Sulfur Emissions Abatement in the International Shipping Industry
A Case for Marine Exhaust Gas Scrubbers

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Abstract

In response to the recent amendments to Annex VI of the International Convention for the Prevention of Pollution from Ships, 1973 (a.k.a. “MARPOL 73/78”), the international shipping industry is currently meeting sulfur emission caps by blending and burning higher priced distillate fuels. In the short-term, while emission caps are relatively high (e.g., easy to attain compliance), it is easier and arguably cheaper to opt for distillates. However, as those sulfur caps fall in the coming years, in accordance with the schedule put forth by the International Maritime Organization, more marine distillate will be needed to meet regulations. Despite its inherent environmental and health benefits, said demand will have adverse effects on global supply and in turn price of transportation fuels. Nonetheless, technologies currently exist in the marketplace that remove the sulfur from the vessel’s exhaust gas stream post-combustion and allow for the use of lower grade and lower priced residual fuels (instead of high priced distillates). This masters’ project highlights the current sulfur abatement technologies in the market, specifically exhaust gas cleaning systems or “scrubbers”, and how ship owners and operators can meet sulfur regulations economically. It makes a case for said scrubbers and looks deeper into the levers of financial feasibility of these devices, both presently and in the future. Additionally, it addresses some of the possible effects of a wholesale transition to distillates by the marine shipping industry and its adverse effects on the global marketplace.
Introduction

In early September 2010, Maersk Lines, the largest container ship operator in the world¹, announced that while all of its ships are berthed in the Port of Hong Kong they would voluntarily burn lower-sulfur Marine Diesel Oil (“MDO”) instead of the normal Residual Fuel (a.k.a. “Bunker Fuel”). In an interview with CNN, CEO Maersk North Asia Tim Smith said that “in Hong Kong, you have a lot of maritime activity [near] centers of population, [and] our fuel could have an impact of public health, if we can sort this out, we think we are making a good contribution to improving public health generally.”²

The impact of ship exhaust on human and environmental health is widely recognized. With few exceptions, large ocean going vessels (e.g., tankers, bulk carriers, container ships, cruise ships, etc.), are motivated by residual fuels, a highly viscous by-product of the crude oil refining process. Residual fuel is high in sulfur, carbon, and other heavy metals. When combusted residual fuels produce toxic airborne pollutants and particulates that are detrimental to human and environmental health.

The International Maritime Organization (“IMO”), a sub-group of the United Nations, governs all international shipping rules and regulations. The 1973 International Convention for the Prevention of Pollution from Ships (a.k.a. “MARPOL”, short for “Marine Pollution”), in conjunction with the subsequent Protocol of 1978, is the principal environmental convention governing international shipping. The Convention has six annexes with different focuses. Annex VI, which addresses Air Pollution from ships, was adopted by 56 countries as of October of 2009. This paper will focus exclusively on Annex VI.

The most recent amendments and revisions of Annex VI put forth by the Marine Environment Protection Committee, specifically ‘Resolution MEPC.176(58)’, were adopted on 10 October,

2008. These amendments provide the legal framework and timeline for the sulfur content restrictions in marine bunker fuel going forward.

Resolution MEPC.176(58) mandates that the highest sulfur content by weight that ship owners can burn while motoring within Emission Control Area’s (“ECA’s”; formerly known as Sulfur Emission Control Areas or “SECA’s”) is 1.0%. This level just dropped from 1.5% in July of 2010 and is scheduled to fall again to 0.1% sulfur in 2015. The ‘Global’ limits (e.g., open waters outside of ECA’s) of sulfur content is scheduled to fall to 3.5% in 2012 and further to 0.5% in 2020 – the 0.5% level is subject to a supply feasibility study to be administered in 2018 (see Figure 1 above).

While operating within ECA’s, Annex VI allows for the use of approved “Equivalent Technologies” in lieu of lower sulfur fuels to achieve emissions targets. As of 2010, equivalent technologies only include exhaust gas cleaning (“EGC”) systems, more commonly known as “scrubbers”. Scrubbers are high in upfront costs but remove +90% of sulfur emissions amongst
other pollutants and particulates. These devices employ a process known as shipboard flue gas desulphurization which removes sulfur from the exhaust gases after combustion but prior to its release into the atmosphere. This process is an alternative to desulphurization during the refining process.

