	27
8.4	BATTERY HYBRID POWER PLANT	28
8.5	ADVANCED HULL COATINGS	29
9.	LOW SULFUR FUELS (EMISSIONS SOURCE AND SOLUTION).....	29
10.	ALTERNATIVE FUELS (EMISSIONS SOURCE AND SOLUTION)	30
10.1	NATURAL GAS COMBUSTION	30
10.2	BIODIESELS	31
10.3	HYDROGEN FUEL CELL.....	32
11.	ENGINE BASED APPROACHES (OPTIMIZING ENGINES).....	32
11.1	DESIGN/ENGINE TIMING	33
11.2	DIRECT WATER INJECTION.....	33
11.3	COMBUSTION AIR HUMIDIFICATION (HAM).....	34
11.4	FUEL – WATER EMULSION	34
12.	OFF ENGINE SYSTEMS (POLISHING EMISSIONS, BUT NOT REDUCING CARBON FOOTPRINT).....	35
12.1	SELECTIVE CATALYTIC REDUCTION UNITS.....	35
12.2	DIESEL OXIDATION CATALYSTS	36
12.3	CATALYZED DIESEL PARTICULATE FILTERS	37
12.4	COMBINED SYSTEMS.....	37
12.5	SEAWATER SCRUBBING.....	38
12.6	WIND PROPULSION ASSISTANCE.....	38

13.	OPERATIONS & MAINTENANCE (ON BOARD EFFORTS AFTER VESSEL IS BUILT)..	39
13.1	HULL MAINTENANCE	39
13.2	ENGINE/PROPULSION SYSTEM MAINTENANCE.....	39
13.3	OPTIMAL ENGINE OPERATING POINT	40
13.4	AUXILIARY EFFICIENCY POINT	40
14.	VESSEL LOGISTICS (SMART BUSINESS, LOW EMISSIONS).....	40
14.1	VESSEL SPEED REDUCTION	41
14.2	ROUTE PLANNING	41
15.	INFRASTRUCTURE SOLUTIONS (SHIFTING EMISSIONS OFF VESSELS)	42
15.1	SHORE POWER.....	42
15.2	SHORE SIDE EXHAUST CAPTURE.....	43
16.	GLOSSARY OF TERMS	44
17.	REFERENCES	47

Appendix A

- Emissions Reductions Opportunities: Review Summary
- Regulatory Initiatives and Rules: Review Summary
- Regulatory Initiatives and Rules: Notes and References

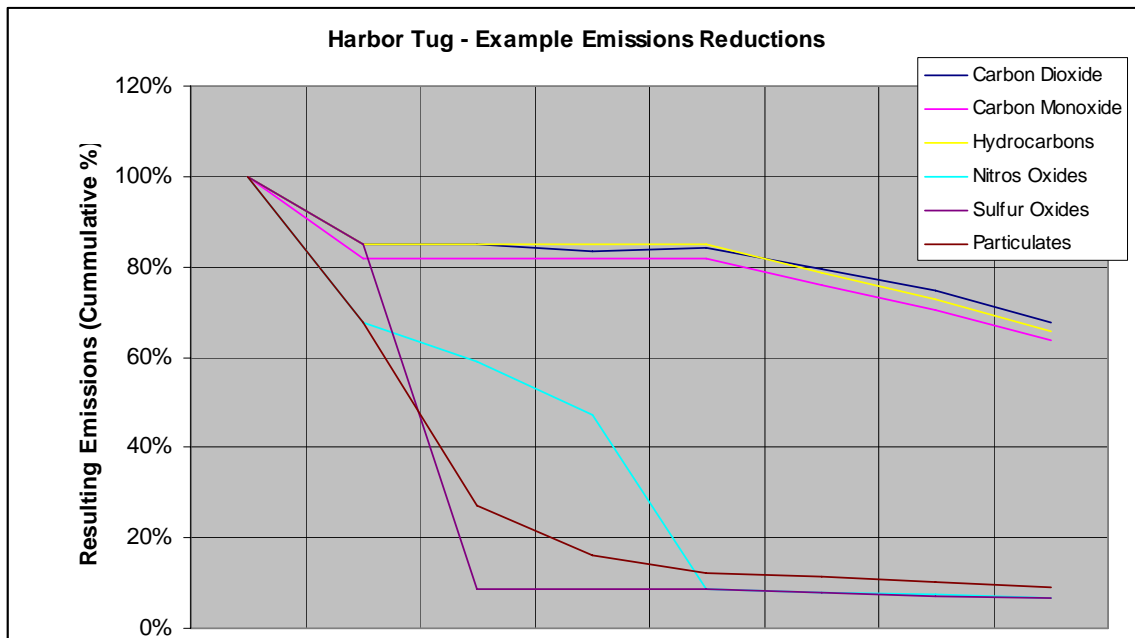
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MARINE VESSEL EMISSIONS, STRATEGIES FOR ABATEMENT

1. Executive Summary

After years of debate, the beginning of 2008 found broad industry recognition that marine vessel emissions have a significant impact on population health in coastal areas, and to a lesser extent global warming. Following these concerns, regulatory efforts (international, federal and local) have focused on use of low sulfur fuels in localized areas and standards for pollutants from engine exhaust gas streams. Technology-based solutions are maturing quickly, with many lessons learned available from new installations and retrofits on a wide range of vessel types and trades.

The Harbor Tug figure, below, illustrates how emissions abatement efforts extend to the ways in which a vessel is designed and operated. In this case, the harbor tug is designed with energy-efficient auxiliary consumers, a battery-hybrid propulsion system, low NO_x tuning of the engines, and a selective catalytic reduction unit. Additionally, the vessel decreases speed when transiting to various job sites, keeps a well-tuned machinery plant and clean hull, and plugs into shoreside power when at the dock.



Emissions Reductions	Emissions Reductions							
	Baseline	Vessel Design	Fuel	On-Engine	Off-Engine	Operations	Logistics	Infrastructure
Carbon Dioxide		15%		2%	-1%	6%	6%	10%
Carbon Monoxide		18%				8%	7%	10%
Hydrocarbons		15%				8%	7%	10%
Nitros Oxides		33%	13%	20%	82%	8%	6%	10%
Sulfur Oxides		15%	90%			6%	10%	10%
Particulates		33%	60%	40%	25%	8%	10%	10%

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The following summarizes the state of regulatory efforts through March 2008.

Harbor Craft Regulation. The enacted and proposed marine vessel regulations of the US Environmental Protection Agency (EPA) are aggressive and broad reaching. These regulations cover fuel quality, engine discharge standards, and eventually require the use of exhaust processing equipment.

- EPA proposed tier 3 and 4 regulations of category 1 and 2 marine engines are aggressive.
- EPA proposals do not apply new standards to existing vessels. However, California Air Resources Board proposed regulations identify an approach for applying the EPA emissions standards to the existing fleet. This approach is expected to retire many vessels, with others being re-powered and/or outfitted with advanced technology.

Ocean-Going Vessel Regulation. Given the nature of international trade and the conventions which govern it, the most effective means of impacting ocean-going vessel emissions is through the Marine Environmental Protection Committee (MEPC) at the International Maritime Organization (IMO). This is the body which is capable of amending Annex VI – Control of Air Pollution from Ships, of the Marine Pollution Convention (MARPOL).

- Annex VI recognizes certain environmentally sensitive areas as sulfur emissions control areas (SECAs). In these areas, use of relatively low sulfur fuel or scrubbing technology is required. These efforts have been focused on geographic areas that impact human health.
- INTERTANKO, an independent oil tanker association, has proposed to MEPC that low sulfur fuel be required not just in SECAs, but globally. These tank ship Owners and operators are opposed to installing sulfur scrubbing equipment on board their vessels or carrying multiple grades of low sulfur fuel to burn in different geographic areas. This “distillate only” approach would focus technology on efficiency and NOx reductions rather than SOx reductions, and broadly improve the operability of ships. However, there has been significant push-back on this initiative, mostly concerning refinery capacity.
- ***2009 Note: The IMO significantly changed Annex VI, and the U.S. Signed the Convention – Update to this Section Pending further Review.*

Carbon Dioxide Reduction Strategies. Most marine vessel emissions reduction efforts to date have focused on pollutants. This has resulted in less attention being paid to the significant reductions that can be achieved through design and logistics.

- Advanced fuel efficient vessel design methods have mostly been pursued in competitive market ocean-going cargo trades. However, other markets do not pursue these considerations and miss significant emissions reductions, either because there is an inadequate understanding of the savings or a lack of incentive. Up to a 30% reduction in all emissions, including carbon dioxide, can be realized through advanced design methods; e.g., hull and propeller design, energy efficient auxiliaries, waste heat capture, and hybrid battery power systems.
- Vessel speed reduction has enjoyed limited application in the reduction of local emissions. However, the global impact of a 20% reduction in average vessel speed would result in a greater than 30% reduction in all emissions, including carbon dioxide.

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Appendix A provides two summary tables. One captures the various regulatory requirements and proposals of the International Maritime Organization, U.S. Environmental Protection Agency, and California Air Resources Board. One matches various emissions reduction strategies with a vessel group, identifies potential emissions reductions, and reviews the feasibility of the approach.

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2. Introduction

There are opportunities to reduce emissions from maritime shipping in every aspect of the trade. From the moment that an expansion of service on a certain trade route is conceived, to the actions taken when such a vessel departs the harbor after a port call – there are opportunities to reduce emissions. This white paper attempts to provide an outline of these opportunities. As the authors are marine engineers and naval architects, the paper leans towards transportation study, ship design, and engine/system engineering solutions.

The first three sections of the paper provide background information on the state of the maritime shipping industry and a brief overview of marine fuels. The background provides the reader with the tools to understand the various enacted and proposed regulations, as well as the applicability of the technology.

- Maritime Shipping (Nature of Business and Environmental Focus)
- Vessel Grouping (As Emissions Sources)
- Marine Fuels (Introduction)

Regulatory Practices (Current and Proposed Efforts) stands alone. This section reviews regulations, conventions and guidelines – both in force and proposed. Although this section covers international, U.S. federal, and California regulations, there are many other local regulations in the U.S. and federal regulations world-wide that have not been captured. What is captured, however, is perhaps the most stringent “drill-down” in the world, which includes vessels that might call in California waters, or operate there as harbor craft, being subject to international, U.S. federal and California regulations and voluntary programs.

The next sections provide analysis on various emissions abatement technologies and approaches. Where possible, these sections refer back to previous parts of the paper. This is particularly valid when analyzing fuels as a means of emissions abatement. These sections are broad in scope, but not necessarily comprehensive. For example, selective catalytic converters, a topic of many studies and reports, are covered in only a few paragraphs.

- Vessel Design (Reducing Carbon Emissions Before Building)
- Marine Fuels (Emissions Source And Solution)
- Alternative Fuels (Emissions Source And Solution)
- Engine Based Approaches (Optimizing Engines)
- Off Engine Systems (Polishing Emissions, But Not Reducing Carbon Footprint)
- Vessel Operations (On Board Efforts After Vessel Is Built)
- Vessel Logistics (Smart Business, Low Emissions)
- Infrastructure Solutions (Shifting Emissions Off Vessels)

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One highlight of this paper is that each of the reviewed technologies and approaches are led with an analysis table. Each table reflects a collection of the reports, papers, regulations, and/or promotional materials reviewed for that strategy. The emissions reductions reported in these sources are totaled and averaged. In addition, Glosten has weighed in on a few key questions: What is the development status (commercially ready, prototype only, experimental)? Can this be readily implemented? How does it compare in terms of life-cycle cost? What vessel categories does this apply to?

Another highlight of the report is Appendix A, which contains large format tables which provide a visual summary of some very complex information.

- Marine Vessel Emissions Regulatory Summary, In-Force and Proposed
- Marine Vessel Emissions Abatement Strategies, Practicality and Effectiveness

Each topic covered can be explored in greater detail with further effort. One relevant example would be a review of the issues regarding the handling of collected sludge from exhaust gas scrubbers. A few of the topics that could be reviewed further are outlined in the last section of the report.

3. Maritime Shipping (Nature of Business and Environmental Focus)

This section provides an overview of maritime shipping. The report considers two separate fleet categories: Blue Water Shipping and all other marine vessels.

3.1 Blue Water Shipping

This report considers blue water shipping as those vessels which are engaged in international commerce and are over 400 gross tons, international admeasurement (GT). This distinction is made, as these are the vessels which are governed in large part by international treaties and conventions primarily negotiated at the International Maritime Organization (IMO), the maritime shipping arm of the United Nations. As such, the following sections provide an overview of this very broad category of shipping.

3.1.1 Blue Water Shipping - General

The 2007 *International Shipping and World Trade, Facts and Figures* report of the IMO provides a general description and outlook of the shipping sector of the maritime industry. The following excerpts provide a broad picture of the merchant shipping market.

We live in a global society which is supported by a global economy – and that economy simply could not function if it were not for ships and the shipping industry. Shipping is truly the lynchpin of the global economy: without shipping, intercontinental trade, the bulk transport of raw materials and the import/export of affordable food and manufactured goods would simply not be possible (International Shipping and World Trade; Facts and Figures 4).

It is generally accepted that more than 90 per cent of global trade is carried by sea. Throughout the last century the shipping industry has seen a general trend of increases in total trade volume (International Shipping and World Trade; Facts and Figures 5).

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As with all industrial sectors, however, shipping is not immune to occasional economic downturns – a notable fall in trade occurred, for example, during the worldwide economic recession of the early 1980s. However, although the growth of seaborne trade was tempered by the Asian financial crisis of the late 1990s, there has generally been healthy growth in maritime trade since 1993 (International Shipping and World Trade; Facts and Figures 5).

Ships are high value assets, with the larger of them costing over US \$100 million to build. They are also technically sophisticated: you are more likely to find one of today’s modern vessels being controlled by a single joystick and a mouse-ball in the arm of the helmsman’s seat than a horny-handed bosun grappling with a spoked wheel; the chief engineer will probably have clean hands and the calluses on his or her fingers will be from tapping a keyboard rather than wielding a spanner. The crew accommodation will be clean, light and airy with modern recreation facilities; the food will be good; and you may well find the first officer exchanging emails with his family at home via the satellite communication system.

International Shipping and World Trade; Facts and Figures 6

3.1.2 Blue Water Shipping – Fleet and Age

The IMO provides summary statistics of the size and age of the various fleets. These can be reviewed in detail annually in the *International Shipping and World Trade, Facts and Figures* report. The following table provides a basic overview of the numbers of vessels considered. This table underestimates the number of “blue water” vessels as it only considers vessels over 1,000 GT. Fleet average age is also summarized below.

Number of Vessels in Fleet, By Country of Controlling Interest (Over 1,000 GT)					
Interest	Qty	Interest	Qty	Interest	Qty
Japan	3,330	Denmark	781	Canada	340
China	3,184	Italy	739	France	309
Greece	3,084	Netherlands	739	Thailand	298
Germany	2,964	Hong Kong, China	689	Philippines	256
Russian Federation	2,203	Taiwan, China	574	Belgium	226
Norway	1,810	India	456	Cyprus	222
United States	1,766	Switzerland	370	Iran, Islamic Republic	184
Republic of Korea	1,041	United Arab Emirate	366	Brazil	151
Turkey	874	Malaysia	357	Saudi Arabia	150
United Kingdom	855	Viet Nam	352	Australia	85
Singapore	794	Spain	347	Kuwait	68
Indonesia	793	Sweden	346		
Existing Fleet Grand Total (Top 35 Countries)			31,103		
New Shipbuilding					
(Annual Avg, Last 7 yrs) 1702					
<i>Data Source: United Nations Conference on Trade and Development, Review of Maritime Transport, 2007</i>					

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World Fleet Age - Over 1,000 GT (2007)						
	0-4	5-9	10-14	15-19	20 years	Average
Type	years	years	years	years	and over	age
Bulk carriers	21.6	19.0	19.1	9.0	31.3	12.9
Containerships	34.7	25.7	18.6	8.0	13.0	9.1
General cargo	10.1	12.6	10.9	9.6	56.8	17.4
Oil tankers	30.3	25.0	16.4	14.6	13.6	10.0
Other types	19.6	14.4	10.7	9.1	46.3	15.1
All	25.1	21.0	16.7	10.9	26.2	12.0

Data Source: UN Conference on Trade and Development, Review of Maritime Transport, 2007

3.1.3 Blue Water Shipping – General Environmental Challenges

The importance and prominence of facing environmental challenges in maritime shipping was highlighted in 2007 when the IMO named *IMO Response to Current Environmental Challenges* as its theme for World Maritime Day. The following are excerpts from this address.

