TECHNOLOGIES AND OTHER OPTIONS FOR REDUCING MARINE VESSEL EMISSIONS IN THE GEORGIA BASIN

DRAFT

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EXECUTIVE SUMMARY

Approximately seven million people live and work within the Georgia Basin/Puget Sound (GB/PS) airshed. Air pollution is of growing concern within this airshed both because the population is rapidly increasing and because society is becoming increasingly aware of the high health costs that air pollution incurs upon them. These health-related costs have been estimated to be in excess of $2 billion/year.

Marine vessel emissions within the GBPS area form a significant fraction of the total atmospheric emissions, especially in the case of sulphur oxides (SOx) and nitrogen oxides (NOx). For example, the Greater Vancouver Regional District (GVRD) emission inventory for the year 2000 indicates that marine vessels contribute 33% of the SOx, 22% of the NOx and 7% of the particulate matter (PM) in the Lower Fraser Valley, which is comprised of the GVRD plus the Fraser Valley Regional District.

A previous, 2002 Environment Canada project *Fuel Quality Options for the Reduction of Marine Vessel Emissions in the Georgia Basin* investigated the cost-effectiveness of different clean-fuel options for reducing emissions marine vessels and suggested how these options might be implemented.

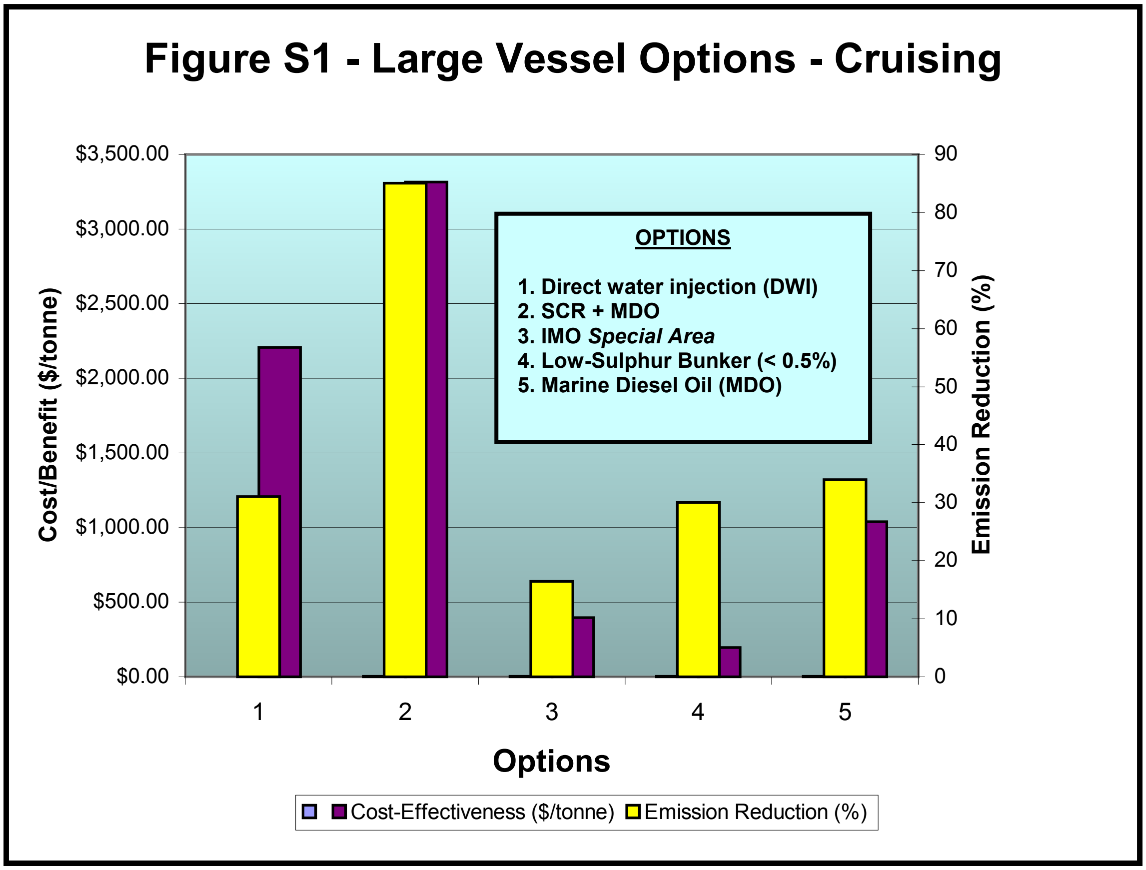
This project is an extension of the above investigation. Here we look at the cost-effectiveness of different technological options for reducing marine vessel emissions for four classes of vessels – large, ocean-going vessels, cruise ships, ferries and work boats. Clean-fuel options will also be included, where appropriate, for purposes of comparison. Examples of where these emission reduction options have already been used will be given, as will suggestions on how they may be implemented through economic or regulatory instruments.

S.1 Ocean-Going Vessels (Tankers, Freighters, Container Ships)

There were in excess of 1,500 different large, ocean-going vessels entering the GB/PS area during the year 2000. They were responsible for over half of the total marine vessel emissions that year - NOx emissions of 40,571 tonnes (45.2%), SOx emissions of 16,881 tonnes (74.2%) and particulate emissions of 2,635 tonnes (59%). Docking emissions are responsible for approximately 52% of the total emissions from large, ocean-going vessels.

Figure S1 shows different options for reducing emissions from large, ocean-going vessels while underway. It can be seen from Figure S1 that while the greatest reduction of emissions can be achieved with Option 2 (Selective Catalytic Reduction plus using Marine Diesel Oil), this option also is the least cost-effective (highest cost/benefit ratio).

Option 4 (using low-sulphur bunker) provides the greatest pollution reduction (mainly reduced SOx and particulate emissions) per dollar spent. Tankers that enter the Port of



Valdez in Alaska are presently practicing this option. The operators have a voluntary agreement with the State of Alaska to burn low-sulphur bunker (< 0.5% S) while in the Port of Valdez. The low-sulphur bunker that they use comes from the Tesoro Refinery in Puget Sound at a cost premium of $60/tonne over regular bunker (IFO 380). At present there is insufficient low-sulphur bunker for all large vessels operating in the GB/PS area. However, when there is a demand for this product then it will be made available.

MDO (Option 5) is also already being used by large vessels to reduce their smoke and SOx emissions while underway in a sensitive area (e.g. the *Iver Pride* within the GB/PS area.). The advantage of this option over Option 4 is that MDO is readily available, even though more expensive than low-sulphur bunker.

A combination of Option 1 (DWI) and Option 4 (MDO) would result in large reductions of NOx, PM and SOx. Total emissions would be reduced 65.4% at a cost of $1,542/tonne. This is probably the most cost-effective way to significantly reduce emissions from large vessels while they are underway. Wartsila presently uses DWI on some of their large marine diesels, however, as a retrofit technology for other manufacturer's engines it may require further development.

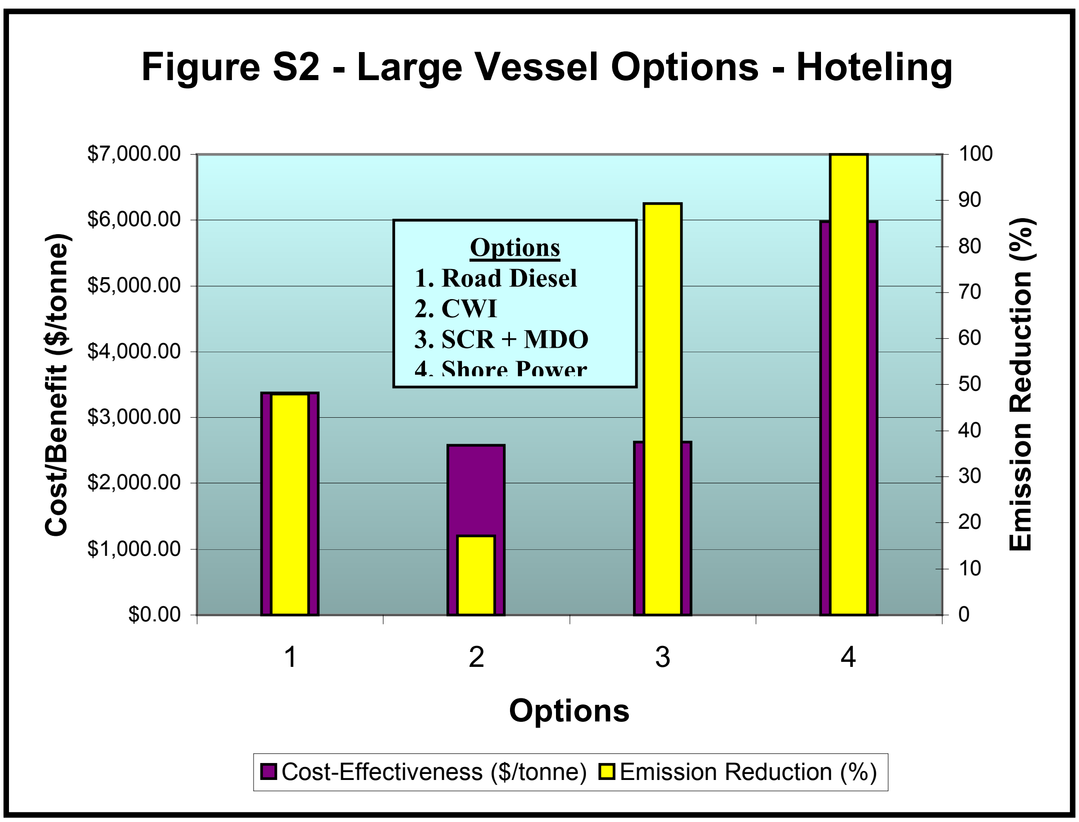
Probably the most effective way to implement these options in the GB/PS area, where most of the large vessels are foreign-flagged, is through the use of differential port fees, similar to the system that is in place in Sweden for NOx and sulphur. Fees would be based upon certifications and guarantees of fuel sulphur and machinery NOx emissions. To prevent port avoidance by vessel operators, a system of special port fees based upon fuel sulphur and certified NOx emissions would have to be applicable to all ports on the West Coast.

Figure S2 shows some of the options that are available for reducing emissions from large, ocean-going vessels while they are docked. Docking emissions are estimated to form approximately 52% of their total emissions.

Shore power (Option 4) achieves the maximum emission reduction (100%) but is also the most expensive option ($6,000/tonne). It would not be applicable to vessels moored at anchor. This option is, however, being implemented in Los Angeles as a technically feasible way of significantly reducing emissions from large vessels while they are in port.

One of the most cost-effective technologies for reducing total hoteling emissions by nearly 90% is seen to be Option 3, a combination of selective catalytic reduction (SCR) for NOx control, and MDO for reducing particulates and SOx. This option has a cost-effectiveness of $2,700/tonne.

Not shown is the use of MDO for hoteling. This option would be similar to Option 1 in cost-effectiveness.



Vessel emission reductions while at dock could be implemented through differential port fees, which are an economic instrument, or through regulations imposed by local State air pollution regulatory bodies for stationary sources. Of these two options, the Swedish system of certification for fuel sulphur and machinery NOx emissions would be the easiest and least costly to implement. Again, it would have to be implemented equally by all ports on the West Coast.

S.2 Cruise Ships

Cruise ships are becoming an increasingly significant fraction of the vessel fleet within the GB/PS area. During the year 2000 twenty-six separate cruise ships operated within the GB/PS waters. Their emissions formed 13.8% of the total marine vessel emissions during 2000 – NOx emissions were 11,079 tonnes (12.3%), PM was 638 tonnes (14.3%) and SOx was 4,446 tonnes (19.5 %). Emissions while at dock form approximately 14% of the total cruise ship emissions within the GB/PS area.

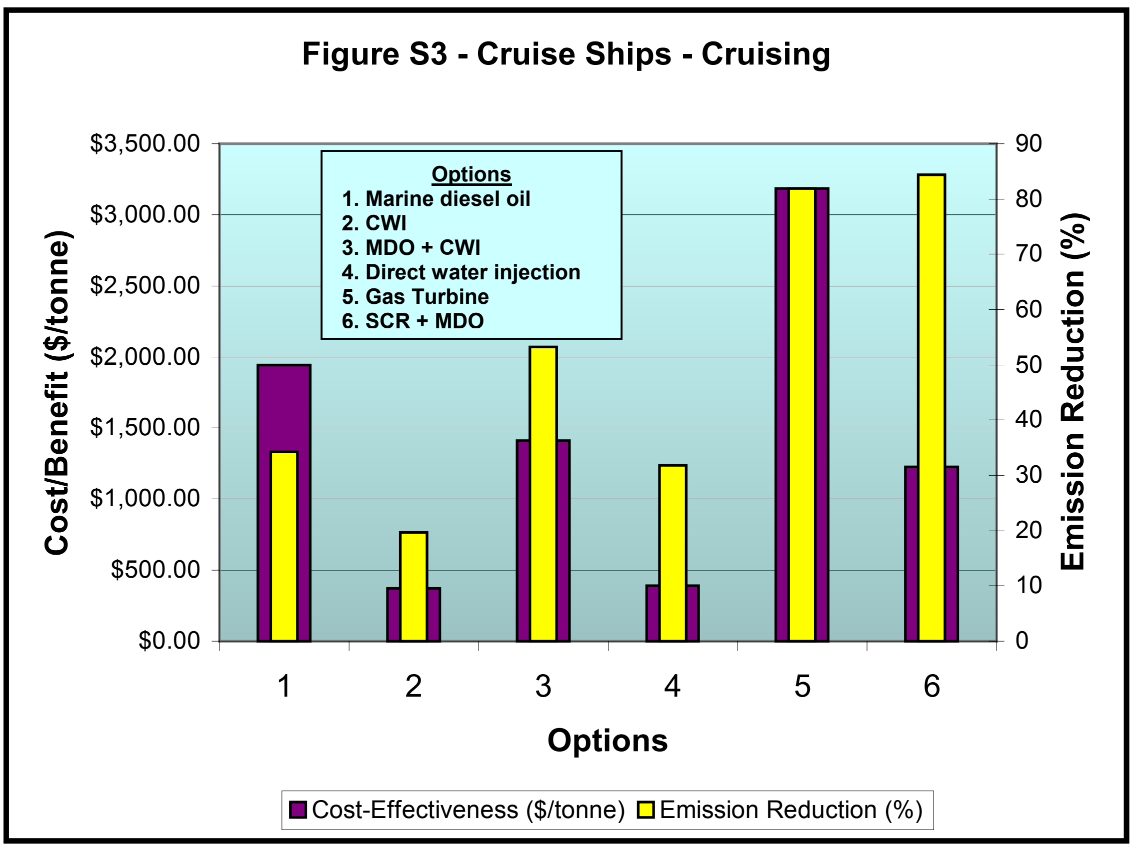


Figure S3 shows the cost-effectiveness and reduction (%) for some of the emission reduction options that were studied for cruise ships.

It can be seen that Option 2, CWI (continuous water injection) is one of the most cost-effective technologies but only reduces total ship emissions by about 20%. Option 6, SCR (selective catalytic reduction of NOx) plus MDO, results in the greatest emission reduction and is much more cost-effective than using say gas turbines. However, gas turbines may have weigh and space saving credits as well as other advantages that have not been factored into the cost-effectiveness equation. Cruise ship companies are introducing vessels powered with gas turbines (e.g. Princess Cruises' *Coral Princess* is engined with a GE LM2500+ aeroderivative gas turbine), so the advantages must outweigh the operational cost penalty.

SCR is widely used in Scandinavia to reduce vessel emissions; the technology is mature and the costs are well known.

Implementation by the cruise ship industry of emission reduction initiatives for vessels while underway within the GB/PS region could be voluntary or through differential port fees as discussed above regarding large, ocean-going vessels. Presently most vessels voluntarily burn a lighter bunker (IFO 180) instead of a heavier but cheaper bunker (IFO 380) in order to reduce their emissions of visible smoke.

Figure S4 - Cruise Ship - Hoteling

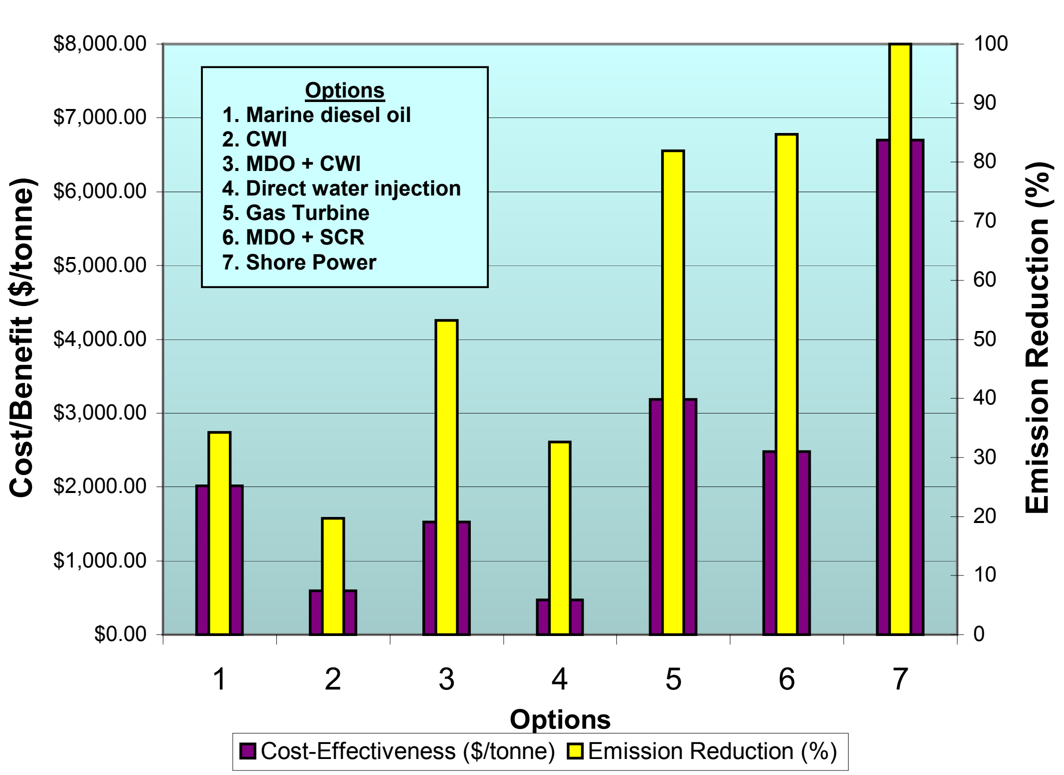


Figure S4 shows the cost-effectiveness and emission reduction (%) for some of the emission reduction options that were looked at for cruise ships while they are at dock.

Option 4, direct water injection, is seen to be the most cost-effective option (mainly NOx and particulate reduction) while Option 7, shore power, results in the greatest reduction. Option 6, SCR (selective catalytic reduction of NOx) plus MDO, is almost as effective as shore power but at a much lower cost. As previously discussed, SCR is widely used in Scandinavia and is proven technology.

Shore power is coming into increasing favor within the cruise ship industry as a way of eliminating visible emission complaints while at berth. Princess Cruise has converted two of its vessels to shore power for berthing in Juneau, Alaska, where there are very stringent and expensive regulations concerning visible emissions.

Implementation of emission reduction measures for hoteling cruise ships could be carried out using differential port fees, through stringent and expensive regulations concerning visible emissions as is done in Alaska, or via state emission limits for stationary sources. The differential port fees would be a logical strategy to employ if already used to reduce underway emissions.

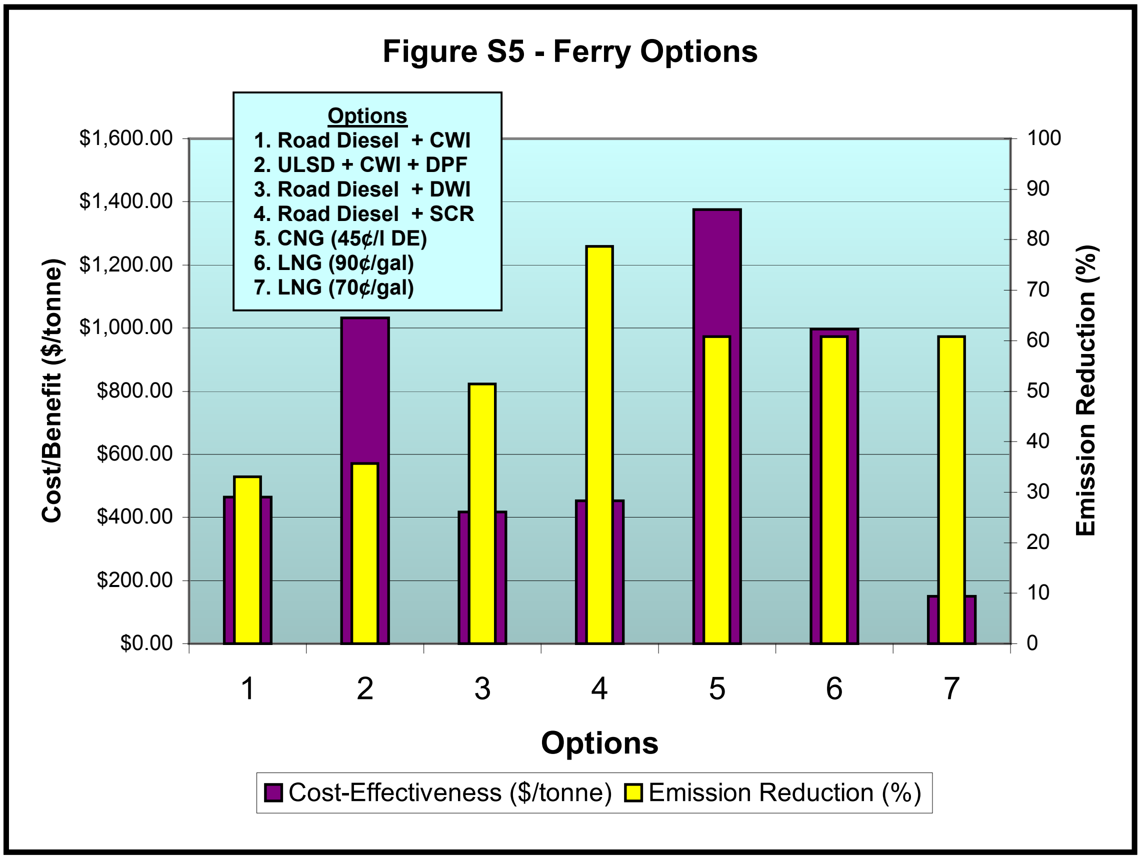
S.3 Ferries

There are a total of over 100 ferries operating within the GB/PS area. Total emissions during year 2000 were 15,910 tonnes, or 13.6% of the total marine vessel emissions in this region. NOx emissions were 15,140 tonnes (16.85%), PM emissions were 263 tonnes (5.9%) and SOx emissions were 507 tonnes (2.2%). Ferry emissions while at dock comprised 17.7% of the total ferry emissions in the GB/PS area.

Figure S5 shows the cost-effectiveness and percent emission reduction for the emission reduction options that were studied for ferries. (ULSD is ultra-low sulphur diesel (< 15 ppm S), CWI is continuous water injection, DPF is catalytic diesel particulate filter, DWI is direct water injection and SCR is selective catalytic reduction of NOx.) The CNG and LNG costs are based upon estimated delivered prices by the natural gas distribution company ENRG, and are highly sensitive to commodity prices.

It can be seen that the greatest emission reduction can be achieved using Option 4, SCR (selective catalytic reduction) and low-sulphur road diesel (< 500 ppm S). This is also cost-effective compared to other options. Option 7, using LNG, is seen to be the most cost-effective option if the price of LNG can be reduced through negotiations and long-term contracts.

LNG is presently being used the 100-car, 95-metre ferry *Glutra* entered service near the city of Molde, Norway in 1999. The ferry is refueled by tank truck at night. In Canada and in the USA the use of LNG would have to be approved by the Coast Guard. This may present problems but they should not be insurmountable.



Ferry emission reduction implementations could be left to local state air pollution regulatory bodies in the form of some sort of phased-in emission regulations or emissions cap and trade. The cap and trade strategy is very effective in California for controlling air pollution. New stationary source owners have to buy offsets as required by district *New Source Review* programs. The 2001 average price paid for NOx was $27,100/ton, for PM10 was $46,150/ton and for SOx was $12,810 per ton. As can be seen from Figure S5, the ferry operators could quickly recover the cost of their pollution control investments at these prices.

S.4 Work Boats

There are about 490 workboats (tugboats, tenders, etc.) and 45 government vessels that operate within the GB/PS area. Workboats generally use medium to high-speed diesel engines that burn regular diesel, or low sulphur diesel if that is all that is available.

The workboats emitted 23,240 tonnes of NOx, PM and SOx during the year 200, or about 20% of the total marine vessel emissions. NOx emissions were 22,310 tonnes (24.8% of total NOx), PM was 249 tonnes (5.6% of total PM) and SOx was 681 tonnes (3.0% of total SOx).

The engines used in workboats are typically in EPA Category 1 and hence the engine manufacturers are subject to EPA Tier 1 and Tier 2 regulations. These regulations will significantly reduce emission from new diesel engines by the year 2004. However, the phase-in period for workboat engines is well in excess of 10 years, unless there is a government-subsidized engine replacement program such as California's Carl Moyer program. Therefore it may be desirable to implement other, more immediate, alternatives for reducing emissions from this class of vessels.

Figure S6 - Work Boat Options

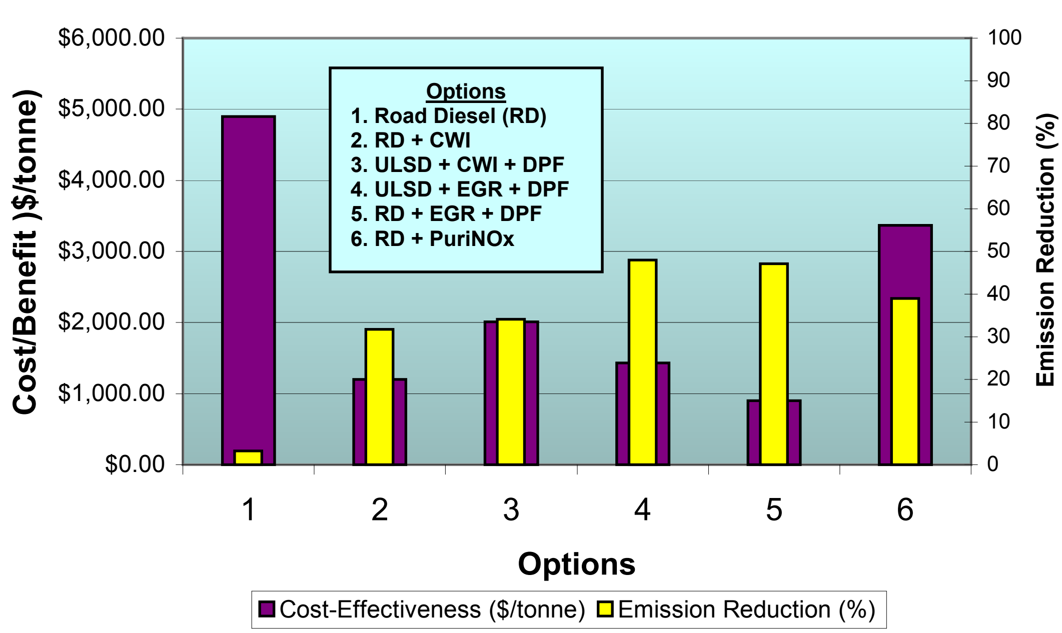


Figure S6 shows the cost-effectiveness and percent emission reduction for various emission reduction options for workboats. (CWI is continuous water injection; ULSD is ultra-low sulphur diesel (<15 ppm S), DPF is catalytically regenerated diesel particulate filter, EGR is exhaust gas recirculation, PuriNOx is a diesel-eater emulsion.)

Workboats, such as tugboats, in Canada are regulated by the Ship's Registry (Transport Canada) according to their size (volume). Increasing the boat size by installing a bulky exhaust-treatment system may bump the vessel into the next size category, resulting in different ship safety regulations and costs. The options shown in Figure S6 have been selected to minimize their impact upon vessel volume.

The greatest emission reductions are seen to be those using EGR (Options 4 & 5). These options are also cost effective. The EGR system that is the basis of the cost-effectiveness estimate is the Johnston-Matthey system. This system is compact and has been retrofitted to diesel buses; therefore the space limitation that exists in workboats should not be a barrier to the use of this and similar compact technology.

Implementation of workboat options is best done through some sort of emission trading program, wherein existing operators are paid for their emission reductions and can therefore economically benefit when installing the control devices.

The optimal strategy for reducing marine vessel emissions within the GB/PS area would be via economic instruments wherein the vessel owners can choose the most cost-effective option for their situation.

It is recommended that further studies be carried out to explore the feasibility of introducing differential port fees and emission trading to the entire West Coast.

ACKNOWLEDGEMENTS

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TABLE OF ACRONYMS

BHP	Brake Horse Power
BSFC	Brake Specific Fuel Consumption
CAC	Criteria air contaminants (CO, VOC, NOx, SOx, PM)
CARB	California Air Resources Board
CNG	Compressed Natural Gas
CORE AREA	GVRD and Fraser Valley of B.C.
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CWI	Continuous Water Injection
DPF	Diesel Particulate Filter
DWI	Direct Water Injection
EPA	US Environmental Protection Agency
EXTENDED AREA	Coastal Washington & lower coastal B.C., excluding CORE AREA
FVRD	Fraser Valley Regional District
DOC	Diesel Oxidation Catalyst
GB/PS	Georgia Basin/Puget Sound airshed
GEORGIA BASIN	Georgia Coast Cascade Air Basin (same as GB/PS)
GHG	Green House Gas (example – CO_2)
GVRD	Greater Vancouver Regional District
GCCAB	Georgia Coast Cascade Air Basin (same as GB/PS)
HFO	Heavy Fuel Oil
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
LFV	Lower Fraser Valley

LNG	Liquefied Natural Gas
MECA	Manufacturers of Emission Controls Association
MDO	Marine Diesel Oil
MOU	Memorandum of Understanding
NOx	Oxides of Nitrogen, reported as nitrogen dioxide
PM	Particulate Matter (example – diesel fume)
$PM_{2.5}$	Particulate Matter less than 2.5 microns in diameter
PPM	Parts per Million
S	Sulphur
SCFT	Standard Cubic Foot
SCR	Selective Catalytic Reduction (for NOx removal)
SHP	Shaft Horse Power
SOF	Soluble Organic Fraction
SOx	Oxides of Sulphur, reported as sulphur dioxide
TONNE	Metric ton (1000 kilograms)
TPY	Tonnes per Year
ULSD	Ultra-Low Sulphur Diesel (< 15 PPM S)
VOC	Volatile Organic Compounds

Note: **All dollars in this study are $ USA unless otherwise stated. This is because marine fuel prices are usually quoted in $ USA.**

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Report Objectives:

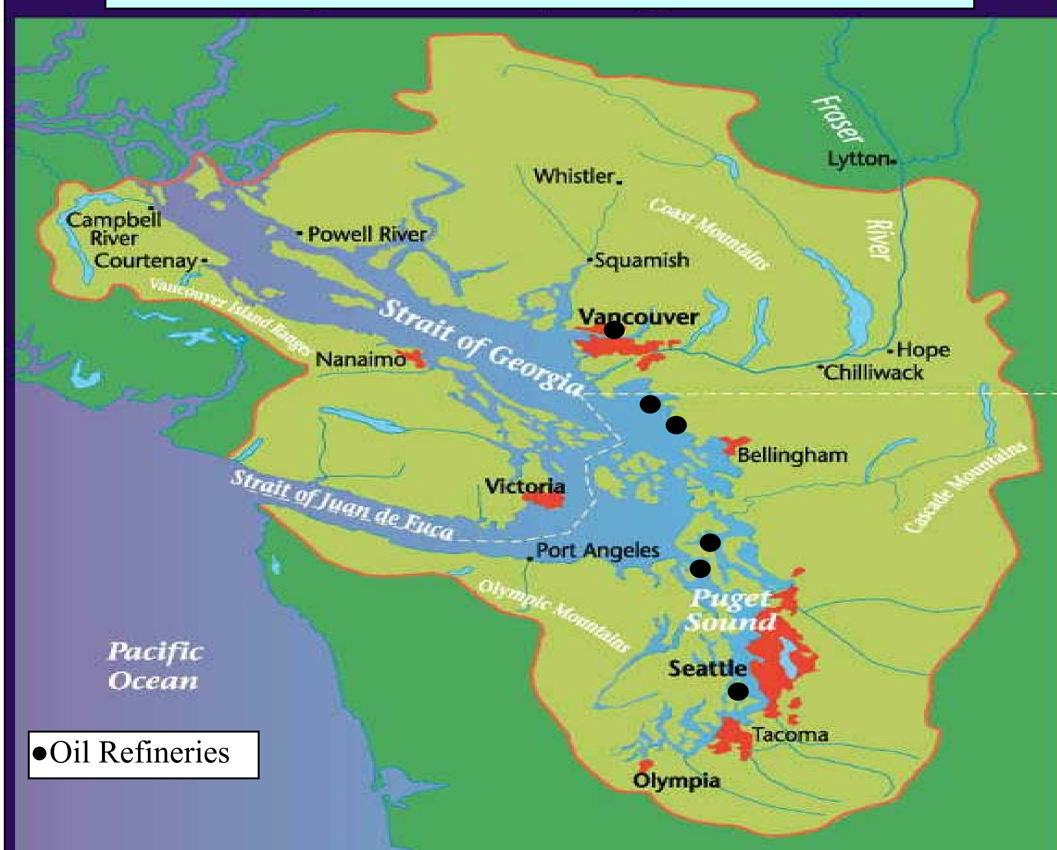
- The object of this report is to investigate the feasibility for reducing marine vessel emissions of SO_x, NOx and PM into the Georgia Basin airshed through the use of improved diesel engine technologies; exhaust treatment systems, shore-power systems and advanced fuel-engine combinations. Both the cost of implementing these technologies, and the associated reduction in vessel emissions, are studied.