As described in the opening paragraph, ship owners and operators are opting to buy and burn more expensive low sulfur marine fuels to meet current regulations, both mandated and not. At the current price levels of low sulfur fuel oil (“LSFO”), it is cheaper to achieve compliance by paying the premium over high sulfur fuel oil (“HSFO”) in the short run rather than investing in costly scrubbers. At the current supply levels, there is sufficient low sulfur marine fuel to meet demands and successfully operate the below the sulfur content ceilings, both in and out of the ECA’s.

However, shipping is not alone in its thirst for low sulfur transportation fuels; many industries and sectors are transitioning to low sulfur fuels including, but not limited to, on-road transportation, off-road transportation and home-heating. This is happening while the size and number of ECA’s are growing globally and the mandated sulfur content by weight in marine fuels is ratcheting ever tighter. Due to the uncertainty surrounding the preferred or required method(s) of sulfur abatement, there is great uncertainty regarding the future supply of marine fuels, especially those of the low sulfur and middle distillate variety. The uncertainty surrounding the future supply of marine fuels in light of the recent IMO regulations is so great that the International Chamber of Shipping (“ICS”), the Baltic and International Maritime Council (“BIMCO”), the Oil companies International Marine Forum (“OCIMF”), and the International Association of Dry Cargo Shipowners (“INTERCARGO”) have filed a joint submission to the IMO asking for the MEPC to assess the supply of MARPOL Annex VI compliant fuels “as soon as possible”.

Nonetheless, experts agree that global demand for all marine fuels will continue to grow into the near future. As recently as mid September 2010, a “realistic” annual growth rate for global marine fuel demand was pegged at ~2% annually as calculated by

EnSys Energy and Navigistics, two energy think-tanks used by the US EPA and the ICS. These demand figures includes both residuals and marine distillates.\textsuperscript{4}

There are two methods to achieve compliance while operating in the ECA’s, both now and in the coming years: burn lower sulfur and higher grade marine distillates or employ scrubbers allowing for the use of higher sulfur residual fuels. This paper will show the current and future economic viability of scrubbers of the recent MEPC resolution. Additionally, it will highlight why scrubbers are the preferred choice of abatement over fuel blending or a wholesale switch to marine distillates from a perspective of global supply and demand.

New Global and Regional Emissions Standards

Effective immediately, marine vessels will be required to burn 1.0% sulfur bunker fuel when sailing within Emissions Control Areas (“ECA”). At the time of writing, only two enforceable ECA’s existed worldwide - the Baltic Sea and the North Sea (includes English Channel). However, a similar 1.0% ECA has been declared off the coasts of Canada and the United States becoming effective during the summer 2012 (see Figure 2 below). It is projected that Mexico will join this ECA in coming months and years. According to the EPA website, “we have also had discussions with the Mexico National Institute of Ecology (INE) regarding inclusion of Mexico in the joint application . . . we expect to work with Mexico separately, if necessary to extend the ECA in the future.”

Figure 2

(Source: EPA)

Beyond the tightening regulations in the ECA’s, which will tighten further to 0.10% in 2015, the global standard fuel standard (e.g., the fuel burned on open waters) will drop to 3.5% starting in

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2012 and then 0.5% in 2020 which is subject to feasibility study (supply focused) beginning in 2018. See Figure 1 for representation of the new regulations.

**Global Trend towards Marine Distillate in Shipping**

As described in the opening paragraph of the introduction, MAERSK, the world’s largest container ship company, has voluntarily switched to a lower sulfur middle distillate, specifically MDO, while sailing through or berthed in the Port of Hong Kong. For the sake of human and environmental health, they are encouraging their competitors to follow suit.

Similarly, INTERTANKO, the International Association of Independent Tanker Owners, is a vocal proponent of an industry-wide wholesale transition to middle distillates over fuel blending or on-board scrubbers. INTERTANKO states that “low sulfur marine distillate fuel offers the best net environmental impact compared to the current alternative measures.” They contend that an industry wide switch to marine distillates would comply with MARPOL Annex VI mandated sulfur limits by weight, while reducing emissions of sulfur oxide, nitrous oxide, carbon dioxide and particulates. Additionally, a transition to marine distillates would reduce overall fuel consumption due to its higher energy content compared to residuals. Lastly, they believe that MDO provides the greatest safety advantages “that cannot be matched by the use of LSFO and/or HSFO together with scrubbers.”