There is today, quite rightly, a growing concern for our environment and a genuine fear that, if we do not change our ways right now, the damage we will inflict on our planet will render it incapable of sustaining – for future generations – the modern, industrial economy that much of humankind has grown accustomed to over the better part of the past two centuries.

Mitropoulos 1

As marine and atmospheric pollution from land-based sources is reportedly reduced, so shipping, like every conspicuous user of energy and every conspicuous contributor to climate change and global warming, is under pressure, as never before, to adopt greener practices and to do even more to clean up its act. However, while there is no doubt that shipping, and IMO, still have more to do in this respect, one can also, equally, point to an impressive record of continued environmental awareness, concern, action, response and other relevant successes scored by the Organization, the maritime community and the shipping industry, over many year.

Mitropoulos 5

The wide-ranging MARPOL Convention, with its six Annexes, has been the bedrock of the world's regulatory framework for the prevention of pollution from ships for decades. It is the most important international Convention on preventing the pollution of the marine environment and the atmosphere by ships, whether from operational or accidental causes.

Mitropoulos 5

And so, to conclude: the huge volume of goods and products transported by sea makes shipping the premier facilitator of world trade and a direct contributor to global economic growth. Without shipping, there would be virtually no international commerce and, as a result, one half of the world would starve, while the other would freeze. Moreover, statistics reveal that shipping is extremely fuel-efficient and the least environmentally-damaging form of commercial transport and, set against land-based industry, it is a comparatively minor contributor, overall, to marine pollution from human activities. Therefore, both the economic and environmental costs of using any form of transport other than shipping, to move more than 90 per cent of global trade, would be unthinkable high.

Mitropoulos 21

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IMO Environmental Protection Measures Listed in Address (includes Annexes and Initiatives):

- Annex I – Prevention of Pollution by Oil
- Annex II – Prevention of Pollution by Noxious Liquid Substances
- Annex III – Prevention of Pollution by Harmful Substances in Packaged Form
- Annex IV – Prevention of Pollution by Sewage from Ships
- Annex V – Prevention of Pollution by Garbage from Ships
- Annex VI – Prevention of Air Pollution from Ships
- Marine Environmental Protection Committee (MEPC) Initiatives:
 - Reduction of Green House Gases from Ships
 - The International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969. It provides the right of a coastal State to take such measures on the high seas as may be necessary to prevent, mitigate, or eliminate danger to its coastline or related interests from pollution by oil or the threat thereof, following upon a maritime casualty. It entered into force in 1975 and has subsequently been amended on a number of occasions, principally to extend its coverage to substances other than oil.
 - International Convention for the Control and Management of Ships' Ballast Water and Sediments, adopted by IMO 2004. It will, among other things, require all ships to implement a Ballast Water Management Plan. All ships will have to carry a Ballast Water Record Book and will be required to carry out ballast water management procedures to a given standard.
 - International Convention on the Control of Harmful Anti-fouling Systems on Ships, adopted by IMO 2001.
 - 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, entered into force 2006.
 - Guidelines for Ships Operating in Arctic Ice-Covered Waters (23 December, 2002). The Maritime Safety Committee and the Marine Environment Protection Committee (MEPC) of the IMO have both formally recognized the need for “recommendatory provisions applicable to ships operating in Arctic ice-covered waters, additional to the mandatory and recommendatory provisions contained in existing IMO instruments.” In response, the IMO has created and approved the guidelines. These Guidelines “aim to promote the safety of navigation and to prevent pollution from ship operations in Arctic ice-covered waters.”

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3.1.4 Blue Water Shipping – Air Emissions Threat to the Environment

The following is an excerpt from the 2007 *IMO Response to Current Environmental Challenges*, which paints a general picture of the challenges of shipping air emissions to the environment, a comparison of shipping emissions to other transportation modes, and a call for reducing the impact of shipping on the environment.

Scientific evidence that the environment is increasingly damaged by greenhouse gas emissions is causing growing concern globally and the conclusion of recent research, that a significant share of ship emissions, occurring along coastlines, travels inland over much longer distances than previously realized, is serving to galvanize the maritime community into prompt action.

Disconcerting as the research findings are, it has to be acknowledged that there have already been significant improvements in engine and propulsion system efficiency, while improved hull design and the use of ships with larger cargo-carrying capacities have led to a reduction in emissions and an increase in fuel efficiency. While further research in this field is to be encouraged, data from the United Kingdom's Department for Transport shows that energy consumption of road transport by truck lies in the range 0.7 to 1.2 Mj/tonne-km. By comparison, the consumption of a 3,000 dwt coastal tanker at 14 knots is about 0.3 Mj/tonne-km and a medium size container ship (1,226 TEU) at 18.5 knots, about 0.12 Mj/tonne-km.

Mitropoulos 4

Now that there is widespread recognition that the greenhouse effects represent a real, present, clear and serious threat to the environment and to planet Earth as a whole, public opinion – stimulated by information about the depletion of the ozone layer, gas emissions and climate change – is impatient for action. The ball is clearly in the court of politicians, both in developed and developing countries, in established and emerging economies. In responding, sooner rather than later, they should feel encouraged by the recent review of Sir Nicholas Stern (the former World Bank Chief Economist), which suggested that the economic cost of action against global warming is far lower than the cost of inaction. In acting now – and, in the maritime field, through IMO, particularly as far as atmospheric pollution emanating from ships is concerned – they will also respond positively to the wishes of the 2000 Millennium Summit and the 2005 World Summit, giving, at the same time, effect to one of the Millennium Development Goals (calling for environmental sustainability), in the implementation of which the world community has quite rightly placed so much hope.

Mitropoulos 22

3.2 Other Marine Vessels

For the purposes of this report, all marine vessels which are not subject to IMO conventions are considered a single category. This is applicable as they are then subject to a patchwork of national or regional regulations. For example, a coastwise tug and barge operation in the State of California needs to comply with U.S. EPA requirements, as well as those measures imposed by California Air Resources Board (CARB), and any local level regulations imposed by various county air boards.

CARB provides an excellent summary of one fleet of “non-blue water” marine vessels:

The vessels that make up California's harbor craft population serve a variety of purposes and vary in size. Each category of harbor craft makes an important contribution to California's economy and well being – from fishing vessels that provide food to work boats that perform rescue missions at sea.

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CARB documents provide a break-down of the harbor craft emissions.

Table III-7: Estimated 2004 Statewide Harbor Craft Emissions

Vessel Category	2004 Pollutant Emissions, Tons/Day			
	PM	NOx	HC	CO
Commercial Fishing	0.8	17.4	1.3	4.8
Charter Fishing	0.6	12.7	0.9	3.3
Ferries/Excursion	0.9	21.0	1.4	5.6
Tugboat	0.6	15.3	1.0	3.8
Towboat	0.1	3.0	0.2	0.7
Crew and Supply	0.1	1.4	0.1	0.4
Pilot	<0.1	0.4	<0.1	0.1
Workboats	<0.1	0.5	<0.1	0.1
Other	0.1	1.5	0.1	0.4
Totals	3.3	73.2	5.0	19.2

(Proposed Regulation for Commercial Harbor Craft III-12)

Table III-1 provides CARB’s estimate of the numbers of the various types of harbor craft operating in California in 2004. These estimates are based on information gathered from multiple data sources. Those sources included the U.S. Coast Guard, the California Department of Fish and Game, the CARB Survey, and information submitted by the Port of Los Angeles. The CARB staff chose 2004 as the base year for the harbor craft inventory because the most complete data was available from the different sources for that year. As shown in Table III-1, CARB staff estimates that in 2004 there were approximately 4,200 harbor craft serving various industries. Staff estimates that the 2007 statewide harbor craft population is 3,750 vessels. The decline in vessel population is due to a decrease in commercial fishing vessels.

Table III-1: 2004 Statewide Population of Harbor Craft by Vessel Type

Vessel Type	Vessel Population ^A
Commercial Fishing	2,727
Charter Fishing	563
Ferries and Excursion	416
Tugboats	128
Towboats	35
Crew and Supply Boats	64
Pilot Boats	27
Work Boats	89
Other Vessels	136
Total	4,185

^A Statewide numbers of harbor craft have been estimated based on the 2004 baseline harbor craft emission inventory.

(Proposed Regulation for Commercial Harbor Craft III-1)

4. Vessel Grouping (Matching with Emissions Reduction Strategy)

Vessel groupings such as “blue water shipping” and “all other marine vessels” provide a means of “counting” all the ships, boats, and floating platforms in the world. Other efforts exist that consider counts by region, by a given trade, by vessel type, and designations by country of origin or controlling interest. Each of these designations serves its designed purpose. These designations also work well for estimating emissions from maritime vessels. However, these designations do not best support efforts to match emissions reduction strategies to various maritime vessels.

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This paper has developed a unique set of **vessel groups** in an effort to pair appropriate emissions strategies with broad ranges of marine vessels. Once strategies are paired with a vessel group, that strategy can be evaluated head-to-head with only those other strategies that are also applicable.

This grouping effort recognizes that there hundreds of unique vessel configurations. However in each of these configurations, the paper considers that only a few considerations will impact which emissions reduction strategies are applicable. These are:

- How tolerant is the vessel of weight and footprint? Is the vessel like a car carrier, which has significant space for the location of large equipment? Is the vessel like a harbor tug, where added weight can compromise stability and added volume will compromise maneuverability?
- What is the power plant size? Is the plant small like in a crew boat, where modified truck emissions technology might be applicable? Is the plant medium-sized like a supply boat, where modified locomotive technology might be applicable?
- What combination of regulatory regimes will the vessel engines fall under? Is it a large, slow-speed diesel classified by the EPA as “category 3” and by IMO based on its particular rotations per minute?
- What is the vessel duty cycle? Is it continuous like an ocean going containership, which during a long transit to its next port call has time for equipment to reach steady state? Is it intermittent like a short haul ferry, supply vessel, or escort tug, which rarely reaches a steady-state operation as its ability to quickly change speed, pull, or direction is critical to its operations?

It is next recognized that not all permutations of these criteria match a vessel. For example, the smallest power plant size will not be considered EPA category 3. A broad listing of vessel types was compared to these considerations. All were found to fall within eight unique combinations – vessel groups. The following figures identify these groups, and provide some examples of vessels within each of these.

VESSEL GROUP DEFINITION					
Group Number	Footprint & Weight Tolerance	Power Plant Size	EPA Category	IMO Rating	Duty Cycle
1	Large	Greater Than 10 MW	3	Slow	Continuous
2	Large	Greater Than 10 MW	3	Medium	Continuous
3	Large	Greater Than 10 MW	3	Medium	Intermittent
4	Large	1 MW to 10 MW	2	Medium	Intermittent
5	Small	1 MW to 10 MW	2	Medium	Continuous
6	Small	1 MW to 10 MW	2	Medium	Intermittent
7	Small	1 MW to 10 MW	2	High	Intermittent
8	Small	Less Than 1 MW	1	High	Intermittent

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VESSEL GROUP EXAMPLES			
Ocean Going Cargo Vessels	Group	Other Cargo Vessels	Group
Container	1	Heavy Lift	1
General Cargo	1	Lake Freighter	2
Dry Bulk	1	River Transport	6, 7
Crude Oil Tanker	1	Work/Service/Misc	Group
General Cargo		Oceangoing Science/Research	2
<i>General Cargo Liner</i>	1	Drill Ships	3
<i>Reefer (w/(out) Container)</i>	1	Offshore Platforms	3
<i>Roll-on/Roll-off (Various)</i>	1	Cable Layer	3
Chemical Tanker	1, 2	Ice Breakers	3
Petroleum Product Tanker	1, 2	Platform Supply	4
Natural Gas Carrier	1, 2	Anchor Handling Tug Supply	4
		Ocean Tug/Tow	5
Passenger		Coastal/Harbor Tug/Tow	7
Ferry (Long Haul)	1, 2	Fireboat	7
Cruise/Tour (Long Haul)	2	Construction/Crane	8
Ferry (Short Haul)	6, 7, 8	Near Shore Science/Research	6, 7, 8
Cruise/Tour (Short Haul)	6, 7, 8		
High Speed Ferry	6, 7, 8	Fishing	
Crew Transport	8	Ocean Going	5
		Processing	5
Military Vessels	DNA	Near Shore	8

5. Marine Fuels (Overview)

This paper utilizes fuel nomenclature which is used by Bunkerworld.com, a leading information source for the world trade and supply of fuel oils for ships. This approach simplifies bunkering into the four basic fuel choices which are most prevalent on the open market. A table is provided here with product name, simple description, and price on a given day.

Fuel Name			Rotterdam 2/22/08	
Industrial	ISO	Description	USD/MT	USD/BBL
IFO 380	RMG35	Viscosity 380 cSt 50°C, Residual w/ 3% Gas Oil Typical	\$447	\$72
IFO 180	RME25	Viscosity 180 cSt 50°C, Residual w/ 7% Gas Oil Typical	\$472	\$76
MDO	DMB	Marine Diesel Oil, Gas Oil w/ Limited Residual	\$813	\$144
MGO	DMA	Marine Gas Oil, Unblended	\$896	\$160

The fuels market is complex, with an International Standard for 17 different bunker products. These standards provide detailed maximum and minimum levels for many variables in the fuels. The details of the Fuel Specification within these maximums and minimums are negotiated between the supplier and the consumer. For example, the maximum level of sulfur for a given product could be negotiated – but certainly limited by what is available. The following tables provide the specifications of these international standards for various residual and distillate fuels.

Disclaimer: All information presented here is based on Glosten data as of March 2008, is not peer-reviewed, and should not be referenced by others.