- A second objective is to review and document marine vessel emission reduction initiatives in major international ports, and discuss the applicability of these initiatives to the Georgia Basin area.

1.2 Background

The Georgia Basin airshed is shown in Figure 1. It shares a common airshed with the Puget Sound region of the USA. Major cities (shaded in red) include Vancouver and Victoria in British Columbia, Canada and Seattle and Tacoma in Washington, USA.

Figure 1: GEORGIA BASIN/PUGET SOUND

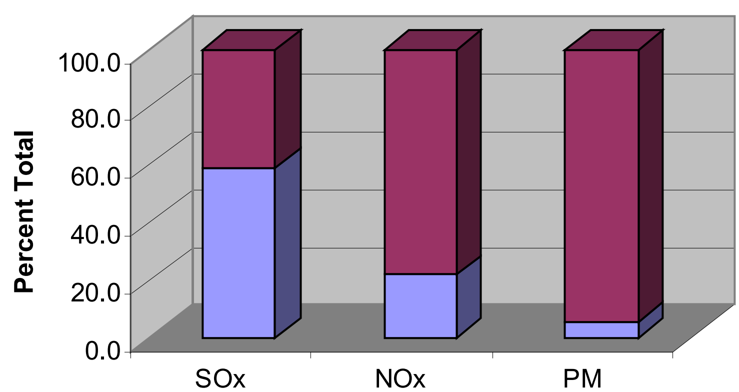


Also shown in Figure 1 are the approximate locations of six oil refineries. Major shipping lanes are from the Vancouver and Seattle/Tacoma areas out to the Pacific Ocean through the Juan de Fuca Strait.

Approximately seven million people live within the Georgia Basin/Puget Sound airshed.[1] Air pollution can accumulate because of limited mixing due to the surrounding mountains. The Lower Fraser Valley (LFV, roughly the region extending from the Greater Vancouver Regional District (GVRD) up the Fraser River valley to Chilliwack) hosts in excess of two million people. The annual cost of air pollution on human health within the LFV has been estimated at $830,000 in 1990, and is projected to rise to $1.5 billion in 2005 ($Canadian).[2]

Up to 16,000 Canadians die prematurely each year due to air pollution. A Health Canada study reviewed 10 years of data and found that non-accidental deaths in Greater Vancouver increased by 8.3% on high pollution days.[3] Clearly there is an incentive to control air pollution and to protect human health within this sensitive airshed.

Figure 2 - Contribution of Marine Vessels to Air Pollution in the Lower Fraser Valley



The Greater Vancouver Regional District (GVRD) estimates that for the year 2000 marine vessels contributed 33% of the SOx, 22% of the NOx and 7% of the particulate matter (PM) in the Lower Fraser Valley.[4]

While emissions from on-road sources (light-duty and heavy-duty vehicles) are being held in check by increasingly stringent vehicle emission regulations and clean-fuel regulations, no similar regulations apply to off-road mobile sources. As a result nonroad emission sources (marine vessels, locomotives, road-building machinery, etc.), generally heavy-duty diesel engines, are becoming a more significant component of the total pollution emission inventory.

This report will look at different technologies and clean fuel options that can be used to reduce the emission of pollutants from marine vessels within the Georgia Basin. Many of the technologies and clean fuel options that will be discussed here are already being used elsewhere, such as in Scandinavia where marine vessels are a significant source of air pollution.

2.0 MARINE VESSEL EMISSIONS

2.1 INTRODUCTION

A ship differs in many aspects from other means of transport, such as trucks or railway. In addition to transporting different types of goods or passengers, a ship must also contain accommodation and other necessary facilities for the crew. In many cases it must also be able to handle different kinds of cargo in the harbors. In order to make this possible, a ship must be capable of a high degree of self-sufficiency and of handling its own energy supply under very varying conditions. This is why ships are equipped with different types of energy suppliers. These are identified as the main engine, auxiliary engines and the boiler.

The principal sources of marine exhaust emissions are as follows:

- Main engine – used for propulsion.
- Auxiliary engine – used for the generation of electricity.
- Boiler. Heating of accommodation, engines and sometimes cargo.

The propulsion engines installed in today's ships are of the following types:

- Steam turbines
- Gas turbines
- Diesel engines

Steam for steam turbines may be produced by burning fossil fuels or by means of nuclear reactors. Steam powered vessels are rapidly disappearing from merchant fleets because their specific fuel consumption is approximately 300 g/kWh, which is nearly twice as much as that of a modem diesel engine. Some steam powered ore carriers apparently still ply the Great Lakes, and a single steam powered cruise ship visits the Port of Vancouver during the summer months. However, these vessels are a small minority of the total marine vessel fleet and hence steam engines will not be addressed in the following sections.

Gas turbines are characterized by the combination high output/low weight. As such they are widely used in military ships and in modern fast ferries. But their fuel efficiency is low (approx. 215 g/kWh) as compared with diesel engines (approx 160 – 180 g/kWh), which makes them uneconomic for most commercial vessel applications. However, gas turbines are recently appearing in cruise ships where they are used to augment diesel-engined gensets. Princess Cruise's new Coral Princess, for instance, uses a 30.2 MW gas turbine (General Electric LM2500+) in conjunction with two Wartsila diesel engines (Model 9L46 @ 9.45 MW and Model 8L46 @ 8.4 MW). The gas turbine is used as a low-emission power source while hoteling as well as to meet peak power demands. The two diesels meet normal cruising power requirements. They have a fuel efficiency (85% load) of 180 g/kWh, as compared with 215 g/kWh for the LM2500+ gas turbine.

The diesel engine has undergone a powerful development process resulting in a completely new generation of engines with considerably improved performance. The specific fuel consumption of a modern two-stroke diesel engine may be in the order of 160 g/kWh, as compared to 210 g/kWh for older engines. Today the largest two-stroke diesel engines have an output of over 80 MW, which should be sufficient even for future proposed high-speed container ships. Owing to the high efficiency of diesel engines, the emissions of CO_2, CO and hydrocarbons are relatively low, however, high emissions of NOx are also characteristic of diesel engines. The same high combustion temperatures that give a high thermal efficiency in the diesel engine are also most conducive to NOx formation. By running on low quality fuels with a low fuel consumption, large diesel engines offer enormous savings in fuel costs compared with those of alternative prime movers.

On some smaller, more specialized ships such as cruise ships, diesel-electric engines have been installed. This means that the electrical output from several diesel-electric generators, running at constant speed, have been connected to each other. The propulsion then occurs by means of large electric motors, contrary to the conventional way wherein the propeller is fitted on a shaft connected directly, or via a driving gear, to the main engine. However, diesel-electric propulsion is still uncommon today except in cruise ships and in some of the smaller passenger-car ferries. As regards emissions, diesel-electric propulsion does not lead to any significant difference compared to a conventional installation and may experience a net increase in emissions due to the lower efficiency of the total system.

Auxiliary engines are running almost constantly in order to take care of part of the ship's power supply. Power is needed for pumps, cranes, cooling and heating plants, lighting, etc. Some ships have generators connected to the shaft of the main engine (known as shaft generators). These substitute for the auxiliary engines, usually while cruising at sea when the main engine is running. Since most ships turn off their main engines while in port, the auxiliary engines are the dominating source of emissions during the time spent in port. The older auxiliary engines burned a lighter fuel oil (e.g. marine diesel oil) so that their emissions were cleaner than those from the main engine. However, modern auxiliary diesel engines are designed to burn the same heavy bunker oil as the main engines do.

Figure 3 presents a mass balance for a modern ship's main diesel engine, with 8 kg/kWh coming into the engine as fuel, air and lubricating oil; and with 8 kg/kWh leaving the engine as exhaust gas. About 0.40% of the exhaust is comprised of the air contaminants NOx, SOx, hydrocarbons and particulate, while 6.2% consists of the greenhouse gas CO_2.

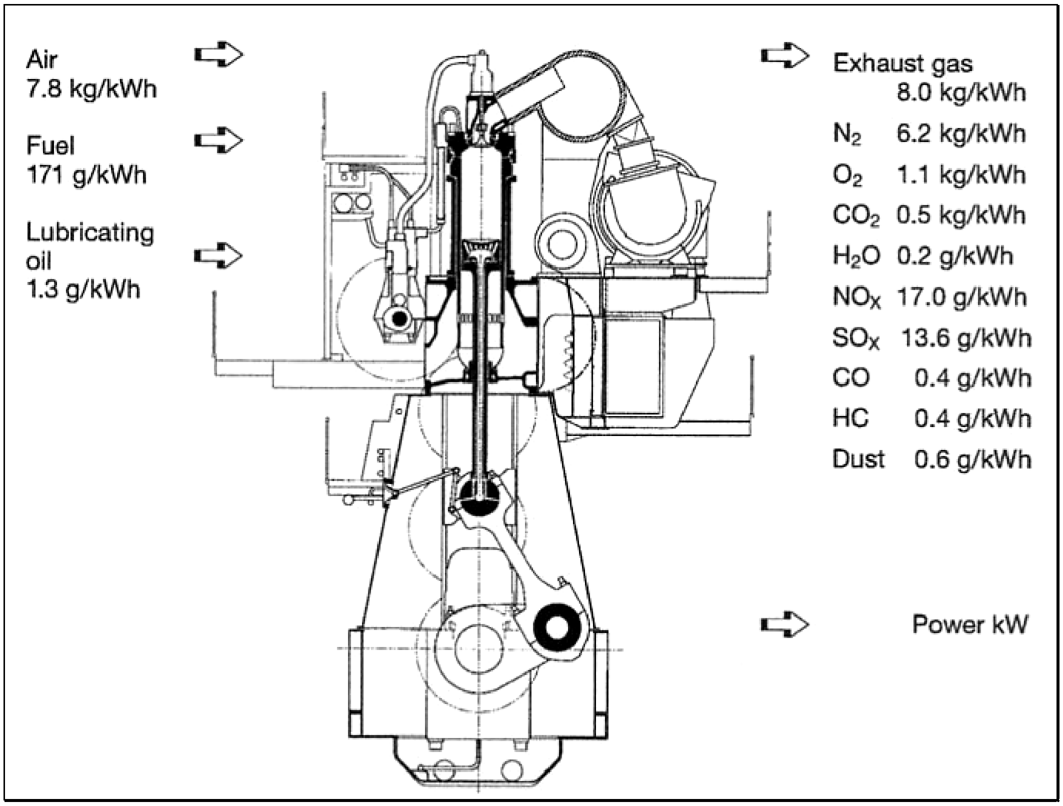


FIGURE 3 – EMISSIONS FROM A MODERN DIESEL ENGINE (Ref. 5)

Most ships also have a boiler plant for the production of steam for varying purposes (heating, turbine pumps etc.). Heat for the production of steam is sometimes taken directly from the exhaust stream of the main engine, known as exhaust boiler, and does not add to the exhaust emissions. In many cases, however, there are separate boilers installed for producing steam. The installed boiler output on merchant vessels is usually rather small in relation to the installed output of the main engine.

Since the combustion temperature within the boilers is much lower than that of a diesel engine the generation of NOx is lower and, given the smaller energy rating of the boiler, results in boiler NOx emissions which are much less than those deriving from the main engine. Therefore the incremental emissions from the boilers will not be further included in the discussion of ship's emissions.

2.2 TYPES OF EMISSIONS

As stated in the Introduction, uncontrolled emissions from heavy-duty diesel engines have a significant impact upon our society. This section will highlight some of the adverse impacts that are caused by the various emission components. A more comprehensive review was recently carried out by the State and Territorial Air Pollution Administrators and the Association of Local Air Pollution Control Officers (two USA national associations), who discuss health and welfare impacts from heavy-duty diesel engines and quantify the financial benefits that result from reducing these emissions.[22]

2.2.1 Nitrogen compounds

In most combustion processes nitrogen oxides are normally formed and the most common of these are nitrogen oxide, NO, and nitrogen dioxide, NO_2. These compounds are usually labeled 'NOx", of which NO_2 forms approximately 5 per cent. Other oxides, such as N_2O and N_2O_5, are also present in trace amounts. In the atmosphere the NO is oxidized to NO_2 and nitric acid, HNO_3. Excessive emissions of NOx results in various environmental problems: a) nitrogen saturation of forest soil resulting in ground-water acidification, b) increased photochemical smog, e.g. ozone, O_3, in the troposphere, c) direct gaseous damage to plants and organisms, d) the formation of inhalable (PM_{10}) nitrate particles which contribute to human morbidity and increase atmospheric haze, and e) increased global warming due to the potent "greenhouse" gas N_2O that has a global warming potential which is 320 times that of CO_2. Even though present in the atmosphere in only trace amounts, N_2O is expected to be responsible for approx. 5 - 6 per cent of the expected global temperature rise.

Acidification of the soil means an increase in the acidity of the soil, resulting in a dramatic change in the health of the soil. When an ecosystem receives an addition of "fixed" nitrogen in the form of ammonia or nitrates there is initially an increased growth in most plants. However, when the ecosystem receives more nitrogen than these organisms are able to process the excess nitrogen, in the form of nitrates, enters the groundwater, carrying with them important nutrients such as magnesium, calcium and potassium. There is also a release of metals, e.g. aluminum and cadmium, which are poisonous to the roots of trees, to fish and to other organisms.

Hydrocarbons and nitrogen oxides act together under the influence of sunlight, forming photochemical oxidants. Most important of these oxidants is ozone, which is directly injurious to human health, causes significant economic damage to organic materials such as paints, plastics, rubber and textiles, and which is responsible for damage to forests, crops and other vegetation.

Apart from damage from acidification and photochemical oxidants, several types of direct gaseous damage also affect the environment. Nitrogen oxides damage trees and crops directly through leaves and pine needles and may affect the health of sensitive groups of the population causing respiratory and other problems.

2.2.2 Sulphur compounds

The sulphur compounds occurring in the exhausts from ships are sulphur oxides (SOx), predominantly SO_2, and to a lesser extent SO_3 (2-3 per cent). Sulphate, SO_4, may also be emitted in small amounts combined with metals (Na, Ca) in particulate matter. The emission of sulphur oxides is a major cause of the acidification of soil and water. Furthermore, the emissions of sulphur oxides lead to directly adverse effects on human health (i.e. an increase in respiratory problems) and to corrosion of buildings and other materials. Sulphur dioxide is converted to sulphate particles in the atmosphere. These are a major contributor to ambient $PM_{2.5}$ (particulate matter less than 2.5 microns in diameter), which has a strong impact on human morbidity as well as contributing to atmospheric haze.

2.2.3 Hydrocarbon compounds

Hydrocarbons are formed partly as a consequence of incomplete fuel combustion and partly from free-radical reactions within the combustion process. Hydrocarbons may exist in several different forms and more than 300 different compounds have been identified in emissions from diesel-powered vehicles[6]. Polycyclic aromatic hydrocarbons, PAH, occur both in a gaseous phase as well as in a particle bound form in the exhausts. This group of hydrocarbons include several which have proved to cause cancer and are mutagenic substances; such as benzo (a) pyrene, cyclopenta (cd) pyrene and fluoranthene. PAH derivatives, such as nitro-PAH and methyl-PAH, may be responsible for a significant part of the carcinogenic effect. Another environmental hazard from the emission of hydrocarbons, which now frequently attracts attention, are the organochlorine derivatives, which may form in trace amounts during combustion. These include chlorophenols, chlorobenzenes, polychlorinated biphenyls (PCB), dioxins and furans. These substances, and particularly PCB and dioxins, are soluble in fats, extremely difficult to break down and are among the most toxic compounds we know. Their possible origin from ships engines may be: a) lubricating oil, which contains additives such as chloroparaffins and chlorinated solvents, b) addition of waste oil in the fuel and c) chloride compounds in the combustion air.

Aldehydes and other light hydrocarbons, e.g. alkenes and alkyl benzenes, occur in the diesel exhausts. These compounds, in conjunction with NOx, may contribute to the formation of photochemical oxidants, which may damage crops and forests and also directly affect human health (carcinogenicity, mutagenicity, irritation of eyes and mucous membranes).

2.2.4 Particulate Matter

For purposes of discussing the effects of particulate matter upon human health, particulate matter is classified as total particulate matter (PM), inhalable particulate matter (PM_{10}), or as respirable particulate matter ($PM_{2.5}$). Total particulate matter is the total material that can be collected upon a filter under specified temperature conditions. PM_{10} is all filterable particulate mater with a diameter of less than 10 microns, which is the approximate cut-off diameter for nasal inhalation. $PM_{2.5}$ is all filterable particulate matter with a diameter of less than 2.5 microns in diameter, which is the approximate cut-off diameter for particles that can penetrate deep into the lungs. Total particulate matter includes both PM_{10} and $PM_{2.5}$. It is the $PM_{2.5}$ particles that are of major human health concern.

Particulate matter in the exhaust gases consists mainly of unburned carbon and ashes but will also contain trace metals and bound polynuclear aromatic hydrocarbons (PAH). In general the particles are small (90 per cent < 1 micron) and are therefore able to penetrate into the finest cavities of the lungs (alveoli) and cause health problems. Certain PAH compounds have a direct mutagenic effect and may cause cancer. The most important trace metals emitted from ships are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, molybdenum, nickel, lead, vanadium and zinc. Of these, cadmium, lead and mercury have attracted most attention due to their toxic effect. Many large diesel engines have operated on heavy fuel oil with comparatively high sulphur content, and therefore use lubricating oil with alkali-metal additives (Na, Ca) that counteracts the corrosive effect of the sulphur compounds. As a consequence there are also alkali-metal sulphates combined in the particles.

In 1998, following an exhaustive 10-year scientific assessment process, the California Air Resources Board (CARB) identified particulate matter from diesel-fueled engines as a toxic air contaminant. In the California South Coast Air Basin, the potential risk associated with diesel particulate emissions is estimated to be 1,000 per million people. Compared to other air toxics the Board has identified and controlled, diesel particulate emissions are estimated to be responsible for about 70% of the total ambient air toxics risk. As a result of this study, CARB has initiated a comprehensive plan (Diesel Risk Reduction Plan) to significantly reduce these emissions[23].

2.2.4 CO and CO_2

Carbon monoxide, CO, forms as a consequence of incomplete combustion. The gas is photochemically active and directly toxic in high proportions, and persons suffering from heart and vascular diseases are particularly sensitive to it.

Carbon dioxide, CO_2, is formed in comparatively large amounts in all types of combustion processes. In spite of the fact that CO_2 has no direct harmful effect on nature it is the most important of the so-called greenhouse gases. Elevated concentrations of these gases disturb the global heat balance by returning the long-wave radiation that is normally emitted away from the earth. At present, CO_2 from the burning of fossil fuel amounts to almost three times the quantity that vegetation is able to consume.

2.3 EMISSION FORMATION

2.3.1 NOx

Nitrogen oxides, NOx, are formed during combustion through several chemical reactions[7]; a) through a reaction between the oxygen and the nitrogen in the combustion air ("thermal NOx"), b) through oxidation of the nitrogen bound in the fuel ("fuel NOx"), and c) through a two-step mechanism where the nitrogen of the air reacts with hydrocarbon radicals during the forming of cyano- and amino-radicals then oxidizing to NOx ("prompt NOx"). In marine diesel engines most NOx is formed via the thermal mechanism described below.

The transformation of air nitrogen to thermal NOx may be described in a simplified way by the following gas phase reactions (known as the 'Zeidovich mechanism') [8]:

$$O + N_2 \Rightarrow NO + N \quad (1)$$

$$N + O_2 \Rightarrow NO + 0 \quad (2)$$

$$N + OH \Rightarrow NO + H \quad (3)$$

Eqn 1 controls the speed of the overall reaction, and the concentration of O radicals is crucial. In order for NO to form, the combustion temperature and the concentration of oxygen must be sufficiently high for there to be sufficient atomic oxygen O; an increase in temperature and added air will lead to increased NO formation. In practice, the rate of formation of NO will be insignificant if the combustion temperature drops below approx. 1200°C. And as a rule of thumb, it can be said that NOx formation at temperatures above 1200°C increases by a factor of ten for every 100°C rise. At each temperature there is an equilibrium concentration of NO, which, however, takes a certain time to establish itself. This means that the shorter the duration at a high temperature the less thermal NO is formed. Taking these factors into account (combustion temperature, availability of oxygen and duration) the process can be controlled so that it reduces the formation of NO.

The nitrogen compounds in the fuel constitute approximately 0.2 - 0.5 per cent by weight of heavy fuel oil and are present in the fuel as different types of organic substances (pyrides, amines, amides, etc.). During combustion volatilization occurs and then pyrolysis, giving lighter volatile nitrogen compounds which will further react. These substances (mainly volatile amines and cyanides) can react through either a) an oxidation where 'fuel NO' is formed or b) a formation of nitrogen, N_2, from a simple breakdown or from a reduction reaction with NO. Both reactions may occur mainly in the gaseous phase and to a certain extent as surface-catalyzed reactions, e.g. on solid soot particles. The exact mechanisms are complex and many different radicals are involved. In order to simplify the process it is possible to describe reaction chains with three global reactions (eqn 4 - 6), where NH_3 represents the volatile nitrogen compounds.

$$NH_3 + O_2 \Rightarrow NO \quad (4)$$

$$NH_3 + NO \Rightarrow N_2 \quad (5)$$

$$NH_3 \Rightarrow N_2 \quad (6)$$

Among the different combustion variables, it is the fuel/air ratio that has the most important effect on the formation of fuel NO. The formation increases, however, rather slowly when the surplus of air rises above stochiometric amounts, but decreases rapidly when going towards more fuel-rich mixing conditions. A temperature decrease does not reduce fuel NO very much over 800 - 1700°C, while thermal NO decreases dramatically with a lower temperature. The formation of fuel NO is not significantly affected by the way that nitrogen is bound in the fuel.

During combustion the above mentioned mechanism may be used to control the emission of NO, as a surplus of fuel promotes the formation of N3, while a surplus of air causes mainly NO to be formed. Certain NOx control technologies use similar reactions to Eqn. 5 through an addition of nitrogen compounds in the exhaust gases, e.g. NH_3, $(NH_2)_2CO$ (urea), etc., with or without a catalyst (respectively known as Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR)[9].

Formation of prompt NO occurs through what is known as the 'Fenimore Mechanism' [10] (eqn 7-12) and contributes only to a small extent to the total NO emission. Reaction mechanisms where the nitrogen originates from the air occur in the gas phase in flames over a comparatively wide temperature range.

$$CH + N_2 \Rightarrow HCN + N \quad (7)$$

$$N + O_2 \Rightarrow NO + O \quad (8)$$

$$N + OH \Rightarrow NO + H \quad (9)$$

$$C2 + N_2 \Rightarrow 2CN \quad (10)$$

$$CN + O \Rightarrow C + NO \quad (11)$$

$$CN + O_2 \Rightarrow CO + NO \quad (12)$$

The NO_2 share of the total NOx emission is comparatively low (5-10 per cent) and is formed through an oxidation of NO partly at high temperatures with HO_2

radicals (eqn 13), and partly at lower temperatures and longer durations with O_2 (eqn 14).

$$NO + HO_2 \Rightarrow NO2 + OH \qquad (13)$$
$$2NO + 02 \Rightarrow 2NO_2 \qquad (14)$$

2.3.2 SOx and $SO_4^{=}$

Unlike the nitrogen oxides, sulphur oxides are formed solely from the oxidation of the fuel-bound sulphur compounds[7]. When fuel is burned almost all the sulphur (95 per cent is a general opinion) is emitted to the air, while a smaller part is bound as sulphate in ashes and particles. Both organic and inorganic sulphur compounds contained in the fuel are rapidly oxidized at combustion temperatures primarily to sulphur dioxide, $S0_2$ (eqn 15), which may then be oxidized by means of O radicals or O_2 to sulphur trioxide, SO_3 (eqn 16 -17) [11].

$$\text{Fuel S} + O_2 \Rightarrow SO_2 \qquad (15)$$
$$SO_2 + O \Rightarrow SO_3 \qquad (16)$$
$$2SO_2 + O2 \Rightarrow 2SO_3 \qquad (17)$$

If there were to be sufficient time for the thermodynamic balance to stabilize in the exhaust flue, the SO_2 would be more or less completely oxidized to SO_3. In practice, however, only a very small share (1-5 per cent) of the S02 has sufficient time to oxidize to SO_3. The fraction of formed SO_3 increases with combustion temperature and surplus air. SO_3 cannot exist in a free condition if traces of water vapor are present. Instead, it leads to the forming of a mist of sulphuric acid, H_2SO_4, through a rapid reaction (eqn 18) most frequently at low temperatures after the gas has been emitted to the air.

$$SO_3 + H_2O \Rightarrow H_2SO_4 \qquad (18)$$

Furthermore, a part of the sulphuric acid reacts with basic compounds in the fuel, which gives neutral sulphates. Alternatively, condensation may occur on particles and other surfaces, depending on the temperature and moisture of the flue gas (eqn 19). For a given SO_3 content and moisture in the flue gas there is a temperature (the so called acid dew point, approx. 110-160°C), below which the flue gas temperature should not be cooled if condensation of sulphuric acid is to be avoided.

$$H_2SO_4 + H_2O \Rightarrow H_3O^+ + HSO_4^- \qquad (19)$$

The drops of condensation and acidic soot are very corrosive.

2.3.2 Hydrocarbons

Most hydrocarbon compounds that can be measured in the exhaust gases are not originally present in the fuel, but have been formed from the fuel during incomplete combustion. Alternatively, some of the heavy hydrocarbons may come from residual products originating from the fuel. Polycyclic aromatic hydrocarbons, PAH, may be formed through radical reactions between hydrocarbon fragments, with subsequent ring closure and dehydration (i.e. hydrocarbon radicals form stable fragments of the benzene type). Optimum formation temperature for benzo (a) pyrene and many other similar PAH compounds is 700°C. A prerequisite for low hydrocarbon emissions is a sufficiently high combustion temperature and an excess of combustion air (conditions normally occurring within modern diesel engines). Under such circumstances a complete combustion of any hydrocarbon compounds that have been formed to CO_2 and water will occur.

2.3.3 Particulate

Occurrences of particles in flue gases from diesel engines may be considered as originating from four different sources:

1. Gas phase polymerization reactions originating from acetylene, C_2H_2 (a pyrolysis product) may happen very fast and also, within 1 msec, small spherical carbon (soot) particles are formed. These particles grow to approx 50 nanometers (nm) in diameter and then undergo aggregation, finally forming large chains of molecules (emitted particles). The polymerization of the acetylene begins with an abstraction step with hydrogen radicals, which is then followed by further reactions with acetylene molecules (the so called 'Frenklach Mechanism' [7]). Furthermore there are ring closure and dehydration reactions resulting in the formation of large polycyclic aromatic compounds. The rate-determining step is considered to be the formation of the first aromatic ring and the pyrolysis speed is of vital importance for the formation of soot. Fuels with high contents of aromatics and conjugated hydrocarbons often lead to high emissions of soot[7]. Depending on the type of flame in the combustion chamber the temperature may affect the soot emission in both positive and negative ways. In the diffusion flames, higher combustion temperatures result in higher soot emissions, but in the premixed flames more typical of diesel engines it is the other way around[7].
2. During combustion residual noncombustible ash products, e.g. cenospheres from the burned-out oil drops contribute to the soot emission. This source increases with increasing ash content and sulphur content of the fuel and forms an important component of PM_{10} emissions from diesel engines.

3. A certain amount of soot may condense on the walls of the combustion chamber. As a result soot flakes may build up and then detach from the walls, providing a source for the largest soot particles.
4. The lubricating oil may also contribute to the soot production in ways that are similar to the ones already mentioned, e.g. dispersion and condensation aerosols.

Combustion measures to decrease particle emissions usually resemble those used to decrease emissions of hydrocarbons, i.e. higher combustion temperatures and more excess air. As a consequence there is a compromise between emissions of NOx and those of hydrocarbons and particles. In order to solve this problem with regards to heavy diesel-powered trucks, engine manufacturers have in some cases chosen to adjust their engines in order to reduce NOx, and then reduced the other emissions by means of an exhaust oxidation catalyst (oxidation of hydrocarbons) and a diesel-soot particle trap (filter) [12].

2.4 THE EFFECT OF FUEL OIL CHARACTERISTICS ON LEVELS OF EMISSION

The heavy, residual oil from the bottom of the vacuum distillation column in an oil refinery is enriched in sulphur and metals. In the past this residual oil was usually sold as a heavy "bunker oil" for power generation or for burning in large marine vessels. Typically the market price for this residual oil stream is equal to, or less than, the price of the parent crude oil. Hence it is a "waste" stream. Refineries may be able to upgrade the residual oil to more valuable products through difficult and expensive processing. In this case no heavy oil is available for sale as marine fuel. Low-sulphur heavy fuel oils are significantly more expensive than the normal residual oils and are produced by starting with an expensive, "sweet" crude oil and by allowing more of the potential distillate product to join the bottom stream, i.e., by changing the set up of the distillation column. Distillates are used to make the revenue-generating products such as diesel oil, light fuel oils, jet fuel and gasoline. The distillates are first desulphurized by catalytically reacting them with hydrogen (hydro-treating) so that the products meet federal limits on sulphur concentration.

Marine fuels that are used in large ocean-going vessels are of two types: heavy fuel oils or bunker, and marine diesel oil (MDO). The fuel oils in turn are classified as Intermediate Fuel Oils (IFO-380 and IFO-180) and are inexpensive mixtures of residual oil and distillates. IFO-380 has a viscosity of 380 centistokes and is a mixture of approximately 98% residual oil and 2% distillate. (The distillate is added as a "flux" to reduce the viscosity of the fuel.) IFO-180 is a mixture of roughly 88% residual oil and 12% distillate and has a viscosity of 180 centistokes. Since IFO-180 contains more valuable distillate than does IFO-380, it fetches a higher market price, typically USA$9/tonne more. (One tonne equals one thousand kilograms). The heavy bunkers have to be heated and cleaned (centrifuged and filtered) before burning in specially designed diesel engines.

Heavy fuel oil has much higher organic nitrogen content, sulphur content and metals content than does the lighter distillate fuels. This results in higher emissions of NOx, SOx and particulate.

Diesel engines on smaller vessels, such as ferries and workboats, burn a lighter, less viscous diesel oil (MDO). This diesel is made from valuable distillates and therefore fetches a much higher price than does the heavy bunker oils. The MDO designation is generic, as are the IFO's, and simply requires that the fuels meet a minimum specification designated, for example, by ISO 8217 –1996E. (ISO is the International Standards Organization). Low sulphur MDO may be a rebranded road diesel.

Where diesel fueled vessels are concerned, NOx emissions usually originate from the reaction between the oxygen and nitrogen of the air at high temperatures, and thus the nitrogen content of the fuel (rather low) does not overly effect the total emission. However, fuel-derived NOx becomes important when using heavy fuel oil because such fuels contain more organic nitrogen than marine diesel oil and other distillate fuels. Heavy fuel oil can contain up to 0.5% nitrogen which increases the total NOx emissions by as much as 10% [5]. The fuel-air ratio that is required by a certain fuel oil therefore has a significant effect on the NOx emission. Also, the high temperature and the larger surplus of air in a direct-injected diesel engine (marine application) favor the formation of NOx as compared to a pre-chamber diesel engine (passenger cars) [13].

The sulphur content of the oil, on the other hand, is of vital importance to the SOx and particulate emissions. Oils with alkaline elements, e.g. Ca, Na, Mg, often present in additives to the lubricating oil, may counteract the formation of particles of a corrosive character. The emission of particles has proved to increase with fuels containing more sulphur, while emissions of NOx, CO and hydrocarbons have remained more or less the same[14].

A high content of aromatics and olefins lowers the cetane rating (ignitability) resulting in the fuel giving higher emissions of hydrocarbons, NOx, CO and particles. In general lighter fuels (low density and lower content of aromatics) lead to lower particle and NOx emissions[14].