Nonetheless, INTERTANKO recognizes the higher fuel costs associated with burning marine distillates, both in upfront costs and operating costs. Ships designed and built to burn residual fuels require costly modifications and upgrades in order to burn marine distillates to prevent fouling and misfiring of the fuel pumps and injectors - imagine putting gasoline in a diesel car engine. With regard to fuel costs, 0.10% Sulfur Marine Gasoil traded at a 58% and 68% premium to 1.0% Sulfur Northwest Europe Fuel Oil (“1% NWE”) and 3.5% Sulfur Rotterdam Fuel Oil (“3.5% ROTT”) at the Port of Rotterdam in 2009. It must be noted that these increased fuel costs are typically passed onto the charter party; therefore, the operator is not absorbing the

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7 According to the 52 week average price per metric ton as printed by Bloomberg
increased cost of operation by using marine distillates. In the same press release, INTERANKO references the concerns surrounding the future availability of marine distillates, but does not expound on the topic.

At the time of writing, there are only two Emissions Control Areas in the world, a moderate global supply of LSFO and marine distillate, and a spread between LSFO and HSFO of between $25 and $35\(^8\). Therefore, it is easier and arguably more economical to burn a blend of HSFO and LSFO or marine distillate to meet the current sulfur regulations rather than installing costly scrubbers. However as sulfur emissions regulations tighten and the size and number of ECA’s grows, scrubbers will quickly become more economical.

**What Does a Wholesale Transition to Marine Distillates Look Like?**

In 2010, when the sulfur limit by weight while operating inside the ECA is 1.0% and the Global limit is 4.5%, compliance can be met with relative ease by purchasing a mix of low and high sulfur residual fuels. As sulfur emissions regulations tighten further in 2012, again in 2015 and later in 2020, it will be increasingly difficult to meet emissions regulations without extensive fuel blending or switching to distillates (see Figure 3 below) especially when operating within ECA’s.

\[\text{Figure 3}\]

(Source: Purvin & Gertz)

\(^8\) From January 2006 until mid September 2010, the mean spread of NWE 1% over 3.5% ROTT is $33.07, mode of $25.00 and a median of $25.25. The 38 week average in 2010 was $29.67.
Energy Futures Inc., a transportation energy and environmental think-tank/consultancy, gives some perspective on what an industry-wide transition to marine distillate looks like. They contend that a wholesale fuel switch of 300 million tons annually (rough estimate of annual global bunker demand) of marine fuel from residuals to distillates would “require an increase in global oil production of 900 million tons per year, which translates to about 6.6 mmBPD. This is greater than the entire oil production today from any country other than Saudi Arabia or Russia.”

In a 2009 article released by the US Energy Information Administration, they reference the effects of the MARPOL Annex VI sulfur regulations on the distillate supply and prices.

“Lowering the sulfur content of bunker fuel would necessitate either the use of desulfurized marine diesel . . . or a massive investment in exhaust scrubbers . . . Given the tightening supply of diesel, potential new demand for more diesel to fuel marine freight travel would bring additional pressure on diesel supplies, further increasing the price differentials between distillate and other petroleum fuels . . . although marine bunker fuel makes up less than 5 percent of total global petroleum product consumption, it nevertheless has served as an important market for high-sulfur heavy residual fuels.”

Poten and Partners, a shipping and energy broker and advisor, estimates that in a scenario where “marine exhaust scrubbing technology is not commonly used” to meet fuel exhaust restrictions that “there does not seem to be sufficient diesel/gasoil to blend into resid[ual] to meet global bunker demand.” They continue that “the [former Soviet Union] and the Middle East [are] expected to meet the bunker fuel blending demand [with gasoil and diesel]. However Europe, Asia and both Americas are expected to come up short.”

As noted by the EIA and Poten and Partners above, the exact demand and supply of distillates globally is difficult to estimate, but it is agreed that a transition to distillates by the shipping

industry would have profound negative effects on the global price and supply nonetheless. In addition to the negative supply and demand effects on distillates, residual fuels would be in great oversupply. As residual fuels are phased out of terrestrial power-generation for cleaner burning technologies (e.g., natural gas), the marine shipping industry is becoming the primary and dominant demand center for the residual fuel stream.

In a separate edition of Fuel Oil Monthly, Poten and Partners calculates that if distillates are used, rather than scrubbers, that “residual bunker fuel demand will be about 50 million metric tons in Europe in 2015.” Taking into account fuel oil production and inland plus bunker demand, Europe might be long 10 million metric tons of fuel oil.” This compares to a relatively “balanced” supply and demand scenario if scrubbers are “widely utilized.”