INTERNATIONAL STANDARD ISO 8217:1996 (E)						
Petroleum Products - Fuels (class F) - Specifications for marine fuels						
Requirements for marine distillate fuels						
Characteristics	Test method	Limit	DMX	DMA	DMB	DMC
Appearance			Visual	Visual	-	-
Density at 15°C, kg/m ³ ⁽¹⁾	ISO 3675 or ISO 12185	min.	1	890	900	920
Viscosity at 40°C, mm ² /s ⁽²⁾	ISO 3104	min.	1.4	1.5	-	-
		max.	5.5	6	11	14
Flash point, °C	ISO 2719	min.	43	60	60	60
Pour Point (upper), °C ⁽³⁾	ISO 3016	max.	-	-6	0	0
Winter quality		max.	-	0	6	6
Summer quality						
Cloud Point, °C	ISO 3015	max.	-16 ⁽⁴⁾	-	-	-
Sulphur, % (m/m)	ISO 8754	max.	1	1.5	2	2
Cetane number	ISO 5165	min.	45	40	35	-
Carbon residue (micro), (10%b), % (m/m)	ISO 10370	max.	0.3	0.3	-	-
Carbon, residue (micro), % (m/m)	ISO 10370	max.	-	-	0.3	2.5
Ash, % (m/m)	ISO 6245	max.	0.01	0.01	0.01	0.05
Sediment, % (m/m)	ISO 3735	max.	-	-	0.07	-
Total existent sediment, % (m/m)	ISO 10307-1	max.	-	-	-	0.1
Water, % (V/V)	ISO 3733	max.	-	-	0.3	0.3
Vanadium, mg/kg	ISO 14597	max.	-	-	-	100
Aluminium plus silicon, mg/kg	ISO 10478	max.	-	-	-	25

INTERNATIONAL STANDARD ISO 8217:1996 (E)									
Petroleum Products - Fuels (Class F) - Specifications of marine fuels									
Requirements for marine residual fuels									
Designation(3) ISO - F -									
Characteristics	Test Method	Limit	RMA10	RMB10	RMC10	RMD15	RME25	RMF25	RMG35
Density at 15°C, kg/m ³	ISO 3675 or ISO 12185	max.	975	981	981	985	991	991	991
Kinematic viscosity	ISO 3104	max.	10	10	10	15	25	25	35
		at 100°C, mm ² /s	max.	50	50	50	100	225	225
at 50°C, mm ² /s									
Flash point, °C	ISO 2719	min.	60	60	60	60	60	60	60
Pour Point (upper) ⁽²⁾ °C	ISO 3016	max.	0	24	24	30	30	30	30
Winter quality		max.	6	24	24	30	30	30	30
Summer quality									
Carbon residue, % (m/m)	ISO 10370	max.	10	10	14	14	15	20	18
Ash, % (m/m)	ISO 6245	max.	0.1	0.1	0.1	0.1	0.1	0.15	0.15
Water, % (V/V)	ISO 3733	max.	0.5	0.5	0.5	0.8	1	1	1
Sulphur, % (m/m)	ISO 8754	max.	3.5	3.5	3.5	4	5	5	5
Vanadium, mg/kg	ISO14579	max.	150	150	300	350	200	500	300
Aluminium plus silicon, mg/kg	ISO 10478	max.	80	80	80	80	80	80	80
Total sediment, potential, % (m/m)	ISO 10307-2	max.	0.1	0.1	0.1	0.1	0.1	0.1	0.1

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INTERNATIONAL STANDARD ISO 8217:1996 (E)								
Petroleum Products - Fuels (Class F) - Specifications of marine fuels								
Requirements for marine residual fuels								
Designation(3) ISO - F -								
Characteristics	Test Method	Limit	RMH35	RMK35	RMH45	RMK45	RMH55	RMK55
Density at 15°C, kg/m ³	ISO 3675 or ISO 12185	max.	991	1010	991	1010	991	1010
Kinematic viscosity	ISO 3104	max.	35	35	45	45	55	55
at 100°C, mm ² /s		max.	390	390	585	585	810	810
at 50°C, mm ² /s								
Flash point, °C	ISO 2719	min.	60	60	60	60	60	60
Pour Point (upper) ⁽²⁾ °C	ISO 3016	max.	30	30	30	30	30	30
Winter quality		max.	30	30	30	30	30	30
Summer quality								
Carbon residue, % (m/m)	ISO 10370	max.	22	22	22	22	22	22
Ash, % (m/m)	ISO 6245	max.	0.2	0.2	0.2	0.2	0.2	0.2
Water, % (V/V)	ISO 3733	max.	1	1	1	1	1	1
Sulphur, % (m/m)	ISO 8754	max.	5	5	5	5	5	5
Vanadium, mg/kg	ISO14579	max.	600	600	600	600	600	600
Aluminium	ISO 10478	max.	80	80	80	80	80	80
plus silicon, mg/kg								
Total sediment, potential, % (m/m)	ISO 10307-2	max.	0.1	0.1	0.1	0.1	0.1	0.1

A broader explanation of marine fuels is provided by the EPA Fuel Assessment 2006. EPA provides interesting details about various fuel types, but is confusing as the terminology does not match industry practice. Specifically, it is not common to refer to the industrial products IFO380 and IFO180 as “marine diesel fuel.” Specifically, there is no cross-reference between DMB and the very common term “marine diesel oil.” The following excerpt is provided to further explain the various fuel types.

Marine fuels used in vessel bunkering are primarily comprised of heavy distillate and residual fuels. For this reason, the remainder of this subsection focuses on these two refinery production outputs (the complete refining process is discussed in more detail in Section 2.2). There are three major types of marine fuel: diesel, residual, and a combination of the two to create a fuel type known as “intermediate” fuel oil (IFO). A large number of marine fuel grades within these three types represent the broad spectrum of fuels available to the shipping industry for vessel bunkering. In this section, the various grades of marine fuel are introduced using the colloquial industry names to group the different fuels types. See Section 4 for a more specific breakdown of the product specifications of marine fuels.

Distillate and residual fuels are blended into various combinations to derive the different grades of marine fuel oil. Table 2.1 lists examples of the major marine fuel grades and their vernacular industry nomenclature. In terms of cost, distillates are more expensive than intermediates, and residual fuels are the cheapest marine fuel-oil option.

Table 2-1. Marine Fuel Types

Fuel Type	Fuel Grade	Colloquial Industry Name
Distillate	DMX, DMA, DMB, DMC	Gas Oil or Marine Gas Oil (MGO)
Intermediate	RME/F-25, RMG/H-35	Marine Diesel Fuel or Intermediate Fuel Oil (IFO180 and IFO380)
Residual	RMA- RMH, RMK, and RML	Fuel Oil or Residual Fuel Oil

Source: Adapted from EPA, 1999.

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Distillates and/or residual fuel oil stocks are blended with blending components or cutter stocks to achieve internationally-accepted product specifications provided by the 1987 (revised in 1996) international standard, ISO 8217, that defines the requirements for fuel grades for use in marine diesel engines. Marine fuel grades carry three letters: The first “D” or “R” specifies “distillate fuel” vs. “residual fuel”; the second “M” signifies “marine fuel” use; the third letter designates the individual grade. Distillate marine (DM) fuels have three grades from A to C. Residual marine (RM) fuels have fifteen grades depicted by letters A through H, K, and L. For example, RME -35 stands for “Residual Marine fuel E at a maximum viscosity (at 100 degrees C) of 35 centistokes” (EPA, 1999).

Marine Fuel Blending Stocks

As described in Section 2.2, “hydroskimming” type refineries produce straight run stocks used in marine fuel blending, including light diesel, heavy diesel, and straight run residue. More complex refineries derive similar blending stock components as the output from fluidized bed catalytic cracking (FCC) units, which include light and heavy diesel, as well as light cycle gas oil (LCO) and heavy cycle gas oil (HCO). HCO also comes from the residual output from visbreaker units. These blending stocks are mixed with existing product streams from a refinery, to manufacture a variety of marine fuel grades.

Marine Gas Oil (MGO)

Marine gas oil is the result of blending LCO with distillate oil to produce one of the highest marine fuel grades. MGO is more expensive because it is a lighter fraction and better quality fuel than diesel fuel. This type of fuel is produced at cracking refineries after vacuum distillate feedstock is put through a FCC catcracker. The catcracker produces FCC gasoline and LCO. MGO is a fuel best suited for faster moving engines (Spreutels and Vermeire, 2001).

Marine Distillate Oil (MDO)

Straight run marine gas oil and distillate type marine distillate oil (MDO) are manufactured by combining kerosene, light, and heavy gas-oil fractions. DMA and DMB are typically used in small- to medium-sized marine vessels. Distillate fuels or heavy (high and low sulfur) distillates, and light fuel oil represent the more expensive range of marine fuels as they are most closely related to diesel fuel used in other transportation sectors. DMC is heavier fuel oil, and may sometimes be referred to as an intermediate fuel oil because it can be blended with residual fuel. MDO is manufactured by blending DMC with 10- to 15-percent residual fuel (Spreutels and Vermeire, 2001). MDO is more expensive than the more common intermediate fuel types.

Intermediate Fuel Oil (IFO)

Residual marine fuel grade G (RMG-35) is one of the more common residual fuels used in transoceanic sea-going vessels. Also known as IFO380, this residual marine fuel is manufactured at the refinery and contains visbroken residue, HCO, and LCO (Spreutels and Vermeire, 2001). IFO380 typically has a high sulfur content of 5 percent. IFOs less than 380, such as IFO180, start with IFO380 and blend it with a cutterstock of marine diesel, gasoil, LCO, or some combination of the three. IFO180 has a lower viscosity and metals content, but maintains the same sulfur content as IFO380 (Global Trade and Fuels Assessment 2-2).

6. Regulatory Practices (Current and Proposed Efforts)

A summary of the marine vessel air emissions regulatory initiatives of the International Maritime Organization, U.S. Environmental Protection Agency, and State of California is provided in Appendix A. These initiatives include rules, regulations, and guidelines, some of which are in force and others which are voluntary or proposed. The status of proposed regulations is continually changing as additional information on fuel supplies, technology, and practices become available.

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These initiatives are overlapping in several manners. For example, a regulation covering medium-size engines will impact both coastal and ocean going vessels. The characteristics of these initiatives include:

- **Geographic-Based:** Designate a distance from shore or certain area where a different set of requirements must be met. For example, vessels operating in the North Sea must limit sulfur oxide emissions to below 6.0 grams per kilowatt-hour, or use fuel with sulfur content below 1.5%.
- **Vessel Trade:** Targets vessels based on their trade routes or home ports. For example, harbor craft in California must use fuel with sulfur content less 15 parts per million.
- **Fuel Particulars:** Bunkers must meet particular characteristics. For example, no bunkers may be sold anywhere in the world with a sulfur content more than 4.5%.
- **Performance Standard:** The end of pipe emissions must meet a particular standard. For example, marine engines sold in the United States since 2005 with a cylinder bore size less than 30 liters must control their carbon monoxide emissions to less than 5.0 grams per kilowatt-hour.

6.1 International Maritime Organization (IMO) Annex VI

The rules of IMO, MEPC, and Annex VI in international shipping are outlined in a previous section of this report. The details of the requirements of Annex VI are tabulated in Appendix A.

***2009 Note: The IMO significantly changed Annex VI, and the U.S. Signed the Convention – Update to this Section Pending further Review.*

Significant changes to Annex IV are to be accepted on 1 January 2010; the amendments shall enter into force on 1 July 2010.

6.2 Marine Environmental Protection Committee (MEPC)

MEPC is the working group of the IMO MARPOL Convention. Changes to the Convention must originate from MEPC. The 57th session of MEPC met from 31 March to 4 April 2008. The agenda included the working group for “prevention of air pollution from ships.” This meeting included review and debate of several key proposals. The proposals reviewed here, and in Appendix A, are those by INTERTANKO and EPA. The many additional proposals by other flag states have not been reviewed.

***2009 Note: The IMO significantly changed Annex VI, and the U.S. Signed the Convention – Update to this Section Pending further Review.*

6.3 INTERTANKO “Distillates Option” Proposal to MEPC 57

INTERTANKO, an organization representing independent tank ship owners, is promoting the “Distillates Option.” A thirteen page position paper presents justification for this option ranging from crew and vessel safety to environmental impacts.

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In response to the IMO's initiative to revise MARPOL Annex VI on air emissions from ships, INTERTANKO recommends that SOx, NOx and Particulate Matter (PM) emissions from ships can be further reduced by mandating the global use of Marine Diesel Oil (MDO) and including a specification for this fuel in the revised MARPOL Annex VI regulations. INTERTANKO further suggests that the specification of the mandated fuel should be a slightly modified specification for the ISO 8217 DMB grade, with an initial sulphur content of maximum 1.0% with a later reduction to 0.50% subject to product availability. This may be summarised as the Distillates Option.

Furthermore INTERTANKO recommends a mandatory global low sulphur cap on the fuel used by ships which removes the need of SECAs. This will ease implementation, bring global uniformity to the regulations, promote safety, efficiency and simplicity to ship operations, and bring a straight-forward element to law enforcement and monitoring.

Swift 1

Using ships as waste management plants is an obstacle to innovation that could achieve further reductions of air emissions from ships and further increases in ships' energy efficiency, including reduction of CO2 emissions.

Swift 2

The International Energy Agency (EIA) is an "energy policy advisor" to its 27 member countries, with the goals of "security, economic development and environmental protection." The United States, Canada, Japan, Republic of Korea, and much of Western Europe are members. The EIA has entered the debate, providing commentary on the potential impact of following such a "Distillate Option."

There are consequences, both economic and environmental, which need to be better understood.

Einemo 1

The deeper the cuts in sulphur content, the more energy that is expended in its removal. At some point, the environmental trade-off between low-sulphur and higher CO2 emissions becomes blurred.

Einemo 1

Moreover, using diesel as the solution to lower sulphur standards, would stress a refining system already struggling to meet current transportation needs

Einemo 2

6.4 EPA Proposals to MEPC 57

EPA has recognized that in order to be effective in reducing emissions from Ocean-Going Vessels (OGV) it must work within the confines of MEPC. In particular, this involves efforts to harmonize proposed EPA rules for Category 3 engines (those with cylinder displacements over 30 liters) with MARPOL Annex VI. The importance of this harmonization and the relationship between these organizations is summarized by the EPA.

Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL) addresses air pollution from ships. Annex VI was adopted by the Parties to MARPOL at a Diplomatic Conference on September 26, 1997, and it went into force May 20, 2005. As of July 31, 2007, the Annex has been ratified by 44 countries, representing 74.1 percent of the world's merchant shipping tonnage.⁶⁷

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Globally harmonized regulation of ship emissions is generally recognized to be the preferred approach for addressing air emissions from ocean-going vessels. It reduces costs for ship owners, since they would not be required to comply with a patchwork of different standards that could occur if each country was setting its own standards, and it can simplify environmental protection for port and coastal states.

The significance of international shipping to the United States can be illustrated by port entrance statistics. In 1999, according to U.S. Maritime Administration (MARAD) data, about 90 percent of annual entrances to U.S. ports were made by foreign-flagged vessels (75,700 total entrances; 67,500 entrances by foreign vessels; entrances are for vessels engaged in foreign trade and do not include Jones Act⁶⁸ vessels). At the same time, however, only a small portion of those vessels account for most of the visits. In 1999, of the 7,800 foreign vessels that visited U.S. ports, about 12 percent accounted for about 50 percent of total vessel entrances; about 30 percent accounted for about 75 percent of the vessel entrances.⁶⁹

The emission control program contained in Annex VI was the first step for the international control of air pollution from ships. However, as early as the 1997 conference, many countries “already recognized that the NOx emission limits established in Regulation 13 were very modest when compared with current technology developments.”⁷⁰ Consequently, a Conference Resolution was adopted at the 1997 conference that invited the Marine Environment Protection Committee (MEPC) to review the NOx emission limits at a minimum of five-year intervals after entry into force of the protocol and, if appropriate, amend the NOx limits to reflect more stringent controls.

The United States began advocating a review of the NOx emission limits in 1999.⁷¹ However, MEPC did not formally consider the issue until 2005, after the Annex went into effect. Negotiations for amendments to the Annex VI standards, including NOx and SOx emission limits, officially began in April 2006, with the most recent round of negotiations taking place in April 2007. The United States submitted a paper to that meeting (April 2007 Bulk Liquids and Gases Sub-Committee meeting, referred to as BLG-11) setting out an approach for new international engine and fuel standards. That approach forms the basis of the program outlined in this ANPRM.⁷² Discussions are expected to continue through Summer 2008 and are expected to conclude at the October 2008 MEPC meeting. We will continue to coordinate our national rule for Category 3 emission limits with our activities at IMO.

Johnson 30

Following many years of debate and discussion, EPA provided MEPC with a proposal in February 2008. The following table summarizes these proposals.

Summary of Key Elements of the Proposal
NOx standards for new build engines with a cylinder displacement greater than 30 liters: a) Tier II: 15-25% reduction effective in 2011; and b) Tier III: 80% reduction for engines on vessels applicable only in defined areas (x miles from shore) effective in 2016.
PM & SOx: Limits applicable to all vessels operating in defined areas [x miles from shore] effective in [2011]. Shipowners may choose to comply through the use of low-sulphur distillate fuel and/or the use of scrubbing technology.
NOx standard for existing engines: 20% reduction applicable to pre-2000 large-displacement engines with exceptions to be defined for certain engines where the reduction is impractical. Reduction to be met through in-cylinder changes and simplified certification procedures by [2012].