Conversion of crude oil to diesel fuel may in some cases lead to deterioration in operative quality and hence there are many additives used to improve the characteristics of both fuel oil and lubricating oil[15]. Examples of additives that may be used in fuel oils and lubricating oils are combustion improvers, anticorrosives, detergents, 'pour point depressants', sediment inhibitors, etc. These substances often represent sources of chlorine and metals that are later emitted to air, leading to potential environmental impacts. Concerning the analysis of oils, there are no regular analyses of undesirable ingredients in the fuel, e.g., the chlorine compounds.

2.5 DIESEL ENGINE EMISSION STANDARDS

2.5.1 USA Marine Diesel Engines (Ref.24)

Background

On September 27, 1997, the International Maritime Organization (IMO) adopted International Convention on the Prevention of Pollution from Ships, also referred to as MARPOL 73/78. Annex VI to that Convention contains requirements to limit NOx emissions from marine diesel engines (but sets no limits for HC, CO, or PM). The Annex VI NOx limits, listed in Figure 4, apply to new engines greater than 130 kW installed on vessels constructed on or after January 1, 2000, or which undergo a major conversion after that date.

On November 23, 1999, the EPA signed the final rule "Control of Emissions of Air Pollution from New CI Marine Engines at or above 37 kW" *[40 CFR Parts 89, 92 | FR 64, No. 249, 73300-73373, 29 Dec 1999]*. The adopted standards for small- and medium-size engines are based on the land-based standard for nonroad engines, while the largest engines (so called "Category 3") are expected, but not required by the 1999 rule, to comply with MARPOL Annex VI limits.

The decision to leave the largest Category 3 engines unregulated triggered a lawsuit against the EPA by environmental organizations. A court settlement was reached that required the EPA to propose NOx emission limits for Category 3 engines. The proposal published by the EPA on May 29, 2002 *[40 CFR Part 94 | FR 67, No. 103, 37548-37608]*, calls for establishing Category 3 emission standards virtually equivalent to the MARPOL Annex VI limits.

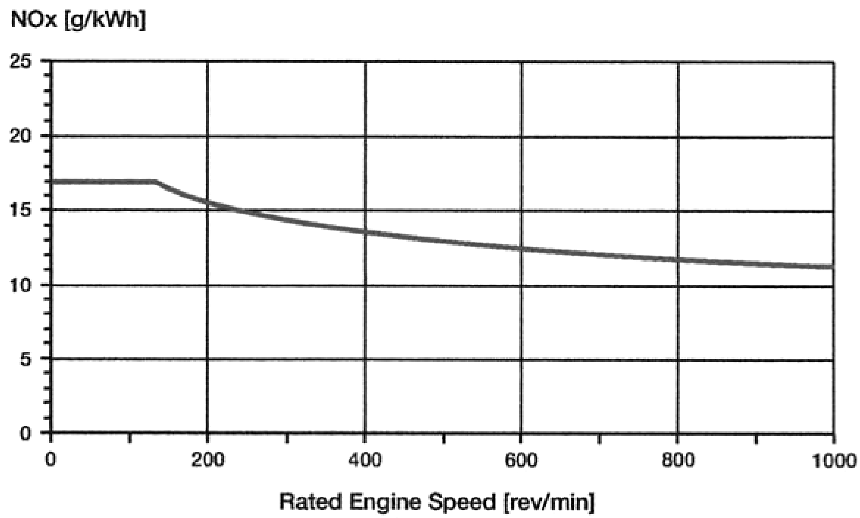
Diesel engines used in recreational vessels, exempted from the 1999 marine rule, are covered in the "Emission Standards for New Nonroad Engines—Large Industrial Spark-ignition Engines, Recreational Marine Diesel Engines, and Recreational Vehicles" regulation, signed on September 13, 2002.

Applicability

The scope of application of the marine engine rule covers all new marine diesel engines at or above 37 kW, including both propulsion and auxiliary marine diesel engines. A propulsion engine is one that moves a vessel through the water or assists in guiding the direction of the vessel (for example, bow thrusters). Auxiliary engines are all other marine engines.

Classification of drilling rigs depends on their propulsion capability. Drilling ships are considered marine vessels, so their engines are subject to the marine rule. Semi-submersible drilling rigs that are moored to the ocean bottom, but have some propulsion capability, are also considered marine vessels. In contrast, permanently anchored drilling

i) 17 g/kWh when n is less than 130
II) $45^*n^{-0.2}$ g/kWh when n is 130 rpm or more, but less than 2000 rpm
iii) 9.84 g/kWh when n is 2000 rpm or more
where n = rated engine speed



The three test cycles D2, E2 and E3 apply to three different engine categories namely:
D2: Generating sets with intermittent load, including shipboard generating sets
E2: Constant-speed heavy-duty engines for ship propulsion, including engines with a controllable-pitch propeller
E3: Variable-speed heavy-duty engines for ship propulsion equipped with a fixed-pitch propeller

Table: Weighting factors (f) for the test cycles D2, E2 and E3 in the Technical Code of the IMO regulation for NO_X emissions

% rated speed		100	100	100	100	100	100	91	80	63
% rated load		100	75	50	25	10	100	75	50	25
Weighting factor [f]	cycle D2	0.05	0.25	0.30	0.30	0.10	–	–	–	–
	cycle E2	0.20	0.50	0.15	0.15	–	–	–	–	–
	cycle E3	–	–	–	–	–	0.20	0.50	0.15	0.15

$$NO_x weighted = \frac{\sum_i f_i \times NO_{x_i}\left(\frac{g}{h}\right)}{\sum_i f_i \times P_i\,(kW)}$$

Figure 4 – NOx Emission Limit – IMO Reg. 13, Annex VI of MARPOL73/78 (Ref.5).

platforms are not considered marine vessels, so none of the engines associated with one of these facilities are marine engine.

Consistently with the land-based nonroad regulation, a portable auxiliary engine that is used onboard a marine vessel is not considered to be a marine engine. Instead, a portable auxiliary engine is considered to be a land-based auxiliary engine and is subject to the land-based nonroad requirements. To distinguish a marine auxiliary engine installed on a marine vessel from a land-based portable auxiliary engine used on a marine vessel, EPA specified in that rulemaking that an auxiliary engine is installed on a marine vessel if its fuel, cooling, or exhaust system are an integral part of the vessel or require special mounting hardware. All other auxiliary engines are considered to be portable and therefore land-based.

The following engine categories are exempted from the 1999 marine regulation:

Engines used in recreational vessels (recreational diesel engines are subject to separate standards, outboard and personal watercraft spark ignited engines are regulated by another rule)

- Emission certified new land-based engines modified for marine applications (provided certain conditions are met)
- Competition (racing) engines
- Engines used in military vessels (National Security Exemption)
- Engines Category 1 and 2 used on ocean vessels with Category 3 propulsion, so called Foreign-Trade Exemption (proposed to be eliminated)
- Other exemptions (testing, display, export...) may also apply to marine engines.

Not all of the above exemptions are automatic. Engine or vessel manufacturers, or vessel owners, may need to apply for a specific exemption to the EPA.

The same emission standards apply to engines fueled by diesel fuel and by other fuels.

Engine Categories

For the purpose of emission regulations, marine engines are divided into three categories, as listed in Table 1. Each of the categories represents a different engine technology. Categories 1 and 2 are further divided into subcategories based on the engine displacement per cylinder.

Table 1 – Marine Engine Categories

Category	Displacement per Cylinder (D)	Basic Engine Technology
1	$D < 5\ dm^3$ (and power >= 37 kW)	Land-based nonroad diesel
2	$5\ dm^3 \le D < 30\ dm^3$	Locomotive engine
3	$D \ge 30\ dm^3$	Unique marine design

As an example, the container ship COSCO *YUN HE* has a MAN B&W main engine with a bore/stroke of 900mm x 2916mm with a cylinder displacement of 1,855 dm^3 (liters).

Therefore this is a Category 3 engine. The *YUN HE*'s auxiliary engine, on the other hand, has a bore/stroke of 320mm x 350mm and a cylinder displacement of 28.1 liters. It is a Category 2 engine.

The B.C. Ferry fleet's main engines are Category 2 and 3 in the larger ferries and Category 1 in the smaller vessels, such as the MV Quinsam and the Skeena Queen. The auxiliary engines in the larger vessels are mainly Category 1. Workboats also use typically Category 1 engines.

Emission Standards

Engines Category 3

Category 3 engines are very large marine diesel engines, which can achieve power ratings in excess of 75,000 kW, typically used for the propulsion of ocean-going vessels. Emission control technologies that can be used on these engines are limited. The most important of the limitations is the fuel on which they are operated, called residual fuel. This fuel is the by-product of distilling crude oil to produce lighter petroleum products. It possesses high viscosity and density, which affects ignition quality, and it typically has high ash, sulfur and nitrogen content in comparison to marine distillate fuels. Furthermore, residual fuel parameters are highly variable because its content is not regulated. The EPA estimated that residual fuel can increase engine NOx emissions from 20-50% and PM from 750% to 1250% when compared to distillate fuel.

In the 1999 rule, EPA has not adopted any emission standards for the Category 3 engines. The proposal of May 29, 2002 considers three sets of standards: (1) first tier standards, (2) second tier standards, and (3) voluntary low-emission engine standards. The first tier standards would be equivalent to the internationally negotiated IMO MARPOL NOx limits, as shown in Figure 4. They would be enforceable under U.S. law for new engines built in 2004 and later. These limits would be achieved by engine-based controls, without the need for exhaust gas after treatment. A subsequent second tier of standards, also achieved through engine-based controls, would apply to new engines built after 2006 or later. The voluntary low-emission engine standards would require advanced control technologies such as selective catalyst reduction, water-based emission reduction techniques, or fuel cells.

The proposed standards would apply to engines installed on vessels flagged in the U.S. It is currently not clear if the U.S. government has the authority to impose such standards for foreign ships, which present the vast majority of vessels entering U.S. ports.

The Annex VI is not yet in force, pending ratification by a number of member states, including the U.S. Once adopted, the Annex VI limits will apply retroactively, effective January 1, 2000. Therefore, many ocean vessel operators worldwide started installing complying engines beginning in the year 2000.

Engines Category 1 and 2

Emission standards for engines category 1 and 2 are based on the land-based standard for nonroad and locomotive engines. The emission standards, referred to as Tier 2 Standards by the EPA, and their implementation dates are listed in table 2 below. The regulated emissions include NOx+THC, PM, and CO. There are no smoke requirements for marine diesel engines. The regulators believed that the new PM standards would have a sufficient effect on limiting smoke emissions.

In the earlier proposal, the EPA also listed a more stringent Tier 3 standard to be introduced between 2008 and 2010. The Tier 3 standard was not adopted in the final 1999 rule. The EPA intends to address this next tier of emission standards in a separate ruling.

Table 2 – Tier 2 Marine Emission Standards*

Engine Category	**Cylinder Displacement (D)** (dm^3)	**NOx+THC** (g/kWh)	**PM** (g/kWh)	**CO** (g/kWh)	**Date**
1	Power >= 37 kW D < 0.9	7.5	0.40	5.0	2005
	0.9 <= D < 1.2	7.2	0.30	5.0	2004
	1.2 <= D < 2.5	7.2	0.20	5.0	2004
	2.5 <= D < 5.0	7.2	0.20	5.0	2007[a]
2	5.0 <= D < 15	7.8	0.27	5.0	2007[a]
	15 <= D < 20 Power < 3300 kW	8.7	0.50	5.0	2007[a]
	15 <= D < 20 Power >= 3300 kW	9.8	0.50	5.0	2007[a]
	20 <= D < 25	9.8	0.50	5.0	2007[a]
	15 <= D < 30	11.0	0.50	5.0	2007[a]

* - Tier 1 standards equivalent to IMO NOx limits.
a – Proposed Tier 1 certification requirement starting in 2004.

Blue Sky Series Program

The regulation sets a voluntary "Blue Sky Series" program that permits manufacturers to certify their engines to more stringent emission standards. The qualifying emission limits are listed in Table 3.

Table 3 – "Blue Sky Series" Voluntary Emission Standards		
Cylinder Displacement (D), (dm^3)	**NOx+THC** (g/kWh)	**PM** (g/kWh)
Power >= 37 kW & D < 0.9	4.0	0.24
0.9 <= D < 1.2	4.0	0.18
1.2 <= D < 2.5	4.0	0.12
2.5 <= D < 5.0	5.0	0.12
5.0 <= D < 15	5.0	0.16
15 <= D < 20 & Power < 3300 kW	5.2	0.30
15 <= D < 20 & Power >= 3300 kW	5.9	0.30
20 <= D < 25	5.9	0.30
15 <= D < 30	6.6	0.30

The Blue Sky program begins upon the publication of the rule and extends through the year 2010. At that time the program will be evaluated to determine if it should be continued for 2011 and later engines.

Test Cycles

The engine Category 1 emissions are tested on various ISO 8178 cycles (E2, E3, E5 cycles for various types of propulsion engines, D2 cycle for auxiliary engines). Engines belonging to Category 2 are tested on locomotive test cycles.

In addition to the ISO test cycle measurement, which are averages from several test modes, the regulation sets "not-to-exceed" (NTE) emission limits, which provide assurance that emissions at any engine operating conditions within an NTE zone are reasonably close to the average level of control. NTE zones are defined as areas on the engine speed-power map. The emission caps within the NTE zones represent a multiplier (between 1.2 and 1.5) times the weighted test result used for certification for all of the regulated pollutants (NOx+THC, CO, and PM).

The test fuel for marine diesel engine testing has a sulfur specification range of 0.03 to 0.80 %wt, which covers the range of sulfur levels observed for most in-use fuels.

Useful Life and Warranty Periods

For Category 1 engines, EPA established a useful life of 10 years or 10,000 hours of operation. For Category 2 engines, EPA established a useful life of 10 years or 20,000 hours of operation. The warranty periods are 5 years or 5,000/10,000 hours for engines Category 1/2, respectively.

Other Provisions

The regulation contains several other provisions, such as emission Averaging, Banking, and Trading (ABT) program, deterioration factor requirements, production line testing, in-use testing, and requirements for rebuilding of emission certified engines.

2.5.2 European Union Diesel Engines (Ref.24)

The European legislation for nonroad diesel engines was promulgated on February 27, 1998. The regulations for nonroad diesels were introduced in two stages: Stage I implemented in 1999 and Stage II from 2001 to 2004, depending upon engine size. Engines used in ships were not covered by the Stage I/II standards. On December 27, 2002 the European Commission finalized a proposal for Stage III regulations, whose limits and timing is harmonized with the USA Tier 2 standards shown in Table 2 above. The Stage III standards apply to marine engines used for inland waterway vessels. Presumably emission-reduction technology developed to meet these standards would also carry over to engines used in salt-water vessels.

2.5.3 International Maritime Organization (IMO)

The International Maritime Organization (IMO) is a Specialized Agency of the United Nations dealing with the technical aspects of shipping**.** IMO has 150 Member States and two Associate Members. Proposals from Member States are passed to a Committee for discussion prior to sending to the IMO Assembly for endorsement in the form of a Resolution. The Marine Environmental Protection Committee (MEPC) handles environmental matters. Regulations and amendments to regulations that are passed by the IMO Assembly take the form of Annexes and Protocols to the original International Convention for the Prevention of Pollution From Ships (MARPOL 73/78).

In 1997 MEPC completed Annex VI and the Assembly endorsed the Annex. However, in order for the Annex to be fully implemented it must be ratified by at least 15 nations controlling at least 50% of the world shipping, followed by a one-year implementation period. As of December 2001 only five Member States (Bahamas, Norway, Sweden, Malawi and Singapore) controlling only 7% of the tonnage, had ratified Annex VI. Recent discussions with senior MEPC representatives have indicated that it is expected that the required number of nations and tonnage will ratify the Annex within approximately two years.

Within Annex VI, Regulation 14 limits marine fuel sulphur to 4.5% (w/w), except in SOx Emission Control Areas, where the limit is either 1.5% or, where gas-cleaning equipment is used to reduce exhaust emissions, to less than 6.0 g SOx/kWh. A SOx Emission Control Area is a type of Special Area, which is defined as a sea area in which, for technical reasons relating to oceanographical and ecological conditions and sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required. The Baltic Sea and North Sea area are at present the only designated SOx Emission Control Areas.

Proposals to the IMO for designation of a SOx Emission Control Area have to include:

1. A clear delineation of the proposed area of application of SOx controls.
2. A description of land and sea areas at risk from ship SOx emissions.
3. A complete environmental assessment of the land and sea impacts of the ship SOx emissions, along with meteorological and other conditions which may exacerbate the impacts.
4. The nature of the ship traffic in the proposed SOx Emission Control Area, including the traffic patterns and density of such traffic.
5. A description of control measures taken by the proposing State to address land-based sources of SOx emissions that affect the sea area at risk.

During 2000 the sulphur concentration in 54,000 samples of residual oil, representing 49 million metric tonnes, or 40% - 50% of the heavy fuel bunkers sold annually worldwide, was measured by MEPC Committee members.[47] The average sulphur concentration was 2.7%, with over 80% of the samples between 2 and 4%, and 50% between 2.5% and 3.5%.

In addition to their clean fuels regulations, the IMO also have adopted NOx standards in 1997. The standards apply to all vessels over 130 kW (174 h.p.) installed on new vessels. However, the standards are not enforceable until 15 countries representing at least 50% of the gross tonnage of the world's merchant shipping ratify them. To date, this has not occurred, and the United States is among the countries that have not yet ratified it. Nevertheless, most marine engine manufacturers are currently producing IMO compliant engines because the standards when implemented are retroactive to January 1, 2000.[48]

The MEPC committee is currently focused on greenhouse gas emissions from ships and has a working group developing an IMO strategy for greenhouse gas reduction.[49]

Although the process to have the BC coast designated a *Special SOx Emission Control Area* under the IMO mechanism is expected to be complex and protracted, there are a number of advantages to working within the IMO framework, most notably in the areas of compliance and enforcement. Under the IMO regulations of Annex VI all ships will be required to keep logs of fuel quantity and sulphur levels, and must make these logs available for inspection to all port authorities. Also, engine logs must be made available and these logs will indicate the time and location where the engines were switched to low sulphur fuel. While there are other possible courses of action that could be considered, including a mix of voluntary non-regulatory early actions and regulatory or economic instruments over the long term, these actions will be difficult to apply off shore due to the international protocol of "right of free passage".

Presentations and discussions at recent marine workshops have indicated a desire by a number of U.S. federal, state and regional authorities for a total west coast of North America solution to the problem of marine emissions. This could be an IMO Special SOx Control Area covering all of the coast from California to Alaska, or a coordinated and compatible U.S. and Canada federal, state, provincial and municipal regulatory action plan.

Further information on IMO activities can be obtained from their web site www.imo.org

2.5.4 Swedish Environmentally Differentiated Fairway Fees (Ref. 26)

In 1996 a tripartite agreement was reached between the Swedish Maritime Administration, the Swedish Ship Owners Association and the Swedish Ports' and Stevedores' Association to reduce sulphur and nitrogen oxides emissions from ships calling at Swedish ports by 75 in the early years of the 21st century.

In 1998 a Swedish Maritime Administration ordinance on environmentally differentiated fairway dues entered into force. The system is based on two charging components. The first one, which is environmentally differentiated, is based on the size, the gross tonnage (GT), of the ship. This portion of the due is charged a maximum of 18 times a year for a passenger ship and a maximum of 12 times a year for each individual cargo ship. The second component is based on the amount of goods loaded and/or unloaded in Swedish ports and is not affected by the differentiation. The differentiation aims at establishing economic incentives for ships, irrespective of flag, to reduce emissions of sulphur and nitrogen oxides, while not per se altering the total sum of SMA charges for ships calling at Swedish ports. Thus the scheme is supposed to be income neutral for the fee-financed Swedish Maritime Administration.

The charging levels for the size-related part of the fairway dues are differentiated with respect to the sulphur content of the bunker fuel and the certified emission levels of NOx per kWh for the ships' machinery. The differentiation with respect to sulphur in the ships' bunker fuel is straightforward. A ship that certifies that it only uses low sulphur bunker fuel (0.5% sulphur or less for ferries and 1% sulphur or less for other ships) will be granted a discount of 0.9 SEK per GT. For NOx-emissions the differentiation scheme is slightly more complicated. The charges per GT vary according to the NOx emission rate per kWh for the ship's machinery. For ferries and other ships (not tankers) the charge is 3.40 SEK/GT if emissions are 2 g/kWh or less. The charge is increasing linearly up to the level of 5 SEK/GT if emissions are 12 g/kWh or more. (US$0.1188/SEK; Feb.27, 2003).

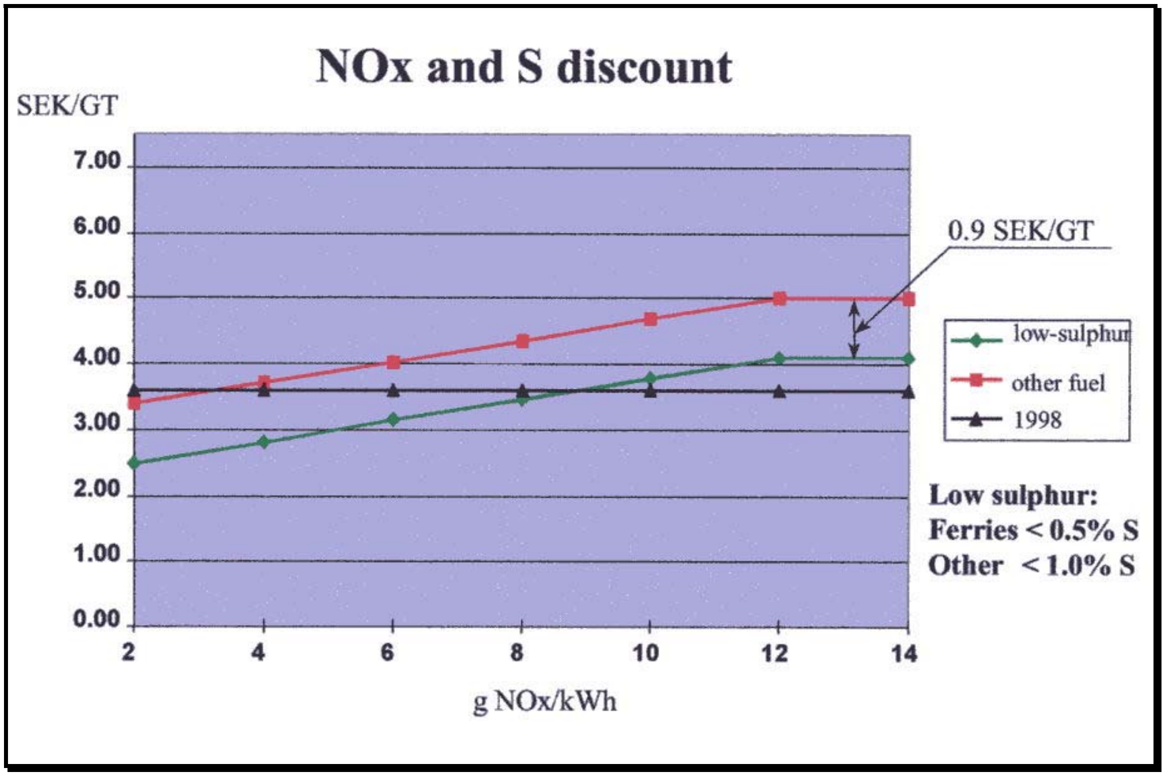


Figure 5. SWEDISH FAIRWAY FEES (Swedish Kroners /Ship Gross Tonne, ref. 26)

In order to encourage the installation of NOx abatement technique, especially catalytic converters, the Swedish Maritime Administration granted reimbursement as high as 40% of the investment cost if the technique was installed before the year 2000, and up to 30% for installations thereafter. The possibility to receive such reimbursement ceased in January 2002.

To receive reimbursement for low-sulphur bunker fuel the ship owner has to provide a document declaring that the ship permanently and under all conditions is operated with a bunker fuel containing less than 0.5% sulphur for ferries and less than 1% sulphur for other ships. Ships apply for a document of compliance for reduced fairway dues via *Sulphur Oxide (SOx) Reduction Attestation*, a form that is sent to the Swedish Maritime Administration. The Swedish Maritime Administration then issues a *Document of Compliance for reduced Fairway Dues from Sulphur Oxide Reduction (SOx)*. The Swedish Maritime Administration also issues a *National Air Pollution Prevention Certificate (NOx)* to ships with certified levels of NOx/kWh. The certificate is mainly based on MARPOL Annex VI NOx Technical Code.

According to a recent estimate (SMA Annual Report 2001) the charging system for Swedish fairways and ports has helped to induce substantial decreases of maritime emissions of NOx and SOx. The overall emission reduction in the areas of the Baltic Sea and the North Sea has been estimated to 50,000 tons for SOx and 27,000 tons for NOx (calculated as NO_2).

The existing system is presently under review, not for the fact that it is not a success, but because of the overall principle of how to more accurately relate the dues to environmental marginal costs that would encourage a more environmentally friendly shipping.[37]

3.0 TECHNOLOGIES FOR EMISSION REDUCTION

3.1 Introduction

Much research is underway into developing technology for reducing exhaust emissions from marine vessels. This research is being done by Scandinavian marine technology research institutes, by marine engine manufacturers in response to proposed IMO and national standards, and by pollution-control equipment manufacturers. Scandinavian research is driven by the density of marine traffic in their coastal waters and fiords and by the very large contribution that these vessels make to air pollution in these areas. For instance, the relative amount of ship emissions, as compared to the total Norwegian national emissions, is about 20% for SOx and about 60% for NOx[16].

Technology for emissions reduction can be divided into three general areas:

1. In-engine technologies, which modify the conditions of combustion, are used mainly to reduce NOx emissions and are favored by engine manufacturers since they are relatively easy to implement.

2. Fuel-related technologies that yield cleaner combustion through modified or alternative fuels. These technologies have the largest potential for reducing SOx emissions by lowering the sulphur content in the fuel.

3. Exhaust cleaning technologies that use some form of scrubber or reactor to remove contaminants from the exhaust stream. These technologies can remove 80 - 95 of NOx and SOx from exhaust gases, but are generally heavy, bulky and expensive and hence are not used unless absolutely necessary.

A summary of the efficiency and the cost of implementing selected emission reduction technologies was presented in a 1989 Norwegian submission to the IMO[17]. Typical emission reduction potentials and costs are presented in the table below. They are based upon 6000 hours per year operating time, a specific fuel consumption of 200 g/kWh for motor ships, and an annual cost of investment of 11%. Although this table is somewhat dated, it does give an overview of some of the commonly used technologies and their effectiveness.

Table 4 - SUMMARY OF EMISSION REDUCTIONS MEASURES (Ref. 11)					
Measures	**Low Sulphur Fuel**	**Water Emulsion**	**Natural Gas**	**Engine Modifications**	**Selective catalytic reduction**
Sulphur Dioxide	20% – 90%	0	90% - 100%	0%	0%
Nitrogen Oxides	0	0 – 30%	25% - 75%	0 – 50%	25% - 90%
Carbon Dioxide	0	0 – 2% Increase	20% - 30%	0 – 8% Increase	0
Hydrocarbons	0	?	50%	0 – 50%	0 – 60%
Particulates	0 – 25%	?	90% – 100%	0 – 50%	0

From the above it can be seen that the most effective way to reduce SOx emissions are to utilize a low-sulphur liquid fuel or to use natural gas. The most effective technologies for NOx reduction are either SCR or to burn natural gas. (We will see later that direct water injection is now achieving 50% NOx reduction, making it competitive with dual-fuel natural gas in this respect).

These emission reduction techniques will be further discussed in the following sections.

3.2 In-Engine Methods For Reduction of Nitrogen Oxides

As previously discussed, nitrogen oxides from diesel engines derive from two sources:

1. Oxidation of the nitrogen in the combustion air under high temperature, called thermal NOx.
2. Oxidation of the nitrogen compounds of the fuel, known as fuel NOx.

Almost all the nitrogen present in the fuel reacts with the oxygen in the air to nitrogen oxides, but this still constitutes only a small part of the total quantity of nitrogen oxides. The formation of thermal NOx depends on excess-air ratio, pressure, temperature and combustion duration. During combustion nitrogen oxide, NO, is formed first. Later, during expansion and while in the exhaust system, some of this thermal NO is converted to nitrogen dioxide, NO_2, and also to nitrous oxide, N_2O, (approx 5 and 1 per cent respectively of the original NO quantity).

The main factors affecting the emissions of nitrogen oxides are:

- The design and optimization of the engine:
  - Injection timing.
  - Injection Pressure (higher pressure results in smaller fuel droplets and cleaner combustion).
  - Injection geometry.
  - Combustion chamber design.
  - Compression ratio.
  - Supercharging.

- Valve timing, etc.

- Ambient conditions:
  - Humidity.
  - Atmospheric pressure.
  - Ambient Temperature.
  - Cooling water temperature (lower temperature results in less NOx).
  - Exhaust system back-pressure (higher back pressure results in more NOx).

- Fuel:
  - Cetane rating (ignitibility).
  - Nitrogen concentration (Heavy bunker contains approx. 10% – 15% more nitrogen than diesel oil).
  - Viscosity (size of fuel drops in combustion chamber).

Today's engines are mainly optimized to minimize fuel consumption. It is possible to reduce emissions of nitrogen oxides by 20-30 per cent by modifying the optimization of the engine to minimize pollution emissions. This may, however, give an increase in fuel consumption of up to 5 to 10 per cent in older engines. Some of the in-engine measures can be carried out without any increase of the manufacturing cost of the engine, as the additional costs will mainly be on the operative side. Still larger emission improvements can only be achieved through design changes leading to new engines, and usually resulting in increased engine prices.

Optimizing an engine with respect to NOx emissions and fuel consumption is a complicated task. It is not possible to select one method of the ones mentioned below and pronounce this to be the correct one. Instead, it is up to the engine manufacturer to optimize every engine type utilizing a number of measures, some of which are required to reduce operational problems created with the NOx reduction methods.

In addressing primary NOx reduction methods, Wartsila Diesel identified a number of measures that can affect the reaction temperature in the cylinder and hence influence the amount of NOx formed (the higher the temperature and the longer the residence time at high temperatures, the more thermal NOx will be formed) [18]. Among the design measures are:

- A lower air manifold temperature (more efficient inter-cooling or lower ambient temperature) results in lower combustion temperatures.

- A slower injection rate normally implies lower combustion temperatures because less fuel is injected before the piston reaches top dead center (TDC), thus yielding a lower maximum pressure.

- Retarded injection timing and changed valve timing also results in lower combustion temperatures and pressures.

- The geometry of the combustion space and the flow pattern within it may affect temperature distribution.

- A fuel with a poor ignition quality affects NOx formation.

- A lower compression ratio cuts down on the peak pressure and reduces temperature.

- Water emulsified in the fuel or introduced to the combustion space with the air or via separate nozzles will consume energy in evaporation, thus lowering the combustion temperature.

- Exhaust gas recirculation reduces NOx because the CO_2 and H_2O molecules have higher molar heat capacities and thereby dampen the combustion temperature.

In-engine measures presently being used for diesel engine emission reduction is summarized below.

- Retarded Fuel Injection - A later injection time leads to most of the combustion occurring after TDC. As a consequence, the maximum flame temperature in the combustion space will be lowered and the formation of nitrogen oxides will be reduced. Since this method is easily applicable and significantly reduces NOx formation, it is regarded as one of the most important tools for in-engine emission reduction. Using retarded injection exclusively leads to increased fuel consumption. To a certain extent this increased consumption may be compensated by other measures when the engine is optimized for low emissions[19]. To re-establish low fuel oil consumption the compression ratio of the engine is increased, resulting in low NOx emissions and no penalty in terms of fuel consumption[20]. Some newer engine designs are incorporating variable injection timing that allows the timing to be adjusted so as to optimize engine performance for different requirements. Electronic fuel injection control also accommodates shutting off the fuel flow to some of the cylinders during low speed operation, thereby allowing the remaining cylinders to operate more efficiently and with less pollution.

- Increased Fuel Atomization - Increased fuel atomization leads to better combustion; a higher indicated thermal efficiency and reduced emissions of NOx and particulate. Improved injector tips and/or increased injection pressure can accomplish better fuel atomization. Injector tip design is limited by the need for the fuel to properly mix with the combustion air. Injection pressure is limited by mechanical strength considerations of the injector pump drive train. Older engines use a maximum injection pressure of 1000 - 1200 bar while the newer designs can accommodate a pressure of 1500 bar [19]. Future designs may increase the injector pressure up to 2500 bar (36,000 psi) [21].