The Refining Problem

Many contend that the squeeze of low sulfur fuels in the coming years is an issue of refining. Sweeter crudes are required when cracking low sulfur products due to the presence of metals (e.g., vanadium and nickel) in sour crudes which “poisons the sulfur extraction catalysts” during the fuel oil refinement process.” Furthermore, “amongst [crude] reserves, there are more heavy crudes and [sour crudes] than the mix of crudes that is produced today . . . the average crude sulfur content is expected to increase from the current 1.2% to 1.4% by 2020.” Therefore, as demand for low sulfur products increases, the supply of low sulfur products feedstock decreases.

Despite the marginal decrease in sweet crudes, the real supply lever of both residual fuels and distillates will be global refining capacity. Since residual fuels are technically a by-product of the refining process and trade at a discount to crude, both the supply and the price of residual fuels

will be dependent upon the price of crude and the demand for lighter and higher valued products.

The demand for distillates is undoubtedly going up, both in and out of the shipping industry. However, the refining capacity will change little in the medium and long term. Due to the engineering complexity, high capital costs, and general NIMBYism, the time to site, build, and bring a new refinery online is roughly four to five years per refinery. Bunkerworld estimates a fifteen year lead time to build out enough refining capacity to meet the growing demand of distillates; “designing and constructing these [refining] units around the world would take at least 15 years.”¹⁵ Shell Global Solutions says that “we could find that when 2020 arrives much of the refining infrastructure may look as it does today.”

Uncertainty is the greatest obstruction to refining capacity investment and growth, especially as it relates to distillate demand within the shipping industry. Currently, it is unclear whether distillates or scrubber technology will be the preferred method of emissions abatement.

“On-board ship abatement technology may prove to be a viable and cheaper alternative to comply with the desired emissions levels. Should that turn out to be the case, the demand for the new marine [distillate] fuels will be lower and the refiner may be left with an expensive production capacity and no market.”¹⁶

It is agreed that economics, rather than policy, will determine the preferred method of abatement; at this time, the market is still undecided on its direction. Consequently, uncertainty begets inaction and little to no additional capacity will be created. Therefore, future distillate demand will outstrip supply.

**Current Scrubber Technologies**

Section 4.1.2.1 of Annex IV dictates that “an EGC unit should be certified as capable of meeting the limit value, specified by the manufacturer, with fuel oils of up to the highest global

¹⁶ Ibid.
[percentage] sulfur content under MARPOL Annex VI regulation 14(1)”. Section 2.3.1.1 and 2 of Annex 13 dictates that “when a ship operates within an Emission Control Area . . . the ship uses fuel oil with sulfur content that does not exceed the applicable limit . . . or an equivalent arrangement approved in accordance with regulation 4.1.”17 Put simply, ships may use scrubbers within ECA’s in lieu of fuel switching as long as the fuel used meets the global standard (e.g., 3.5% sulfur on open water starting in 2012).

As demand and prices for low sulfur marine fuels rises, the economics of scrubber installation becomes increasingly more attractive. A 2009 article in the Oil & Gas Journal explained that “scrubbing economics on large and medium-sized oceangoing vessels appear attractive in our analysis and could mitigate the fuel-quality changes required once the global requirements take effect.”18

There are a number of marine scrubber technologies on the market from various industrial manufacturers. However, there are two main categorizations of the technology:

**Wet, Open-Loop or Seawater Systems** use the natural alkalinity of seawater to neutralize or wash the exhaust gases. Wash water is discharged back into the ocean after reaching a mandated level of cleanliness as dictated by the IMO. These systems also produce a solid waste stream, specifically a non-hazardous sludge that requires on-land disposal (see Appendix Figure 1 for schematic).

**Dry, Closed-Loop or Freshwater Systems** combine freshwater (or brackish seawater with a lower pH to seawater) and an alkaline solution (e.g., Sodium Hydroxide -NaOH) to neutralize the exhaust gases. A small amount of wash water is disposed of overboard; however they can be operated in a zero-discharge mode. Similar to the wet system, sludge is produced and does require on land disposal (see Appendix Figure 2 for schematic).