(Development of Standards for NOx, PM, and SOx 6)

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In the same proposal, EPA furthers the debate on significantly tightening fuel sulfur concentrations not just in limited SECAs, but world-wide.

In order to achieve meaningful long-term reductions in both PM and SOx from OGVs, two basic approaches have been discussed to date. One is a tightening of the sulphur limits applicable in existing SOx Emission Control Areas (SECAs); the second is a reduction in the global fuel sulphur standard. The first approach, as discussed at the first intersessional meeting of the BLG Working Group on Air Pollution in Oslo in November 2006, focuses on the sequential tightening of sulphur requirements in SECAs. The second approach, as described in the recent proposal by INTERTANKO (BLG-WGAP 1/2/5), would result in a long-term reduction in the global cap for fuel sulphur of nearly 90% (from 4.5% to 0.5%), and the elimination of residual fuel from the marine market. This approach would achieve substantial reductions in both SOx and PM on a global basis. The United States believes that the use of distillate fuel will provide significant public health and welfare benefits, and the proposal from INTERTANKO should be evaluated by the Sub-Committee.

Development of Standards for NOx, PM, and SOx 4

6.5 United States Environmental Protection Agency (EPA)

In recent years, EPA has adopted major new programs designed to reduce emissions from diesel engines. When fully phased in, these new programs for highway¹ and land-based nonroad² diesel engines will lead to the elimination of over 90 percent of harmful regulated pollutants from these sources.

Johnson 5

EPA implementation dates, applicability, and standards are tabulated in Appendix A.

The EPA program generally follows either engine size or an emission performance standard.

6.5.1 PM and SOx Standard

- Performance based standard for all vessels using either technology or low sulfur fuels,
- Option to meet standard using a prescribed maximum sulfur content in fuel.

6.5.2 Category 3 Diesel Engines (30 or more liters displacement per engine cylinder)

- Coordinated effort with the IMO MEPC (see above) reflecting the global nature of maritime trade implied with this size engine,
- NOx Standards:
 - Retrofitting existing vessels with “known in-cylinder technical modifications” to meet the MARPOL Annex VI NOx standard (Tier I),
 - Near term standards for newly built engines focusing on in-cylinder technologies to reduce NOx and PM (Tier II),
 - Long term standards for newly constructed vessels reflecting the use of selective catalytic reduction (SCR) (Tier III).

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6.5.3 Category 1 and 2 Diesel Engines (Less than 30 liters displacement per engine cylinder)

- Performance standards when existing engines are remanufactured,
- Near term standards for newly built engines focusing on in-cylinder technologies to reduce NOx and PM (Tier III),
- Long term standards for newly constructed vessels reflecting the “application of high-efficiency catalytic after-treatment technology enabled by the availability of ultra-low sulfur diesel (ULSD) fuel.” (Tier IV).

The following tables provide details on the various emissions standards in force or proposed by EPA for Category 1 and 2 engines. Tier 1 and 2 standards came into effect, as indicated in the tables. Tiers 3 and 4 are proposed to phase in as shown in the tables below. Tier 4 standards are only expected to be achievable only with use of exhaust after-engine treatment.

Table II-2: U.S. EPA Tier 1 Standards for Marine Diesel Engines Used in Harbor Craft

Category	Horsepower	Engine Speed	Effective Date	PM (g/bhp-hr) ^A	NOx (g/bhp-hr) ^A	NOx + HC (g/bhp-hr) ^A
Small	< 11	-	2000	0.75	-	7.8
	11 to < 25	-	2000	0.60	-	7.1
	25 to < 50	-	1999	0.60	-	7.1
1 and 2	50 to <5000	rpm = 2000	2004	-	7.3	-
		130 = rpm <2000	2004	-	33.57Xrpm _{0.2}	-
		rpm <130	2004	-	12.7	-

(40 CFR Part 94)

^A Converted standards from 40 CFR 94, which are expressed in grams per kilowatt-hour (g/kW-hr), to grams per brake horsepower-hour (g/bhp-hr), by the following: g/kW-hr X 0.746 = g/bhp-hr (Proposed Regulation for Commercial Harbor Craft II-3)

Table II-3: U.S. EPA Tier 2 Standards for Marine Diesel Engines Used in Harbor Craft

Category	Horsepower	Displacement (liters/cylinder)	Effective Date	PM (g/bhp-hr) ^A	NOx+ HC (g/bhp-hr) ^A
Small	< 11	-	2005	0.60	5.6
	11 to < 25	-	2005	0.60	5.6
	25 to < 50	-	2004	0.45	5.6
	50 to <100	< 0.9	2005	0.30	5.6
1	100 to <175	0.9 to < 1.2	2004	0.22	5.4
	175 to <750	1.2 to < 2.5	2004	0.15	5.4
	≥750 to <~2500	2.5 to < 5.0	2007	0.15	5.4
2	≥750 to <5,000	5.0 to < 15	2007	0.20	5.8

(40 CFR Part 94)

^A Converted standards from 40 CFR 94, which are expressed in g/kW-hr, to g/bhp-hr, by the following: g/kW-hr X 0.746 = g/bhp-hr

Disclaimer: All information presented here is based on Glosten data as of March 2008, is not peer-reviewed, and should not be referenced by others.

Table II-4: Proposed U.S. EPA Tier 3 Standards for Marine Diesel Engines Used in Harbor Craft

Category	Horsepower	Displacement (liters/cylinder)	Effective Date	PM (g/bhp-hr)	NOx + HC (g/bhp-hr)
1	< 25	<0.9	2009	0.30	5.6
	25 to <100	<0.9 ^A	2009	0.22	5.6
			2014	0.22 ^B	3.5 ^B
	100 to <4960	<0.9	2012	0.10	4.0
			2013	0.09	4.0
			2014	0.08 ^C	4.2
			2013	0.08 ^D	4.2
2012			0.08 ^D	4.3	
2	≤ 4960	7 to <15	2013	0.10	4.6

(EPA, 2007)

^A Engines less than 100 hp at or above 0.9 L/cyl. are subject to the corresponding 100-4960 hp standards

^B Option: 0.15 g/bhp-hr PM / 4.3 g/bhp-hr NOx in 2014

^C This standard drops to 0.07 g/bhp-hr in 2018 for engines <800hp

^D This standard level drops to 0.07 in 2018 for engines <800 hp

(Proposed Regulation for Commercial Harbor Craft II-4)

Table II-5: Proposed U.S. EPA Tier 4 Standards for Marine Diesel Engines Used in Harbor Craft

Category	Horsepower	Effective Date	PM (g/bhp-hr)	NOx (g/bhp-hr)
1 and 2	800 to <1877	2014	0.03	1.3
	1877 to 4960	2016 ^A	0.03	1.3

(EPA, 2007)

^A Optional compliance start dates are proposed within these model years

(Proposed Regulation for Commercial Harbor Craft II-5)

6.5.4 Marine Fuels Low Sulfur Requirements

The following figure summarizes the EPA's marine fuels low sulfur requirement. Note: This applies to all marine diesel fuel, but does not apply to the residual fuels typically used in propulsion machinery of large ocean going vessels.

Non-road Diesel Fuel Standards

Who	Covered Fuel	2006	2007	2008	2009	2010	2011	2012	2013	2014
Large Refiners & Importers	Non-road	500+ ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm
Large Refiners & Importers	Locomotive & Marine	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm
Small Refiners & Other Exceptions	Non-road, Locomotive & Marine	500+ ppm	500+ ppm	500+ ppm	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm

(Clean Diesel Fuel Alliance)

Disclaimer: All information presented here is based on Glosten data as of March 2008, is not peer-reviewed, and should not be referenced by others.

6.6 California Air Resources Board (CARB)

The California Air Resources Board (CARB), like the EPA, has regulations targeting OGVs and regulations targeting “harbor craft.” These regulations are tabulated in Appendix A. CARB goals are summarized as follows:

Staff projects that, by 2020, the proposed regulations, in conjunction with U.S. EPA cleaner marine new engine standards, use of low sulfur fuel in harbor craft, port clean air plans, engine replacement incentive programs, and a negative growth factor for California’s fishing fleet, would reduce in-use commercial harbor craft diesel PM emissions about 70 percent and NOx emissions about 60 percent relative to the 2004 baseline. These emission reductions will occur in areas along waterways and near ports where environmental justice concerns are especially prevalent, as well as further inland.

The proposed regulations would also reduce diesel PM and NOx emissions that contribute to exceedances throughout the State of ambient air quality standards for both PM2.5 and ozone. These reductions will assist California in its goal of achieving state and federal air quality standards.

Cackette 6

The OGV regulations include:

- The State of California Ocean-Going Vessel Auxiliary Diesel Engine Regulation: This requires the use of marine gas oil or marine diesel oil (ISO 8217 MDA and MDB respectively) with a low sulfur content of 1.5% and 0.5% by weight, respectively. This regulation, although briefly challenged in court, went into affect in January 2007. In 2010, MGO will be required for use in auxiliary engines with a maximum sulfur content of 0.1%.
- A similar regulation for main engines and boilers is proposed. This would either phase from 1.5%/0.5% sulfur MGO/MDO in 2009 and 0.1% MGO in 2012, or require a single step to 0.1% MGO in 2010.

Harbor craft regulations follow. CARB considers:

In general, commercial harbor craft include a variety of vessel types such as ferries, excursion vessels, tugboats, oceangoing tugboats, tow boats, crew vessels, work boats, fishing boats, barges, and others. Industries that use these vessels, such as those providing ferry services, offshore platform suppliers, commercial fishing, touring and excursion services, and many others would be subject to these regulations.

Cackette 8

- Newly acquired vessels and engines must meet current EPA requirements.
- In-use vessels and engines must meet current EPA requirements on a time-phased schedule.
- All harbor craft must use “CARB Diesel”, which is the same on on-road diesel with 15 ppm sulfur content.

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7. Leveraging Opportunities (Stacking the Deck to Minimize Emissions)

Significant emissions reductions can be gained when several approaches for a given vessel are effectively combined or stacked. The below table provides a rough listing of various approaches that could be stacked for a harbor tug. The use reductions reflect that some approaches may not be applicable at all times. For example, while shoreside electrification might remove 100% of vessel emissions it is only plugged when a tug is at the dock, and at very light loads compared to transit or pushing modes.

Stacking Emissions Reduction Strategies - Harbor Tug Example		
Approach	Opportunity	Use Reduction
Vessel Design	Energy Efficient Auxiliary Systems	
	Battery Hybrid Propulsion/Aux	
Fuel	15 ppm Sulfur Distillate	
On Engine	NOx Tuned Engine	
Off Engine	SCR Exhaust Scrubbing	
Operations	Hull Maintenance	0.2 Vessel Transits are Limited
	Engine Maintenance	
	Propulsion Efficiency Point	
Logistics	Vessel Speed Reduction	0.2 Vessel Transits are Limited
Infrastructure	Shoreside Electrification	0.1 Vessel Load at Dock is Limited

Note: This harbor tug example is an aggressive combination of design, technology and operational efforts. It is noted by the “use reductions” that the effectiveness of a given opportunity must be reduced by the actual usage factor of the vessel in that mode of operation.

INDIVIDUAL Emissions Reductions - Harbor Tug Example								
Emission	Baseline	Vessel Design	Fuel	On-Engine	Off-Engine	Operations	Logistics	Infrastructure
Carbon Dioxide		24%		2%	-1%	6%	6%	10%
Carbon Monoxide		29%				8%	7%	10%
Hydrocarbons		24%				8%	7%	10%
Nitros Oxides		36%	13%	26%	82%	8%	6%	10%
Sulfur Oxides		24%	96%			6%	10%	10%
Particulates		36%	60%	40%	25%	8%	10%	10%
CUMMULATIVE Emissions Reductions - Harbor Tug Example								
Emission	Baseline	Vessel Design	Fuel	On-Engine	Off-Engine	Operations	Logistics	Infrastructure
Carbon Dioxide	100%	77%	77%	75%	76%	72%	67%	61%
Carbon Monoxide	100%	72%	72%	72%	72%	66%	61%	55%
Hydrocarbons	100%	77%	77%	77%	77%	71%	66%	59%
Nitros Oxides	100%	64%	56%	42%	7%	7%	7%	6%
Sulfur Oxides	100%	77%	3%	3%	3%	3%	2%	2%
Particulates	100%	64%	26%	15%	12%	11%	10%	9%

Note: This chart factors the individual emissions reductions with the “use factors” in order to determine a cumulative reduction in emissions. This is stacking the deck. For example particulate emissions are driven down by a combination of approaches, none of which are more than 60% effective. Yet used together, the cumulative reduction is over 90% effective.

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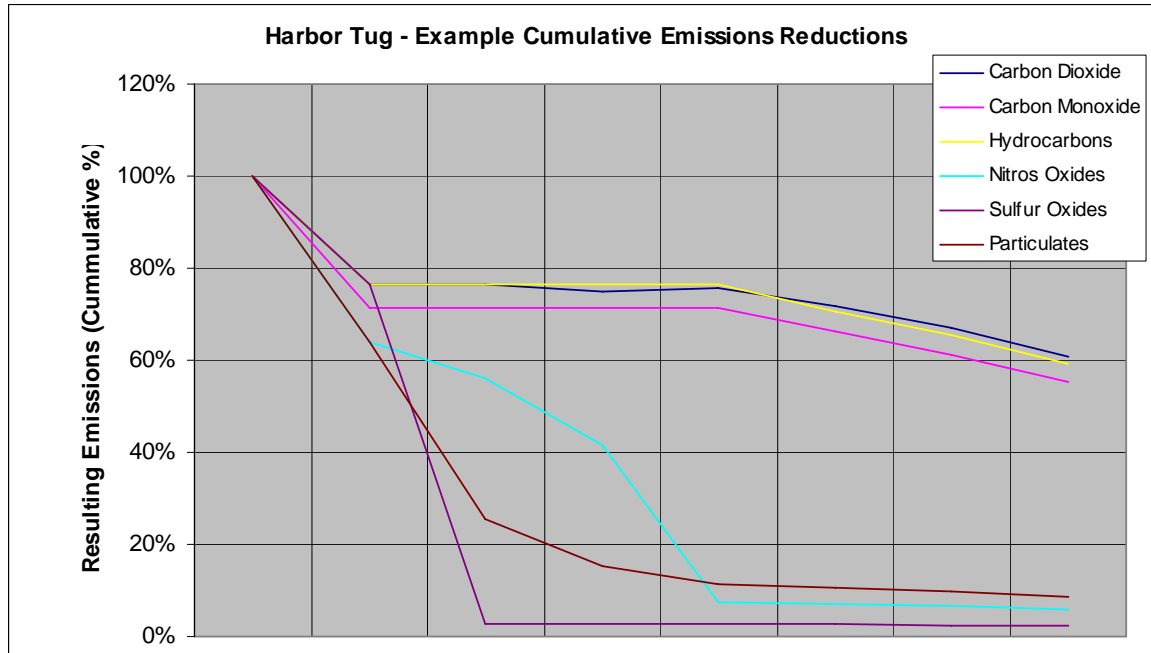


Figure (repeated from Executive Summary) provides graphical representation of applying emissions reductions in multiple steps.

The next sections provide analysis on various emissions abatement technologies and approaches. Where possible, these sections refer back to previous parts of the report. This is particularly valid when analyzing fuels as a means of emissions abatement. These sections are broad in scope, but not necessarily comprehensive. For example, selective catalytic converters, a topic of many studies and reports, are covered in only a few paragraphs.