- Pre-injection - By injecting a small quantity of fuel before the regular injection, the ignition of the main charge is facilitated and the amount of premixed fuel can be reduced. Reduced premixed fuel leads to a more modest pressure and temperature increase at the beginning of combustion, leading to a lower maximum temperature and reduced formation of nitrogen oxides. Wartsila, a leading Finnish-based medium speed engine designer, uses separate injectors and injector pumps to effect pre-injection on their medium speed VASA 46 engine and claim a nitrogen oxide reduction of 15 %. Trials by Steyr, on a high-speed diesel engine, show reductions of the emissions of nitrogen oxides by 12% - 25% using pre-injection. The use of pre-injection also allows the use of two-fuel operation, wherein a more easily ignitable fuel is used for ignition, while an inferior fuel with a lower cetane rating is used as the main fuel. (This is done, for instance, when natural gas is used as the main fuel in a diesel engine.) Because of the extra expense and the reliability considerations, pre-injection is rarely used on existing large ship engines[19]. However, the new diesel engines being introduced by major engine manufactures use electronic injection so that pre-injection should be possible.

- Charge Air Techniques - Practically all medium-speed and low-speed diesel engines use turbocharging and intercooling to yield improved fuel economy. These measures can also contribute to reductions in the emissions of nitrogen oxides and other pollutants. Large diesels use seawater cooling that gives lower temperatures and hence lower nitrogen oxides emissions than if recycled engine-cooling water is used. However, over-cooling of the charge air may result in an ignition delay and hence actually increase nitrogen oxides and soot emissions. Therefore precautions have to be taken to achieve optimal charge air temperature. Over-cooling will especially present a problem during low-speed engine operation hence manufacturers may resort to using combustion air preheat. [19]

  Wartsila uses a clever “Miller supercharging” strategy in their 4-stroke Sulzer ZA40S engines in order to reduce the temperature of the charge in the cylinder. By using a high-pressure turbocharger, and closing the intake valves before the pistons reach bottom dead center during the intake stroke, the same amount of air as before can be charged into the engine. However, the expansion before compression cools the air charge in the cylinder. Tests showed that NOX emissions could be reduced by 15 to 20 percent without any increase in fuel consumption. [5]

- Engine Design Changes - These changes pertain to valve timing changes, combustion chamber and swirl chamber design changes, etc.

3.3 Reduction of Nitrogen Oxides by Water Addition

To achieve greater NOx reductions than those achievable by internal engine modifications and tuning processes described above, techniques such as exhaust gas recirculation (EGR), direct injection of ammonia, and the addition of water to the diesel process, may be employed. They can result in reductions of NOx in the order of, or even greater, than 50%. However, some of these measures are not compatible with the use of heavy fuel oil, are excessively expensive, or may result in an increase in other emissions.

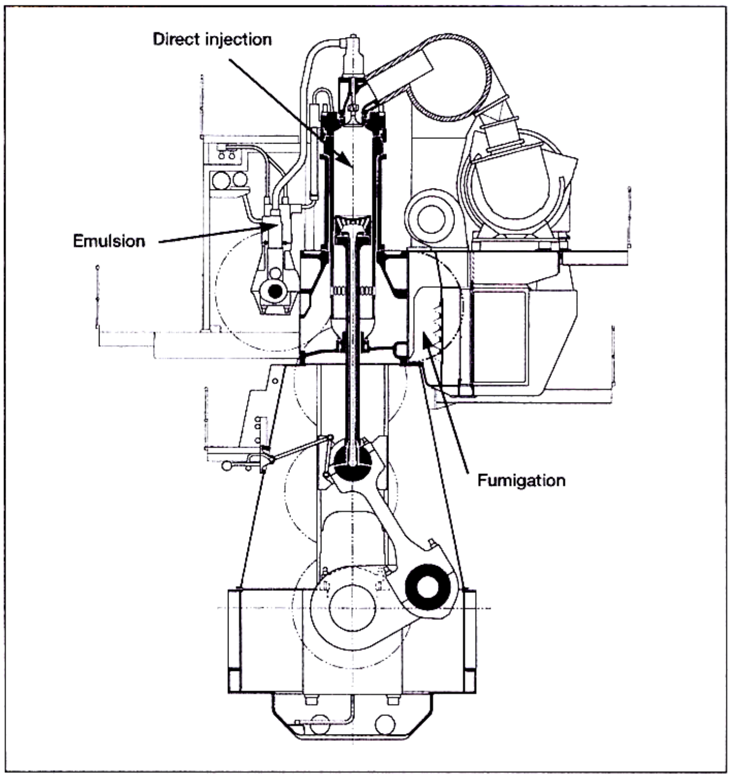


Figure 6 – DIFFERENT MODES OF WATER ADDITION

The introduction of water into the combustion chamber is a well-known NOx reduction technique. A potential problem with this process would occur if liquid water droplets impinge against the surface of the cylinder liners. In this case there would be an immediate disintegration of the lubrication oil film.[5] Therefore it is important that a water addition process be designed so that liquid water evaporates before it contacts the cylinder liners.

There are basically three ways to add water to the diesel engine combustion process: by direct injection in parallel with fuel injection, by fumigation (humidification) of the scavenge air, and by an emulsion with the fuel oil. These different processes are shown below in Figure 6.

3.3.1 Direct Water Injection (DWI)

Wartsila NSD Switzerland started in 1993 to develop direct water injection to achieve high NOx reduction rates. The water is handled by a second, fully independent injection system, preferably under electronic control. This offers the possibilities of firstly injecting very large amounts of water without having to derate the engine and secondly, having the ability use different timing for the fuel and the water injection. Independent injection systems allow water injection to be switched on and off without influencing fuel injection.

Based upon the 4RTX54 engine tuned for low NOx emissions, Wartsila realized a NOx reduction of greater than 60% through the combination of retarded fuel injection and direct water injection at approximately 140 g/kWh. Figure 7 below shows the effect of tuning and water injection upon NOx emissions and upon specific fuel consumption.

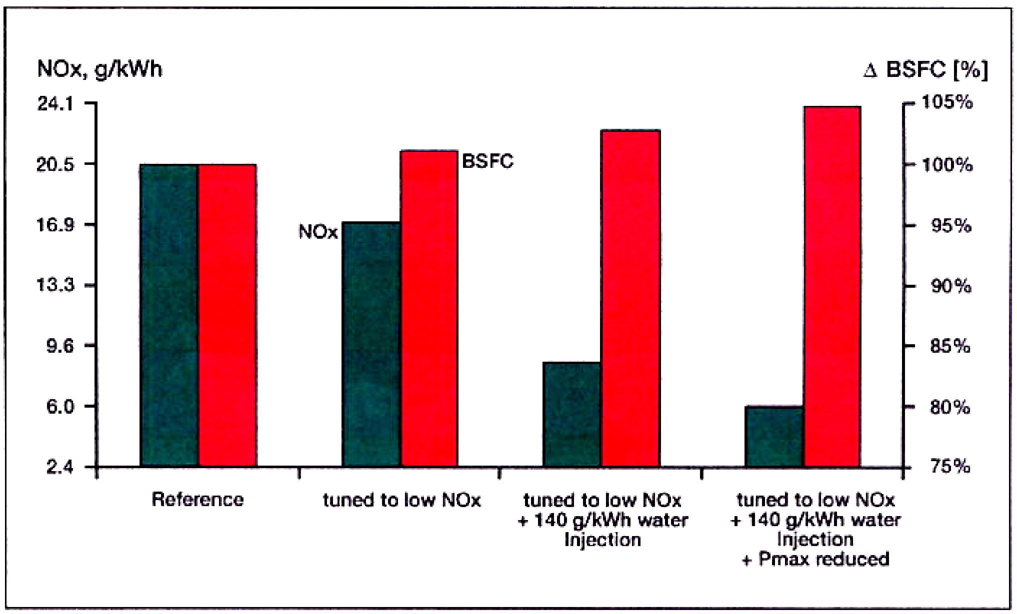


Figure 7 – Effect of water injection on NOx emissions (Ref.5)

It can be seen from Figure 7 that a dramatic reduction in NOx can be realized through a combination of DWI and engine tuning, although at the expense of an increase in fuel consumption.

The DWI package offered by Wartsila[27] for their four-stroke diesels includes the following components:

- Low-pressure module (1.7 m^3) to supply 3.5 bar water pressure to the high-pressure module, or a dual filter unit if suitable water is available.
- High-pressure module (1.7 m^3) to supply 200 – 4—bar water to the injection valves.
- Injection valves (Figure 8) and flow-fuse for each cylinder.
- Control unit, piping and cabling.

Figure 8. Wartsila DWI valve

The benefits claimed by Wartsila[27] for this DWI system include:

- NOx reductions of 50 – 60 %; typically 4 – 6 g/kWh on MDO and 5 – 7 g/kWh on HFO.
- Ratio of water to fuel typically 0.4 – 0.7.
- No negative effects upon engine components.
- Can be installed while the ship is in operation.
- Transfer to “non-water” mode at any mode. This transfer is done automatically in an engine alarm situation.
- Low capital and operating costs. ($15 - $20 US per installed kilowatt, $1.5 - $5.0 US per MWh operating cost) [28].

The downside of the DWI system is that it cannot be used at low loads (under 30% - 40% of full load). [28]

Assuming a 1000 kW engine running 2000 hours per year, a discount rate of 11%, and a NOx emission reduction of 50% (from 10 g/kWh down to 5 g/kWh), then the cost benefit of this technology would be in the range of $500 - $1,200 US per tonne NOx reduction.

To date Wartsila has 23 vessels, with a total of 568 cylinders and 526 MW power, equipped with DWI.[28] The main driving force behind this is the high Swedish fairway fees for polluting marine vessels. Similar technology is being developed for their large 2-stroke diesel engines.

3.3.2 Scavenge Air Humidification

Scavenge air humidification attempts to saturate the air between the turbocharger and the engine with water vapor. Different companies use different approaches:

M.A. Turbo/Engine Design's CWI System - The simplest system is that being developed by M.A. Turbo/Engine Design, called Continuous Water Injection (CWI) [29]. Here a very fine water mist is sprayed into the air intake side of the engine, typically after a turbocharger. The water injection system is automatically controlled to turn on only when the engine is under medium to high loads. NOx is reduced by up to 30% and PM by up to 50% at no increase in fuel costs or loss in engine power. In fact tests on a BC Ferry Wartsila 9R32D engine (3375 kW @ 750 rpm) have shown that the fuel consumption actually decreased by roughly 1% with CWI. Water consumption is around 30% of fuel consumption.

The CWI system has been tested on a number of vessels. The test installation cost for one Wartsila engine is quoted to be " $4,5000, for 4 engines each 360 hp at ferry OSKI (San Francisco) - $3,600, for 4 engines (one main Sulzer 4,500hp and three aux. Wartsila engines @ 550kw each) - $7,000. Systems operate practically maintenance free; only once in two months softener should be replaced (cost $50 for small engines and about $140 for main engines)". [29] NOx emission reduction, compared with CARB diesel, was 26% for the OSKI.[30]

Actual commercial, installed costs of the CWI can be expected to be considerably higher than the above quoted prototype costs. In the case of the Wartsila, which was one of two main engines on B.C. Ferry's Queen of New Westminster, an installed price for both engines of approximately $35,000, and annual maintenance costs of $3,500, would be more reasonable. The annualized (15 years@7%) operating cost for two engines would then be $3,843. Fuel savings at 1% would amount to $12,320 if MDO costs $320/tonne. Hence CWI has the potential to reduce NOx by up to 30% and PM by up to 50% at little or no increase in the cost for vessel operation. (Not included is the cost of water. A more detailed analysis of this option is carried out in Section 6.) Long term testing is needed, however, to ascertain the cumulative effects of CWI upon engine life and reliability. Such long-term testing is now underway on the auxiliary engine of a B.C. Ferry vessel.

Wartsila's CASS System – Wartsila is developing a "Combustion Air Saturation System", or CASS, that potentially reduces NOx by up to 70% at no increase in fuel consumption. This technology will be able to reduce NOx emissions down to about 4 g/kWh.[28]

Figure 9 presents a schematic of the CASS concept. Water is sprayed in after the turbocharger. If necessary, the intercooler is used as a heater to evaporate most of the water. Water droplets not evaporated are removed with a demister, resulting in saturated air at 70 - 90ºC.

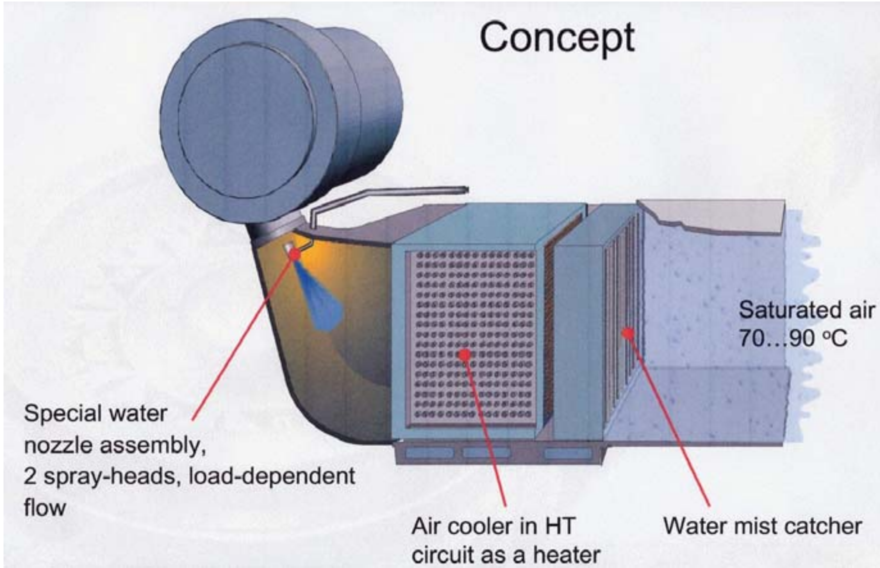


Figure 9. Wartsila Combustion Air Saturation System (Ref. 25)

Presumably the advantage of CASS over CWI is that the CASS system can safely achieve higher humidification levels without the fear of water droplets carrying over into the engine. The disadvantage is a higher installation cost for the demister system and the increased turbo pressure. However, the claimed 70% NOx reduction at no increase in fuel consumption makes this an upcoming technology to watch. No data is currently available to allow a $/tonne NOx reduction calculation.

3.3.3 Fuel-Water Emulsions

Both MTU and MAN depend on the use fuel-water emulsions to reduce water consumption. Wartsila has used fuel-water emulsions but have subsequently gone over to the DWI system. Their reasons are given below.

According to Wartsila[5], running an engine on fuel-water emulsions makes it theoretically possible to reduce NOX emissions by up to 50% with the required water quantity being about 1% for each percentage point reduction in NOx, as is shown in Figure 10 for 75% load. The limiting factor for fuel-water emulsions is the maximum delivery capacity of the injection pumps so that, in practice, the engine has either to be derated or the maximum achievable NOx reduction limited to about 10 – 20%. To obtain the maximum NOx reduction under full load, it may be necessary to redesign not only the injection system but also the camshaft, camshaft drive, etc. Because of these problems Wartsila developed their DWI system that was discussed in 3.3.1.

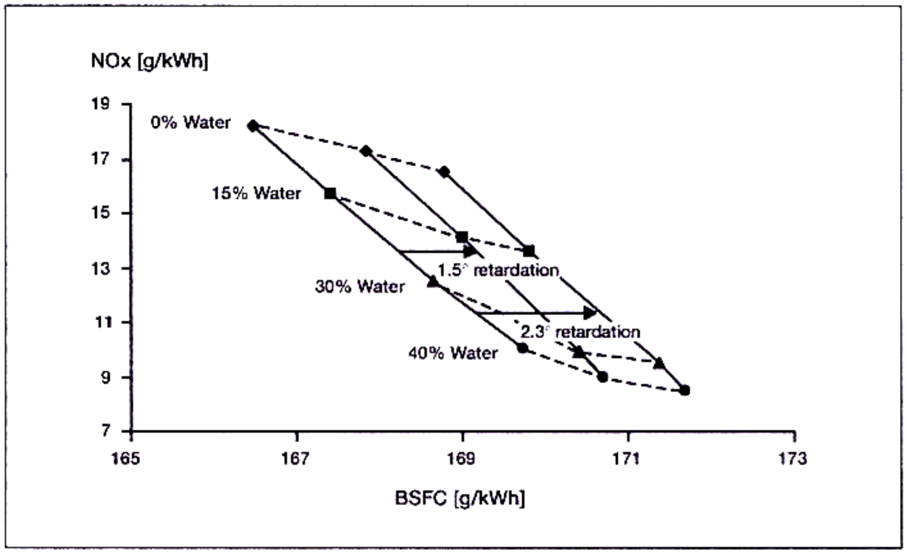


Figure 10. Effect of Water Content and Timing Upon NOx (Ref.5)

MTU – claims that the fuel-water emulsion system offers advantages in a small installation package, maximum effects can be obtained at partial load, low maintenance costs, no increase in exhaust back pressure and no increase in specific fuel consumption. A side benefit is a large reduction in soot emissions. The new system does not affect starting characteristics or behavior under load acceptance or load shedding conditions compared to a pure diesel unit. The only condition for use of this technology on MTU Series 396 8-, 12-, and 16-cylinder engines with split-circuit cooling system is the necessity for a flushing cycle after running on emulsion. This takes only up to 5 minutes and is activated automatically at 20% load.

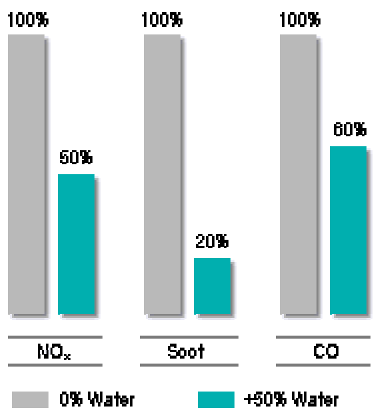


Figure 11 – MTU Water Emulsion

Figure 11 shows the reduction in emissions that are attainable when using an emulsion of 2/3 fuel and 1/3 water.[31]

MAN – MAN has adopted fuel-water emulsion (FWE) injection in combination with variable injection timing at part load as the most suitable measure to cut NOX emissions from their medium-speed diesel engines. Emulsification has the advantage that it uses the lowest amount of water for a given NOx reduction requirement. The other advantage is a large reduction in soot emissions as compared to either DWI or intake air humidification [32]. Since 2000 four RoRo vessels equipped with 12V 48/60 type medium speed diesel engines with FWE (max 20% water) are in operation. (The fresh water content is limited to 20% because it has to be produced onboard.) By simultaneously retarding injection at engine loads below 80% and using 20% FEW, NOx is reduced from 14.5 g/kWh (1996/97 status) down to 6.7 g/kWh.[32] No cost data is given by MAN for using FEW system.

Lubrizol Emulsion Additives

The Lubrizol Corp markets its *PuriNOx* emulsion which contains about 20% water, 80% diesel and somewhat less that 1% additives. The *PuriNOx* product is manufactured by fuel marketers and distributors, who mix Lubrizol's proprietary additives with diesel fuel to form a stable product that has the appearance of thick milk.[33] Emission reductions measured in a 8-cylinder, 34.5-litre engine are 15% NOx, 14% THC, 9% CO and 51% PM.[34]

The Port of Houston has been experimenting with the *PuriNOx* fuel emulsions for 2 years in five yard-trucks and 1.5 years in 2 yard-cranes. They have experienced a 25 – 30% reduction in NOx and a 30 – 50% reduction in PM. These reductions are considered to be cost effective at a cost of $7,500/ton of emissions.[35]

Typical emission reductions with *PuriNOx* are 20% for NOx and 50% for PM. Typical fuel cost premium in the USA is about $0.15 per gallon over the rack price for diesel (currently around $1.00 per gallon). However, since the emulsion is 20% water by weight (18% by volume) there is a 10% to 15% volumetric increase in fuel consumption. The net effect is a 20% to 25% increase in fuel costs to achieve the reductions in emissions noted above.

The San Francisco Water Transit Authority has also tried *PuriNOx* during a 3-month trial in a Cat diesel. They noticed 37% reduction in NOx emissions and a 42% PM reduction. The cost premium over CARB diesel was $0.16/gallon.[30]

In B.C.'s Lower Mainland the Chevron Burnaby refinery was slated to be the *PuriNOx* manufacturer and distributor. The capacity was expected to be in the order of 20 – 25 million gallons per year (70,000 – 90,000 TPY). [33]

Diesel can also be emulsified with methanol or ethanol. Lubrizol markets their E-diesel, a blend of ethanol and diesel, as an alternative transportation fuel and claim lower emission levels of particulates. No cost or performance data is available for these emulsions. They certainly have potential for significantly reducing emissions from existing engines.

Cost of Using FWE

Assume a 1000 kW diesel engine with a SFOC of 200 g/kWh, a nominal NOx emission rate of 12 g/kWh, which is reduced 30% using FWE.

- Fuel used: 230 kg/h, approx. 90 US gallons.

- Cost of additive: At $0.16/gal is approx. $14.40/h
- NOx reduction: from 12 kg/hr to 8.4 kg/hr (3.6 kg/h)
- Cost/benefit: $4/kg (<u>$4,000/tonne NOx reduction</u>)

It can be seen from this hypothetical example that FWE incurs a significant cost due to the expense to the Lubrizol additive.

3.4 Reduction of Nitrogen Oxides by Exhaust Gas Recirculation

Another NOx reduction option measure is EGR (Exhaust Gas Recirculation). Here a portion of the exhaust gases are recycled back to the engine charge air, thereby diluting it and reducing peak combustion chamber temperatures. Some laboratory research has demonstrated NOx reductions of 10 % to 30% with only a marginal increase in fuel consumption. Higher NOx reductions will generally significantly increase fuel usage. EGR has not been used on large ships because of complications caused by ship's consumption of residual fuels. These complications are caused mainly by acidic soot deposits which would damage the turbocharger and which cause increased smoke emissions. Remedial actions are usage of a high quality fuel or exhaust gas particulate removal, both significantly increasing the operational costs and, for the latter, strongly affecting system complexity and availability. Cost of EGR is expected to be similar to that for water-in-fuel emulsions if no particulate scrubbing/filtration is required. The necessity for a higher quality fuel will further increase costs.

EGR is being used in heavy-duty diesel vehicles, which typically have smaller, high-speed diesel engines and which burn relatively low-sulphur diesel. In most cases an intercooler lowers the temperature of the recirculated gases. The cooled recirculated gases, which have a higher capacity than air and which contains less oxygen than air, lower combustion temperature in the engine and thereby reduce NOx formation. Diesel particulate filters are often an integral part of any low-pressure EGR system, ensuring that large amounts of particulate matter are not recirculated to the engine.

EGR systems are capable of achieving 40% NOx reduction. The cost for retrofitting EGR on a typical bus or truck engine is about $13,000 - $15,000 US. Over 400 EGR systems have been installed on bus engines in Europe. EGR retrofit systems are now being installed in the USA on solid waste collection vehicles, buses and some city-owned vehicles. Technology demonstration programs have been conducted in Houston, TX and Los Angeles, CA. Additional demonstration programs are being planned in the San Francisco Bay area; Sacramento, CA; and Washington, DC.[36]

The Manufacturers of Emission Controls Association (MECA) instituted a test program at Southwest Research Institute to investigate the performance of a variety of commercially available exhaust emission control technologies with standard No.2 diesel (368 ppm sulphur), low-sulphur diesel (54 ppm sulphur) and, in limited cases, with zero sulphur diesel. A 1998 12.7 liter Detroit Diesel, 400 HP Series 60 engine with electronic injection timing was used as the test bed. EGR was incorporated onto the engine for some of the testing. Figure 12 shows the effect of EGR alone and EGR in combination with different particulate filters, using the heavy-duty engine transient US Federal Test procedure (FTP).

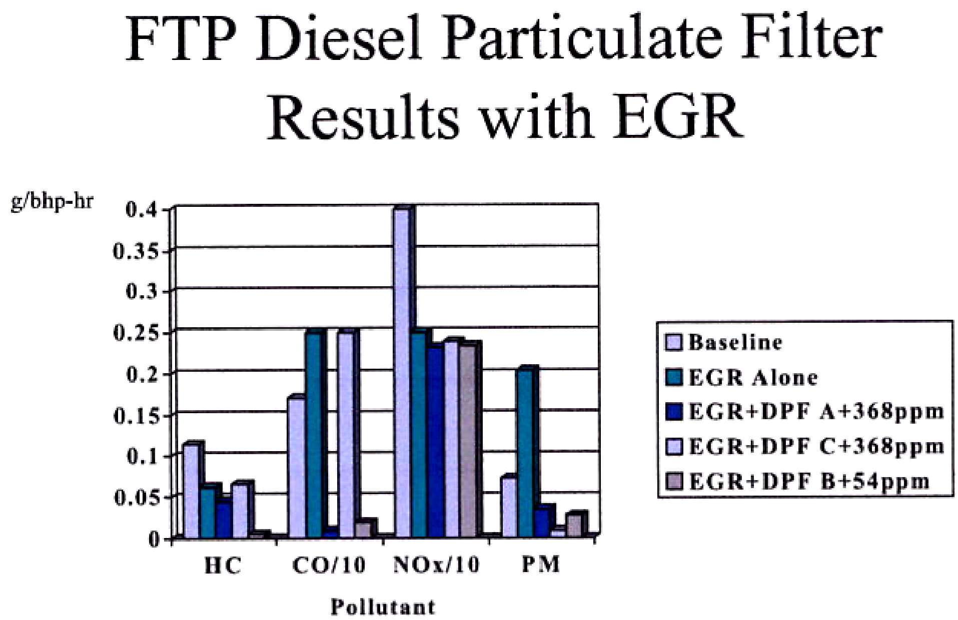


Figure 12 – EGR and DPF (Ref.37)

The results of the testing show that EGR alone will decrease NOx by 38%, but at the expense of increasing CO and particulate emissions. With the addition of a commercially available, self-regenerating catalytic diesel particulate filter, NOx was reduced by approximately 40% and particulate emissions reduced to less than 0.05 g/bhp-hr on both fuel containing 368 ppm sulphur and 43 ppm sulphur.

The diesel particulate filters tested in the MECA study were cylindrical in shape, about 10" diameter and 12" long. This size would be typical for engines with displacements ranging from approximately 7 – 13 liters.[37] These units can be installed as muffler replacements if space limitations are a problem.

DPF maintenance is required when the backpressure increases above a predetermined level. In, practice this filter cleaning is needed approximately every 2,000 hours and takes about 2 hours.[37] EGR, combined with DPF, can be expected to incur a fuel penalty in the order of 3 - 5%.

According to MECA, the average cost of a DPF is about $7,500 US. [36] The cost of retrofitting a 400 hp diesel with EGR is estimated to be $13,000 - $15,000US. [36]

Example: Small Diesel - Estimated Cost-Benefit For EGR + DPF

- Assume a 400 hp diesel engine with a NOx reduction of 1.5 g/bhp-hr and with 2000 operating hours per year, the annual NOx reduction would be 1.2 tonnes.
- Assuming a 4% fuel economy penalty, a SFOC of 200 g/kWh and diesel costing $1.00/gallon, then the additional fuel cost would be $1,800/year.
- Assuming a total installed cost of $15,000, capitalization of 11% and annual maintenance/replacement costs of $1000, then the total annual cost would be $4,450, or $3,700/tonne NOx.

Johnston Matthey is marketing an EGRT ™ system for NOx and particulate reduction. They claim greater than 40% NOx reduction, and greater than 90% reduction in CO, HC and PM. A specially formulated catalyst converts some of the NO in the exhaust to NO_2, which then oxidizes the soot collected in the filter, thereby regenerating the filter. A control module, programmed with engine mapping to optimize the system, is important to prevent plugging of the catalyst filter. The use of ULSD is recommended for maximum emission reduction and filter regeneration. Over 1200 on-road installations have proven the durability of their system, which is approved by the engine manufacturers and which therefore maintains the engine warranty.[41]

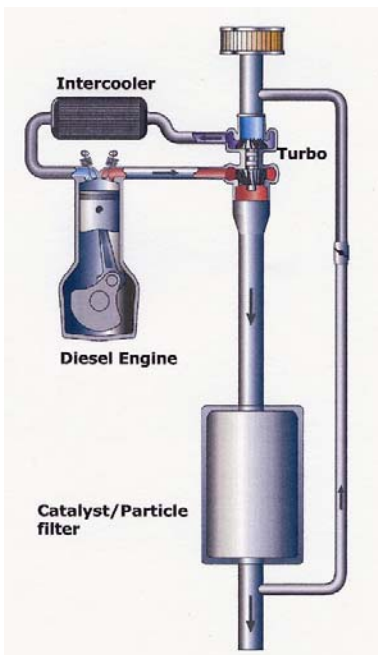


Figure 13 (Ref. 41)

Figure 13 shows the EGRT ™ low-pressure EGR system. A cooler can be fitted onto the recycle line to further reduce NOx. The whole system is quite compact and can be retrofitted into a typical city transit bus. The filter is approximately 13" in diameter and 30" long.

The installed cost for a EGRT ™ for say a 12.7-liter Detroit Diesel 400 hp Series 60 would be in the order of $20,000 - $23,000, with the price being reduced based on the total number of units (>20). The expected service life is at least 5 years, with filter ash cleaning about once per year, or every 60,000 – 100,000 mile of operation. The increase in fuel consumption is expected to be less than 2%. The cost effectiveness of this technology ranges from $950/ton NOx to $1,600/ton NOx.[45, 46]

A 2002 study for the San Francisco Water Transit Authority to look at technologies to reduce emissions from ferries concluded that EGR, while being suitable for engines under about 500 hp, are not yet fully developed for the larger marine diesels.[38]

Wartsila has investigated EGR for their large marine engines and concluded that there are too many problems because of fouling and corrosion due to the burning of heavy fuel oil. To avoid these problems they use "internal recirculation" to keep a portion of the burned gases within the combustion chamber by reduced scavenging ports and smaller turbochargers. The temperature within the combustion chamber is then reduced down to the level it would be without internal recirculation by using direct water injection.[5] Wartsila is now achieving up to 70% NOx reduction (down to 5 g/kWh) with their *Water Cooled Residual Gas* system through a combination of internal EGR, direct water injection and RT-flex (common rail and variable exhaust valve timing).[25]

The EGR system is very effective for NOx reduction in medium-sized, clean burning, natural-gas engines. Wartsila has shown that the NOx emission can be reduced from over 8 g/kWh down to less than 2 g/kWh. This is, however, at the expense of an increase in fuel consumption of about 4% (Figure 14). Depending upon the duty cycle of the engine, this may be a lees expensive option than using SCR to dramatically reduce NOx.

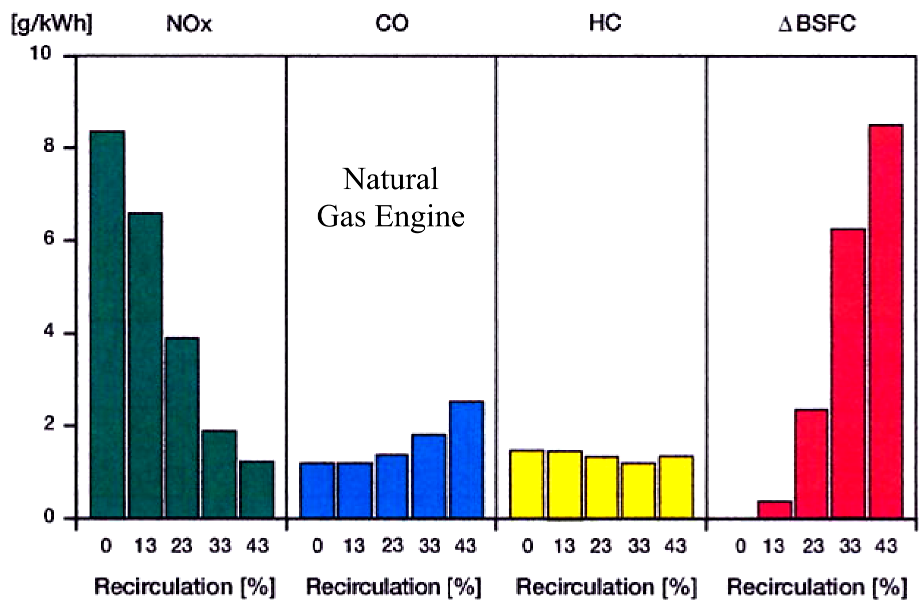


Figure 14. Effect of EGR on Emissions and Fuel Consumption (Ref. 5)

At this stage of development external EGR technology is probably limited to workboats burning low sulphur diesel (ULSD) and to larger engines burning natural gas.