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Despite the wide variety of manufacturers, this paper will focus exclusively on the Hamworthy Krystallon Exhaust Gas Cleaning System (Wet) and Wartsila SOx Scrubber (Dry). The EPA qualified the Krystallon system as an “Emerging Technology” to reduce particulate matter and the Wartsila system was awarded a SECA Compliance certificate. The cost per unit varies upon the displacement of the engines and the complexity of the installation. Krystallon systems are quoted between $700m to $3mm depending upon the displacement of the vehicle\textsuperscript{19}; limited information was available for the pricing of the Wartsila systems.

**Economic Analysis of Scrubber Technologies**

As outlined in the sections above, ship owner/operators will be required to reduce their sulfur emissions while operating in an ECA. They may either blend lower sulfur fuels or employ an equivalent technology (e.g., scrubbers). Despite their high upfront costs, scrubbers allow ship owners and operators to burn a cheaper and higher sulfur fuel while sailing in ECA’s. Since it is not necessary to purchase the more expensive lower sulfur fuel, scrubbers create savings over the life of the installation. The savings are the difference of between the more expensive low sulfur fuel and the cheaper high sulfur fuel multiplied by the time spent operating in the ECA. The percentage time of the journey spent in the ECA is the multiplier because high sulfur fuel (e.g., 3.5% ROTT) can be burned outside the ECA in open waters without the necessity of scrubbers (or blending).\textsuperscript{20} Therefore, the costs and savings are calculated as follows:

**Identities**

\[
\begin{align*}
T & = \text{Percentage Time Spent inside ECA’s} \\
(1-T) & = \text{Percentage Time Spent outside ECA’s} \\
L & = \text{Price per Ton of Low Sulfur Fuel} \\
H & = \text{Price per Ton of High Sulfur Fuel} \\
(L-S) & = \text{Spread between Low Sulfur and High Sulfur Fuels} \\
C & = \text{Monthly Vessel Consumption} \\
P & = \text{Estimated Cost of Scrubber Installation} \\
R & = \text{Monthly Interest Rate}
\end{align*}
\]


\textsuperscript{20} Until 2020 when global sulfur limit by weight will drop to 0.50%, assuming a positive supply/demand feasibility study in 2018 conducted by the IMO.
\[ N = \text{Number of Financing Months} \]

**Monthly Fuel Costs without Scrubbers:**
\[ [T \times L \times C] + [(1-T) \times H \times C] \]

**Monthly Fuel Costs with Scrubbers:**
\[ [H \times C] \]

**Monthly Savings of Scrubbers:**
\[ ([T \times L \times C] + [(1-T) \times H \times C]) - [H \times C] \]

Rewritten:
\[ (L - H) \times T \times C \]

**Monthly Financing Cost(s) of Scrubber**\(^{21}\)
\[ \frac{(P \times R)}{(1 - (1 + R)^{-N})} \]

These savings, specifically the ‘Monthly Savings of Scrubbers’, are compared against the ‘Monthly Financing Cost(s) of Scrubber’. When the two numbers are equal in value that is the breakeven point of the scrubber installation - the point in which it is more economical to install scrubbers than pay for the more expensive lower sulfur fuel. Every vessel is different; each vessel has different fuel efficiency, engine displacement, and charter route(s). However, the three main factors in determining the breakeven point of scrubber installation on a particular vessel are the spread between the low sulfur and high sulfur fuel ("the spread"), the number of financing months and the monthly interest rate. Both the number of financing months and the monthly interest rate are firm specific and referred to as the “payback period” and the “cost of capital” respectively. The payback period, sometimes referred to as an investment horizon, is the number of years it takes to recoup an investment. The “cost of capital” is the cost, in percentage terms, of borrowing money as determined by the capital structure of a firm. It is a benchmark value for new projects and it is used to discount future cash flows for net present value calculations.

For this analysis the following vessel specifications were used for calculations\(^{22}\):

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\(^{21}\) This is the calculation for the fixed monthly payment of a fixed rate mortgage. The amount paid by the borrower every month to ensure the loan is paid off in full with interest at the end of the term.