Each opportunity was analyzed in two manners: Available literature and supplier inquiries were made to gain estimates of the emission reductions expected or advertised; only information that appeared to be valid was considered. Next, a Glosten review of each technology was conducted to (a) determine the feasibility and (b) fill in any gaps in emissions reductions with information available from Glosten past projects or by measured best engineering judgment. Glosten also attempted to match the approach with the previously identified vessel groups and various fuel sulfur contents. The below figure is one example that captures many of these elements. Appendix A provides a summary table.

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Off Engine Systems				Seawater Scrubbing					
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)									
Emissions Reduction				Implementation		Mixed		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development		Prototype		One	Yes
Carbon Dioxide		-1%		Lifecycle Cost		Moderate		Two	Yes
Carbon Monoxide				Fuel Match				Three	Mixed
Hydrocarbons				2.7%	Yes			Four	Mixed
Nitrogen Oxides	3%	4%	5%	1.5%	Mixed			Five	Yes
Sulfur Oxides		95%		0.5%	No			Six	Mixed
Particulates		76%		0.1%	No			Seven	Mixed
				15 ppm	No			Eight	Mixed

Glosten Associates Analysis (Items Not Analyzed Left Blank)									
Emissions Reduction				Implementation		Mixed		Vessel Group	
	<i>Low</i>	Avg	<i>High</i>	Development		Prototype		One	Yes
Carbon Dioxide		-1%		Lifecycle Cost		Moderate		Two	Yes
Carbon Monoxide				Fuel Match				Three	Mixed
Hydrocarbons				2.7%	Yes			Four	Mixed
Nitrogen Oxides				1.5%	Mixed			Five	Yes
Sulfur Oxides				0.5%	No			Six	Mixed
Particulates				0.1%	No			Seven	Mixed
Notes:				15 ppm	No			Eight	Mixed
CO2 estimates assumes 100 HP seawater pump for 10,000 HP propulsion plant, i.e. 1%. Although gaining widespread installation, is still really in prototype phase.									

Reference: Johnson, Control of Emissions, EPA, 2007									
Emissions Reduction				Implementation		Mixed		Vessel Group	
	<i>Low</i>	Avg	<i>High</i>	Development		Prototype		One	Yes
Carbon Dioxide				Lifecycle Cost				Two	
Carbon Monoxide				Fuel Match				Three	
Hydrocarbons				2.7%				Four	
Nitros Oxides				1.5%				Five	
Sulfur Oxides		95%		0.5%				Six	
Particulates		99%		0.1%				Seven	
Notes:				15 ppm				Eight	

Note: This seawater scrubbing example shows (a) a summary that averages the emissions reductions from reference and Glosten estimates and repeats the Glosten feasibility review, (b) an example Glosten review that includes an emissions estimate for CO2 increase from running a scrubber pump, (c) only one of multiple reference sources; i.e., the seawater scrubber efficiency data included three reference sources. Emission reduction ranges are provided given the great number of variables for each opportunity. Effort has been made to see that the summary mean (an average of the averages) provides a reasonable general estimate.

8. Vessel Design (Reducing Carbon Emissions before Building)

A very effective means of improving overall emission is by optimizing the design of the vessel before it is ever built. Methods range from hull and propeller optimization to power plant design and heat recovery, thus increasing the overall efficiency of the vessel. These all have the potential to increase the fuel economy, lower the operating costs, and lower all emissions due to less fuel being burned. Design optimization must take place before the vessel is built and, therefore, has very limited potential for retrofit, short of a major vessel modification. There is also an up-front increase in capital expenditure, since additional design effort is required. However, any optimization that will increase the fuel efficiency of the vessel will pay for itself over the life of the

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vessel by reducing operating cost. Design improvement is one of the most effective means of reducing CO2 emissions without changing fuels.

8.1 Hull/Propeller Optimization

Vessel Design Hull & Propeller Optimization									
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)									
Emissions Reduction				Implementation			Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Easy</i>		<i>Commercial</i>	<i>One</i>	<i>Yes</i>
				Lifecycle Cost	<i>Low</i>			<i>Two</i>	<i>Yes</i>
Carbon Dioxide	5%	13%	20%	Fuel Match				<i>Three</i>	<i>Mixed</i>
Carbon Monoxide	5%	13%	20%	2.7%	Yes			<i>Four</i>	<i>Mixed</i>
Hydrocarbons	5%	13%	20%	1.5%	Yes			<i>Five</i>	<i>Yes</i>
Nitrogen Oxides	5%	13%	20%	0.5%	Yes			<i>Six</i>	<i>Mixed</i>
Sulfur Oxides	5%	13%	20%	0.1%	Yes			<i>Seven</i>	<i>Mixed</i>
Particulates	5%	13%	20%	15 ppm	Yes			<i>Eight</i>	<i>Mixed</i>

The optimization of the hull form and the propeller shape, as well as the placement of the propeller, has the potential to provide dramatic reductions in fuel consumption under the right operating conditions. In applications where vessels have long runs at high power levels, the effect will be most pronounced. This is a very effective technique for large ocean going or coastal transport vessels. Vessels with intermittent operations and short runs between stopping will see less benefit.

8.2 Energy Efficient Auxiliary Systems

Vessel Design Energy Efficient Aux Systems									
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)									
Emissions Reduction				Implementation			Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Mixed</i>		<i>Commercial</i>	<i>One</i>	<i>Yes</i>
				Lifecycle Cost	<i>Moderate</i>			<i>Two</i>	<i>Yes</i>
Carbon Dioxide	1%	4%	6%	Fuel Match				<i>Three</i>	<i>Yes</i>
Carbon Monoxide	1%	4%	6%	2.7%	Yes			<i>Four</i>	<i>Yes</i>
Hydrocarbons	1%	4%	6%	1.5%	Yes			<i>Five</i>	<i>Yes</i>
Nitrogen Oxides	1%	4%	6%	0.5%	Yes			<i>Six</i>	<i>Yes</i>
Sulfur Oxides	1%	4%	6%	0.1%	Yes			<i>Seven</i>	<i>Mixed</i>
Particulates	1%	4%	6%	15 ppm	Yes			<i>Eight</i>	<i>Mixed</i>

The basic concept is the same as installing compact florescent light bulbs and an energy star rated dishwasher in a household. Marine vessels are traditionally not designed with energy efficient auxiliary systems. Areas for savings range from inefficient lights which are always left on, axial fans which run at high loads because they are designed for the hottest day of the year, cooling pumps which are oversized, non-efficient electric motors. Advances in energy efficiency in shore side applications, reliable low-cost variable frequency motors for example, are making their way onto marine vessels. The opportunity is greatest for large ocean going vessels, but even harbor craft can benefit. The savings are scaled down in relation to the relatively small auxiliary consumption of power relative to propulsion demands.

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8.3 Engine Heat Recovery

Vessel Design				Engine Heat Recovery					
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)									
Emissions Reduction				Implementation		Mixed		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	Commercial	One	Yes		
Carbon Dioxide	3%	11%	15%	Lifecycle Cost		Mixed	Two	Yes	
Carbon Monoxide	3%	11%	15%	Fuel Match			Three	Yes	
Hydrocarbons	3%	11%	15%	2.7%	Yes		Four	Yes	
Nitrogen Oxides	3%	11%	15%	1.5%	Yes		Five	Mixed	
Sulfur Oxides	3%	11%	15%	0.5%	Yes		Six	Mixed	
Particulates	3%	11%	15%	0.1%	Yes		Seven	Mixed	
				15 ppm	Yes	Eight	Mixed		

Heat Recovery is a commonly used technology within the marine industry. Typical for very large ocean going vessels is the use of exhaust stack boilers for the production of ship service steam. This saves the vessel fuel that would otherwise be used and reduces both pollution and operating costs. Since these types of vessels operate at a steady state for long periods of time, it is a predictable source of energy and easily exploited. Exhaust stack boilers have been used for many years and are commercially available. They do require complete integration with the vessels steam system, so upfront design effort is required.

Another source of waste heat for potential use on ships is jacket water. The engine jacket water is run through a water to water plate heat exchanger. The secondary loop can be used for any heating requirements that are appropriate for the temperature. A good use of jacket water heat is heat accommodations for the passengers or crew. A supplemental heater will ensure there is always a source of heat even if the engine is turned off.

Using waste heat to produce chilled water is possible using technologies such as absorption chillers. These are commercially proven technologies that use the energy of the waste heat for the compression of the refrigerant in the conventional vapor compression chiller cycle. These have a proven track record in the industrial sector and are increasingly popular due to the potential energy savings. Service steam can be used as a heat source to drive the vapor compression cycle. Therefore, waste heat can potentially supply all of the heating and cooling needs of a vessel, presuming space is available and the vessel operating profile is steady enough to make the capital investment pay off.

There is still significant potential for heat recovery technology to make inroads to the marine industry in the appropriate application. One potential issue is that after the exhaust gasses have been cooled from passing through the waste heat boiler, there may be insufficient pressure and temperature available to use a catalytic after treatment system. It is unclear how to evaluate the environmental trade-offs between increased overall efficiency and decreased stack emissions.

The use of waste heat can also be used to generate electricity on board a vessel. This has been done for some time on large ocean going vessels through the use of steam turbines. The waste heat boiler generates steam and this is run through a steam turbine generator. The generator can be used to supplement the vessels auxiliary power load when sufficient steam is available. This can increase the overall efficiency of the vessel by up to 6%. For example, if a slow speed diesel engine is converting 50% of the available fuel energy into useful mechanical energy, by adding a waste heat boiler, the efficiency of the overall system can be increased to 56%. There is still an opportunity to recover additional heat for vessel heating needs.

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There are other, more exotic methods of waste heat recovery. For example, there are some advanced refrigerants that have been used to capture mechanical energy from very low grade waste heat. United Technologies Corporation has a product that uses the Organic Rankine Cycle to generate electricity from waste heat. The refrigerant is boiled by a waste heat source and when passed through a turbine-generator it produces electricity. The system has limited installations but has very high potential for energy savings under the right circumstances.

The above technology examples are best suited for vessels with fewer space constraints and constant operating loads. This is not to say that waste heat cannot be used in other vessel types, but the maximum benefit will be realized under the more idealized conditions.

8.4 Battery Hybrid Power Plant

Vessel Design Battery Hybrid Power Plant								
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Mixed Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	Prototype	One	No	
Carbon Dioxide	10%	20%	30%	Lifecycle Cost		Mixed	Two	No
Carbon Monoxide	10%	25%	40%	Fuel Match			Three	Yes
Hydrocarbons	10%	20%	30%	2.7%	Yes		Four	Yes
Nitrogen Oxides	10%	33%	40%	1.5%	Yes		Five	Mixed
Sulfur Oxides	10%	20%	30%	0.5%	Yes		Six	Yes
Particulates	10%	33%	40%	0.1%	Yes		Seven	Yes
				15 ppm	Yes		Eight	Mixed

For certain vessel types the power demand can be intermittent, which requires the diesel engines to change loads frequently. Diesel engines operate most efficiently and produce fewer pollutants at high engine loads and constant conditions. By adding a means of storing and absorbing energy (batteries) for short periods of time it is possible to reduce the irregularity of the engine operating cycle. In theory this allows the engine to operate more optimally and use less fuel. The technology is ideally suited to applications with intermittent loads. While new, it is proven and commercially available in cars and busses.

Recently there have been several high profile applications of battery hybrid technology in marine vessels. There is insufficient data to accurately predict what the fuel savings would be, but in the case of a recently designed tug boat, the design estimates emissions reductions of 44% and reduced operating costs. The technology could have potential in the auxiliary power generation sector of the marine industry by allowing generator sets to operate at a more optimum efficiency.

Drawbacks of this technology are that it is experimental and potentially expensive. It is limited to certain vessel types that have intermittent load profiles and requires the use of electric motors. It is ideal for diesel electric vessels, but it is possible to augment conventionally propelled vessels with shaft motor/generators to capture and use energy from the batteries. The battery technology is improving rapidly, but it is still limited in durability and the batteries can wear out after only a few years if the system is abused. The batteries themselves are very expensive and are typically very heavy. Depending on the vessel type, this may or may not be a driving issue.

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8.5 Advanced Hull Coatings

Vessel Design								Advanced Hull Coatings			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)											
Emissions Reduction				Implementation				Easy			
	<i>Low</i>	Mean	<i>High</i>	Development		Commercial		Vessel Group		One	Yes
Carbon Dioxide	1%	2%	3%	Lifecycle Cost		Moderate				Two	Yes
Carbon Monoxide	1%	2%	3%	Fuel Match						Three	Mixed
Hydrocarbons	1%	2%	3%	2.7%	Yes					Four	Mixed
Nitrogen Oxides	1%	2%	3%	1.5%	Yes					Five	Yes
Sulfur Oxides	1%	2%	3%	0.5%	Yes					Six	Mixed
Particulates	1%	2%	3%	0.1%	Yes					Seven	Mixed
				15 ppm	Yes					Eight	Mixed

The material used to coat the hull of a ship below the waterline serves several purposes. The primary purpose is to prevent corrosion of the steel hull. Another purpose is to inhibit the growth of marine organisms on the exterior of the hull (anti-fouling). Marine organisms such as barnacles and mussels can attach themselves to the hull and create drag which reduces the fuel efficiency of the vessel. Historically, tributyltin (TBT) was put in marine paints to inhibit the growth of organisms on the ship's hull. While effective, TBT is also damaging to the marine environment. The use of TBT has now been banned by many countries and IMO. Many suppliers have agreed to stop selling TBT containing antifouling coatings. However, the use of biocides to inhibit hull fouling is only one strategy.

Another strategy is the foul-release hull coating. Using advanced materials, modern foul-release coatings are designed to prevent organisms from getting a good hold on the hull. When the ship is sitting still the organisms can attach themselves to the hull of a ship, but when the ship gets underway the hydrodynamic forces strip the growth away. In this sense, the hulls are 'self cleaning' and do not poison the organism.

The benefits of a clean hull are reduced drag and fuel savings. Due to the chemical nature of the newer hull coatings, they are actually more slippery than conventional paint and can reduce baseline friction. While this may seem like a minor improvement, this can add up to significant reductions in fuel use and emissions over the life of a large ocean-going vessel.

9. **Low Sulfur Fuels (Emissions Source and Solution)**

Low Sulfur Fuels								Reduce from 2.7% to 0.1% Sulfur			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)											
Emissions Reduction				Implementation				Easy			
	<i>Low</i>	Mean	<i>High</i>	Development		Commercial		Vessel Group		One	Yes
Carbon Dioxide				Lifecycle Cost		High				Two	Yes
Carbon Monoxide				Fuel Match						Three	Yes
Hydrocarbons				2.7%	NA					Four	Yes
Nitrogen Oxides	10%	13%	15%	1.5%	NA					Five	Yes
Sulfur Oxides		96%		0.5%	NA					Six	Yes
Particulates	19%	60%	70%	0.1%	NA					Seven	Yes
				15 ppm	NA					Eight	Yes

Previous sections of this report provide an overview of marine fuels, as well as the basics of the arguments for moving towards the INTERTANKO "Distillated Option." This section provides a

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basic background for evaluating the effectiveness of low sulfur fuels and distillate fuels as a marine emissions abatement strategy.

The majority of the air emissions from marine vessels are due to the nature of the fuels burned in the diesel engines, boilers and incinerators. Marine fuel impacts on exhaust emissions include:

- The world average sulfur content of IFO 380 and IFO 180 is 2.7% by weight. This sulfur is the direct source of sulfur oxide emissions.
- The high ash content, in addition to metals and other contaminants, in IFO 380 and IFO 180 is estimated to contribute 80% of the particulate matter emissions when compared to MDO.
- Changing from high sulfur to low sulfur fuel reduces nitrogen oxides emissions, estimated at 13% when switching from 2.7% to 0.5% sulfur.

Moving to low sulfur fuels and to distillate fuels is an effective manner of reducing emissions from marine vessels at the source. In addition, using low sulfur distillate fuels relieve on-engine and after engine technology to advance towards fine polishing of emissions, rather than gross recovery of high sulfur, particulate and NOx emissions.