3.5 Selective Catalytic Reduction (SCR) For NOx Control

SCR of NOx using ammonia or urea has been used for many years in stationary and marine diesel applications, and also for gas turbine NOx control. The first marine SCR units were installed in 1989 and 1990 on two Korean 30,000 metric ton marine carriers. The ship operator was seeking a permit from the Bay Area Air Quality Management District to allow the reduced-emission ships to dock there. Both ships were powered by MAN B&W 8 MW diesel engines. The ammonia SCR systems were designed for 92% NOx reduction and were granted operation and docking permits. Since that time numerous vessels have been fitted with various SCR NOx reduction systems, primarily in Europe. [38]

The catalysts employed for SCR units are typically vanadium pentoxide embedded in titanium dioxide, and additionally are often dosed with tungsten trioxide and molybdenum trioxide to optimize the catalytic properties. Such catalysts are termed "full-contact catalysts", in contrast to "coated catalysts" in which a porous carrier material is coated with the catalytic material.[5] The operating temperature range for various catalysts are given as 175ºC - 250ºC for platinum catalysts, 300ºC - 450ºC for vanadium catalysts and 350ºC - 600ºC for zeolite catalysts.[38]

Ammonia (NH_3) and urea ($CO(NH_2)_2$) have turned out to be the only commercially applicable reducing agents. Both chemicals are widely used as a source of nitrogen in agricultural applications and therefore are readily available at a reasonable price. Ammonia gas is more difficult to handle and to store, whereas urea is used in a water solution, typically at around 40% by weight. As a solution it has a pH of 9 – 11 and a relatively low toxicity. When it is heated urea decomposes to ammonia – this process requires 2 – 3 meters in the hot exhaust pipe.

Diesel exhaust is at a fairly low temperature (250ºC - 400ºC) and the presence of sulphur trioxide (SO_3) poses a limitation on the temperature range in which the SCR system can operate. For exhaust temperatures below about 300ºC (the exact value dependent upon the concentration of ammonia and SO_3, as well as the porosity of the catalyst surface), the ammonia and SO_3 combine to form ammonium sulphate. Ammonium sulphate is an adhesive and corrosive aerosol that can foul the catalyst. At temperatures above 500ºC, ammonia starts to burn in the oxygen-rich exhaust gas, therefore the temperature window for an SCR unit is in the region of about 320ºC - 480ºC, with an optimal temperature of approximately 350ºC. [5]

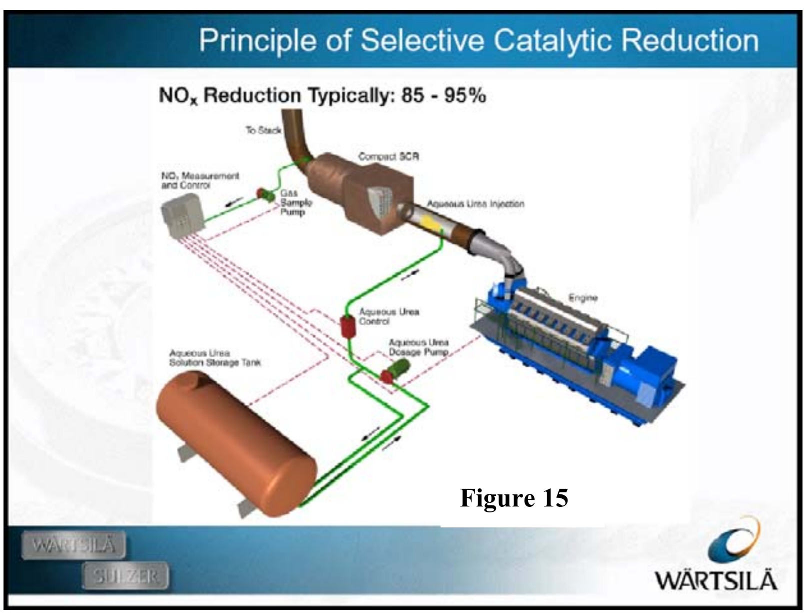
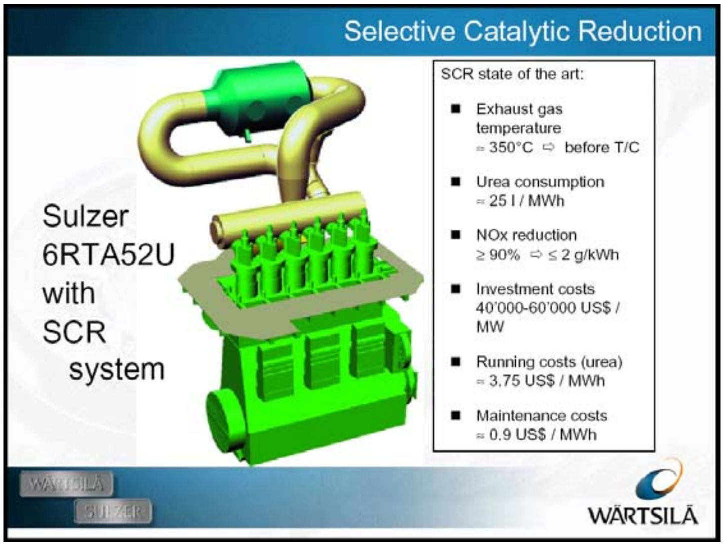


Figure 15

Figure 15 presents a schematic of a SCR system installed on a 4-stroke diesel engine.[25] (For a low-speed 2-stroke diesel the catalyst is usually installed before the turbocharger.)

The rate of urea addition in this Wartsila system is controlled by the amount of NOx measured in the exhaust stream (feed-back control system). Feed-forward control is also used.

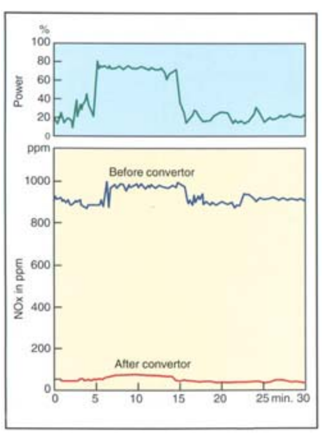


SCR has been successfully used on diesel engines burning low quality fuel oil with a sulphur content of 3.5%.

For 2-stroke diesels Wartsila has developed their "Compact SCR", which combines an SCR unit and silencer, together with built-in soot blowers. This system is shown in Figure 16.

Figure 16 – Wartsila Compact SCR System (Ref. 25)

The SCR reactor housing, including insulation, has a volume of about 2 – 5 m3 per MW engine power (depending upon the catalyst, which is dependent upon fuel quality). The size is more or less independent of the input NOx concentration. The exhaust backpressure imposed by the SCR plant is typically between 15 and 25 mbar. If the SCR is only to be used intermittently, then a burner is absolutely necessary to heat the catalyst before the engine is started. Otherwise ammonium sulphate deposits will inevitably plug the catalyst. [5]



Hug Engineering, who have supplied about 70% of the SCR units in use in Europe, use an engine load signal to control the amount of urea injected into the exhaust. This allows a much faster response than would be attainable if only feedback control was used. Figure 17 shows how this control system follows the load for a ferry installation, where there are frequent large transients in engine load.

Figure 17. Transient Response of SCR (Ref. 42)

For smaller diesel engines, MECA estimated the cost of SCR at about $17,500 - $40,000 for engines in the 100 – 200 hp range, and about $18,500 - $50,000 for engines in the 300 – 500 hp range. [38]

Due to the high installed cost of SCR systems, their cost-effectiveness is highly dependent upon their annual operating hours and upon the degree of NOx removal. RJM Corporation has estimated the cost-effectiveness of using their RJM ARIS system on a 2,336 hp, stationary 4-stroke diesel with 687 ppm NOx.[43] The capital cost is estimated to be $157, 600 for 90% NOx removal, $150,000 for 75% NOx removal, and $142,000 for 50% NOx removal. Table 5 below shows the resulting cost-effectiveness vs. operating hours.

Table 5 – SCR Cost-Effectiveness for NOx Removal (2,336 HP stationary diesel, ref. 43)

Hours/year of operation	90% NOx Reduction ($ per ton reduced)	75% NOx Reduction ($ per ton reduced)	50% NOx Reduction ($ per ton reduced)
1,000	$3,130	$3,422	$4,654
2,000	$1,763	$1,909	$2,475
4,000	$1,080	$1,183	$1,436
8,000	$738	$775	$916

The uncontrolled emissions are given as 101 tons per year for 8000 hours per year operation. This is equivalent to 8.7 g/bhp-hr and 6.6 g/kWh.

Wartsila recently investigated the different machinery concepts for 12,000 DWT RoRo vessels.[44] The most competitive design was a single Wartsila 64 medium speed diesel engine with SCR. Figure 18 shows that the annual cost of SCR is a small, but significant, part of the total annual machinery costs (approximately 7%). (Not shown are the all the other costs – vessel costs, crewing costs, licensing and insurance costs, port fees, etc.)

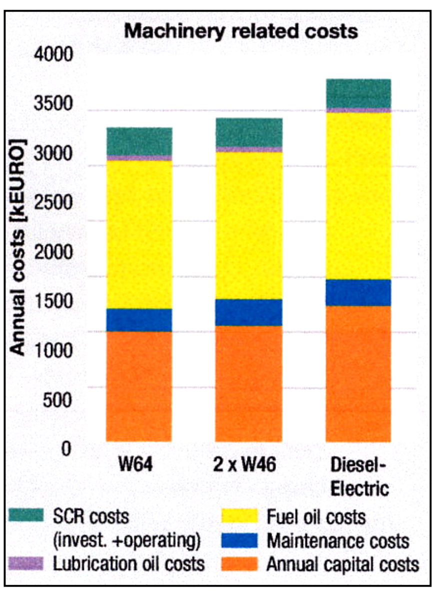


Figure 18. Annual Machinery Costs for RoRo Operation (Ref. 44)

3.6 NOx Adsorbers for NOx Reduction

NOx adsorbers are the newest control technology being developed for diesel NOx control. The technology was originally developed for lean-burn, low-emission gasoline engines but is now being adapted for use in diesel engines. The adsorbers are incorporated into a catalyst wash coat and chemically bind NOx during normal lean (oxygen-rich) engine operation. After the adsorber capacity is saturated the system is regenerated. The released NOx is catalytically reduced during a short period of rich engine operation, using a conventional 3-way catalytic converter. The reactions are shown schematically in Figures 19 & 20 (From Ref. 46).

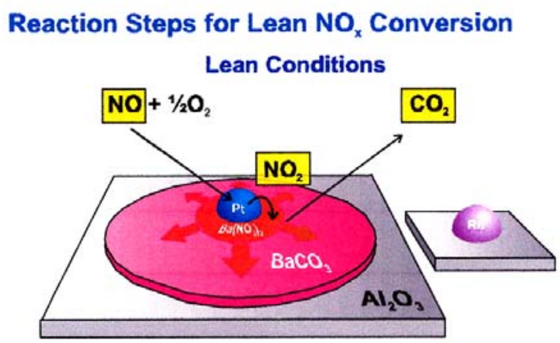


Figure 19

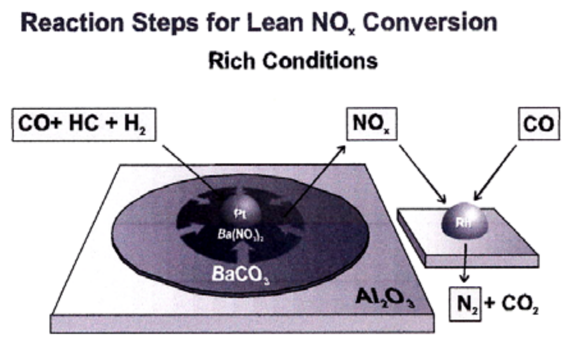


Figure 20

The NO is adsorbed and chemically binds with barium carbonate ($BaCO_3$) to form barium nitrate ($Ba(NO_3)_2$). During regeneration the diesel exhaust gas is rich in CO and unburned hydrocarbons. Theses chemicals reduce $Ba(NO_3)_2$ back to $BaCO_3$, in the process releasing NOx. In a downstream 3-way catalytic converter the NOx is reduced by the rich exhaust gases to nitrogen (N_2).

The regeneration step during lean/rich modulation typically lasts a few seconds. Various methods are used to attain rich conditions:

- Intake air throttling
- Exhaust gas recirculation
- Post-combustion fuel injection.

The technology has demonstrated NOx conversion efficiencies of in excess of 90%. [46] The catalyst is, however, susceptible to sulphur poisoning and hence ULSD must be used as a fuel. Emerachem is developing a system that includes up-stream sulphur "trap" to obviate this problem. [47] (The same company is commercializing a NOx removal system (SCONOx) for stationary gas turbine power plants, where the sulphur concentration in the fuel is extremely low. [48]) Because rich exhaust conditions must be periodically induced for adsorber regeneration, there will be a fuel-economy penalty of 1% - 3%, depending upon the NOx concentration in the exhaust (high NOx requires more frequent regeneration).

The NOx adsorber technology is not yet mature, but initial commercial offerings can be expected to coincide with the 2007 ULSD road diesel requirements.

3.7 Diesel Filters for Particulate Reduction

Diesel Particulate filters (DPF) are commercially available for smaller 4-stroke marine diesel engines that burn low-sulphur road diesel. They are easily plugged by the impurities present in heavy fuel oil and bunker oils. Figure 21 is a schematic of a DPF.

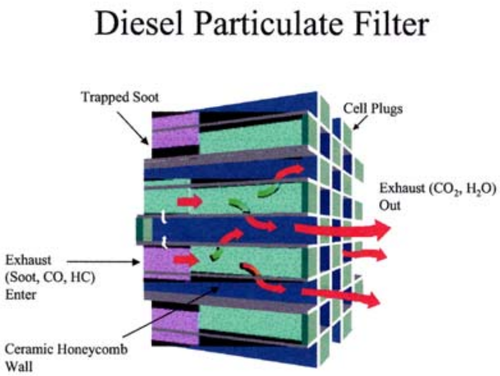


Figure 21. DPF (Ref. 46)

In the figure, particulate-laden exhaust enters the filter from the left. Because the cells of the filter are capped at the downstream end, exhaust cannot exit the cell directly. Instead, exhaust gas passes through the porous walls of the filter cells and particulate matter is deposited on the upstream side of the cell walls. Cleaned exhaust gas exits the filter to the right. Removal efficiencies of over 90% can be achieved.

Many techniques can be used to regenerate a diesel particulate filter. Some of these techniques are used together in the same system to increase regeneration efficiency. The major regeneration techniques are shown below.[36]

- Catalyst-based regeneration using a catalyst applied to the surfaces of the filter. A base or precious metal coating applied to the surface of the filter reduces the ignition temperature necessary to oxidize accumulated particulate matter.
- Catalyst-based regeneration using an upstream oxidation catalyst to convert NO to NO_2. The NO_2 then adsorbs on the collected particulate substantially reducing the temperature required to regenerate the filter.
- Fuel-borne catalysts to reduce the temperature necessary to oxidize accumulated particulate matter.
- Air-intake throttling in one or more cylinders can increase the exhaust temperature.
- Post top-dead-center (TDC) fuel injection. Injecting small amounts of fuel in the cylinders after TDC results in a small amount of unburned fuel in the engine's exhaust, which can then be oxidized in the particulate filter to combust accumulated particulate matter.
- On-board fuel burners or electrical heaters upstream of the DPF, or electrical heating coils within the DPF.

- Off-board electrical heaters – blow hot air through the filter system.

Other regeneration methods currently being investigated include the use of plasma to convert NO to NO_2, and the use of microwave energy to help burn off the collected soot.

The experience with catalyzed filters indicates that there is a virtually complete elimination of odor and in the soluble organic portion of the particulate. However, some catalysts may increase sulphate emission by oxidizing SO_2 to SO_3. Companies selling catalyzed filters have reformulated their catalysts to reduce sulphate emissions to acceptable levels. The use of ULSD will also mitigate this problem.

A recent study of catalyzed soot filters by the University of Utah demonstrated 95% - 98% filtration efficiency in removing particulate matter, 72% - 89% efficiency in total hydrocarbons and 49% - 92% reductions in CO during various transient tests.[49]

Diesel particulate filters are widely used both on-road and off-road. They have been installed on off-road equipment since 1986, with over 20,000 active and passive systems being installed either as OEM or as retrofits worldwide. Some of the off-road systems have been in use for over 15,000 hours or over 5 years and are still in use. [36]

As noted in a previous section, DPF can be combined with exhaust gas recirculation (EGR) to achieve NOx reductions of over 40% and PM reductions of over 90%. Engines equipped with selective catalytic reduction (SCR) and DPF can achieve NOx reductions of 75% - 90% and PM reductions of over 90%. Retuning the engine to minimize NOx, and then using the DPF to control the extra particulate emissions can also achieve combined NOx and PM reductions. [36]

The diesel particulate filters are quite compact and can be designed to replace the existing muffler, although some form of exhaust gas reheat may be needed for a self-cleaning catalytic system, which require a temperature of 200ºC to 280ºC. [38]

DPF unit costs are around $7,500. [36] Installed cost will be higher, depending upon the degree of modifications required. The Washington Metropolitan Area Transit Authority budgeted $4.6 million to retrofit between 208 and 282 Detroit Diesel engined buses. [36] This works out to $16,300 - $22,000 per bus but probably includes research testing and administrative overhead costs.

Cost-Effectiveness for Particulate Reduction on a Work Boat Diesel

The DPF technology is appropriate for small workboats and for the auxiliary engines of larger vessels such as ferries, provided that they burn ULSD road diesel. The cost-effectiveness can be estimated as below.

- Assume a 400 hp diesel engine with particulate reduction of 0.8 g/bhp-hr and with 2000 operating hours per year, the annual PM reduction would be 0.64 tonnes.

- Assuming that the workboat must use ultra-low sulphur road diesel (ULSD), instead of MDO, with an extra cost of $15/tonne and a SFOC of 200 g/kWh, then the additional fuel cost would be $1,800/year.
- Assuming a total installed cost of $10,000, capitalization of 11% and annual maintenance/replacement costs of $800, then the total annual cost would be $3,600, or <u>$5,600/tonne PM</u>.

Much of this cost is due to the use of ULSD, which also results in about 0.15 TPY less SOx emissions to the atmosphere due to its much lower sulphur content as compared to MDO (<15 ppm S vs. 1,300 ppm S).

3.8 Diesel Oxidation Catalysts (DOC) for THC and CO Reduction

The diesel oxidation catalyst is the only catalyst technology that has demonstrated required robustness and durability with presently available on-road diesel fuels and is commercially established in a large number of diesel systems. The diesel oxidation catalyst promotes the oxidation of THC and CO with up to 90% efficiency, as well as the soluble organic fraction of diesel particulates. The catalyst also promotes the oxidation of SO_2 to SO_3, which leads to the generation of sulphate particles and which may actually increase the total particulate emissions (PM) despite the decrease in the soluble fraction. These catalysts are therefore designed to be selective in order to obtain a compromise between high THC and soluble particulate activity and acceptable low SO_2 activity. [38] The performance of the DOC is greatly enhanced by using low sulphur road diesel. [36]

Under EPA's urban bus rebuild/retrofit program, five manufacturers have certified DOC's as providing at least 25% reduction in PM emissions for in-use diesel buses. Certification data also indicates that DOC's achieve substantial reductions in CO and THC emissions. [36]

The DOC's can be combined with engine tuning to reduce NOx, by tuning the engine for low NOx and then using a DOC to control the accompanying increase in CO, THC and PM. [36]

The benefits of DOC include the oxidation of toxic, non-regulated, hydrocarbon-derived emissions, such as aldehydes and PAHs, as well as elimination of the diesel odor. DOC's have been installed in over 250,000 off-road vehicles around the world for over 30 years. Over 1.5 million DOC's have been installed on heavy-duty highway trucks in the USA since 1994. These systems operate reliably and trouble free for hundreds of thousand of miles.[36]

The cost of DOC varies according to engine power. For a muffler replacement on a 100 – 200 hp engine the cost is about $1250. This increases to about $1750 for a 300 – 500 hp engine. [38] It is probable that the average installed cost will be significantly higher than these estimates.

Cost-Effectiveness for THC and PM Reduction on a Work Boat Diesel

The DOC technology is appropriate for small workboats and for the auxiliary engines of larger vessels such as ferries, provided that they burn road diesel in place of MDO. The cost-effectiveness can be estimated as below.

- Assume a 400 hp diesel engine with THC and soluble organic fraction (SOF) reduction of 0.8 g/bhp-hr and with 2000 operating hours per year, the annual reduction would be 0.64 tonnes.
- Assuming that the workboat must use road diesel, instead of MDO, with an extra cost of $5/tonne and a SFOC of 200 g/kWh, then the additional fuel cost would be $600/year.
- Assuming a total installed cost of $2,500, capitalization of 11% and annual maintenance/replacement costs of $250, then the total annual cost would be $1,125, or $1,800/tonne of THC and SOF.

4.0 CLEAN FUEL OPTIONS FOR EMISSIONS REDUCTION

Often the most economical way to reduce vessel emissions is through the usage of clean fuels, especially in the case of SOx emissions. A previous, 2002 study[50] with Environment Canada (*Fuel Quality Options for the Reduction of Marine Vessel Emissions in the Georgia Basin*) investigated six different clean-fuel options. These are summarized below. (Note: all costs below are in $USA)

Options 1 – 3 are applicable to large, ocean-going vessels (freighters, container ships, tankers, cruise ships) whereas options 4 – 6 are applicable to ferries and workboats.

4.1 Option One (Designation as a *SOx Emission Reduction Area*)

Designation of the Georgia Basin/Puget Sound (GB/PS) airshed as an IMO *SOx Emission Reduction Area* would reduce the fuel sulphur content of bunker oil from the present average value of 2.45% sulphur (S) down to less than 1.5% S. This initiative significantly reduces, by 11,000 tonnes or 44%, the amount of marine vessel SOx emissions, at a cost of **$1,300/tonne**. IMO-compliant fuel is readily available, although demanding a premium of approximately $30/tonne, as compared with regular 2.45% S bunker.

The barrier here is acceptance by the IMO stakeholders; this may be difficult and time-consuming but should be pursued. Because ocean-going vessels frequently visit more than one port and have considerable flexibility in where they fuel, it would be best to designate the entire west coast of the USA and southern Canada as a *Special Area*. This blanket coverage would discourage shipping companies from avoiding IMO designated ports in order to save on fueling costs, and would provide for a level playing field.

4.2 Option Two (Port of Valdez Type of Voluntary Agreement)

A somewhat more costly alternative is a "voluntary" agreement like that presently existing for oil tankers in the Port of Valdez. This agreement, between the tanker operators and the State of Alaska, requires the tankers to use low sulfur bunker (< 0.5%) while in the Port of Valdez. Such an Agreement for the GB/PS airshed would result in a major reduction in SOx emissions, by 19,000 tonnes or 79%, at a cost of **$1,340/tonne**.

Since voluntary compliance is unlikely from all foreign vessels, this instrument (and also Option Three below) could be given teeth (e.g.) by implementing differential Port fees, depending upon fuel sulphur content. Cooperation among the entire west coast of the USA and southern Canada is necessary in order to provide a level playing field and obviate avoidance tactics. Some sort of simple fuel logging and fuel monitoring program would have to be instituted.

At present there is an insufficient supply of low sulphur bunker to meet the needs within the GB/PS area (supply of 28,000 tonnes/year versus a potential demand of 477,000 tonnes/year). However, low sulphur bunker can be blended from low sulfur heavy fuel oil (HFO), which is available for commercial power generation within Canada and the USA. The cost premium for low sulphur bunker is currently (2002) $60/tonne over the price for regular bunker.

Vessels may have to be retrofitted with additional bulkheads, within their fuel tanks, as well as extra manifolding and valving so that fuel switching can be easily accommodated while underway.

4.3 Option Three (Large Vessels Switch to MDO Within GB/PS Airshed)

One of the clean-fuel options for large vessels that have been discussed by stakeholders is where vessels switch from bunker oil (IFO 180 and 380) to marine diesel oil (MDO) while within the GB/PS area. MDO has much lower sulphur content than does the heavier fuels (0.13% vs. 2.45%) and therefore results in less SOx and particulate emissions. Vessels normally carry a supply of MDO to start, and in some cases also to run, their auxiliary engines.

Sulphur dioxide emissions from marine vessels within the GB/PS airshed can be reduced by 21,944 tonnes per year (90%) and particulate emissions are reduced by 335 tonnes/year (8.3%). However, this is a more expensive option than the previous two and would incur an increased fuel operating cost of $51 million/year, or **$2,300/tonne** of pollution (SOx + PM). There is an adequate supply of MDO within the GB/PS area.

As was the case with Option Two, this clean-fuel alternative would require application to the entire west coast of the USA and Canada to obviate port avoidance, would require some sort of differential Port fees to provide incentives for cooperation and would require some sort of fuel logging and fuel testing program. Additional fuel tank bulk-heading, as well as extra manifolding and valving may also be required.

Recently the tanker *Iver Pride*, which loads at Chevron's Burnaby, B.C. refinery, started voluntarily using MDO within the BC waters in reaction to complaints about smoke from it's stack.[57]

4.4 Option Four (Ferries and Workboats Use Low-Sulphur Road Diesel)

Road diesel contains less than 500 parts per million by weight (ppmw) of sulphur, whereas regular marine diesel (MDO) contains approximately 13,000 ppmw of sulphur. By using road-diesel, marine-vessel SOx emissions within the GBPS airshed can be reduced by 961 tonnes/year (3.9%) and PM emissions by 42 tonnes/year (1.0%). This results in an extra annual operating cost of $2,400,000, or **$2,400/tonne** emissions.

The federal governments of the USA and Canada are in the process of extending road diesel requirements to off-road vehicles. There is an ample supply of road diesel within the GB/PS area.

4.5 Option Five (Ferries and Workboats Use ULSD, CPF and CWI)

The sulphur content of road diesel in Canada and the USA will be reduced to less than 15 ppm by 2006. Ultra-low sulphur diesel (ULSD) enables operators to reliably use catalytic emission reduction technologies such as catalytic particulate filters (CPF) for removing diesel particulates, and selective catalytic reduction (SCR) for NOx reduction. While continuous water injection (CWI) is not as effective in reducing NOx as is SCR (~30% reduction vs. >90% reduction), it is much less expensive and can be easily retrofitted onto existing engines.

Option Five combines ULSD with CPF and CWI. It is estimated that the increased cost of the ULSD, CWI and the amortization of the associated equipment and CPF, are equivalent to a fuel price increase of 10% over the base case (existing MDO operation). There will soon be ample supplies of ULSD within the GB/PS area.

This clean-fuel option reduces marine vessel SOx by 1,200 tonnes (5%), PM by 48 tonnes (12%), and NOx by 12,000 tonnes (14%). The cost/benefit ratio for this ratio is estimated to be **$550 per tonne** of total emission reductions. (Note that the estimate in Section 6 for this clean-fuel option is significantly higher due to more current data on the installed cost of the catalytic particulate filter.)

Changes in fuel regulations would again be the simplest way to promote the use of ULSD in marine vessels. Setting up an emission trading exchange would provide a strong economic impetus for the installation of CWI and other control technologies.

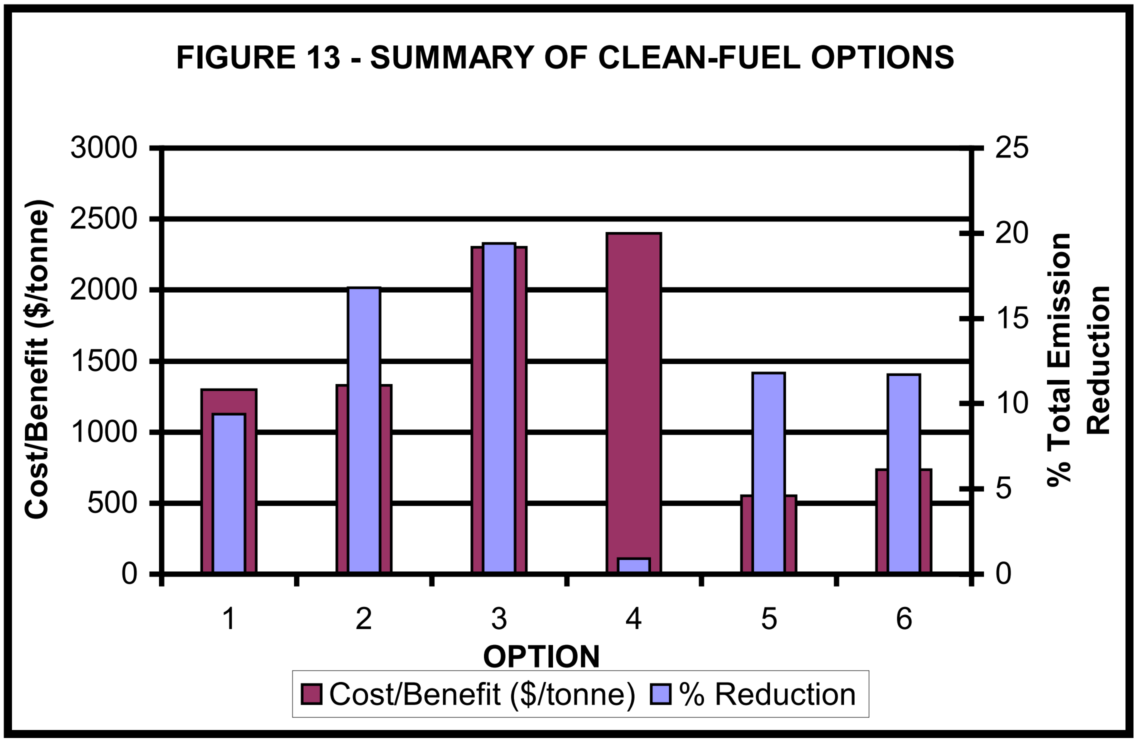
4.6 Option Six (Ferries and Workboats Use CNG or LNG)

This initiative has a higher up-front cost compared to regular diesel but may result in lower life cycle costs, especially if the spread between the price of diesel oil and natural gas increases. But for purposes of this study it is conservatively assumed that the use of natural gas (compressed natural gas, or CNG, and liquid natural gas, or LNG) incurs a total operating cost increase of 12%, as compared with using MDO. It is further assumed that the use of natural gas reduces SOx and PM emissions by 90%, and NOx emissions by 30%.

The result is an estimated decrease in SOx emissions within the GB/PS airshed of 1,100 tonnes (5%), PM of 440 tonnes (11%), and NOx of 12,000 tonnes (14%). The total annualized cost is $10 million, or **$730/tonne** of emission reduction. (Note that this estimate has been revised in Section 6 due to more recent data on the cost of using natural gas.)

The use of natural gas can be encouraged by maintaining the existing preferential tax treatment, by implementing an emission trading exchange and by promoting the use of LNG. LNG is available in the GB/PS area but there is presently little or no infrastructure for supplying this clean fuel to marine vessels. Senior government could provide an example by converting their vessels to LNG.

Figure 13 summarizes the six different clean-fuel options that are explored in the 2002 study. It can be seen that options 5 & 6 provide the least cost for emission reduction



(dark columns) while still providing ample reduction in total emissions (light blue columns). These two options are applicable to ferries and workboats.

The first three options pertain to large vessels (commercial shipping and cruise ships). Option 2 (use of low-sulphur bunker) provides a significant reduction in total emissions while being much less expensive than Option 3 (switching to MDO).

An optimal strategy to reduce marine vessel emissions within the GB/PS area would include a mix of the above strategies, phased in over a period of time. For example, implementation of Options 2 & 5 would reduce total marine vessel emissions by almost 30%, at an annual cost of $33 million. This cost is only 2% of the estimated annual air-pollution related health costs within the GB/PS airshed and should therefore be considered cost effective.

Other clean-fuel options were also explored in the 2002 study, for example, bio-oil, bio-diesel, and hydrogen. While they may have merit in the future, at present they are either unavailable in the quantities required to make a difference, or are much too expensive for commercial use.

Subsequent to the above study, a more in-depth evaluation into the cost of converting part of the BC Ferry fleet to natural gas (either CNG or LNG) was carried out during 2003 by MDA Marine Design in Victoria, BC.

4.7 Converting BC Ferries to Natural Gas

This section is a summary of a 2003 study carried out by M.D.A. Marine Design Associates (naval architects and engineers), on behalf of Genesis Engineering Inc., into the cost, fuel savings and emission reductions resulting from using dual fuel engines in the BC Ferry fleet. The full MDA report is attached as Appendix ‘A’. (The cost-effectiveness of using natural gas in a single, large ferry is explored in Section 6.3.6 for varying prices of natural gas.)

In a dual fuel (natural gas/diesel) mode, a percentage of the fuel oil used in the present BC Ferries operation would be replaced with Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG), the percentage depending on the duty cycle of the route involved. In order to present conservative fuel savings and emissions reduction estimates on the BC Ferry fleet, the ratio of 60% natural gas/40% diesel was used in this study, although the ratio may be up to, or greater than, 80% natural gas/20% diesel.

Emission Reductions

Applying the 60% natural gas, 40% diesel ratio to each of the “converted” ferries and identifying their home terminals, the volume of natural gas both in a CNG and LNG form was calculated. Based on the known total horse power for each “converted” ferry at 85% power and the total annual sailing hours of each ferry, the annual reduction in NOx and PM was then estimated using the Wartsila 32DF dual fuel marine engine with water injection system as the basis for dual fuel exhaust emission levels. (Some of the other dual fuel marine engines are the Nigata 8PA5LDF and the Ruston 6RKG engines. Clean Air Partners in San Diego also provide Caterpillar 3406 modified dual fuel engine, as does Detroit Diesel-Allison and Cummins.)