\(^{22}\)
Vessel Classification: AfraMAX  
Vessel Capacity: 100,000 DWT  
Installed Power: ~17 Megawatts  
Daily Operation: 24 Hours/Day  
Annual Operation: 300 Days/Year  
Fuel Consumption: 69 Tons/Day  
Fuel Consumption: 1725 Tons/Month

Breakeven points were calculated and graphed - cost of capital (X-Axis; up to 30%) against fuel spread (Y-Axis) for two and five year payback periods (see Figures 4 and 5 below). Five curves were plotted per graph; each curve represents a percentage split of operation inside and outside of an ECA. For example, the red curve at the top of each of the graphs is the 40/60 % split – 40% of annual operation was inside the ECA and 60% of annual operation was outside the ECA. As can be seen in figures below, the more time spent in the ECA, the lower spread and breakeven curve and the more economical scrubbers become. The red curve (40%) is the least time in the ECA while the orange curve (80%) is the most.

22 Vessel specifications were taken from a presentation by FORCE Technology conducting similar analysis regarding CO₂ abatement in ship exhaust. Available here:  
To give context to these above listed spread levels, the 2010 38 week average European HiLo was superimposed on the graphs (gray dashed line). Graphed in Figure 6 below are the weekly fuel spread between 1% NWE LSFO and 3.5% ROTT HSFO (blue line) as well as 0.10% MGO versus 3.5% ROTT HSFO (red line) at the Port of Rotterdam/Antwerp from 2006 to mid 2010:

![Figure 6](image)

The European HiLo spread has been steadily hovering around $20 differential since early 2009. Therefore, a scrubber install is economical, and has been, for companies with relatively low cost of capital (i.e. large conglomerated shipping companies) for many months and years. In comparison, the average spread between LSFO and HSFO in 2010 (January through September) was $29.67 while the average spread between Marine Gasoil (“MGO”) and HSFO was $226.59. The average spread between MGO and LSFO was $196.91 during the same period. Therefore, as soon as it is necessary the ECA Sulfur Limit by weight drops to 0.1% in 2015, scrubbers become extremely economical for any vessels operating within the ECA for an extended period of time. These figures do not include the increased fixed costs in modifications and maintenance required to burn marine distillates in engines designed to burn residual fuels.
Scrubber Risks

Scrubbers provide ship owners and operators with a cost effective method of meeting MARPOL Annex VI sulfur regulations, both currently and in the future. However, they do carry with them inherent risks, both environmental and health-related.

Both types of scrubbers systems produce waste streams of sludge/slurry and wash water. The sludge/slurry is heavy in sulfur, heavy metals and other particulates and is ultimately dependent upon the quality of fuel burned from the onset. The sludge/slurry is considered non-hazardous waste by the IMO and the EPA, but it does require on-land disposal which has its inherent environmental and health risks.

According to materials prepared by Hamworthy-Krystallon for an Exhaust Gas Cleaning Systems Association workshop in September of this year, their wet/seawater systems generate particular matter in the order of 0.1 kg/MWh (kilogram per megawatt hour). However, the observed collection of particular matter was closer to 0.02 – 0.05 kg/MWh. At a dockside pickup disposal cost of €400 per ton (disposal costs provided by Hamworthy Krystallon) the vessel referenced in the Economic Analysis of Scrubber Technologies section would incur a disposal cost of €489.60 per month, operating 24 hours a day for 30 days consecutively. Although this is a stout figure in absolute terms, when compared to the cost of daily operation and charter rates of these vessels which run in the thousands of dollars a day and millions of dollar per journey, this is a nominal fee.

Similar to the sludge/slurry, the wash water contains trace amounts of the same by-products as the sludge/slurry. However, more importantly the wash water is of a lower pH (more acidic) than the intake water. The dry/freshwater system requires the use of a caustic soda, typically sodium hydroxide, which is extremely basic and dangerous to handle. However, because the caustic soda solution is so basic it requires less intake water to neutralize the exhaust gases than the wet/seawater system. The wet/seawater system depends upon the natural alkalinity

of seawater in order to neutralize the exhaust gases. Consequently, wet/seawater systems are more efficient (intake water per lbs of sulfur removed) in the higher latitudes where the seawater temperatures are lower and the density and pH is higher.

Although all discharged by-products, both marine and terrestrial, are closely monitored by the ship’s crew to ensure compliance with international, domestic, state and/or local laws and regulations, each vessel is creating a new waste stream into the marine and terrestrial ecosystem that had previously not been present. If marine scrubbers are widely adopted within the marine shipping industry it is unclear of the cumulative impact on the terrestrial ecosystem as well as the ocean ecosystem, especially as it relates to ocean acidification.