10. Alternative Fuels (Emissions Source and Solution)

Burning cleaner fuels can be an effective way of reducing the emissions from marine vessels. However, many alternative fuels also require an alternative means of conversion. They may require anything from slight engine or fuel system modifications to an entirely new prime mover.

10.1 Natural Gas Combustion

Alternative Fuels				Natural Gas Combustion			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	Low	Mean	High	Development	Mixed Commercial	One	No
Carbon Dioxide	15%	25%	34%	Lifecycle Cost	Moderate	Two	Yes
Carbon Monoxide	-60%	-13%	34%	Fuel Match		Three	Yes
Hydrocarbons						2.7%	NA
Nitrogen Oxides	78%	89%	97%	1.5%	NA	Five	Yes
Sulfur Oxides		99%		0.5%	NA	Six	Yes
Particulates		50%	95%	0.1%	NA	Seven	Mixed
				15 ppm	NA	Eight	Mixed

Natural gas is a commonly used 'clean fuel' for off and on road settings. Typically it is stored for vehicle use as Compressed Natural Gas (CNG) in pressurized cylinders. Natural gas is primarily composed of methane, CH₄, with other impurities making up a small fraction. Typically it is combusted in Spark-Ignited (SI) engines, similar to gasoline engines.

In the marine sector, natural gas has been combusted on board large Liquefied Natural Gas (LNG) carriers as a way to dispose of the boil off from the cryogenic storage containers. In recent years LNG has been used as a fuel on board passenger ferries and supply vessels in Norway. There are at least two manufacturers of marine-approved gas engines. Typically, the only way to combust natural gas is with a spark ignited engine. However, there are manufacturers of diesel engines that

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are able to burn natural gas by injecting a small amount (~1%) of diesel pilot fuel into the cylinder to provide the ‘spark’. The advantage of this method is the ability to switch from diesel to natural gas on the fly.

Natural gas engines emit lower levels of NO_x, CO, PM, and emit nearly zero SO_x. Gas engines also emit less CO₂, but because the fuel is less energy rich, it requires a larger displacement engine to achieve the same amount of work as a diesel engine. Therefore, it is not clear if there is a net CO₂ benefit to the use of natural gas.

The practice of using natural gas on a marine vessel is complex. The largest challenge is that the fuel storage and handling system must be designed to handle the cryogenic temperatures (-164°C). The gas is typically stored under low pressure, but does require a certified pressure vessel. The overall storage density of the LNG is much less efficient than the storage of diesel due to the insulation and cylindrical-shaped tanks. This means that fitting the tank onboard becomes a space challenge since structural tanks cannot be used. There are also significant explosion risks, and many redundant safety systems are required to compensate. The gas engines available today are best suited for either electric generation or constant speed with a controllable pitch propeller. Using electric propulsion does have many advantages but also has weight and cost penalties.

10.2 Biodiesels

Alternative Fuels				Biodiesel					
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)									
Emissions Reduction				Implementation		Easy		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development		Commercial		One	Yes
Carbon Dioxide				Lifecycle Cost		Low		Two	Yes
Carbon Monoxide	12%	22%	32%	Fuel Match				Three	Yes
Hydrocarbons		20%	40%	2.7%	Yes			Four	Yes
Nitrogen Oxides	-11%	-7%	0%	1.5%	Yes			Five	Yes
Sulfur Oxides				0.5%	Yes			Six	Yes
Particulates	10%	18%	25%	0.1%	Yes			Seven	Yes
				15 ppm	Yes			Eight	Yes

Biodiesel is an increasingly popular fuel for both marine and shoreside use. Mixed results have been observed in trials of biodiesel use in marine vessels. Biodiesel is a fairly general term that can be used to describe pure biodiesel, or blends of biodiesel with conventional diesel. Though it may be derived from a variety of sources, commercial biodiesel is most commonly derived from either soybeans or rapeseed (canola). The vegetable oil is processed via transesterification into biodiesel. While there is some controversy over the production of biodiesel, proponents claim that it reduces the amount of CO₂ when considering lifecycle energy costs. Standards for the production of biodiesel have evolved. The most common international standard is EN 14214. U.S. standards are governed by ASTM D 6751, which shares similarities to the international standard.

Commercially, biodiesel is most commonly used by blending it with conventional diesel in varying amounts, from 5% (B5) and higher. The more common blend in the marine industry is B20 (20% biodiesel) which is reflected in the figure above. While successes have been reported in some trials, the issues surrounding the use of biodiesel on marine vessels are complex and cannot be discussed in full in this report.

Emissions from biodiesel combusted in a marine engine are difficult to quantify in a simple way since they are dependant on numerous variables including engine type, biodiesel blend, etc. The general trend (primarily of data collected on-road) is a reduction of all EPA-regulated pollutants

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except for NO_x, which is higher. Biodiesel is considered much less toxic than conventional diesel and has much less odor.

There have been problems associated with the use of biodiesel. Biodiesel will corrode natural rubber, so hoses or gaskets in a fuel system should be replaced prior to use. Filter clogging is a commonly reported issue with the use of biodiesel. There are various potential causes of filter clogging, one of which is that biodiesel will dissolve deposits left in the fuel system from the diesel. Biodiesel has a higher affinity for water, so it can potentially cause problems in centrifugal fuel separators.

Nearly all biodiesel for sale today is made from extracting oils from food crops. In the near future, biologically-derived diesel fuel will be made using a variety of methods and will not use food crops as a feedstock. These ‘second generation’ biofuels are purported to use less energy in production and, therefore, will have a lower carbon ‘footprint’. Additionally, second generation biofuels may be engineered to be fully compatible with the conventional diesel infrastructure, making distribution seamless.

10.3 Hydrogen Fuel Cell

Alternative Fuels				Hydrogen Fuel Cell			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	Low	Mean	High	Development	Difficult	One	No
Carbon Dioxide		60%		Experimental		Two	No
Carbon Monoxide		98%		Lifecycle Cost	High	Three	No
Hydrocarbons		100%		Fuel Match		Four	No
Nitrogen Oxides		99%		2.7%	NA	Five	No
Sulfur Oxides		100%		1.5%	NA	Six	No
Particulates		100%		0.5%	NA	Seven	No
				0.1%	NA	Eight	Mixed
				15 ppm	NA		

The use of hydrogen as a marine fuel is possible and has been put into practice in numerous applications. Typically, the hydrogen is stored in pressurized vessels. To convert the hydrogen into useful energy, it is fed into a fuel cell and converted to direct current, similar to a battery. In fact, hydrogen is not a fuel since it takes energy to produce it. It is more correct to consider hydrogen an energy storage medium, similar to a battery. The advantage of hydrogen use in transportation is zero emissions from the vehicle. There may be emissions from the production and transportation of hydrogen, but the gas itself only produces water and depleted air as a byproduct.

There are many competing technologies for the storage and conversion of hydrogen. The majority of work is not for the marine sector, although there has been increasing interest due to the potential for cutting air pollution.

11. Engine Based Approaches (Optimizing Engines)

A host of ‘on engine’ design strategies have been implemented by engine manufacturers to control emissions. Injection timing, charge air cooling, exhaust gas recirculation, electronic fuel injection, high pressure injection, common rail injection, and fuel injection rate shaping are a few of the technologies being applied to more accurately control the combustion process and optimize power, emissions, and fuel consumption variables.

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11.1 Design/Engine Timing

Engine Based Approach		Engine Tuning, Turbochargers, Injectors						
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Vessel Group		
	Low	Mean	High	Development	Easy	One	Yes	
Carbon Dioxide	-1%	2%	10%	Lifecyle Cost		Commercial	Two	Yes
Carbon Monoxide				Fuel Match			Three	Yes
Hydrocarbons				2.7%	Yes		Four	Yes
Nitrogen Oxides	0%	26%	70%	1.5%	Yes		Five	Yes
Sulfur Oxides				0.5%	Yes		Six	Yes
Particulates	30%	35%	40%	0.1%	Yes		Seven	Yes
				15 ppm	Yes		Eight	Yes

Engine timing is an important parameter in the control of emission. Retarding the timing will decrease the peak combustion temperature and therefore reduce the formation of NO_x. However, typically the NO_x reductions are accompanied with an increase in PM. Conversely, by advancing the timing the PM can be reduced due to more complete combustion but the NO_x will be increased. It is possible to adjust the engine timing after the factory but this is a component of the manufacturer's strategy to balance emissions and fuel consumption.

11.2 Direct Water Injection

Engine Based Approach		Direct Water Injection						
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Vessel Group		
	Low	Mean	High	Development	Mixed	One	Yes	
Carbon Dioxide	-2%	0%	3%	Lifecyle Cost		Prototype	Two	Yes
Carbon Monoxide				Fuel Match			Three	Yes
Hydrocarbons				2.7%	Yes		Four	Yes
Nitrogen Oxides	35%	45%	60%	1.5%	Yes		Five	No
Sulfur Oxides				0.5%	Yes		Six	No
Particulates				0.1%	Yes		Seven	No
				15 ppm	Yes		Eight	No

Direct Water Injection (DWI) is an established NOX reduction technology that injects a stream of water into the cylinder to lower the temperature of combustion. The injection can be directly into the cylinder, or in the intake air. The technology can be applied to slow speed and medium speed engines. It may not be appropriate for high speed engines. There are marine installations from which some data is available. The decreases in NOX are modest, and in some cases the emissions of PM can increase slightly. There is a slight penalty in power levels since the energy density of the fuel is decreased slightly. Modifications to the engine can void the warranty, depending on the manufacturer. Because fresh water is consumed, the normal fresh water supply may not be adequate and as such, additional storage or generating capacity may be required.

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11.3 Combustion Air Humidification (HAM)

Engine Based Approach Combustion Air Humidification							
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	Mixed Prototype	One	Mixed
Carbon Dioxide				Lifecycle Cost		Two	Mixed
Carbon Monoxide				Fuel Match		Three	Mixed
Hydrocarbons				2.7%	Yes	Four	Mixed
Nitrogen Oxides	60%	43%	80%	1.5%	Yes	Five	Mixed
Sulfur Oxides				0.5%	Yes	Six	Mixed
Particulates				0.1%	Yes	Seven	No
				15 ppm	Yes	Eight	No

In one variation of this technology, water is injected into the compressed air stream after the compressor and before the charge air cooler. As the air stream becomes saturated, it is cooled. Some of the water is condensed out in the charge air cooler and any water droplets are removed in a mist catcher. The result is a saturated air stream that is between 40° and 70°C. The cool air reduces the temperature of combustion and the NO_x formation. Another variation of the technology has the air pass through a humidification chamber containing seawater before entering the cylinder. Installation is not simple, and the costs are fairly high (\$80-\$90 per kW). One potential drawback is that the technology consumes a very high quantity of water (up to 2 times the fuel consumption). With one supplier, the source of water is seawater, but with another it requires either a source of fresh water or a dedicated water maker. In both cases, the exhaust temperature is reduced, making it more difficult to apply other catalytic reduction strategies in the exhaust. The technology does not claim to reduce PM or other pollutants. As with other ‘wet’ technologies, the specific fuel consumption rate is slightly increased due to the water introduced into the cylinder.

11.4 Fuel – Water Emulsion

Engine Based Approach Fuel-Water Emulsion							
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	Mixed Commercial	One	Yes
Carbon Dioxide	-2%	1%	5%	Lifecycle Cost		Two	Yes
Carbon Monoxide		50%		Fuel Match		Three	Yes
Hydrocarbons		50%		2.7%	Yes	Four	Yes
Nitrogen Oxides	30%	30%	50%	1.5%	Yes	Five	No
Sulfur Oxides				0.5%	Mixed	Six	No
Particulates				0.1%	Mixed	Seven	No
				15 ppm	Mixed	Eight	No

Fuel Water Emulsion (FWE) is a proven strategy for NO_x reduction. A quantity of fresh water is mixed and emulsified in to the fuel prior to delivery to the engine. The effect is a reduction of peak flame temperatures leading to lower NO_x. The reduction potential is approximately 1% NO_x reduction per 1% of water mixed with the fuel. In other words, a 50% water-fuel mixture will reduce the NO_x by 50%. However the fuel consumption is increased due to the water in the fuel, which will increase operating costs. Some modification to the fuel delivery system, such as pipes, pumps or injectors, is required due to physical property changes in the fuel. The amount of water consumed is less than with DWI or HAM.

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12. Off Engine Systems (Polishing Emissions, But Not Reducing Carbon Footprint)

After treatments are methods of processing exhaust gasses downstream of the engine turbo charger(s). Variations of after treatments have been shown to be effective with a significant installation base. Treatment technologies vary in complexity and reliability. They typically target specific classes of pollutants with some crossover. Some have been proven in the marine industry through years of use. Combining these technologies maximizes the results. The new EPA Tier 4 marine engine standards for Category 1 and 2 diesel engines embrace exhaust after treatment as a necessary method for reducing emissions beyond what is technologically feasible via the engine. The Tier 4 standards are not yet finalized. However, assuming the proposed rules are adopted, after-treatment requirements will be phased in between 2014 and 2017.

12.1 Selective Catalytic Reduction Units

Off Engine Systems				Selective Catalytic Reduction			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	Low	Mean	High	Development	Mixed	One	Yes
Carbon Dioxide	-2%	-1%	0%	Lifecycle Cost	Prototype	Two	Yes
Carbon Monoxide				Fuel Match	Moderate	Three	Mixed
Hydrocarbons						2.7%	Mixed
Nitrogen Oxides	57%	82%	90%	1.5%	Mixed	Five	Yes
Sulfur Oxides				0.5%	Yes	Six	Mixed
Particulates		25%		0.1%	Yes	Seven	Mixed
				15 ppm	Yes	Eight	Mixed

Because the exhaust from a diesel engine always contains excess oxygen (an oxidizing environment) there is no easy way to “reduce” NOX emissions to harmless N₂ and O₂. The oxidizing environment of a typical diesel engine can be overcome by Selective Catalytic Reduction (SCR). SCR is a process where a gaseous or liquid reductant, such as ammonia or urea, is added to the exhaust gas stream and is absorbed onto a catalyst where it reduces NOX to N₂ and H₂O.

Typical shipboard SCR reactors use an aqueous solution of approximately 30-40% urea and 60-70% de-ionized water. The amount of urea consumed depends on the level of NOx reduction required. SCRs can be designed to reduce the NOx by 20-99% of the base value, depending on the amount of urea used and the space available.

The system operates by pumping the urea solution through a control valve, injecting it into the exhaust stream after the turbocharger where it is atomized by pressurized air. After passing through several mixing sections in the exhaust pipe, the gas mixture passes into the reactor where the exhaust is scrubbed. The injection controller modulates the urea injection rate based on the engine RPM and load data. This allows the emissions to be controlled over varying engine loads. More sophisticated controls are also possible that monitor the emissions and temperature, and use these data to actively adjust the injection rate.

The reaction process is temperature dependant and will operate best between 250°C and 500°C, depending on the catalyst. Some catalysts are designed to achieve higher conversion rates at lower temperatures. This can complicate the control of emissions in vessels that have operating profiles that significantly vary between low and high load operation. In theory, it is possible to achieve 100% conversion, but the space and weight of the reactor would be prohibitive.

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Urea ((NH₂)₂CO) is a commonly used and widely available chemical commodity. The urea solution is corrosive to Copper and its alloys, so epoxy-coated steel or stainless steel are recommended for containment and handling. Consumption rates are typically 5-8% by weight of the fuel consumption, depending on the amount of NO_x reduction desired.

It is common to add an oxidizing catalyst downstream of the reactor known as a 'slip catalyst'. This will oxidize any remaining ammonia in the exhaust. Ammonia slip can be reduced with active controls and sensors in the exhaust. This allows the dosing of the urea to be constantly controlled to an optimum level based on exhaust temperature.