The estimated total NOx reduction was estimated to be 3, 484 tonnes and the particulate reduction (mainly $PM_{2.5}$) was 143.3 tonnes per year (TPY). The MDA study did not include SOx reductions resulting from using natural gas. But based upon a total fuel usage of 98 million liters (86,000 TPY) of MDO with 0.21% S, the SOx reduction would be 108 TPY. Therefore the total emission reduction would be 3,736 TPY.

<u>Unit Costs For Natural Gas Conversion</u> ($CDN)

The costs of conversion are based upon those estimated for two smaller vessels to CNG, resulting in an average cost of $337.70/kW engine rating. It was assumed that the on board infrastructure costs for LNG would be similar to this. Cost savings due to reduced engine maintenance, and lube oil changes, were estimated from experience with the Albion ferries to be $7.54/kW-year and $4.75/kW-year**,** respectively. The conversion cost will be less (approximately $293.00/kW) if the conversion is done during an engine change where the replacement engine is already designed to use natural gas.

Fuel costs are based upon estimates from ENRG, who would supply the natural gas as either CNG or as LNG. Based upon a natural gas commodity price of $4.00/GJ, the cost of LNG would be about 79 ¢ per LNG gallon or about 35.5 ¢ per liter diesel equivalent.

Section 6.3.6 investigates the costs for the *Spirit of Vancouver Island*. The cost benefit varies between US$1,376/tonne emission reduction and –US$36/tonne, depending upon the assumptions made regarding fuel costs and whether the existing engines are converted or if new dual-fuel engines are installed.

Genesis Engineering Inc. has a spreadsheet that facilitates cost-effectiveness calculations for a ferry. (It is available to other parties upon request.) The cost for the B.C. Ferry fleet was estimated, assuming the above costs for conversion and for natural gas. Fuel consumption and emissions while idling at dock were also included in this estimate. Therefore the emission reduction will be somewhat greater than that estimated in the MDA study.

Total Fleet Costs ($US)

- Installed capital $37.3M
- Total Emission Reduction (TPY) 4,256.
- Annual cost using CNG $9.2M
- Cost-Effectiveness of CNG $2,173./tonne
- Annual cost of using LNG $2.3M
- Cost-effectiveness using LNG $548./tonne

5.0 SHORE-POWER FOR EMISSIONS REDUCTION

The total air pollution that was emitted by cruise ships while docked within the Port of Vancouver during 2000 was 458.3 tonnes.[4] In addition, a total of 15,332 tonnes of green house gases were emitted. Most of these emissions can be prevented by the use of shore-power, wherein the vessels are connected to an on-shore electrical-energy distribution grid via a system of transformers and cables. The following section discusses how this is done, what it will cost, and where it is already being used to reduce pollution emissions.

(This section is adapted from a study carried out by Mr. Colm Corcoran, Envirochem Services Inc, Ph. 604 986-0233, on behalf of Genesis Engineering Inc., March 2003.The full report is attached as Appendix 'B')
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5.1 INTRODUCTION

During the 2002 Alaska cruise ship season (from May to September) 27 ships operated by 13 companies docked a total of 342 times at Canada Place and Ballantyne Pier in the Port of Vancouver. On-board generation of "hotelling power" which is the power required to maintain the lighting, heating, cooking, air conditioning systems, etc. while they are docked in port, results in the release of considerable airborne emissions. This report addresses the logistic, technical and economic issues related to providing shore power to eliminate the need to run one of the ship's engines to generate hotelling power while in port.

Alaska Electric Light and Power Company have constructed a shore-based infrastructure at Juneau to provide shore power for Princess Cruise Lines, which was put into service on July 24, 2001. Four of their vessels have currently been modified to accept shore power at Juneau and all of their future vessels will be constructed to accept shore power.

Studies are presently being conducted to provide shore power for container ships that dock in the Port of Los Angeles. Also, the United States Navy is currently utilizing shore power for some of their vessels.

5.2 HOTELLING POWER REQUIREMENTS

Initial indications are that a guideline for the hotelling power required for the larger cruise ships, which would be utilized during the hottest days in summer when the air conditioning load is highest, would be 7 to 8 megawatts (MW). Shore power would be from a three-phase four-wire 60-cycle supply at 6.6 kV. Some of the very large ships will require an 11 kV supply and up to 10 megawatts power consumption.

In order to eliminate temporary shedding or short term outages of power on the ships, however brief, the modifications to the Princess Cruise ships required synchronization of the on-board generators to the AEL & P's shore power grid at Juneau, Alaska prior to transfer to shore power. Synchronization requires that the frequency, phasing and voltage of the shipboard generator be exactly matched to the shore supply before a "seamless" transfer of power is initiated. We assume that this would be a requirement of all the cruise line companies.

The vast majority of cruise ships dock in Vancouver at 7am and leave at 5pm, according to information provided by the Port of Vancouver. Assuming that it takes 30 minutes after docking to connect to shore power and 30 minutes before sailing to disconnect, this means that typically each cruise ship will require shore power for about nine hours while docked. For the 342 separate times that the cruise ships docked in Vancouver between May and September 2002, if we assume that the average power requirement per ship was 7.5 MW, the total shore power energy requirements for 2002 would have been 7.5 x 9 (hours docked) x 342 = <u>23,085 megawatt hours</u>.

The 7.5 MW estimate is based on an average of the range of tonnages and passenger capacities of the ships, which will determine the shore power requirements for individual vessels.

Considerably more data is required to accurately determine the projected energy requirements, including tabulation of additional data to be obtained from the cruise line companies and other factors including fluctuating electrical load due to varying air conditioning requirements throughout the cruise ship season. The energy requirements will factor into economic feasibility studies by determining the net savings in energy to the cruise ship companies (to be offset against the capital costs of the electrical modifications to the ships and, presumably, the shipping lines share of the capital cost of the shore-based infrastructure). The projected energy consumption will also be factored into the amount of the capital cost of the shore-based infrastructure that will be borne by B.C. Hydro.

There are three docking berths at Canada Place, which vary in length from 276 to 507 meters. The north berth, which is 276 meters long, cannot accommodate the largest ships, such as, the Star Princess that is a little more than 300 meters long. Because Canada Place cannot accommodate three of the largest ships at any one time, we would estimate that the total power required for all three berths would be approximately 25 MW with the largest ship requiring 10 MW.

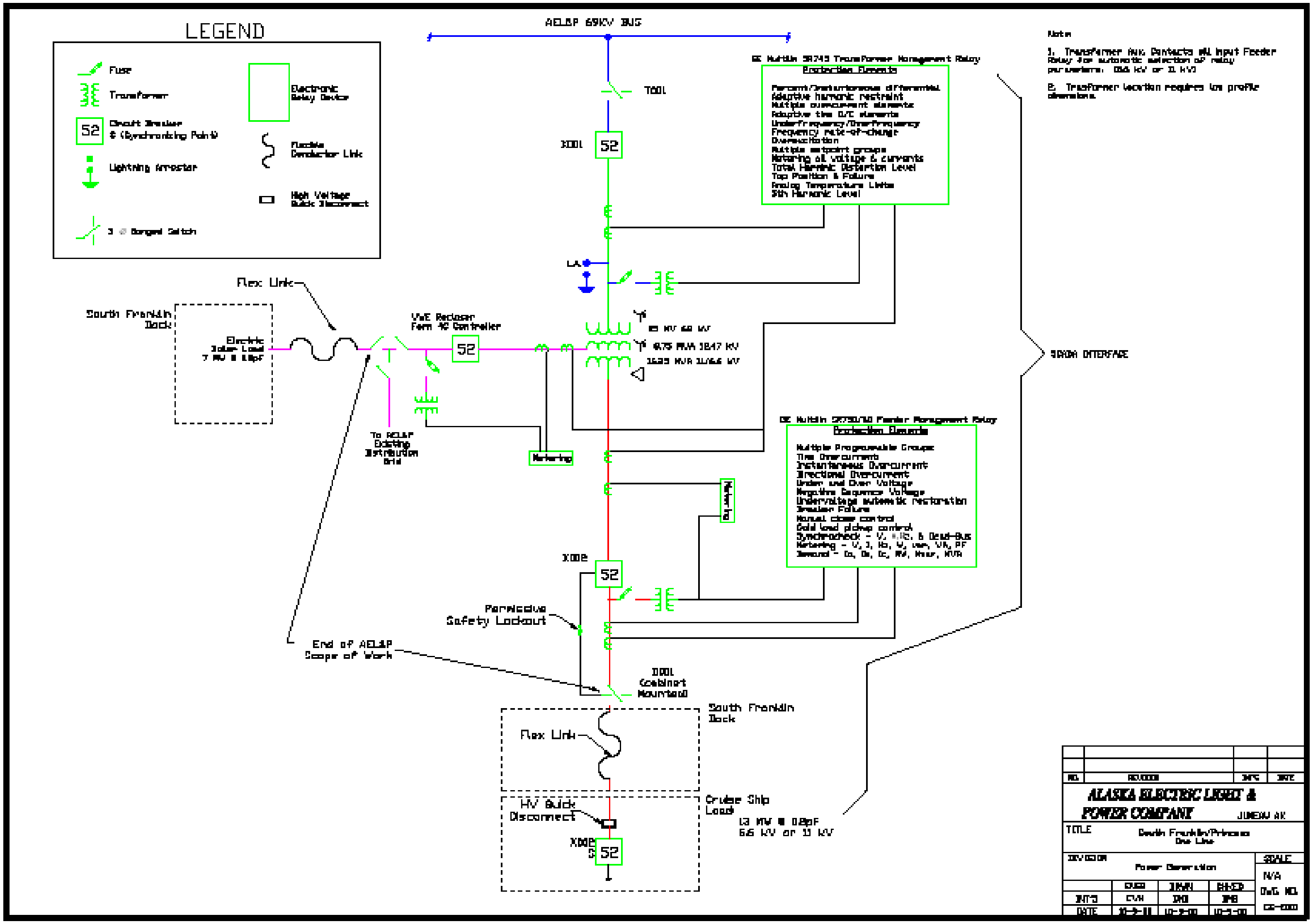
There are very few dockings at Ballantyne Pier such that the relative energy consumption would be small compared to Canada Place. For the purpose of preliminary discussions with BC Hydro, we have assumed a maximum shore power load of 10 MW for Ballantyne Pier.

5.3 Shore-Based Infrastructure Constructed for Princess Cruise Lines at Juneau, Alaska

Three-phase power from AEL&P's grid is fed to a substation, located across the street about 1,000ft. from the dock, at a primary voltage of 69 kV. The 25 megawatt transformer in the substation has three secondary voltages; 6.6 kv which is the shore power voltage required for most cruise ships, 11 kv which is required for some of the newer, larger ships and 12.5 kv which powers a shore based steam plant. The substation contains other electrical equipment including circuit breakers, potential and current transformers, protection and SCADA (supervisory control and data acquisition) equipment etc. The secondary 6.6 kv or 11 kv supplies are fed 1,000 ft. to a dock mounted disconnect/grounding switch.

The shore power is connected from the dock-mounted switch to the ship via four three-inch diameter electrical cables that hang from a special gantry on the dock, which is designed to accommodate a 20-foot variation in tides. The cable connection on the vessel is made via large male/female plugs and sockets, which are modified versions of connectors used in the mining industry. There is an additional smaller cable for carrying the SCADA interface information, metering, protection and control wiring between the vessel and the shore power substation.

It is understood from Mr. Corry Hildenbrand of AEL&P (Ph. 907 463-6320; email corry.hildenbrand@aelp.com), that they are discussing the possible provision of shore power at Juneau with Holland America Cruise Lines. He has also forwarded an electrical schematic diagram for their shore power installation that is included on the next page.


LEGEND
Fuse
Transformer
Circuit Breaker
Lightning Arrester
Electronic Relay Device
Flexible Conductor Link
High Voltage Quick Disconnect
AEL&P 69KV BUS
Note
1. Transformer Aux. Contacts all Input Feeder Relay for automatic selection of relay parameters.
2. Transformer location requires low profile dimensions.
Protection Elements
Adaptive harmonic restraint
Multiple overcurrent elements
Underfrequency/Overfrequency
Frequency rate-of-change
Overexcitation
Multiple setpoint groups
Metering all voltage & currents
Total Harmonic Distortion Level
Tap Position & Failure
Analog Temperature Limits
5th Harmonic Level
Flex Link
South Franklin Dock
Electric
VWE Recloser
Form 4C Controller
To AEL&P Existing Distribution Grid
Metering
SCADA INTERFACE
Multiple Programmable Groups
Time Overcurrent
Instantaneous Overcurrent
Directional Overcurrent
Under and Over Voltage
Negative Sequence Voltage
Undervoltage automatic restoration
Breaker Failure
Manual close control
Cold load pickup control
Permissive Safety Lockout
End of AEL&P Scope of Work
Cabinet Mounted
HV Quick Disconnect
Cruise Ship Load
ALASKA ELECTRIC LIGHT & POWER COMPANY
JUNEAU AK
TITLE
One Line
Power Generation
SCALE
N/A
DATE

5.4 Modifications Made to Princess Cruise Ships to Accept Shore Power at Juneau

The power cables from the shore-based substation are fed via the male/female connectors into a receiving circuit breaker that is contained in an electrical room (together with ancillary metering, protection and control equipment) that is located behind a "shell door" constructed in the side of the vessel. Power cables are routed through the ship from the receiving breaker to another circuit breaker in the main electrical room that is used to transfer to shore power when the shipboard generator has been synchronized to the AEL&P power grid's frequency and voltage. After the initial safety checks, the transfer process, which is highly automated and utilizes sophisticated software especially developed to facilitate synchronization and a "seamless" transfer of power, takes about two minutes.

In the case where the on-shore BC Hydro infrastructure and substations will be required to provide power to a wide range of ships manufactured by different companies, it will be necessary to standardize the SCADA interface and protection and control systems through discussions with the various cruise lines and ship manufacturers. It will also be necessary to standardize the male/female power connectors to the ships.

5.5 On-shore Infrastructure to Provide Shore Power from the BC Hydro Grid

Provision of shore power from the BC Hydro grid to Canada Place and Ballantyne Power is much more complex and costly than AEL & P's installation at Juneau, Alaska for the following reasons.

1. The supply voltage to the shore power substation at Juneau is 69 kV that is provided by an overhead pole line at a cost of only US$55,000.

B.C. Hydro have advised us that it is impractical for them to supply 69 kv service to Canada Place and Ballantyne Pier because the costs would be prohibitive due to substantial infrastructure additions.

Power to the downtown area of Vancouver is currently provided by underground cables at 12 kv. Each 12 kv circuit is only capable of carrying about 6.5 MW which is very much less than the capacity of the single 69kv feed at Juneau which powers a 25 MW transformer.

2. Supply to Canada Place would require four separate 12kv underground cable circuits from Cathedral Square substation and two circuits from Murrin substation to Ballantyne Pier to provide the required power capacities. Installation of underground cables is also very expensive.

3. There are technical issues pertaining to paralleling the 12kv circuits at the dockside substations because of the resultant high ground fault currents. It may be necessary to provide three separate substations at Canada Place to supply each docking berth.

4. Land or available space is at a premium and may require taking space from the parking or other currently utilized areas at Canada Place. It is not possible to assess detailed substation area requirements or costs at this time until further studies are conducted.

5.6 Budgetary Estimates

5.6.1 Cruise Ship Modifications

Callenberg Engineering of Miami, Florida modified four of the Princess Cruise Line ships to accept shore power at Juneau at a cost of US$500,000 per ship.

Corry Hildenbrand of AEL & P provided a very rough estimate that, even for small cruise ships requiring less power, similar modifications to those made to Princess Cruise vessels would probably not cost less than US$300,000 per ship.

We assume that, in time, modification costs to cruise ships would decrease somewhat because of lower design and software development costs and installation of the shore power modifications during the construction of new vessels. Corry Hildenbrand also provided a very rough estimate that, if some of the smaller ships did not require synchronization to the shore power grid, the modification costs could decrease by US$60 – 70,000.

Corry Hildenbrand also said that there are plans to provide shore power at Victoria shipyards where their vessels are maintained. Currently, only limited power is supplied utilizing a 480 volt three phase supply. Additional power supplied at 6.6 or 11 kv will lessen the time required in dry dock resulting in more cruise ship passenger revenue and elimination of the expense of shore-based accommodation for the crew while in dry dock.

5.6.2 Shore-based Infrastructure at Juneau, Alaska

The approximate costs for construction of the shore power infrastructure at Juneau, which were provided by AEL & P, are as follows:

69 kV overhead supply line:	US $55,000.00
Substation alone:	US$1,300,000.00
Substation cabling to dockside disconnect switch:	US $300,000.00
Disconnect switch to ship cable and delivery system:	US $600,000.00
TOTAL COST:	**US $2,255,000.00**

5.6.3 Shore-based Infrastructure at the Port of Vancouver

Because of the technical complexity of providing shore power from the B.C. Hydro grid to Canada Place and Ballantyne Pier, further studies would be required in order to design and properly estimate the costs of the shore-based infrastructure. For the purpose of this project, however, we have prepared the following rough cost estimate from the information provided by AEL & P on the Juneau installation and on input from B.C. Hydro:

Canada Place (25 MW)

Four 12 kV feeders from Cathedral Square substation............................$3,000,000
Maximum of three substations at an average of $1,500,000
per substation $4,500,000
Cabling and infrastructure from substations to three vessels at
$1,000,000 per berth $3,000,000

...TOTAL $10,500,000

Ballantyne Pier (10 MW)

Two 12 kV feeders from Murrin substation $1,500,000
One substation...$1,500,000
Cabling and infrastructure from substation to one vessel.......................$1,000,000

...TOTAL $4,000,000

The above rough estimates for four docking berths at Vancouver approximately correlate to the US$50M – US$60M estimate for providing power to up to 20 cargo-containing ships simultaneously at the Port of Los Angeles (i.e., C$3,625,000 per berth at Vancouver versus C$4,125,000 per vessel at Los Angeles).

B.C. Hydro may absorb some of the capital costs to construct the 12kv supply circuits, but none of the capital cost to construct the dockside substations and cable connections to the ships.

5.6.4 Energy Costs ($ Cdn)

Please refer to **Appendix B-4** for information on B.C. Hydro's rate schedule #1211. Mr. Harold Nelson (Ph. 604 528-3226; email ron.nielson@hydro.com) of B.C. Hydro's Customer Projects organization advised that this rate schedule is based on normal year-round energy consumption, whereas, shore power for the cruise ships will only be required for the five month cruise season.

However, for the purpose of calculating a preliminary rough estimate of energy costs, we have utilized schedule #1211, which is comprised mainly of energy costs and demand charges.

Demand charges are designed to recover B.C. Hydro's total infrastructure costs to supply power and are a function of the maximum power to be supplied irrespective of energy consumption. In the case of providing our estimated shore power and energy requirements, the demand charges are actually higher than the energy costs.

For preliminary budgetary purposes, we have estimated an energy cost, including demand charges of approximately 8 cents (Cdn) per kilowatt-hour utilizing rate schedule #1211.

This estimate is based on demand charges of $6.12 (Cdn) per kilowatt for the power requirements and 3.07 cents (Cdn) per kilowatt-hour for the energy charges as shown on B.C. Hydro's rate schedule.

Based on our 23,085 megawatt-hours estimate of the total energy required for all of the 27 cruise ships which docked in Vancouver in 2002, the total cost of energy would be $1,846,800 (Cdn) or an average of $68,400 (Cdn) per vessel, per cruise ship season.

The actual energy costs would be based on future discussions and negotiations with B.C. Hydro, and include considerations of decreased emissions of air pollution and global warming gases, such as CO_2.

5.7 Shore Power Initiative at the Port of Los Angeles

The Port of Los Angeles, the mayor of Los Angeles and the Los Angeles Department of Water and Power have initiated a program entitled "Alternative Maritime Power Research and Development Program" to supply shore power to commercial "in-service container" vessels which dock at the Port of Los Angeles.

The document in Appendix 2-3 gives a brief outline of the philosophy and objectives of the program that is the first of its kind for supplying shore power to cargo container ships.

The Los Angeles port is the world's seventh busiest. With 27 major cargo terminals, the port carries cargo worth $104 billion a year. There were approximately 2,200 cargo ship visits to the Port of Los Angeles in 2001, with an average length of stay of two days. Construction of the on-shore infrastructure to supply shore power at the Port of Los Angeles is expected to cost $50-60 million US over about 10 years.

The shore power infrastructure will ultimately be capable of providing power simultaneously for up to twenty cargo container ships at docking berths that can accommodate up to three vessels.

The philosophy of the program is based on achieving a net savings for the container cargo shipping companies (seven companies have signed an agreement to participate in the program) taking into account the savings in cost of shore power energy and the eventual recovery of the capital cost to convert the ships and construct the on-shore infrastructure.

Note that the energy savings for container ships utilizing shore power would be several more times than with cruise ships because they spend considerably more time in port (two days compared to ten hours for cruise ships). The energy savings would obviously vary with the power requirements for individual ships whereas the cost of shipboard modifications per megawatt are expected to increase with ships requiring less shore power.

The above information was provided verbally by Mr. Randy Howard of the Los Angeles Department of Water and Power (Ph. 213 367-0381; email randy.howard@ladwp.com) who said that there was a workshop in Los Angeles in the first week of March pertaining to issues related to their shore power program. He will provide information on the workshop and other future developments that we will forward to Genesis Engineering and Environment Canada.

5.8 Conclusions - Shore Power

1. In the year 2002, 27 cruise ships operated by 13 companies docked a total of 342 times at Canada Place and Ballantyne Pier during the Alaska cruise season. Most of the ships dock at 7am and leave at 5pm such that they could be connected to shore power for about 9 hours allowing for one hour to connect and disconnect the shore power supply. The larger ships require approximately 7-8 MW of hotelling power to be supplied at 6.6 kV. Some of the very large ships will require as much as 10MW and an 11kv supply voltage.

2. Shore power has been successfully implemented by Princess Cruise Lines in Juneau, Alaska since July 24, 2001. In order to eliminate temporary shedding or short-term outages of power on the ships, the modifications to the cruise ships required synchronization of the on-board generators to the shore power grid. Synchronization requires that the frequency, phasing and voltage of the shipboard generator be exactly matched to the shore supply before a "seamless" transfer of power is initiated. We assume that this would be a requirement of all of the cruise ships companies.

3. Modifications to accept shore power at Juneau were made to four of the Princess Cruise ships by Callenberg Engineering of Miami, Florida. The total cost was US$500,000 per ship. Alaska Electric Light and Power constructed the shore-based infrastructure for a total cost of US$2,255,000.

4. Provision of shore power from the BC Hydro grid to Canada Place and Ballantyne Pier will be much more technically complex and expensive to provide than the 69kv overhead conductor supply at Juneau for the following reasons:

a) B.C. Hydro has advised us it is impractical to supply 69 kv service because the costs would be prohibitive due to substantial infrastructure additions.

b) Power to the Vancouver down-town area is currently provided by 12kv underground circuits that can carry only about 6.5 MW per circuit such that four circuits would be required to provide the estimated 25 MW at Canada Place and two circuits to provide the estimated 10 MW load at Ballantyne Pier. There are also technical issues related to paralleling the circuits at the dockside substations. In may be necessary to provide separate substations at Canada Place to supply each of the three docking berths.

c) The cost of installing underground cable is very much higher than overhead lines.

d) Land or available space is at a premium and may require taking space from parking or other currently utilized areas at Canada Place. It is not possible to assess detailed substation area requirements at this time until further studies are concluded.

For preliminary budgetary purposes, we estimated the following costs to provide shore power from the B.C. Hydro grid ($Cdn)

Canada Place $10,500.00
Ballantyne Pier..$4,000,000
Energy Costs .... 8 cents per kilowatt-hour
Estimated average electrical energy costs per ship, per cruise-ship season $68,400

5. The US Navy has implemented shore power for their ships. Information on their shore installations and shipboard modifications has not been included in the scope of this report. We have included some preliminary information in this report on an initiative to provide shore power for <u>container</u> ships in the Port of Los Angeles. It should be noted that one factor to be included in any economic analysis pertaining to shore power is the length of time that the ships will be utilizing the less expensive energy provided by shore power

while in dock. The cruise ships typically dock for about 10 hours, the container ships for two days and the US Navy ships could be docked for some weeks at the same location.

6. In order to construct a shore-based infrastructure at the Port of Vancouver, which will be compatible with a wide variety of cruise ships, it will be necessary to develop a high degree of standardization for the modification to the ships. Standardization will include the male/female power connectors and the SCADA (supervisory control and data acquisition) and other protection and metering interface systems between the ship and shore electrical systems in addition to providing the required power and voltages.

7. In general, provision of shore power is technically complex and expensive and will require extensive co-operation from the shipping lines, power utilities, government agencies, etc.

5.9 Recommendations – Shore Power

a) Additional information is required from the cruise ships companies to fine-tune the shore power, voltage and energy consumption of the cruise ships. We will forward any detailed information which we requested from the North West Cruise Ship Association on the power and voltage requirements for the cruise ships that dock in Vancouver when it is received.

b) In order to provide a more accurate budgetary estimate for a shore-based infrastructure and energy costs at the Port of Vancouver further studies and negotiations with B.C. Hydro will be required.

c) On-going feedback should be obtained from the shore power studies for container ships at the Port of Los Angeles with particular reference to the discussions with the shipping lines pertaining to standardization of the shipboard modifications and shore-based infrastructure to accept shore power.

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5.10 Cost to the Cruise Ship Industry

This section will use the above information to roughly estimate the total annual costs to the cruise ship industry. It is assumed that the shore-based infrastructure costs are shared among 27 vessels and are amortized over 15 years at 7%, and that the annual maintenance and operations costs (excluding power) are 2% of installed capital. The capital recovery factor (CRF) is 0.1098. During 2000 the vessels burned 4773 tonnes of fuel, mainly IFO180, while at dock. The cost of this fuel, at approximately US$220/tonne, could be avoided by the use of shore-power.

Cost Estimate Summary ($USA)

1.	Shore infrastructure costs	$9.7M
2.	Vessel modifications (27 @ $0.5M each)	$13.5M
3.	Annual capital cost (CRF = 0.1098)	$2.5M
4.	Annual maintenance costs (2% installed capital)	$0.5M
5.	Annual electrical costs (@ 80 mils CDN)	$1.2M
6.	Fuel savings (IFO180 @ $220/tonne)	-$1.1M
	Total	US$3.1M

Hence the total annual cost to the cruise ship industry would be approximately $3.1M US, or $4.6M CDN. The cost per tonne of pollution reduction would be the total annual costs divided by the total annual dockside emissions of 458.3 tonnes, or US $6,764/tonne.

This cost may be on the high side as some of the vessels have already being converted to use shore-power in Alaska, and the electrical costs may be reduced through negotiations with BC Hydro.

The cost-benefit ratio for different emission reduction options for cruise ships, including shore-power, will be further discussed in Section 6.

6.0 EMISSION REDUCTION OPTIONS FOR SPECIFIC VESSELS

This section will estimate the cost of different technological and clean-fuel options for reducing the emissions from specific classes of marine vessels. Then the cost-effectiveness of the different options will be compared. The classes of vessels that will be investigated are:

- Freighters, tankers and container ships.
- Cruise ships
- Ferries
- Workboats (tugs, patrol vessels, self-propelled barges, etc.)

6.1 Freighters and Container Ships

There were in excess of 1,500 different large, ocean-going vessels entering the GBPS area during the year 2000.[51] Large ocean-going vessels have a single, turbo-charged, slow-speed diesel engine that is direct coupled to the propeller shaft. These engines are designed to operate on low-cost heavy bunker oil that has to be cleaned and heated prior to combustion. Usually additives are also added to the bunker to aid in combustion and to reduce deposits within the engine and associated systems. The bunker used on the West Coast is essentially residual oil (#6 bunker oil or HFO) to which a small amount (e.g. 2%) of distillate has been added to reduce the pour point and viscosity. The resultant heavy "intermediate fuel oil" is designated as IFO 380 because it has a viscosity of 380 centistokes. It is blended to meet international ISO 8217-1996E specifications. The main engine will operate steadily at approximately 90 – 100 rpm, which is about 85% of maximum capacity. The newer container ships have main engines rated in excess of 60,000 shp.

Engines are started using one or more large tanks of compressed air to turn them over. Some engines, especially the older ones that are not equipped with electronic control of the injectors, are started on lighter diesel (MDO) and then switched to IFO 380.

In addition to the main engine the larger ships typically have 3 auxiliary diesel engine generators (gensets). Two of these would be running (the third on standby) while cargo is being loaded or while the bow thrusters (if installed) are being used for maneuvering at dock. Once underway one of the gensets would be running while another is on standby. The gensets are typically medium speed (700 – 800 rpm) diesels of around 3000 brake horse power (bhp) that burn IFO 380, or a blend of IFO 380 and MDO while under load, but which are started on MDO.

Large ships are fueled from barges that draw alongside during loading/unloading operations. Some ports do not allow fueling to take place while the vessel is taking on a hazardous (combustible) cargo. Generally a vessel will take on anywhere from a couple hundred to a few thousand tons of IFO 380, and in addition perhaps 50 – 200 tons of MDO.[52]

Clean-fuel options were briefly discussed in Sections 4.1 – 4.3 and will included here in a table (Table 6) summarizing the different options.

6.1.1 Base Case For Emission Reductions

<u>Assumptions</u>

- Main Engine: 2-stroke, 8 cylinder; average cruising power = 16,000 kW @ 80 rpm; SFOC = 193.5 g/kWh.
- Gensets (3): 1000 kW @ 600 rpm; typical hoteling load = 400 kW; SFOC = 200 g/kWh; typical dockside fuel usage = 13 tonnes[53].
- Average annual time cruising within the GB/PS area = 87 hours.
- Average stops within the GB/PS area = 8.7 @ 4.5 days each.
- Capital amortization 15 years at 7% (capital recovery factor = 0.1098).
- Emission factors (Ref. 53): NOx = 18 g/kWh, PM = 1.5 g/kWh, SOx = 10.3 g/kWh (2.45 % sulphur).

The average cruising time was estimated from the total annual fuel usage of 205,880 tonnes, the total number of vessels (1528), the above engine load and SFOC.

The resulting annual emissions for an average vessel are presented as the Base Case in Table 6 below.

6.1.2 Direct Water Injection on Main Engines

The US EPA did a recent study[54] and cost estimate for controlling emissions from Category III engines (displacement > 30 liters per cylinder). They looked at direct water injection (DWI) and selective catalytic reduction (SCR) as two technologies appropriate for reducing emissions. Their cost data will be used in this study, where it is assumed that these emissions are only applied while in the GB/PS area and that costs are based only upon this near-shore operation.

It is also assumed that there is a 40% water injection, resulting in DWI reducing NOx by 50% and PM by 20%. Water costs are $16/hr, maintenance 5% of capital, and CRF of 0.1098. The resulting annual costs and emission reductions are shown in Table 6.

Annual costs of 428,480 result in a reduction of 12.9 tonnes per year (TPY) of total emission reduction. The cost-effectiveness of this approach is therefore **$2,207/tonne.**

Table 6 – EMISSION REDUCTION OPTIONS FOR A LARGE VESSEL							
Control Option Description	**Additional Installed Cost ($US)**	**Annual Cost ($US)**	**Emissions (tonnes per year)**			**Emission Reduction (TPY)**	**Cost-Benefit ($/tonne)**
			NOx	**PM**	**SOx**		
A. Cruising (main engine only)*							
1. **Base Case** – No controls	-	-	**25.1**	**2.1**	**14.3**	-	-
2. Direct Water Injection	$169,400	$28,480	12.6	1.7	14.3	12.9	$2,207
3. Selective Catalytic Reduction + MDO Fuel	$779,400	$137,530	5.0	0.56	0.76	35.2	$3,314
4. *IMO Special Area* (1.3% S)	-	$2,695	25.1	2.1	7.5	6.8	$397
5. Low-Sulphur Bunker (0.4% S)	-	$8,082	25.1	2.1	1.8	12.5	$195
6. MDO Fuel (0.13% S)	-	$14,817	25.1	1.4	0.76	14.2	$1,040
B. Hoteling (auxiliary engines only)**							
1. **Base Case** – No controls	-	-	**6.0**	**0.71**	**5.5**	-	-
2. Road Diesel (300 ppm S)	-	$20,010	6.0	0.29	0.068	5.9	$3,373
3. Continuous Water Injection (CWI)	$35,000	$5,423	4.2	0.50	5.5	2.1	$2,582
4. Selective Catalytic Reduction + MDO	$120,000	$28,680	0.60	0.48	0.30	10.9	$2,628
5. Shore Power (Electricity Cdn$0.080/kWh)	$550,000	$73,560	0.0	0.0	0.0	12.3	$5,980

* Two-stroke 16,000 kW main engine underway at 50% MCR for 87 hours/year in GB/PS

** 3x1000 kW gensets loaded at average 600 kW total power while hoteling for 39 days/year in GB/PS (average of 8.7 visits per year, 4.5 days per visit)

6.1.3 Selective Catalytic Reduction on Main Engine

The EPA study[54] assumed that SCR provided a 80% reduction in NOx emissions, but that it required the use of MDO in lieu of heavy fuel oil to prevent catalyst fouling. The resulting emission reductions are 80% for NOx, 73.3% for particulate matter (PM) and 94.7% for SOx. The annual costs include urea ($3,149) and the MDO fuel premium ($9,831).