Conclusions

Today, in 2010, there are two distinct pathways to achieve current and future compliance with MARPOL Annex VI’s sulfur emissions regulations: A) the burning of higher grade and lower sulfur marine distillates; or B) the installation and employment of marine based exhaust gas scrubbers.

At this point in time, with only two existing ECA’s, a Global sulfur limit of 4.5% and an in-ECA limit of 1.0%, it is relatively easy to achieve compliance by purchasing and burning low sulfur fuel oil when operating within the boundaries of the two ECA’s. However, as early as 2012 compliance will be more difficult and costly as ECA’s grow in number and in size and the sulfur limit in and out of the control areas falls.

By burning lower sulfur and higher grade distillate in order to reach compliance, ship owners and operators will increase the cost of shipping over time as the price of marine distillates rises and the spread between low sulfur marine diesel (e.g., MGO) and high sulfur residual fuel widens. This will cause an upward pressure on the global distillate supply, both terrestrial and marine, which could have cascading effects on the price of transportation and finished goods. As the marine shipping industry consumes more distillate and less residuals, stock piles of residual will grow. The growth of residual stockpiles will undoubtedly necessitate massive
investment in refining capacity worldwide (e.g., hydrocrackers and cokers) as refiners look to extract more refined products from the low-grade fuel.

By installing and employing exhaust gas scrubbers, individual vessels remove the unwanted sulfur after combustion rather during the refining process. Scrubbers do carry a high up-front cost, however the payback period is short especially with a low cost-of-capital and a high spread between low and high sulfur fuels. Most importantly, scrubbers allow for the continued burning of lower grade and higher sulfur (by weight) residual fuels that would otherwise necessitate disposal, storage or further refining.

The decision to purchase and install scrubbers should be made on a case-by-case basis by the vessel owner/operator as it relates to the organization’s operating costs, financing costs and trade routes. For some ship owner/operators, especially those who operate outside of and away from Northwest Europe and/or North America, scrubbers may not prove economical for many years to come. However, as was seen in Figures 3 and 4, fuel spreads do not have to be especially high to justify the purchase and installation of scrubbers. As we saw with AP Moeller Maersk’s brave announcement in September, when it comes to matters of human and environmental health, sometimes the analyses go beyond breakeven curves and payback periods.
Works Cited


APPENDIX
Appendix Figure 1

Appendix Figure 2

Closed loop works with freshwater, to which NaOH is added for the neutralization of SO₂.

Exhaust gas

Closed loop = Zero discharge in enclosed area

NaOH unit

Source: Finnish Institute of Marine Research
## Appendix Figure 3

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### Fuel and Consumption

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### Fuel Costs and Mix

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<td>ECA Emissions Limit by Weight</td>
<td>1.00%</td>
</tr>
<tr>
<td>Global Emissions Limit by Weight</td>
<td>3.50%</td>
</tr>
<tr>
<td>Time Spent In ECA's (Percentage)</td>
<td>80%</td>
</tr>
<tr>
<td>Time Spent Outside ECA's (Percentage)</td>
<td>20%</td>
</tr>
<tr>
<td>Low(er) Sulfur Fuel</td>
<td>NWE 1%</td>
</tr>
<tr>
<td>High(er) Sulfur Fuel</td>
<td>3.5% ROTT</td>
</tr>
<tr>
<td>Low(er) Sulfur Fuel Price</td>
<td>$348.12</td>
</tr>
<tr>
<td>High(er) Sulfur Fuel Price</td>
<td>$324.57</td>
</tr>
<tr>
<td>Fuel Spread</td>
<td>$23.55</td>
</tr>
<tr>
<td>Monthly Fuel Cost w/o Scrubbers</td>
<td>$592,374.95</td>
</tr>
<tr>
<td>Monthly Cost w/ Scrubbers</td>
<td>$559,878.61</td>
</tr>
<tr>
<td>Cost of Scrubbers per Month</td>
<td>$103,995.99</td>
</tr>
<tr>
<td>Fuel Spread</td>
<td>$32,496.35</td>
</tr>
<tr>
<td>Difference b/t Scrubbers and Fuel Switch</td>
<td>$(71,499.64)</td>
</tr>
</tbody>
</table>