SCRs will have the best durability when operating on fuel with sulfur content below 1%. Higher sulfur content in the fuel will increase the operating expense and reduce the effectiveness of the reactor. There are at least 35 installations of SCR units on ships burning HFO with sulfur content up to 3%.

The U.S. EPA estimates that marine SCRs require a volume of approximately 2.5 times that of the engine. Increasing the volume of the reactor will decrease the backpressure losses, and increases the NO_x reduction potential.

The challenge of designing an SCR system into a new vessel varies with the vessel size and operating profile. A large vessel with a steady operating profile (ocean-going vessel) is less of a design challenge than a small vessel with an intermittent operating profile (harbor tug). Also, smaller, lighter vessels such as high-speed craft will face particular challenges due to the weight of the system.

Cost of the SCR systems varies widely. For some larger installations, costs have been reported to be between \$60k - \$100k per MW of installed power. In the U.S. EPA Regulatory Impact Analysis (RIA) of the recent draft, Tier 3 and 4 standards for marine engines, it is estimated that the cost to the consumer will fall to about \$7500/MW (for installations above 600kW) once widespread use is required in the 2014 timeframe.

12.2 Diesel Oxidation Catalysts

Off Engine Systems				Diesel Oxidation Catalyst			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	Low	Mean	High	Development	Mixed	One	Mixed
Carbon Dioxide				Prototype		Two	Mixed
Carbon Monoxide	70%	86%	95%	Moderate		Three	Mixed
Hydrocarbons	70%	85%	90%	Fuel Match		Four	Mixed
Nitrogen Oxides		0%		2.7%	No	Five	Mixed
Sulfur Oxides				1.5%	Mixed	Six	Mixed
Particulates	8%	23%	50%	0.5%	Mixed	Seven	Mixed
				0.1%	Mixed	Eight	Mixed
				15 ppm	Yes		

A diesel oxidation catalyst (DOC) is a catalytic pollution control device used to reduce emissions of hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). These pollutants are reacted into CO₂ and water. The devices can stand alone or be integrated into another device. In marine applications, they are often combined with an SCR by alternating the catalyst layers to reduce package size and weight. Like many catalytic devices, the catalyst can be poisoned by sulfur from the fuel. Therefore, effectiveness and durability are maximized by the use of low

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sulfur fuel. The DOC is passive and requires minimum maintenance. A DOC contains precious metals and, therefore, the costs can fluctuate with these commodities.

12.3 Catalyzed Diesel Particulate Filters

Off Engine Systems				Catalyzed Diesel Particulate Filter			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	Mixed	One	No
				Lifecycle Cost	Prototype	Two	No
Carbon Dioxide					Moderate	Three	No
Carbon Monoxide		90%		Fuel Match		Four	Mixed
Hydrocarbons		90%		2.7%	No	Five	Mixed
Nitrogen Oxides				1.5%	No	Six	Mixed
Sulfur Oxides				0.5%	Mixed	Seven	Yes
Particulates		88%		0.1%	Mixed	Eight	Yes
				15 ppm	Yes		

A Catalyzed Diesel Particulate Filter (CDPF) is a catalytic after-treatment device used to reduce the emissions of diesel particulate matter (DPM). The devices are designed to allow the filter to ‘recharge’ by burning off the built up PM in the filter. This is achieved by the application of a catalyst to the ceramic or metallic substrate of the filter. The catalyst allows the collected material to combust at a lower temperature than would be possible using exhaust heat alone. This allows the passages to continually cleanse themselves, reducing the backpressure losses and maximizing the effectiveness of the filter.

What is left behind after combustion of the PM is ash. The source of the ash can come either from the fuel or from the lubricating oil. Heavy fuels have high ash content, as do marine engine lubricants. The ash content will eventually build up and clog the passages within the filter. The filter can be cleaned as part of scheduled maintenance, but with heavier fuels or lubricants with high ash content this could become a prohibitive practice. This is the main reason that DPFs are recommended for use with low ash, low sulfur fuels and lubricants with low sulfated ash, phosphorus, and sulfur content (low-SAPS oil).

The use of sulfur in fuel requires the use of engine oils with a high total base number (TBN). The ash in the oil is related to the TBN which is needed to neutralize the acids formed when sulfur from the fuel finds its way into the engine crankcase. Therefore if vessels switch to ULSD fuel, the formation of acids in the crankcase are not a concern allowing the use of low SAPS oil.

12.4 Combined Systems

Advanced after-treatment systems are most effective when several strategies are combined. For example, as a first stage, a DOC can be placed upstream of a CDPF to pre-oxidize NO into NO₂. The first stage will also convert CO and HC to CO₂ and water. In the next stage a CDPF will trap PM and oxidize it into CO₂. In the process the NO₂ will be converted back to NO. Finally, in the last stage, an SCR will remove the NO_x.

When carefully implemented, this strategy can reduce NO_x, CO, HC, and PM by more than 90% from the base levels. These filters all rely on catalytic devices, which are susceptible to poisoning in the presence of sulfur and phosphorus. Therefore, it is most effective to use low sulfur fuel and low SAPS engine oil to achieve the best results and durability. Combined systems form the basis of the EPA’s Tier 4 strategy for drastically reducing pollution from marine diesel engines. The

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particular challenge of combining different devices will be the addition of backpressure to the system.

12.5 Seawater Scrubbing

Off Engine Systems Seawater Scrubbing								
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	Mixed	One	Yes	
Carbon Dioxide		-1%		Lifecycle Cost	Prototype	Two	Yes	
Carbon Monoxide				Fuel Match	Moderate	Three	Mixed	
Hydrocarbons				2.7%		Yes	Four	Mixed
Nitrogen Oxides	3%	4%	5%	1.5%		Mixed	Five	Yes
Sulfur Oxides		95%		0.5%		No	Six	Mixed
Particulates		76%		0.1%		No	Seven	Mixed
				15 ppm		No	Eight	Mixed

Seawater scrubbing is a technology intended to remove sulfur oxides (SOx) from the stack emissions. The technology has been tested and installed on several vessels and the manufacturers claim up to 100% sulfur removal. This technology also removes some types of particulate matter (up to 80% by weight). The PM is collected and separated as sludge waste for later disposal at a shore facility. The SOx in the exhaust is converted to sulfate, which is a naturally occurring component of seawater. Manufacturers claim sulfate levels to be near ambient within a few meters of the discharge pipe. At least one manufacturer claims that the system also removes a small amount of NOx from the stack (5-15%).

The system is complex, requiring pumps, piping, sludge storage, heat exchangers, and hull penetrations. It is not considered a 'plug and play' solution. The manufacturers claim these systems to be scalable up to any engine size; for example, they have been recently installed on large cruise ships. The scrubber itself can be used as a silencer, although we are still waiting to hear from the manufacturers on the level of sound attenuation. Because the exhaust is cooled to near ambient temperatures, there is some concern over corrosion of the exhaust system. The system reduces the exhaust temperature too much to allow for the downstream use of a catalytic type after treatment system such as an SCR or a DOC.

12.6 Wind Propulsion Assistance

Off Engine Systems Wind Propulsion Assistance								
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	Mixed	One	Yes	
Carbon Dioxide	10%	23%	35%	Lifecycle Cost	Prototype	Two	Yes	
Carbon Monoxide	10%	23%	35%	Fuel Match	Moderate	Three	No	
Hydrocarbons	10%	23%	35%	2.7%		0	Four	No
Nitrogen Oxides	10%	23%	35%	1.5%		0	Five	No
Sulfur Oxides	10%	23%	35%	0.5%		0	Six	No
Particulates	10%	23%	35%	0.1%		0	Seven	No
				15 ppm		0	Eight	No

Wind propulsion assistance has regained the imagination of the maritime industry and, perhaps, a small market share given the very high prices of oil. Some recent demonstrations and prototype installations are showing that this is a viable means of reducing fuel costs for certain ocean liner

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trades. It is significant that these fuel savings translate directly into reduced carbon dioxide emissions.

One maker, rather than a traditional mast arrangement, has developed a system which launches a kite. The supplied hardware is supported with sophisticated controls systems, an apparently sound structural approach and weather routing assistance so that wind directions and forces can be maximized. This is a promising and interesting development for certain vessel trades.

13. Operations & Maintenance (On Board Efforts After Vessel is Built)

After a vessel is designed, built, and delivered, the efficient operations and maintenance of that vessel is in the hands of the operating crew and shore-side support such as port engineers and occasionally service crews. The expertise of these crews in keeping operations efficient has a real impact on overall emissions, including carbon dioxide.

13.1 Hull Maintenance

On Vessel O&M Hull Maintenance							
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction			Implementation		Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Easy</i> Commercial	One	Yes
Carbon Dioxide	1%	2%	3%	Lifecycle Cost		Two	Yes
Carbon Monoxide	1%	2%	3%	Fuel Match		Three	Mixed
Hydrocarbons	1%	2%	3%	2.7%	Yes	Four	Mixed
Nitrogen Oxides	1%	2%	3%	1.5%	Yes	Five	Yes
Sulfur Oxides	1%	2%	3%	0.5%	Yes	Six	Mixed
Particulates	1%	2%	3%	0.1%	Yes	Seven	Mixed
				15 ppm	Yes	Eight	Mixed

When marine growth builds up it can increase drag and reduce fuel efficiency. It is important for vessels to periodically clean fouling from the hull. Proper hull maintenance can potentially save several percentage points on fuel consumption.

13.2 Engine/Propulsion System Maintenance

On Vessel O&M Engine Maintenance							
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction			Implementation		Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Easy</i> Commercial	One	Yes
Carbon Dioxide	1%	2%	2%	Lifecycle Cost		Two	Yes
Carbon Monoxide	1%	3%	4%	Fuel Match		Three	Yes
Hydrocarbons	1%	3%	4%	2.7%	Yes	Four	Yes
Nitrogen Oxides	1%	3%	4%	1.5%	Yes	Five	Yes
Sulfur Oxides	1%	2%	2%	0.5%	Yes	Six	Yes
Particulates	1%	3%	4%	0.1%	Yes	Seven	Yes
				15 ppm	Yes	Eight	Yes

As with any complex mechanical or electrical system, proper maintenance is an important part of plant operations. Diesel engines require constant routine (as well as periodic) maintenance to operate at an optimal level.

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13.3 Optimal Engine Operating Point

On Vessel O&M Optimal Engine Operating Point							
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Easy</i> Commercial	One	No
Carbon Dioxide	0%	2%	4%	Lifecycle Cost		Two	Yes
Carbon Monoxide	0%	3%	6%	Fuel Match		Three	Yes
Hydrocarbons	0%	3%	6%	2.7%	Yes	Four	Yes
Nitrogen Oxides	0%	3%	6%	1.5%	Yes	Five	Yes
Sulfur Oxides	0%	2%	4%	0.5%	Yes	Six	Yes
Particulates	0%	3%	6%	0.1%	Yes	Seven	Mixed
				15 ppm	Yes	Eight	Mixed

The slow-speed diesel engines of large, ocean-going vessels are generally well matched with the expected hull speed of the vessel and resulting drag. This matching considers the optimal engine operating point, where fuel economy will be best and emissions will be lowest. This concept also applies to diesel electric plants, but is generally not implemented. Significant emissions reductions can be realized if the propulsion power is tuned such that the engines which are on the electrical bus are running at their most efficient point.

13.4 Auxiliary Efficiency Point

On Vessel O&M Auxiliary Efficiency Point							
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction				Implementation		Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Mixed</i> Commercial	One	Yes
Carbon Dioxide	0%	1%	2%	Lifecycle Cost		Two	Yes
Carbon Monoxide	0%	1%	2%	Fuel Match		Three	Yes
Hydrocarbons	0%	1%	2%	2.7%	Yes	Four	Mixed
Nitrogen Oxides	0%	1%	2%	1.5%	Yes	Five	Mixed
Sulfur Oxides	0%	1%	2%	0.5%	Yes	Six	Mixed
Particulates	0%	1%	2%	0.1%	Yes	Seven	No
				15 ppm	Yes	Eight	No

The auxiliary fans, pumps, compressors, lights and other power consumers on a vessel make up the auxiliary loads. Each of these consumers are generally sized for peak demands; e.g., very cold outside, people in a space, consumer at full load. As a result, significant amounts of energy are wasted during the non-peak times. Operational considerations, ranging from turning off lights, to running fans on low-speed settings, utilizing gravity fluid transfers, and turning off equipment when not needed, can have a significant impact.

Auxiliary loads can range from greater than the propulsion plant load on a large cruise ship to very small on day boat harbor craft. As such, the impact on overall vessel emissions will scale

14. **Vessel Logistics (Smart Business, Low Emissions)**

The effect of vessel logistics on overall emissions is a significant saving that most vessel operators strive for. The examples are numerous, and the impacts are almost immeasurable. The following are a few antidotal examples known in the industry.

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Low Emissions Example	High Emissions Comparison
Bulk Carrier which transits 50 nautical miles empty from discharge port to gain next load	Bulk carrier which transits 1,000 nautical miles empty from discharge port to gain next load
Emma Maersk at 11,000 TEUs, with very low fuel consumption per cargo ton mile	Resoluton Bay with 2,344 TEUs, with relatively high consumption per cargo ton mile
Tug escort fleet which is docked adjacent to ship escort location	Tug escort fleet which is docked several miles up an inlet, away from escort location
Pilot boat which holds station where ship's need pilots	Fast pilot boat or helicopter which cruises out to meet ships

14.1 Vessel Speed Reduction

Transportation Logistics Vessel Speed Reduction								
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Easy</i> Commercial	One	Yes	
Carbon Dioxide		31%		Lifecycle Cost	Low	Two	Yes	
Carbon Monoxide		37%		Fuel Match		Three	Yes	
Hydrocarbons		31%		2.7%		Four	Yes	
Nitrogen Oxides		37%		1.5%		Five	Yes	
Sulfur Oxides		49%		0.5%		Six	Yes	
Particulates		49%		0.1%		Seven	Yes	
				15 ppm		Yes	Eight	Yes

The amount of fuel a vessel burns is highly sensitive to the speed that the vessel is traveling, since speed-power relationship for a marine vessel is cubic. This means that a small change in vessel speed can have large effects on the vessel's fuel consumption and exhaust emissions. When considered on a ton-cargo per nautical mile, divide by distance. This results in fuel consumption being proportional to the square of speed. There are, however, many additional factors including ships length, hull shape, design speed, and weather that must be considered on an individual vessel basis to gain an accurate estimate of fuel savings related to vessel speed.

A voluntary speed reduction program has been used in the State of California to reduce air pollution. The example table above reflects the California estimates for this program, using a 12-knot speed limit.

14.2 Route Planning

Transportation Logistics Route Planning								
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Vessel Group		
	<i>Low</i>	Mean	<i>High</i>	Development	<i>Mixed</i> Commercial	One	Yes	
Carbon Dioxide	0%	17%	33%	Lifecycle Cost	Low	Two	Yes	
Carbon Monoxide	0%	17%	33%	Fuel Match		Three	Mixed	
Hydrocarbons	0%	17%	33%	2.7%		Four	Mixed	
Nitrogen Oxides	0%	17%	33%	1.5%		Five	Yes	
Sulfur Oxides	0%	17%	33%	0.5%		Six	Mixed	
Particulates	0%	17%	33%	0.1%		Seven	Mixed	
				15 ppm		Yes	Eight	Mixed

Route planning encompasses activities from avoiding bad weather to favoring good currents. These activities provide very modest reductions in fuel consumption. Route planning also considers efforts to engage in triangular trade, always having a back cargo. Route planning also

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considers efforts such as coordinating tug and supply vessels such that distances between jobs are minimized. Avoiding legs of voyages with little cargo can result in significant savings on a cargo per ton-mile basis.