Table 8 shows that SCR costs 4137,530 per year and results in a total of 35.2 tonnes of emission reduction. The cost-effectiveness is $**3,314/tonne.**

6.1.4 *IMO Special Area* - Compliant Fuel in Main Engine

IMO Special Area - compliant fuel is assumed to contain 1.3% sulphur and cost a premium of $20/tonne. The annual increase in operating cost is therefore $2,695 and the emission reduction in SOx is 6.8 TPY. The cost-effectiveness is **$397/tonne**.

6.1.5 Low-Sulphur Bunker in Main Engine

It is assumed that low-sulphur bunker (0.4% S) is used within the GB/PS area at a cost premium of $60/tonne. The annual increase in operating cost is therefore $8,082 and the emission reduction in SOx is 12.5 TPY. The cost-effectiveness is **$195/tonne**.

6.1.6 MDO Fuel in Main Engine

It is assumed that MDO (0.13% S) is used within the GB/PS area at a cost premium of $110/tonne. The annual increase in operating cost is therefore $14,817 and the emission reduction is 14.2 TPY. The cost-effectiveness is **$1,040/tonne**.

6.1.7 Road Diesel While Hoteling

It is assumed that road diesel (300 ppm S) is used while hoteling at a cost premium of $120/tonne. The annual increase in operating cost is therefore $20,010 and the emission reduction is 5.9 TPY. The cost-effectiveness is **$3,373/tonne**.

6.1.8 Continuous Water Injection (CWI) While Hoteling

It is assumed that CWI reduces NOx by 30%, PM by 30% and reduces fuel consumption by 1%. Total installed cost for two engines is $35,000 and maintenance is 5% capital cost per year. The resulting annual cost is $5,423 and the emission reduction is 2.1 TPY. Therefore the cost-effectiveness is **$2,582/tonne**.

6.1.9 Selective Catalytic Reduction While Hoteling

It is assumed that the SCR unit is sized for 2000 kW but is connected to all three gensets. Exhaust gas reheat is used to maintain operating temperature with this 3-into-1 arrangement. MDO fuel is needed to maintain high catalyst activity. The installed capital cost, at $60/kW, is $120,000 and the operating cost is $5/MWh.[28] In addition, it is assumed that the fuel consumption increases 2% because of exhaust reheat.

The annual costs are estimated to be $28,680 and the total emission reduction (NOx 90%, PM 67%, SOx 95%) is 10.9 TPY. The cost-effectiveness is $**2,628/tonne.**

6.1.10 Shore Power While Hoteling

Shore power eliminates emissions from the gensets while hoteling. Here is assumed that all hoteling is at dock where shore power is available. (No allowance for time at anchor where shore power is not available.) It is assumed that the system is capable of supplying 2000 kW but that only 600 kW is used on the average and that the vessel cost is $300,000. The shore infrastructure is assumed to cost $5M, but is shared between an average of 20 vessels. The total installed cost per vessel is therefore $550,000.

If electricity is 80 mils (Cdn)/kWh, the maintenance cost is 2% of installed capital, and the CRF is 0.1098, then the annual cost is estimated to be $73,560. For a total emission reduction of 12.3 TPY the cost-effectiveness is estimated to be **$5,980/tonne**. If the electricity costs 30 mils (Cdn)/kWh, then the total annual costs are reduced to $44,420 and the cost-effectiveness becomes $3,611/tonne.

From the above analysis and Table 6 it can be seen that the least cost options for the main engine are clean-fuel options, while the least cost options for hoteling are CWI and SCR.

6.2 Cruise Ships

During the year 2000 twenty-six separate cruise ships operated within the GBPS waters.[51] Cruise ships are designed for speed, convenience and maneuverability/flexibility. Therefore they typically use 4 - 5 medium speed (500 rpm) diesel generators that not only supply the ship's large internal energy requirements, but also drive the bow and stern thrusters during maneuvering as well as the two propeller shafts while underway. Each genset may produce in the order of 8 MW. The engines use IFO 180 both while underway and while in port. The engines are designed to burn IFO 380 but use 180 to reduce smoke emissions. Some MDO may be used for engine startup. Refueling is done with barges as is done with other large ocean-going vessels.

Some of the newer cruise ships are switching to gas turbines because gas turbines produce more power out of a smaller and lighter package, thereby creating more capacity for paying passengers. Gas turbines also produce less visible smoke compared to large diesel engines. The gas turbines are used when fuel costs are not a dominant cost factor (military vessels and cruise ships) and where space savings are important. Marine Gas Oil (MGO or DMA) is typically used in the gas turbines.

Cruise ships emission reductions can be applied while the ship is hoteling at dock and/or while the ship is underway within the GB/PS area. Both of these scenarios will be investigated. Applicable emission control options include:

- Use MDO fuel to reduce PM and SOx.
- Continuous Water Injection (CWI) to reduce PM and NOx.
- Combination of CWI and MDO to reduce PM, NOx and SOx.
- Direct Water Injection (DWI) to reduce PM and NOx.
- Gas Turbine and MGO to reduce PM, NOx and SOx.
- Selective Catalytic Reduction (SCR) with MDO to reduce PM, NOx and SOx.
- Shore Power while hoteling to reduce PM, NOx and SOx.

6.2.1 Base Case For Emission Reductions

Assumptions:

- Cruising: 2 x V12 Sulzer 2AV-40 4-stroke engines; 8640 kW @ 514 rpm MCR. Operate at 80% MCR to give total of 13.8 MW, SFOC = 193.5 g/kWh of IFO 180. Total cruising time in GB/PS = 1130 hours/season (5-month season).
- Hoteling: 2 x V8 Sulzer AL40S 4-stroke engines; 5760 kW @ 514 MCR. Total average output at dock 7.5 MW with SFOC of 200 g/kWh of IFO 180. Average of 37 stops per year in the GB/PS region with 8.5 hours per stop, 12.8 tonnes fuel burned per stop.
- The emission factors are 18 g/kWh for NOx, 1.0 g/kWh for PM and 10 g/kWh for SOx (Ref. 53).

(The cruising time and hoteling time estimates above derive from estimates[53] of the total number of cruise ships, total number of port visits, the total fuel consumption for cruising and hoteling and the above assumed engine loads and SFOC's.)

The above assumptions lead to the base line emissions listed in Table 7 below. Total annual emissions per vessel are estimated to be 452 tonnes while cruising and 68.5 tonnes while hoteling at dock within the GB/PS area.

Table 7 – EMISSION REDUCTION OPTIONS FOR A CRUISE SHIP							
Description	**Installed Cost ($US)**	**Total Annual Cost ($US)**	**Emissions (tonnes per year)**			**Emission Reduction (TPY)**	**Cost-Benefit ($/tonne)**
			NOx	**PM**	**SOx**		
1a. Base Case – Cruising the GB/PS area*	-	-	281	15.6	156	-	-
1b. Base Case – Hoteling the GB/PS area**	-	-	42.5	2.36	23.6	-	-
2a. Use MDO Fuel - Cruising	-	$301,758	281	7.8	0.55	155	$1,944
2b. Use MDO Fuel - Hoteling	-	$47,360	42.5	1.2	1.3	23.5	$2,017
3a. CWI - Cruising	$35,000	$33,057	196.7	10.9	-	89.0	$371
3b. CWI - Hoteling	$35,000	$7,961	29.7	1.65	-	13.5	$589
4a. CWI & MDO Fuel – Total In GB/PS	$70,000	$390,146	226	8.4	9.9	276	$1,412
4b. CWI & MDO Fuel – Only Hoteling	$35,000	$55,321	29.7	1.1	1.3	36.4	$1,522
5a. Direct Water Injection - Cruising	$178,500	$56,000	140.5	12.5	-	144	$390
5b. Direct Water Injection - Hoteling	$120,000	$21,544	20.7	1.9	-	22.3	$467
6. Gas Turbine in the GB/PS Region - Total	$6,900,000	$1,360,000	80.8	3.1	9.8	427	$3,185
7a. Selective Catalytic Reduction - Cruising	$783,000	$468,000	56.2	6.2	8.6	382	$1,225
7b. Selective Catalytic Reduction - Hoteling	$550,000	$143,000	8.5	0.94	1.3	58	$2,482
8. Shore Power (Port of Vancouver only)	$859,000	$118,500	-	-	-	17.6	$6,700
* Cruise using two V12 5760 kW medium speed diesels, average load 13.8 MW for 1130 hours per year, SFOC = 193.5 g/kWh.							
** Hoteling using three Sulzer V8 5760 kW med. speed diesels, average load 7.5 MW, SFOC = 200 g/kWh; 37 visits/year with 8.5 hours per visit.							

6.2.2 Use MDO Fuel Within the GB/PS Region

It is assumed that 0.13% S MDO is used in place of 2.45% IFO 180 fuel oil, with a cost premium of $100/tonne. Particulate is reduced 50% and SOx by 94.5%. The cost-effectiveness for **cruising is $1,944/tonn**e and for **hoteling is $2,017/tonn**e, as shown in Table 7 above. Total average cost effectiveness is $1,954/tonne.

6.2.3 Use Continuous Water Injection (CWI) Within the GB/PS Region

Continuous Water Injection (CWI) is assumed to reduce NOx by 30% and PM by 30% with 50% water injection (tonnes water per hour = 0.5 x tonnes fuel per hour). Water is assumed to cost $26.40/tonne underway (ref.54) and $10/tonne at dock. Water is the dominant cost factor while cruising, forming 83% of the total annual cost (balance is maintenance and amortization of capital). It is assumed that CWI is installed on the two main engines and also on two of the smaller gensets. No allowance has been made for any improvement in fuel economy.

Table 7 shows the cost-effectiveness of CWI while cruising of $371/tonne and $589/tonne while hoteling.

6.2.4 Use CWI and MDO Fuel Within the GB/PS Region

The combination of CWI and MDO fuel provides significant reductions in all three criteria pollutants. At is assumed that NOx is reduced 30%, PM reduced 53.3%, and SOx reduced by 94.5%. Two cases are investigated: hoteling only and total (hoteling plus cruising). For hoteling only two of the V8 engines are fitted with CWI, while for cruising fours engines are fitted with CWI. Again it is assumed that CWI uses 50% water injection which cost $10/tonne at dock and which is made while underway for $26.40/tonne per Ref. 54.

Table 7 shows the cost-effectiveness of this combination when used within the GB/PS area ($1,412/tonne) and while used only for hoteling ($1,522/tonne).

6.2.5 Use Direct Water Injection (DWI) Within the GB/PS Region

Direct Water Injection (DWI) can reduce NOx by 50% and particulate by 20% using 50% water injection. The capital costs used here are those estimated by EPA in a 2003 study[54]. The water costs will be the same as those assumed for CWI in Section 6.2.3. It is assumed that DWI is installed on the two V12 Sulzers and on two of the three V8 Sulzer 4-strokes.

Table 7 shows the cost-effectiveness of DWI while cruising is $390/tonne and $467/tonne while hoteling.

6.2.6 Use a Gas Turbine Within the GB/PS Region

Gas turbines are starting to be used on cruise ships to reduce weight and emissions. Their fuel consumption is greater that that of diesels; SFOC = 220 (SFOC = 190 for large 4-stroke diesels). Hence they are normally used only for hoteling and when needed for fast cruising. The General Electric LM2500+ has a maximum output of 30,200 kW. Typical emission factors when on 0.1% S MGO are NOx = 4.5 g/kWh, PM = 0.17 g/kWh and SOx = 0.55 g/kWh.

No cost data is available for this engine. Therefore the installed cost is derived from that of a 5,000 kW turbine, or a 5,000 kW diesel, installed in a 400-passenger ferry (ref. 55), using the 2/3 power-law to scale-up. The estimated costs for a 30.2 MW gas turbine is $10.5M and for a 30.2 MW diesel is $3.6 M. Therefore the extra cost for the turbine is roughly $6.9M. It is assumed that the annual maintenance costs are approximately the same for both engines. The gas turbine requires marine gas oil (MGO), which is assumed to cost $345/tonne, as compared with IFO 180 at $225/tonne.

Table 7 shows that the gas turbine burning MGO in the GB/PS area costs an extra $1,360,000 per year and reduces total emissions by 427 tonnes. Therefore the cost effectiveness of this option is $3,185/tonne. (No credit has been taken for weight and space savings.)

6.2.7 Use Selective Catalytic Reduction Within the GB/PS Region

Selective catalytic reduction (SCR) in conjunction with MDO fuel can easily reduce NOX emissions by 80%, PM by 60% and SOx by 94.5%. It is assumed that separate SCR systems are installed on the two V12's for cruising and that separate SCR's are also installed on two of the V8's for hoteling.)Savings may be had by combining the SCR units and by using some exhaust gas reheat to ensure proper catalytic operation, but this was not assumed in this estimate.) Cost data is from the EPA study for Category III diesel engines.[54] The MDO is assumed to cost an extra $100/tonne and urea at $317.30/tonne.

Table 7 shows the estimated cost-effectiveness for cruising ($1,225/tonne) and hoteling ($2,482/tonne).

6.2.8 Use Shore Power For Hoteling

Shore power was discussed in Section 5 as a means of reducing emissions during hoteling. The cost-effectiveness of this option is sensitive to the relative costs of fuel oil (IFO 180) and electricity. Emission reductions will only apply to where shore power is available within the GB/PS region, which is assumed to be the Canada Place and Ballantyne Terminals in the Port of Vancouver. Section 5 gave the year 2000 annual hoteling emissions here as 458.3 tonnes total for 26 vessels, or 17.6 tonnes per vessel.

From Section 5 we assume that the total shore-based infrastructure cost for 27 vessels is $9.7M. The cost of $9.7M is shared between the present 27 vessels ($359,000 per vessel). In addition, a vessel must spend approximately $500,000 for internal electrical modifications. Therefore the total capital cost per vessel will be approximately $859,000, or $94,320/year (CRF = 0.1098). Maintenance is assumed to be 2% of capital, or $17,180 per year.

The electricity, at CDN$0.08/kWh, was estimated in Section 5 to cost $45,910 per year. The avoided fuel cost (IFO 180 at $250/tonne) was $38,891. Therefore the net energy cost is $7,019 per year. Total annual costs are therefore $118,519 per vessel

If it assumed that this option results in no emissions (hydroelectric power is substituted for diesel electric power) then the cost-effectiveness of this approach is **$6,734/tonne**, as shown in Table 7. If the BC Hydro feed is assumed to come from a blend of hydro and gas turbines with SCR, then the hoteling emission reduction will be slightly less, but not significantly so.

6.3 Ferries

There are a total of over 100 ferries operating within the GBPS area. BC Ferries operate a substantial fleet of 40 vessels along the BC coast. Their large ferries typically have two main engines, each about 3000 - 4000 shaft horsepower (shp) at approximately 700 rpm. In addition, they typically have three smaller (e.g. 600 kW at around 1200 rpm) gensets for internal power requirements. Both the main engines and the gensets are operated on either low-sulphur road diesel or regular diesel/MDO. The ferries are fueled from shore-based tanks.

The smallest ferries typically use a couple of high-speed (e.g. 1800 rpm) Cat diesels that produce around 500 bhp and which burn regular or low-sulphur road diesel.

6.3.1 Base Case For Emission Reductions

The vessel *Spirit of Vancouver Island* will be used as an example of a ferry because reliable data is available on engine loads and fuel consumption, as well as on emissions. (Genesis Engineering Inc. measured these parameters during 1998 [56].) This ferry carries up to 470 vehicles and 2000 passengers between Tsawwassen and Swartz Bay. The sailing time is approximately 1-½ hours, with ½ hour turn-around at each end. There are three main engines (MAN 6L40/54 6-inline rated at 3900 kW @ 500 rpm). The gensets are run from the main engines (no auxiliary diesels).

During cruise (75% of time) the engine load varies between 70% and 75% of MCR and the SFOC is approximately 181 g/kWh. While docking (25% of time) the load drops down to between 19% and 25% MCR with a SFOC of 218 – 225 g/kWh. For purposes of this study the engine load, SFOC and the emission factors will be averaged over the entire trip by using the time spent at each power setting. (The emission factors will be the B.C. ferry fleet averages as measured[56] during 1998.)

Assumptions:

- Total average power = 6939 kW; SFOC = 191 g/kWh
- Round trips per year = 1323; hours/year = 5292
- Annual fuel = 5292 tonnes; average fuel sulphur = 0.21%.
- Emission factors: NOx = 15.0 g/kWh, PM = 0.50 g/kWh, SOx = 0.88 g/kWh

The above assumptions lead to the base-line emissions listed in Table 8 below. Total annual emissions are estimated to be 600 tonnes (549 tonnes NOx, 18.4 tonnes PM, and 32.4 tonnes SOx).

6.3.2 Use of Road Diesel and Continuous Water Injection (CWI)

Road diesel greatly reduces SOx emissions while CWI reduces NOx and particulate emissions. It is assumed that road diesel cost $10/tonne more than MDO and that CWI results in a 1% reduction in fuel consumption. The installed cost for CWI is assumed to be $50,000 for all three engines. Water is injected at 50% of the fuel rate, and water is assumed to cost $10/tonne.

The combination of road diesel (300 ppm S) and CWI is assumed to reduce NOx by 30%, PM by 30% and SOx by 86%. Total emissions are reduced by 198 TPY with a cost-effectiveness of $465/tonne as shown in Table 8 below.

6.3.3 Ultra-Low Sulphur Diesel (ULSD) plus CWI plus Diesel Particulate Filter

The use of ULSD enables the use of catalytically regenerated diesel particulate filters (DPF), which not only greatly reduce particulates, but also oxidize hydrocarbon and CO emissions. Using a combination of ULSD, CWI and DPF is expected to reduce NOx by 30%, PM by 90% and SOx by 99.5%.

The installed cost of a DPF for a 300 kW bus engine is about $10,000. It is assumed that the cost scales with the engine rating according to the 2/3-power law. Therefore the cost for a DPF for a 3900 kW engine, when available, would be approximately $55,340 and for three engines would be approximately $166,000.

It is also assumed that ULSD demands a price premium of $21.50/tonne over MDO, and that water used for CWI cost $10/tonne. CWI uses 1 part water to 2 parts fuel. The cost for installing CWI on three engines is assumed to be $50,000.

This emission reduction option reduces annual emissions by 214 tonnes, at a cost of $220,400. The cost-effectiveness is therefore $1,032/tonne.

Table 8 – EMISSION REDUCTION OPTIONS FOR A FERRY*

Description	Installed Cost ($US)	Total Annual Cost ($US)	Emissions (tonnes per year)			Emission Reduction (TPY)	Cost-Benefit ($/tonne)
			NOx	PM	SOx		
1. Base Case – No Controls	-	-	549	18.4	32.4	-	-
2. Road Diesel and Continuous Water Injection (CWI).	$50,000	$92,158	384	12.9	4.6	198	$465
3. Ultra-Low Sulphur Road Diesel, CWI and Diesel Particulate Filters (DPF).	$216,000	$220,400	384	1.8	0.2	214	$1,032
4. Road Diesel and Direct Water Injection (DWI).	$147,500	$128,800	274	12.9	4.6	308	$418
5. Road Diesel and Selective Catalytic Reduction (SCR).	$596,100	$214,100	110	12.9	4.6	472	$453
6a. CNG (45 cents CDN/liter diesel equiv.; retrofit)	$3,280,500	$502,000	228	5.2	1.8	365	$1,376
6b. LNG (90 cents CDN/LNG gallon; retrofit)	$3,280,500	$363,700	228	5.2	1.8	365	$996
6c. LNG (70 cents CDN/LNG gallon; retrofit)	$3,280,500	$55,170	228	5.2	1.8	365	$151
6d. LNG (70 cents CDN/LNG gallon; new engines)	$2,857,100	-$13,315	228	5.2	1.8	365	-$36

* *Spirit of Vancouver Island*, 470 vehicles, 2000 passengers, three MAN 6L40/54 diesels rated 3900 kW @ 500 rpm. Average total load 6939 kW, SFOC = 191 g/kWh; 1323 round trips per year; total of 5292 hours; 7014 tonnes fuel.

6.3.4 Use of Road Diesel and Direct Water Injection (DWI)

The cost of using DWI has been estimated in an EPA study[54] to be $49,158 per engine, or $147,474 for three engines. The emission reductions assumed for the road diesel (300 ppm S) and DWI combination are 50% for NOx, 30% for PM, and 85.7% for SOx.

The water cost and fuel cost assumptions will be the same as for the road diesel and DWI combination in Section 6.3.1 above.

The annual costs are estimated to be $128,800 and the resulting total emission reduction is 308 tonnes, yielding a cost-effectiveness of $418/tonne as per Table 8.

6.3.5 Use of Road Diesel and Selective Catalytic Reduction (SCR)

The cost of using SCR has been estimated in the EPA study[54] to be $198,710 per engine, or $596,100 for three engines. The emission reductions assumed for the road diesel (300 ppm S) and SCR combination are 80% for NOx, 30% for PM, and 85.7% for SOx.

The estimated annual cost of $214,100 is comprised of $65,500 for amortization, $29,800 for maintenance, $48,700 for urea reagent, and $70,100 for the road diesel price premium. The resulting cost-effectiveness (Table 8) is $453/tonne.

6.3.6 Use of Natural Gas – Compressed (CNG) or liquid (LNG).

Natural gas promises to not only reduce emissions, but also to greatly extend engine life and lube oil life. However, the cost-effectiveness of natural gas is very sensitive to the relative costs of MDO and natural gas. ENRG estimate the cost of CNG to be 40 – 50 cents per diesel liter equivalent, and LNG to be $.80 - $1.00 per LNG gallon, based upon a natural gas commodity price of $5/GJ (all prices in Canadian $). [56] ENRG would put in place the shore-based infrastructure needed to supply the CNG or LNG at these prices. MDO currently sells for about US$320 - US$350 per tonne, and road diesel costs an extra $10/tonne above this.

For purposes of this study we assume that CNG is available at 45 cents per diesel liter equivalent and LNG costs $0.90 per LNG gallon. It is further assumed that the dual-fuel diesel engines have been optimized to use natural gas and therefore have low emissions. The natural gas to diesel ratio is 60:40 and the diesel used is 300-ppm S road diesel, resulting in a NOx reduction of 58.5%, PM reduction of 72% and a SOx reduction of 94.3%.

The installed cost and the maintenance and lube oil savings have been estimated by MDA (Section 4.7) to be $3.28M US and $0.119M US, respectively, for both CNG and LNG. The displaced diesel cost ($350/tonne) is $1.47M per year, whereas the cost for CNG would be $1.54M and the cost for LNG would be $1.39 per year. Therefore CNG demands a $68,700/year premium over MDO whereas LNG results in a $83,900/year savings compared to MDO.

The above assumptions result in a net cost-effectiveness of $1,376/tonne for CNG and $957/tonne for LNG.

When Westport's high-pressure, natural-gas injectors become available for larger engines and are accepted by Lloyds and the Coast Guard, then much greater NOx emission reductions will be realized and the cost-effectiveness of using natural gas would be greater.

6.4 Workboats and Harbour Vessels

There are about 490 workboats (tugboats, tenders, etc.) and 45 government vessels that operate within the GBPS area.[51] Work boats generally use medium to high-speed diesel engines that burn regular diesel, or low sulphur diesel if that is all that is available. Private vessels or single vessel operations will refuel at a fuel dock, while larger corporate fleets will have their own tanks and refueling facilities.

Emission reduction options that are presently appropriate to these vessels include:

- Using road diesel instead of MDO, to reduce SOx emissions.
- Using road diesel along with continuous water injection (CWI).
- Using ultra-low sulphur road diesel (ULSD) along with CWI and a diesel particulate filter (DPF).
- Using ULSD along with exhaust gas recirculation (EGR) and DPF.
- Using a fuel-water emulsion (PuriNOx with road diesel).

6.4.1 Base Case For Emission Reductions

The assumed vessel will be a tug boat with a 978 hp (729 kW) main engine which operates for 4000 hours per year at an average of 60% MCR and which has an average SFOC of 208 g/kWh.[53] The annual fuel consumption is 364 tonnes. A typical engine would be a Detroit Diesel Series 149-T with 16 cylinders, turning at 1900 rpm at MCR.

The average emission factors are taken to be 12 g/kWh for NOx, 0.20 g/kWh for PM and 0.55 g/kWh for SOx.[53] These relatively low values reflect the low-emission, highway-vehicle origin of many of the smaller, high-speed marine diesel engines.

A tug may also have one or more small auxiliary engines, such as the Mitsubishi 6D16-T which produces 168 hp at 1800 rpm. These engines will not be included in this study.

The baseline emissions (22.3 TPY) are shown in Table 9 below.

Table 9 – EMISSION REDUCTION OPTIONS FOR A WORK BOAT*							
Description	**Installed Cost ($US)**	**Total Annual Cost ($US)**	**Emissions (tonnes per year)**			**Emission Reduction (TPY)**	**Cost-Benefit ($/tonne)**
			NOx	**PM**	**SOx**		
1. Base Case – No Controls.	-	-	21.0	0.35	0.96	-	-
2. Use Road Diesel	-	$3,644	21.0	0.35	0.22	0.74	$4,900
3. Road Diesel plus Continuous Water Injection (CWI)	$20,000	$8,580	14.7	0.24	0.22	7.1	$1,200
4. Ultra-Low Sulphur Diesel, CWI and Diesel Particulate Filter (DPF)	$35,000	$15,250	14.7	0.03	0.01	7.6	$2,010
5a.Exhaust Gas Recirculation (EGR) with DPF and with ULSD Fuel.	$30,000	$15,300	11.6	0.03	0.01	10.7	$1,431
5b. EGR with DPF and with Road Diesel.	$30,000	$9,390	11.6	0.07	0.22	10.5	$897
6. *PuriNOx* Emulsion with Road Diesel	-	$29,150	13.2	0.20	0.22	8.7	$3,370
* 978 HP (729 kW) high-speed diesel operating at 60% maximum for 4000 hours per year; SFOC = 208 g/kWh							

6.4.2 Use Road Diesel Instead of MDO

The use of road diesel (300 ppm S) instead of MDO (1300 ppm S) reduces SOx emissions by 0.74 tonnes per year. If the cost premium for road diesel is $10/tonne, then the extra annual cost is $3,644 and the cost-effectiveness is $4,900/tonne.

6.4.2 Use Road Diesel Plus Continuous Water Injection (CWI)

It is assumed that CWI can be installed for $20,000 and that the combination of road diesel and CWI results in a 30% reduction in NOx, a 30% reduction in PM, a 77% reduction in SOx and a 1% decrease in fuel consumption. The CWI system uses 182 tonnes of water per year at a cost of $10/tonne.

The total annual extra cost is estimated to be $8,662 and to reduce emissions by 7.1 tonnes. Therefore the cost-effectiveness is $1,200/tonne.

6.4.3 Use Ultra-Low Sulphur Road Diesel with CWI and a Diesel Particulate Filter.

The use of ULSD (10 ppm S) allows a self-regenerating catalytic diesel particulate filter (DPF) to be installed at a cost of approximately $15,000. The total installed cost of equipment is therefore $35,000. The ULSD is assumed to demand a premium of $21.50/tonne over MDO.

This combination is expected to reduce NOx by 30%, PM by 90% and SOx by 99.2% (total reduction of 7.6 TPY). With an annual cost of $15,250 the cost-effectiveness is $2,014/tonne.

6.4.4 Use Exhaust Gas Recirculation with ULSD and a DPF

Johnston-Matthey are selling a combination EGR and DPF system which they claim reduces NOx by 45%, PM by 90% and SOx by 99.2% (if used with ULSD) [45]. While ULSD is not necessary it does enhance the performance of their system. The expected installed cost is $30,000.

We assume that the fuel consumption will be slightly (2%) increased because of EGR, and that the premium for the ULSD is $21.50/tonne over MDO. The total annual cost increase is estimated to be $15,300 and the emission reduction to be 10.7 tonnes. The cost effectiveness is therefore $1,430/tonne.

If road diesel (300 ppm S) is used with the Johnston-Matthey system the emissions are reduced by about 10.4 tonnes per year at an annual cost of $9,390, yielding a cost-effectiveness of $897/tonne.

6.4.5 Use a Diesel-Water Emulsion (*PuriNOx*)

The San Francisco Water Transit Authority experimented with using a *PuriNOx* diesel-water emulsion on one of their ferries.[30] The NOx was reduced by 37%, PM by 42% and SOx by 77% (if used with road diesel). The effective cost of the fuel was increased by about 20%. Assuming that MDO costs $350/tonne and that road diesel demands a $10/tonne premium over this cost, the annual increase in fuel costs would be $29,150.

The annual emission reduction would be 8.7 tonnes; hence the cost-effectiveness of this approach would be $3,366/tonne.

7.0 Examples of State and Port Initiatives to Reduce Marine Emissions

(This section of the report was prepared by Fred McCague (Cargo Services, Ph.604 589-7800, Email: McCague@helix.net) on behalf of Genesis Engineering Inc. The references for this section are included at the end of this section as footnotes.)

7.1 UNITED STATES

Environmental Protection Agency (EPA)

The EPA has, in a rule making of January 2003, adopted the same standards as outlined in MARPOL Annex VI for U.S. vessels effective January 1, 2004[i]. The EPA standard will apply with or without the Senate ratification of MARPOL Annex VI or of ANNEX VI formally coming into force. The EPA is also considering but has not yet adopted an additional Tier II requirement of a further 30 percent reduction in NOx effective 2007. These provisions apply only to U.S. registered ships.

Maritime Administration (MARAD)

MARAD has funded some research programs into alternative fuels, notably a CNG-powered ferry in Virginia.

7.2 CALIFORNIA

<u>**California Air Resources Board**</u>

- **Carl Moyer Memorial Fund**

The Carl Moyer Memorial Fund program has approved the replacement of 268 diesel engines on harbour and coastal vessels at a total cost of US$14 million[ii]. Annual NOx reduction is estimated at 400 tons at a cost per ton of $3055. This program has now captured most of the larger qualifying engines. Operators are now replacing smaller auxiliaries and the cost per ton of fuel saved on current installations is now about $4,000 per ton and rising. The diesel replacement program is capped at $12,000 per ton.

- **San Francisco Bay Area**

San Francisco Bay area is home to the major container port at Oakland, plus a number of smaller port authorities including Richmond, San Francisco and Redwood City as well as a number of military and private industrial ports and terminals. Air emissions in the region are regulated through the Bay Area Air Quality Management District (BAAQMD).

- **Water Transit Authority**

The San Francisco Bay Water Transit Authority is the California state-planning agency overseeing expansion of passenger ferry services on San Francisco Bay. The ferries are operated by a number of organizations.

- **Biodiesel**

The WTA received a $25,000 grant from the U.S. Maritime Administration (MARAD) to conduct a five-month test of soy-based biodiesel fuel on the Blue & Gold Ferry Services 400-passenger ferry *Oski* which was conducted in late 2001/early 2002. Blue & Gold contributed $57,000 for the test. Biodiesel cost was about $1.00 per U.S. gallon higher than normal diesel. The tests showed a 24 percent increase in NOx, but a 50 percent decrease in PM using 100 percent biodiesel. Using 20 percent biodiesel, NOx increased by 11 percent.

- **Water Emulsified Diesel Fuel**

In the spring of 2002, the WTA conducted a four-month test of PuriNOx fuel[iii], an emulsified fuel of 77 percent diesel, 20 percent water and 3 percent PuriNOx 1121A additive. The PuriNOx fuel cost 14 cents per gallon more than regular diesel fuel, with the WTA paying the cost differential. The test results showed a 37 percent decrease in NOx and a 42 percent decrease in PM.

- **Fuel Cell**

In February 2003, the WTA received a federal grant of $2.5 million for the construction of a hydrogen fuel cell–powered 49-passenger ferry[iv] to operate between San Francisco, Treasure Island and the East Bay. The grant will cover the cost of the boat, with the WTA paying for the fuel cell engines and interior fittings. Preliminary design plans are for a 24 metre catamaran powered by two 150 to 200 kW fuel cell motors with each motor similar in size and weight to a bus fuel cell installation. The catamaran design is to provide for the expected extra weight. WTA expects the ferry to be in service in 2006 or 2007.

Port of Oakland

- **Vision 2000 Air Quality Mitigation Program**

Dredging of the channel to 50 feet and construction of two new container terminals on a former navy base prompted pushed the Port of Oakland slightly above BAAQMD permitted PM levels. With this plus concerns raised by nearby residents, the port established a comprehensive air quality program. Detailed below, the mitigation program[v] included particulate air quality monitoring, a tug re-engining, terminal equipment modifications and truck modifications. These programs are budgeted to cost $8.9 million. The program also included an off-site mitigation program involving re-engining 28 Oakland transit buses.