### Financing

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Estimated Cost of Install</td>
<td>$3,000,000.00</td>
</tr>
<tr>
<td>Years of Financing</td>
<td>3</td>
</tr>
<tr>
<td>Months of Financing</td>
<td>36</td>
</tr>
<tr>
<td>Weighted Averaged Cost of Capital</td>
<td>15.00%</td>
</tr>
<tr>
<td>Monthly Rate</td>
<td>1.25%</td>
</tr>
<tr>
<td>Monthly Cost of Install</td>
<td>$103,995.99</td>
</tr>
</tbody>
</table>
### Appendix Figure 4

<table>
<thead>
<tr>
<th></th>
<th>17MW</th>
<th>100K DWT Aframax with Scrubbers</th>
<th>500 MW Coal Plant with Wet FGD Scrubbers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost (in millions) per SO(2) (lbs) Removed per Month</strong></td>
<td>$0.77</td>
<td>$0.88</td>
<td></td>
</tr>
<tr>
<td><strong>SO(2) (lbs) Removed per Month</strong></td>
<td>126,449</td>
<td>3,182,735</td>
<td></td>
</tr>
<tr>
<td><strong>SO(2) (lbs) per MMBtu</strong></td>
<td>1.86</td>
<td>1.67</td>
<td></td>
</tr>
<tr>
<td><strong>Fuel Price (MT)</strong> 1 month future week avg (11/26)</td>
<td>$474.35</td>
<td>$73.97</td>
<td></td>
</tr>
<tr>
<td><strong>Cost of Abatement per Month</strong> (3 yr, 10%, 33m)</td>
<td>$96,802</td>
<td>$2,168,333</td>
<td></td>
</tr>
<tr>
<td><strong>MMBtu per Metric Ton Fuel</strong></td>
<td>41.49</td>
<td>26.46</td>
<td></td>
</tr>
<tr>
<td><strong>Fuel Consumption per Month (MT)</strong></td>
<td>1,725</td>
<td>89,213</td>
<td></td>
</tr>
</tbody>
</table>

#### Assumptions:

<table>
<thead>
<tr>
<th>Fuel(s)</th>
<th>RESIDUAL</th>
<th>COAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur Percent by Weight**</td>
<td>3.50%</td>
<td>1.000%</td>
</tr>
<tr>
<td>Sulfur (lbs SO(2)/MMBtu)**</td>
<td>1.860</td>
<td>1.670</td>
</tr>
<tr>
<td>Sulfur Removed (Percentage)*</td>
<td>95.00%</td>
<td>80.75%</td>
</tr>
<tr>
<td>MMBtu/Metric Ton</td>
<td>41.494</td>
<td>26.455</td>
</tr>
<tr>
<td>BTU per Barrel of Resid*</td>
<td>628,700</td>
<td>n/a</td>
</tr>
<tr>
<td>Barrels of Resid per Metric Ton</td>
<td>6.6</td>
<td>n/a</td>
</tr>
<tr>
<td>Short Tons per Metric Tons</td>
<td>n/a</td>
<td>1,102,31131</td>
</tr>
<tr>
<td>Lbs per Metric Tons</td>
<td>2,204,623</td>
<td>2,204,623</td>
</tr>
<tr>
<td>BTU per Lbs (coal)**</td>
<td>n/a</td>
<td>12,000</td>
</tr>
<tr>
<td>$/US Short Ton (Jan 11 Future)</td>
<td>n/a</td>
<td>$67.10</td>
</tr>
<tr>
<td>O&amp;M of WGD (in millions per month)*</td>
<td>$1.10</td>
<td></td>
</tr>
<tr>
<td>Ann’ Capital (in millions per month)*</td>
<td>$1.07</td>
<td></td>
</tr>
<tr>
<td>Installed Power (MW)</td>
<td>17</td>
<td>500</td>
</tr>
<tr>
<td>Daily Operation (Hrs/Day)</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Days of Operation per Annun (Days/Yr)</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Coal Flow Rate (Short Tons/hr)</td>
<td>163.9</td>
<td></td>
</tr>
<tr>
<td>Fuel Consumption per Day (MT/Day)</td>
<td>69</td>
<td>3,568.50</td>
</tr>
<tr>
<td>Bunker Fuel Consumption Per Month (MT/Mo)</td>
<td>1725</td>
<td>89,212,54741</td>
</tr>
<tr>
<td>Bunker Fuel Consumption per Year (MT/Yr)</td>
<td>20700</td>
<td>10,705,50,569</td>
</tr>
</tbody>
</table>

*CEM

**NYMEX Spec Sheet

***Platts Spec Sheets