15. Infrastructure Solutions (Shifting Emissions off Vessels)

Infrastructure solutions are those that shift the burden of emissions management off of the marine vessel. This directly considers plugging vessels into electrical connections and steam connections from shore. This also considers such novel approaches as capturing the stack gases from ships when they are at the dock or even in a harbor.

It is obvious that these efforts are only effective when a marine vessel is near to shore and stationary. These approaches are valid for all scales of vessels. A tug boat can be plugged in to “keep it warm,” as can a containership during cargo operations.

15.1 Shore Power

Off Ship Support				Shore Side Electrification			
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)							
Emissions Reduction			Implementation		Difficult	Vessel Group	
	Low	Mean	High	Development	Commercial	One	Yes
Carbon Dioxide		95%		Lifecycle Cost		Two	Yes
Carbon Monoxide		95%		Fuel Match		Three	Yes
Hydrocarbons		95%		2.7%	0	Four	Yes
Nitrogen Oxides		95%		1.5%	0	Five	Yes
Sulfur Oxides		95%		0.5%	0	Six	Yes
Particulates		95%		0.1%	0	Seven	No
				15 ppm	0	Eight	No

To reduce pollution while a vessel is tied up, some ports are providing shore power connections to supply auxiliary loads to vessels while they are loading and unloading cargo. The technology can also be used on smaller vessels. ‘Cold ironing’ is a technological solution to reduce air pollution and requires operational change of the vessel while in port. The advantage of cold ironing is a significant reduction in pollution while in port. It is possible to achieve 100% reduction in in-port emissions, depending on the modifications made to the vessel. Tankers, for example, rely on boilers to make steam for turbine driven cargo pumps, and the boilers burn diesel fuel. It is possible to use shore steam or electric fired boilers to drive the pumps. It may also be possible to use electric cargo pumps. However, when considering cold ironing it is also important to consider the burden to the vessel owners to pay for all of the equipment that must be added to support a shore power solution.

Problems with cold ironing are numerous. A dedicated shore power connection must be outfitted at each pier, and the connection must be able to supply the right frequency and voltage to every vessel type that ties to that pier. The cables must be designed to be transferred in a timely and safe fashion to the vessel for attachment to the vessel electrical system. This may also require a shore crane to be available to transfer cables. On the vessel, the equipment must be available to accept the electrical cables and interface them with the vessel auxiliary power system. The electrical switchgear may need to be modified or replaced entirely, potentially costing millions of dollars. Space for electrical switchgear is sometimes difficult to find on board vessels. Depending on how

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the system is set up, vessel power may be interrupted when switching to or from shore power. All of these issues make this solution controversial with ship operators.

15.2 Shore Side Exhaust Capture

Off Ship Support				Shore Side Exhaust Capture				
SUMMARY (AVERAGES DATA FROM VARIOUS RESOURCES AND GLOSTEN ANALYSIS)								
Emissions Reduction				Implementation		Difficult	Vessel Group	
	<i>Low</i>	Mean	<i>High</i>	Development	Prototype		One	Yes
Carbon Dioxide		-2%		Lifecycle Cost		High	Two	Yes
Carbon Monoxide				Fuel Match			Three	No
Hydrocarbons	50%	55%	60%	2.7%	Yes		Four	No
Nitrogen Oxides		95%		1.5%	Yes		Five	Yes
Sulfur Oxides	95%	97%	99%	0.5%	Yes		Six	No
Particulates	95%	97%	99%	0.1%	Yes		Seven	No
				15 ppm	Yes		Eight	No

One company, Advanced Cleanup Technologies Incorporated (ACTI), has trialed a novel concept of capturing gases from all the pipes of a ship with a bonnet which fits over the ships stack. It is a very challenging operation for vessels at the dock, given the variable stack configurations. The challenges get more complex if the equipment is fitted on a barge due to a lack of space at a dock, or if targeting vessels at anchor.

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16. Glossary of Terms

Alternative fuel	natural gas, propane, ethanol, methanol, hydrogen, electricity, or fuel cells. Alternative fuel also means any mixture that only contains these fuels.
ASTM	ASTM International, originally known as the American Society for Testing and Materials
Auxiliary Boiler	any fuel-fired combustion equipment designed primarily to produce steam for uses other than propulsion, including, but not limited to, heating of residual fuel and liquid cargo, heating of water for crew and passengers, powering steam turbine discharge pumps, freshwater generation, and space heating of cabins. Exhaust gas economizers that exclusively use diesel engine exhaust as a heat source to produce steam are not auxiliary boilers.
Auxiliary engine	a diesel engine on an ocean-going vessel designed primarily to provide power for uses other than propulsion or emergencies, except that all diesel-electric engines shall be considered “auxiliary diesel engines” for purposes of this section.
CARB	California Air Resources Board
CDPF	Catalyzed Diesel Particulate Filter
CNG	Compressed natural gas
CO	Carbon monoxide
Diesel Engine	an internal combustion, compression-ignition (CI) engine with operating characteristics significantly similar to the theoretical diesel combustion cycle. The regulation of power by controlling fuel supply in lieu of a throttle is indicative of a compression ignition engine.
Diesel Particulate Matter	particles found in the exhaust of diesel engines, which may agglomerate and adsorb other species to form structures of complex physical and chemical properties.
Diesel-electric engine	a diesel engine connected to a generator that is used as a source of electricity for propulsion or other uses.
DOC	Diesel oxidation catalyst
DPM	Diesel particulate matter
DWI	Direct Water Injection
EIA	The International Energy Agency
Emergency Generator	a diesel-electric engine operated only during emergencies or to perform maintenance and testing necessary to ensure readiness for emergencies.

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EPA	U.S. Environmental Protection Agency
FWE	Fuel Water Emulsion
HC	Hydrocarbon; the sum of all hydrocarbon air pollutants.
IMO	The International Maritime Organization, the maritime shipping arm of the United Nations
INTERTANKO	an organization representing independent tank ship owners
ISO	The International Organization for Standardization.
LNG	Liquefied natural gas
Main Engine	a diesel engine on an ocean-going vessel designed primarily to provide propulsion, except that diesel-electric engines shall not be considered “main engines” for purposes of this section.
MARPOL	The International Convention for the Prevention of Pollution from Ships
Master	the person who operates a vessel or is otherwise in charge of the vessel’s operations.
MDO	Marine Diesel Oil; any fuel that meets all the specifications for DMB grades as defined in Table I of International Standard ISO 8217, as revised in 2005, which is incorporated herein by reference.
MEPC	Marine Environmental Protection Committee
MGO	Marine Gas Oil; any fuel that meets all the specifications for DMX or DMA grades as defined in Table I of International Standard ISO 8217, as revised in 2005, which is incorporated herein by reference.
Military Vessel	any ship, boat, watercraft, or other contrivance used for any purpose on water, and owned or operated by the armed services.
NMHC	Non-Methane Hydrocarbons; the sum of all hydrocarbon air pollutants except methane.
NOx	Nitrogen Oxides; compounds of nitric oxide (NO), nitrogen dioxide (NO ₂), and other oxides of nitrogen, which are typically created during combustion processes and are major contributors to smog formation and acid deposition.
OGV	Ocean-going Vessel; a commercial, government, or military vessel meeting any one of the following criteria: (A) a vessel greater than or equal to 400 feet in length overall (LOA) as defined in 50 CFR § 679.2, as adopted June 19, 1996; (B) a vessel greater than or equal to 10,000 gross tons (GT ITC) per the convention measurement (international system) as defined in 46 CFR 69.51-.61, as adopted September 12, 1989; or (C) a

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	vessel propelled by a marine compression ignition engine with a per-cylinder displacement of greater than or equal to 30 liters.
Operate	steering or otherwise running the vessel or its functions while the vessel is underway, moored, anchored, or at dock.
Own	having all the incidents of ownership, including the legal title, of a vessel whether or not that person lends, rents, or pledges the vessel; having or being entitled to the possession of a vessel as the purchaser under a conditional sale contract; or being the mortgagor of a vessel.
PM	Particulate Matter; any airborne finely divided material, except uncombined water, which exists as a liquid or solid at standard conditions (e.g., dust, smoke, mist, fumes or smog).
Roadstead	any facility that is used for the loading, unloading, and anchoring of ships.
SCR	Selective Catalytic Reduction
SECA	SOx Emission Control Area
SI	Spark ignited
Slow Speed Engine	an engine with a rated speed of 130 revolutions per minute or less.
SO2	Sulfur Oxides; compounds of sulfur dioxide, and other oxides of sulfur, which are typically created during combustion of sulfur containing fuels.
Tanker	a self-propelled vessel constructed or adapted primarily to carry, or that carries, oil or hazardous material in bulk as cargo or cargo residue.
TBN	Total base number
TBT	Trybutyltin
Two-stroke Engine	an internal combustion engine which operates on a two stroke cycle where the cycle of operation completes in one revolution of the crankshaft.
ULSD	Ultra-low sulfur diesel
Vessel	any tugboat, tanker, freighter, passenger ship, barge, or other boat, ship, or watercraft, except those used primarily for recreation and any of the following: (A) a seaplane on the water; (B) a watercraft specifically designed to operate on a permanently fixed course, the movement of which is restricted to a fixed track or arm to which the watercraft is attached or by which the watercraft is controlled.

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APPENDIX A

Emissions Reductions Opportunities: Review Summary

Regulatory Initiatives and Rules: Review Summary

Regulatory Initiatives and Rules: Notes and References

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Regulatory Agency	References & Notes	Status				Application						Engine Size/ Speed					Fuel Regulation					Emissions Requirements (grams per kilowatt-hour)																
		In Force	Scheduled	Draft/Proposed	Voluntary	New Builds	Existing Fleet	Global	SECA Region	Other Region	All Tonnage	Over 400 GT	CAT 3	CAT 2	CAT 1	Slow (n <130)	Medium	High (n>2,000)	4.5% Sulfur	1.5% Sulfur	0.5% Sulfur	0.1% Sulfur	15 PPM Sulfur	Carbon Dioxide (Not Regulated)	Carbon Monoxide (Not Regulated)	Nitrogen Oxides + Hydrocarbons (NOx + HC)		Nitrogen Oxides		Sulfur Oxides		Particulate Matter						
																										Gram	% Red	Gram	% Red	Gram	% Red	Gram	% Red					
INTERNATIONAL MARITIME ORGANIZATION		Initiative or Rule																																				
	MARPOL Annex VI	A																																				
	NOx and Fuel - Slow Speed Engines "Tier I"	2005				X	X			X	X			X				X																				
	NOx and Fuel - Med Speed Engines "Tier I"	2005				X	X			X	X	X			X			X																				
	NOx and Fuel - High Speed Engines "Tier I"	2005				X	X			X	X	X			X			X																				
	SECA (Geog. Based PM & SOx)	1,2	2005			X	X		X	X	X	X			X			X																				
	INTERTANKO Proposal to IMO	B																																				
	World Wide Low Sulfur "Distillate Option"	3		2010		X	X	X		X	X	X	X	X	X	X					X																	
	US EPA Proposals to IMO	C																																				
	NOx Standard (Tier I) for Existing Vessels	4,5		2012		X	X			X	X			X	X																							
	NOx Standard (Tier II)	5		2011		X	X			X	X			X	X																							
	NOx Standard (Tier III)	5		2016		X	X			X	X			X	X																							
	SECA - Expand to World Wide	6,7		2011		X	X		X	X	X	X	X	X	X	X					X																	
US ENVIRONMENTAL PROTECTION AGENCY		Category 3 - See IMO Section (All In Force and EPA Proposed for US Flag OGVs)																				D,8																
		Category 1 and 2 Engines																																				
	Tier 1 - New Builds - Slow Speed Engines	F	2004			X			X	X			X	X	X																							
	Tier 1 - New Builds - Med Speed Engines	F	2004			X			X	X			X	X		X																						
	Tier 1 - New Builds - High Speed Engines	F	2004			X			X	X			X	X		X																						
	Tier 2 - New Builds	F	2004 - 2007			X			X	X			X	X		X	X																					
	Tier 3 - New Builds	F		2009 - 2014		X			X	X			X	X		X	X																					
	Tier 4 - New Builds	F		2014 - 2017		X			X	X			X	X		X	X																					
	Diesel Fuel Standard		2007			X	X		X	X			X	X		X	X					X																
		Category 3 - See IMO Section (All In Force and EPA Proposed for US Flag OGVs)																				D																
	Category 1/2 - Large Refineries/Imports	J,12	2007			X	X		X	X			X	X		X	X				X																	
	Category 1/2 - Small Refineries/Exemptions	J,13	2012			X	X		X	X			X	X		X	X					X																
CALIFORNIA AIR RESOURCES BOARD		Auxiliary Engine Fuel																																				
	Auxiliary Engine Fuel	E,9	2007			X	X		X		X	X		X	X						X																	
	Auxiliary Engine Fuel	E,9		2010		X	X		X		X	X		X	X							X																
	Main Engine/Boiler Fuel	E,10		2009		X	X		X		X	X		X	X							X																
	Main Engine/Boiler Fuel	E,10		2012		X	X		X		X	X		X	X								X															
	Harbor Craft CARB Diesel		2007			X	X		X	X			X	X		X	X																					
	New Ferries		2009																																			
	Tier 3 - In Use Engines	G,11		2009 - 2014		X			X	X			X	X		X	X																					
	Tier 4 - In Use Engines	G,11		2015 - 2022		X			X	X			X	X		X	X																					
	Vessel Speed Reduction Program	14		2001		X	X		X		X	X		X	X																							
	At Berth Electrification	H		2014		X	X		X		X	X		X	X																							

REGULATORY REVIEW

Regulatory Review Notes and References

Notes (Numbers)

- 1 Vessels operating in SECA must either use low sulfur fuel, or meet the SOx performance standard.
- 2 SOx Emissions Control Areas (SECA) emissions are currently in force in the North and Baltic Seas. Multiple additional regions are being phased in or proposed, including the US EEZ in 2011.
- 3 An important distinction of the "Distillate Option" is that it is a fuel criteria only, without provision for use of seawater scrubbing or other technology on board the vessel.
- 4 The EPA Category 3 engine (Tier I) proposal expands Annex VI NOx requirements to include Existing vessels.
- 5 EPA NOx percent reductions: Tier I is a reduction from the existing engine's emissions. Tier II is a reduction from Annex VI requirements. Tier III is a reduction from proposed Tier II levels.
- 6 EPA "consider uniformly defined, geographic-based PM and SOx standards beginning in 2011 for all ships operating within [200] nautical miles of land" of a "specific set of coastal waters"
- 7 EPA SECA offers the option of a fuel requirement or SOx/ PM standard. PM: 0.5 grams > 15 liters, 0.27 grams > 5 liters, 0.2 grams < 5 liters
- 8 EPA Category 3 Proposed Rules are harmonized with the EPA IMO proposals. The proposed rules would apply to US registered vessels.
- 9 ARB Rule is for OGV **AUXILIARY** engines fuel sulfur content. It is enforced within 24 nautical miles of California coast.
- 10 ARB Rule is for OGV **MAIN ENGINE AND BOILER** fuel sulfur content. It is enforced within 24 nautical miles of California coast. An alternative ONE STEP in 2010 to 0.1% is also considered.
- 11 ARB Rule is a phase in period for existing engines which targets older engines first. For example a 1976 engine would need to meet current EPA new engine requirements (Tier 3) by 2012 or be replaced.
- 12 EPA Clean Diesel Implementation is for 500 ppm, not 1000 ppm as indicated in chart.
- 13 EPA Clean Diesel Implementation Dates for "small refiners" implements 500 ppm sulfur in 2010, and 15 ppm sulfur in 2014 - lagging "large refiners and importers"
- 14 ARB 2001 voluntary Vessel Speed Reduction Program, as of 2004 is tied to "reductions" in port fees for vessels that slow to a maximum of 12 knots within 24 n.miles of land

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