- **West Oakland Air Particulate Air Quality Monitoring Program**

The Port of Oakland has operated, since 1997, two air quality monitoring stations for particulates[vi], both PM 10 and PM 2.5. The two stations were established in 2001 one in the site of Pier 56/57 and the second in a residential area in West Oakland. They will be shut down in April 2004.

- **Tug**

In 2000, the Port of Oakland paid $408,300 in a grant to fund 50% of the cost of replacing two engines on the 20-year-old Oscar Niemeth Towing Inc. harbour 2,400 hp tug *Silver Eagle* with two new low emission diesel engines. The port estimated this will eliminate .9 tons of particulate matter (PM) and 26 tons of nitrogen oxides (NOx) annually, or 15.5 tons of PM and 431 tons of NOx over the sixteen year life of the project. Cost per ton of NOx reduced per year $1511.

- **Container Terminal Equipment**

A port program for container terminals to repower and/or retrofit equipment including yard tractors, RTGs (rubber tired gantries) and other diesel powered equipment. All operators applied for port funding. Oakland approved funding for changing 150 pieces of equipment to new low-emission diesel engines, installing 151 diesel oxidation catalysts and installing 159 diesel particulate filters. The port notes 50% of the terminal operators now use ultra-low sulfur diesel fuel to further reduce emissions.

The diesel catalyst program is well underway and will soon be completed. The program is viewed as successful and has had no effect on fuel consumption or general maintenance. The particulate filter work is expected to start later this year and be completed by 2005.

The port notes the container terminal equipment program is expected to reduce hydrocarbon emissions by nearly 80%, carbon monoxide emissions by nearly 70%, nitrogen oxide emissions by over 30% and particulate matter emissions by over 70%. The total project will eliminate 60 tons of particulate matter, over 470 tons of nitrogen oxides and over 150 tons of hydrocarbons. Approved Port of Oakland cost of the project is US$5.245 million

- **Trucks**

Highway trucks are a major source of container transportation to and from the port's container terminals. Oakland has established an Air Quality Mitigation Program for trucks. The port will fund retrofitting of diesel truck engines on local trucks with catalysts. The Port is also working with a trucking company to complete a demonstration of alternative diesel fuels and add-on devices that reduce truck diesel emissions.

- **Ships**

At this time, the Port of Oakland has no specific programs regarding ocean-going ship emissions.

Los Angeles/Long Beach

The adjacent Port of Long Beach and Port of Los Angeles occupy San Pedro Bay in Southern California. They are operated by the cities of Long Beach and Los Angeles respectively. The two ports are the top two container handling ports in the United States and major liquid and dry bulk cargo ports.

The South Coast Air Quality Management District (SCAQMD), a five-county regional group sets air quality standards for the entire region.

- **Speed Restriction**

In April 2001, the industry and ports through the Marine Exchange of Los Angeles and Long Beach established a voluntary speed Air Quality Compliance Zone[vii] for ships to reduce speed to 12 knots at 20 nautical miles from Point Fermin. Point Fermin is the VTS radar station operated by the Marine Exchange. It overlooks the pilot stations art the harbour entrances.

The Marine Exchange estimates compliance with the speed restriction at about 65 percent. Using a more strict compliance standard – maximum of 13 knots (one knot over) at 20 miles, 10 miles and 5 miles, the Port of Long Beach pegs compliance at 50 percent. With this compliance level, the Port of Los Angeles estimates NOx reduction for Long Beach and Los Angeles at about 1.5 tons to 2.0 tons per day. The two ports estimate NOx reduction could reach two to four tons per day with full (85 percent) compliance.

This voluntary program was developed by industry in conjunction with the two ports. The California Air Resources Board and the U.S. EPA have both signed the MOU establishing the program. The financial charge for the two ports was a total of US$6000 in set up costs. The Marine Exchange provides the speed and tracking data. The ports analyze and assess the data.

There has been no actual measurement of the effect of the program. Industry concerns are that the across-the-board speed restriction may actually be too low for some of the large container ships with cruising speeds well over 20 knots. The low loads on the engines of these ships may mean they are actually working below optimum emission levels. This is expected to soon be fully studied.

Another proposal to shift the traffic lanes further offshore and outside the Santa Barbara Channel did not proceed as it would have interfered with a naval missile test range off Point Mugu.

- **Alameda Corridor**

The Alameda Corridor[viii] opened in April 2002. It is a 20-mile long double track railroad line built on a separated grade used by both the Union Pacific and the Burlington Northern Santa Fe from the ports to the main railroad junctions. The line was built at a cost of $2.4 billion to speed intermodal rail traffic through Los Angeles. It eliminated 200 level railroad crossings on 90 miles of three separate railroad lines. Environmentally it saves 15,000 hours of idle time by automobiles, and increases mainline locomotive efficiency by 30 percent by permitting higher operating speeds and a more direct route. As different agencies and municipal governments operate the Alameda Corridor, the ports do not track the emissions savings of the line.

- **Bunker Fuel**

Until 1991, Long Beach/Los Angeles was the second largest bunker supply port in the world. The ports provided fuel not only to the thousands of ships that called there for cargo, but, had more than 700 ships per year call just to take on fuel. The fuel sold was generally refined locally with a sulphur content of about 2 percent.

This business ended abruptly in 1991 when the California government imposed a sales tax on bunker fuel. 18 months later, in 1993, bunker fuel taxes were exempted from the sales tax for a five year period, later extended to 10 years. Despite this exemption, the bunker fuel business never recovered and remained at roughly one third of its previous volume.

During this same period, refiners in the area switched from residual fuel production to petroleum coke (petcoke) for export. Particulates from handing petcoke at Long Beach became a new concern.

Most bunker fuel sales in 2002 were of imported fuel oil, generally from Venezuela, with an estimated 2.8 percent sulphur content[ix]. On average about 180 ships called Los Angeles/Long Beach for bunkers fuel only.

On January 1, 2003, due to a governor's veto, the fuel sales tax exemption expired, and the sales tax, now at 8.25 percent was imposed, curbing most bunker fuel sales.

- **Truck retirement**

The Gateway Cities Diesel Emissions Reduction Pilot Program involving the Ports of Long Beach and Los Angeles and 27 city governments is implementing programs to reduce emissions from the 32,000 daily truck movements in the area. The program has $1.7 million fromn the EPA and is gathering addiitonal funds. It has started a plan to buy and scrap trucks built prior to 1983 from regular port users the port subject to them purchasing trucks with modern computer controlled engines built after 1994. The program will cost up to $30,000 per vehicle and has $1.3 million in Long Beach port funds available.

$10 million in mitigation funds from the Port of Los Angeles China Shipping Terminal agreement may be added over the next five years.

Port of Los Angeles

- **Shore Power – Cold Ironing**

Mayor Jim Hahn of Los Angeles visited a number of Asian shipping companies in meetings in Tokyo, Hong Kong and Taiwan in November 2002. These resulted in negotiated memorandums of understanding (MOU) committing the City of Los Angeles and the shipping lines to research the feasibility of installing electrical conduits on shore and retrofitting ships to receive shore power. A press release stated that under the terms of the MOU, a joint working group consisting of the carriers, the Port, the Los Angeles Department of Water and Power (LADWP) and environmental agencies would analyze the capabilities of plugging in vessels. The carriers will identify the cargo ships for conversion and the Port and LADWP will provide the electrical infrastructure needs at the terminals.

The cold ironing concept for in-service ocean-going ships has been considered by Los Angeles for more than ten years, however, to date, little progress has been made. The U.S. Navy has extensive experience with using shore power for laid-up ships. Princess Cruises has used shore power while alongside at Juneau, Alaska for four cruise ships in 2001 and 2002.

The Port of Los Angeles is beginning a study on this program. It would require a separate electrical installation along the dock face for ships at each berth. The power requirements are quite high as it must provide power for both the ship and all of the refrigerated containers on board the ship.

- **Particulate Measurement**

The port will install five or six stations to measure particulates, both PM 10 and PM 2.5. The port needs one year of actual measured results for its computer modeling, but plans to continue to operate the stations on a permanent basis. For NOx measurements, the port uses the existing regional network.

- **Port Equipment**

The port is purchasing only vehicles with alternate fuel including CNG and propane electric and hybrid for its own fleet.

- **Locomotives**

The Port of Los Angeles is eager to have the operator repower, remanufacture or replace switch engines at the port[x]. The estimated cost is US$300,000 for each of the three switch engines. Problems include the length of contract for the current operator. The port and the operator are also working on emulsified diesel fuel at a cost of 30 cents per U.S. gallon or a total of $90,000 per year for the three engines.

- **China Shipping Terminal – Berth 100**

On March 5, 2003, the Port of Los Angeles reached a settlement with environmental and community groups to spend $50 million over five years on environmental programs[xi] in order to lift the stay preventing construction of Phase I of the China Shipping Terminal and to permit its operation to commence immediately subject to court approval.

The agreement includes:
- Use of alternative fuels for container handling equipment at the new terminal
- Use of low-profile cranes at the terminal, if feasible
- Use of Alternative Maritime Power (AMP) (cold ironing) during hoteling
- A traffic mitigation plan for the area around the terminal
- $10 million mitigation funds to the Gateway Cities Program as incentives to replace, repower or retrofit existing diesel-powered on-road trucks
- $20 million for air quality mitigation
- $20 million for community aesthetic mitigation

Actual program details especially in relation to the cold ironing program are very preliminary at this time.

Port of Long Beach

The Port of Long Beach has a $2.75 million air quality program for terminal equipment and highway trucks.

- **Terminal Equipment**

The port estimates there are 230 pieces of terminal equipment – RTGs, yard tractors, fork lifts etc. to be fitted with diesel oxydizing catalytic converters and possibly emulsified diesel fuel. The port hopes to reduce PM by 50 percent and NOx by 20 percent on this equipment[xii].

7.3 ALASKA

The State of Alaska's environmental policy is set through the Department of Environmental Conservation.

- **Opacity**

The State of Alaska has strict opacity limits[xiii] – not to exceed 20% for more than 3 minutes per hour, which have been monitored closely over the past three years.

The state's own information sheets note:
- Opacity is visible emissions from a smoke stack – in these cases, from a cruise ship.
- Opacity cannot be used to measure impacts on public health.
- Opacity is an aesthetic or quality of life issue.

As a result of a court settlement against a cruise line, the DEC used funds to hire a n independent contractor to take opacity readings in 2000, 2001 and 2002 in Juneau, Ketchikan, Haines and Skagway. In 2000 there were 30 alleged violations of 235 readings. In 2001, 20 alleged violations in 230 readings. In 2002, zero violations from 250 readings.

- **Cruise Ship Engine Upgrades**

The improvements in opacity have come from closer attention on board ships while in port. The use of additives on three vessels, and the introduction of gas turbines on three ships operated by Royal Caribbean and Celebrity Cruises. Holland America was doing engine upgrades in conjunction with Wartsila to "EnviroEngine"[xiv] standard with water injection on six ships. The continual introduction of new ships, including the *Carnival Spirit* (in 2001) also helped. *Carnival Spirit* was delivered with two of six Wärtsilä 9L46D engines modified with the "smokeless" EnviroEngine technology.

The engines use a common rail fuel injection system which enables injection pressures to be kept sufficiently high at all engine speeds - even at the lowest levels - to ensure clean combustion with no visible smoke emissions. The line states these are particularly beneficial for use in port, as they produce no visible emissions even when lightly loaded for producing energy for lighting, air conditioning and other hotel systems.

In addition, Princess Cruises began using shore power in Juneau in 2001 and 2002.

"Azipod" type podded propulsion systems are now standard for all new-built cruise ships resulting in significantly lower fuel consumption of up to 40 tons per week which has a significant reduction in emissions while the ships are underway including entering and leaving port.

Juneau

- **Princess Cruises Shore Power**

In 2001, Princess Cruises modified four ships to permit them to use shore power[xv] while alongside the South Franklin Street Dock (Princess Dock) in Juneau. The practice is also known, especially in California, as cold ironing.

Princess Cruises invested $4.5 million installing equipment on four Princess ships and on the dock at Juneau. The City of Juneau allotted $300,000 of the 2001 Cruise Passenger Fees for the project.

According to Princess Cruises, Four ships, each calling Juneau once per week, were modified in 2001, the *Sun Princess*, *Sea Princess*, *Dawn Princess* and *Ocean Princess.* According to Princess Cruises, ship modifications included a new hull door and a custom-built state-of-the-art electrical connection cabinet with equipment that automatically connects the ship's electrical network to the local electrical network ashore. On dock, the electrical power is transmitted from the transformer to the vessel via four 3 1/2-inch diameter flexible electrical cables that hang festooning-style on a special gantry system built on the dock. The gantry and the festooning equipment have been designed to accommodate the 20 feet rise and fall of the tide and withstand the 100 mph winds during the winter. The actual cable connection on the vessel is a traditional, though quite large, male/female plug and socket, adapted from the American mining industry.

A fifth ship, *Star Princess* entered service in 2002 with shore power equipment installed.

The lines states that, to ensure that visible emissions are minimized, Princess will also be shutting down each ship's oil-fired steam boiler even though the amount of emissions from these are quite small. A shoreside electric boiler produces the steam.

The ships use hydroelectric power supplied by Alaska Electric Light and Power Company (AEL&P).

The City and Borough of Juneau has allocated $300,000 from the 2001 Cruise Passenger Fees as a contribution to the cost of the shore power installation.

This is the only installation where active ocean going vessels use shore power. The U. S. Navy uses shore power on its vessels when they are in reduced activity or laid up status.

- **Ambient Air Monitoring**

In response to citizen concerns over air quality with four or more large cruise ships in port , the North West Cruise Ship Association contracted to monitor the ambient air quality in downtown Juneau[xvi].

Three stations were established and operated in 2000 and 2001 monitoring NOX, Sox and PM2.5 particulates. During 2001, the Department of Environmental Conservation independently operated an additional monitoring station. No problems with air quality standards were recorded in either year, and with the state's concurrence the program was ended at the end of the 2001 cruise season.

Valdez

A voluntary agreement between the State of Alaska and tanker operators, tankers switch to very low sulphur (0.5% or lower) IFO 380 bunker fuel[xvii] while entering Valdez or alongside. This special fuel is refined in small quantities at a refinery in Anacortes, Wash. And costs about $60.00 per ton more than regular IFO 380 fuel.

7.4 TEXAS

Port of Houston

- **NOx Emissions**

Houston has a severe NOx problem exceeding limits 39 or more days per year. The city as a whole must reduce NOx emissions by about 1,000 tons per day. The Port of Houston is the second largest in the United States with oil and petrochemical cargo, bulk cargo and containers

The port authority estimates port-related NOx emissions at 34 tons from vessels and 5 tons from terminal equipment.

A port inventory puts NOx emissions from ocean going vessels at 20 tons per day, tugs and towboats 10 tons per day, harbour vessels 4 tons per day.

The port also inventories a total of 800 pieces of terminal equipment including 258 yard tractors, 26 RTGs and numerous forklifts and similar equipment. NOx emissions were placed at 5 tons per day.

The Port of Houston as set a target of a 25 percent reduction in NOx by 2006.

- **PuriNOx trials**

Trials with the PuriNOx additive diesel fuel were conducted over two years with five-yard tractors and one RTG (rubber- tired gantry crane). The trials successfully reduced NOx by 25 to 30 percent and PM by 30 to 50 percent. The port rated the cost at $7,500 per ton. In 2002, the Port of Houston has applied for state funding to expand the PuriNOx program to an additional 15 yard tractors.

- **SCR on RTG (unsuccessful)**

The Port installed a selective catalytic reduction NOx converter (SCR) on an RTG. The SCR reduced NOx by up to 85 percent however there were serious problems with the installation and maintenance of the unit. There wee also overheating problems and a high cost of $18,000 per ton reduced.

7.5 EUROPE

<u>European Union</u>

- **IMO Annex VI**

The Baltic Sea is the only designated SOx Emission Control Area under IMO Annex VI that will require the use of low sulphur fuel with sulphur content of less than 1.5 percent. The North Sea and English Channel are expected to also be designated a Sox Emission Control area. The EU is concerned about the slow pace of adopting Annex VI.

- **Proposed Directive**

On November 20, 2002, a proposed Directive[xviii] was submitted to the European Parliament on low sulphur ship fuel ship. The proposed directive calls for heavy fuel oil HFO to be 1.5 percent or less in SOx Emission Control Areas – the North Sea and Baltic regions as designated by the IMO. The effective date is the earlier of the IMO ratification date or a date to be determined by the EC. In additiona, 1.5 percent HFO is to be used by scheduled passenger ships and passenger ferries by January 1, 2007 anywhere in Europe. The rational for this is to encourage and increase the market for low sulphur fuel.

For inland waterways, the directive calls for marine diesel of 0.2 percent (0.1 percent in 2007).

A cost impact statement estimates capital and operating costs could increase by 4 to 14 percent. It estimates a Euro 50 premium for low sulphur fuel and an increase in ships' fuel bills of Euro 735 million, but, estimates benefits at Euro 1.3 billion.

- **Emissions levels**

A 2002 study indicated there were 1.8 million ship movements in the vicinity of the EU during 2000. NOx emissions from ships transiting between ports was estimated at 3.5 million tonnes and projected to rise to 3.9 million tonnes by 2008, while Sox emissions appeared likely to drop to 2.3 – 2.4 million tonne range due to the IMO mandated low sulphur requirements for the North Sea and Baltic areas.

- **Marginal external costs**

A study for the European Commission estimated the marginal cost per tonne for offshore emissions[xix] in the North Sea at Euro 4,300 for SOx, Euro 3,100 for NOx, Euro 9,600 for PM 2.5, and Euro 2,600 for VOC's. The study found comparable rates for the Northern Mediterranean and Eastern Atlantic, higher for the English Channel and lower marginal cost for the Baltic.

<u>Norway</u>

- **Low NOx**

Two ferries operating across Oslofjord[xx] were converted to reduce NOx emissions in the fall of 1999. The ferries *Bastø I* and *Bastø Ii*each with a 5,400 hp Wartsila Wichmann 12V28B medium speed diesel were modified with fuel injection and turbocharger modifactions to reduce NOx.

The installer, Wartsila NSD Corp. claims that NOx emissions were reduced by 34 per cent to a level that is 40 per cent below the limiting curve set out in the IMO.

After upgrading, reductions, based on 5000 hours of operation a year are:

NOx emissions 150,480 kg
CO_2 emissions 900,000 kg
Fuel consumption 316,000 kg

The Norwegian Government supported the upgrading of the engines in the two ferries.

- **Alternate fuel and dual fuel**

Two generator engines, each developing 3720 kW (5,100 hp) at 720 rev/min, were installed on the FPSO *Petrojarl 1* [xxi] 2001. The engines burn wellhead gas. The ship has a three-year contract on the Glitne field in the North Sea.

Two 95 metre, 4,000 gt offshore supply vessels are being built to enter service in 2003 with dual liquified natural gas (LNG) –diesel power on four Wartsila 2020 kW (2,750 hp) engines. The ships are being chartered by Norway's Statoil for use in the North Sea. LNG is estimated to reduce NOx by 390 tonnes per year that Sttatioil can use as a credit against emissions from its land-based facilities.

The 100-car, 95-metre ferry *Glutra*[xxii] entered service near the city of Molde in 1999. The ferry is diesel-electric powered, with four 675 kW (900 hp) Mitusbishi diesels operating on LNG. The engines are located above the main deck. The ferry is refueled by tank truck at night.

Sweden

- **Selective Catalytic Reduction (SCR)/Water Injection**

As of 1999, according to Per Kageson[xxiii], 38 ships with 139 engines, half Swedish, were using catalytic converters to reduce NOx. The engines were mainly medium speed diesels. Low sulphur fuel was required. He estimated the cost of conversion at Euro 29,000 – 46,500 and for a new installation at Euro 29,000. Urea consumption amounted to 2 to 3 percent of the fuel.

The Swedish Maritime Administration is subsidizing SCR conversions on both Swedish and foreign flag vessels by 30 percent of the cost of installation.

He also noted the large Baltic ferries *Silja Serenade* and *Silja Symphony* had opted for water injection.

- **Harbour Dues/Fairway Dues**

The Swedish Maritime Administration[xxiv] in 1998 raised fairways dues from 3.60 Swedish kroner to 5.00 SEK (Euro .58) per gross ton, then offered a discount of SEK .90 (Euro .10) per gt for low sulphur fuel (0.5 percent for ferries, 1.0 percent for other vessels) and NOx discount of up to SEK 2.50 (Euro .28).

Twenty Swedish ports including Gothenburg, Halsingborg, Malmo and Stockholm offer discounts of between SEK .10 and SEK .20 for low sulphur and sliding scale NOx discounts of up to SEK .20 SEK on their harbour or port dues.

The first year had 1,350 vessels applied for the low sulphur discounts. NOx, requiring physical modifications has been slower.

- **Wallenius Lines low sulphur fuel project**

Wallenius Lines conducted a three-year trial from January 1998 to December 2001 using marine diesel oil (MDO) instead of heavy fuel oil on the main engine and auxiliaries on the 199-meter RoRo vehicle carrier *Turandot*. The ship was built in 1995 and has a capacity for up to 5,800 automobiles and trades worldwide. The company notes the bunker specification was DMB quality but with a Sulphur content of less than 1%.

The company's findings indicate the SO2 emissions were reduced by more than 75%. Fuel consumption was reduced by at least 5%. It also found from the work onboard indicate that savings from a fully utilized MDO operation corresponds to an price difference of about 20 USD/mt compared to ordinary 380cST HFO. The company states, "When comparing to Low Sulphur HFO, an additional 20 USD/mt can be accepted." This costing includes savings in fairway fees; lower fuel consumption and unrealized savings form a possibly reduced crew size.

Following this trial, in 2002 Wallenius conducted comparative trials of low sulphur heavy fuel oil and MDO. These trials were conducted by Wallenius without outside funding.

7.5 CANADA

Nova Scotia

Gypsum Transportation Ltd. of Bermuda has taken delivery of the *Gypsum Centennial*, a 47,950-dwt self-unloading bulk carrier for service hauling gypsum from Nova Scotia to the U.S. East Coast. The ship, which was built in Korea, has the first large (15,380 hp) low speed (93 rpm) diesel with common-rail fuel injection[xxv] in a Sulzer 6RT-flex58T engine.

The engine's exhaust was effectively smokeless throughout the sea trials, even when running on heavy fuel oil.

British Columbia

- **Dual Fuel – Compressed Natural Gas**

One of the first marine dual –fuel compressed natural gas (CNG)/diesel installations was the Fort Langley –Albion ferry *Klatawa* in 1985, followed by the sister ferry *Kulleet* in 1988 then operated by the Ministry of Transportation and Highways. Both ferries remain on CNG but are now operated by Translink. Both ferries use CNG as the prime fuel and diesel as the emergency backup.

The 80-car Kootenay Lake ferry *Osprey 2000* was planned to operate with dual CNG/diesel fuel as there is a natural gas pipeline passing by the Balfour ferry terminal. All necessary approvals were in place for dual fuel, however, due to time pressure, the ship entered service without the CNG capability in 2000. A test of CNG was done in 2001 to ensure engine compatibility, but, full installation has not been done.

- **Bunker Fuel Tax**

A long-standing 7% sales tax on bunker fuel on ocean-going vessels was eliminated in July 2001. Prior to its elimination cruise ships were the only vessels to regularly take on bunker fuel in Vancouver. Other ships took on fuel only rarely when refineries needed to dispose of their residual fuel. Ships calling Vancouver took on their bunker fuel either in Asia, California or Puget Sound.

The removal of the fuel tax prompted an immediate boom in fueling of ships calling Vancouver for cargo. The business is still growing. The fuel tax removal was a successful attempt to expand a moribund business, and, the business is still growing.

A beneficial side effect of fueling in Vancouver is the low sulphur content of the fuel sold. The two main sources are from Canadian refineries in Edmonton via pipeline or rail with a sulphur content of about 1.2 – 1.3 percent or from Puget Sound refineries by barge with a sulphur content of 1.7 percent to 2.2 percent.

- **Vancouver Port Authority/Industry**

In 2003, the VPA, Chamber of Shipping and other industry representatives are planning extensive research into actual in-port fuel consumption and emissions with the focus on hard data obtained on board ships.

- **Chevron Burnaby Refinery**

Recently the tanker *Iver Pride*, which loads at Chevron's Burnaby, B.C. refinery, started voluntarily using MDO within the BC waters in reaction to complaints about smoke from it's stack.[57]

7.6 Section 7 References

(Fred McCague, Ph. 604 589-7800)

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8.0 DISCUSSION and CONCLUSIONS

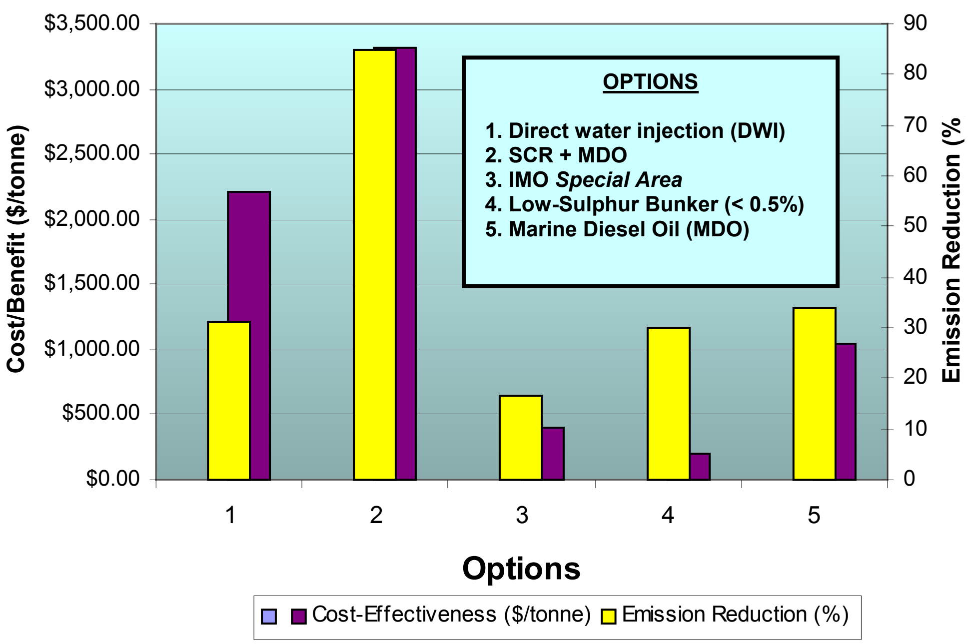
This Section will summarize the technology and clean-fuels emission-reduction options available for the different classes of marine vessels, and will suggest ways to implement the different options.

8.1 Ocean Going Vessels

There were in excess of 1,500 different large, ocean-going vessels entering the GB/PS area during the year 2000. They were responsible for over half of the total marine vessel emissions that year - NOx emissions of 40,571 tonnes (45.2%), SOx emissions of 16,881 tonnes (74.2%) and particulate emissions of 2,635 tonnes (59%). Docking emissions are responsible for approximately 52% of the total emissions from large, ocean-going vessels.

Figure 22 shows different options for reducing emissions from large, ocean-going vessels while underway. It can be seen from Figure 22 that although the greatest reduction of emissions can be achieved with Option 2 (Selective Catalytic Reduction plus using Marine Diesel Oil), this option also is the least cost-effective (highest cost/benefit ration). Option 4 (using low-sulphur bunker) provides the greatest pollution reduction (mainly

Figure 22 - Large Vessel Options - Cruising



reduced SOx and particulate emissions) per dollar spent. Tankers that enter the Port of Valdez in Alaska are presently practicing this option. The operators have a voluntary agreement with the State of Alaska to burn low-sulphur bunker (< 0.5% S) while in the Port of Valdez. The low-sulphur bunker that they use comes from the Tesoro Refinery in Puget Sound at a cost premium of $60/tonne over regular bunker (IFO 380). At present there is insufficient low-sulphur bunker for all large vessels operating in the GB/PS area.

MDO (Option 5) is also already used by large vessels while underway in a sensitive area to reduce their smoke and SOx emissions (e.g. the *Iver Pride* within the GB/PS area.[57]). The advantage of this option over Option 4 is that MDO is readily available, even though more expensive than low-sulphur bunker.

A combination of Option 1 (DWI) and Option 4 (MDO) would result in large reductions of NOx, PM and SOx. Total emissions would be reduced 65.4% at a cost of $1,542/tonne. This is probably the most cost-effective way to significantly reduce emissions from large vessels while they are underway. Wartsila presently uses DWI on some of their large marine diesels, however, as a retrofit technology for other engines it may require further development.

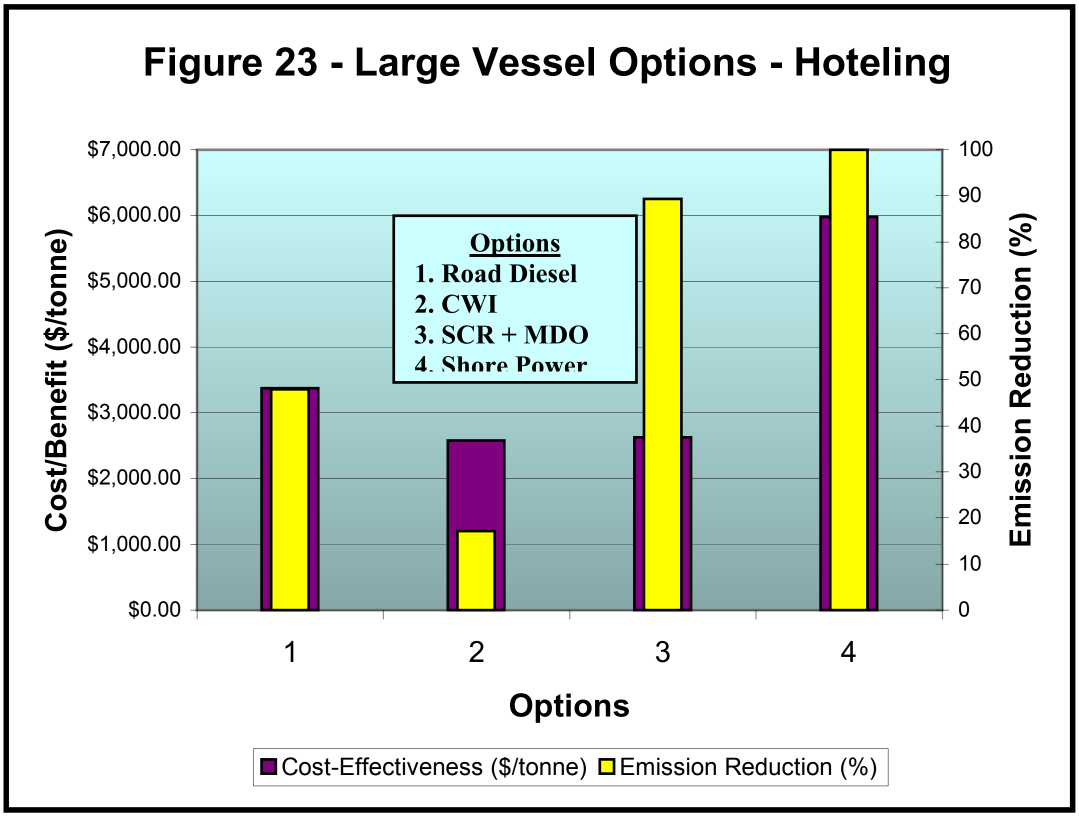
Probably the most effective way to implement these options in the GB/PS area, where most of the large vessels are foreign-flagged, is through the use of differential port fees, similar to the system in place in Sweden for NOx and sulphur and discussed in detail in Section 2.5.4. Fees would be based upon certifications and guarantees of fuel sulphur and machinery NOx emissions. To prevent port avoidance by vessel operators, the system of special port fees based upon fuel sulphur and certified NOx emissions would have to be applicable to all ports on the West Coast.

Figure 23 shows some of the options that are available for reducing emissions from large, ocean-going vessels while they are docked. While at dock one or more auxiliary engines generate the electricity needed for hoteling purposes. The auxiliary engines are much smaller than the main engine but because these vessels spend much more time while in the GB/PS region either docked or moored then they do underway, their total emissions are higher while stationary than while underway. Docking emissions are estimated to form approximately 52% of the total emissions.

Shore power (Option 4) achieves the maximum emission reduction (100%) but is also the most expensive option ($6,000/tonne). It would not be applicable to vessels moored at anchor. This option is, however, being implemented in Los Angeles as a feasible way of significantly reducing emissions from large vessels while they are in port.

One of the most cost-effective technologies for reducing total hoteling emissions by nearly 90% is seen to be Option 3, a combination of selective catalytic reduction (SCR) for NOx control, and MDO for reducing particulates and SOx. This option has a cost-effectiveness of $2,700/tonne.

Not shown is the use of MDO for hoteling. This option would be similar to Option 1 in cost-effectiveness.

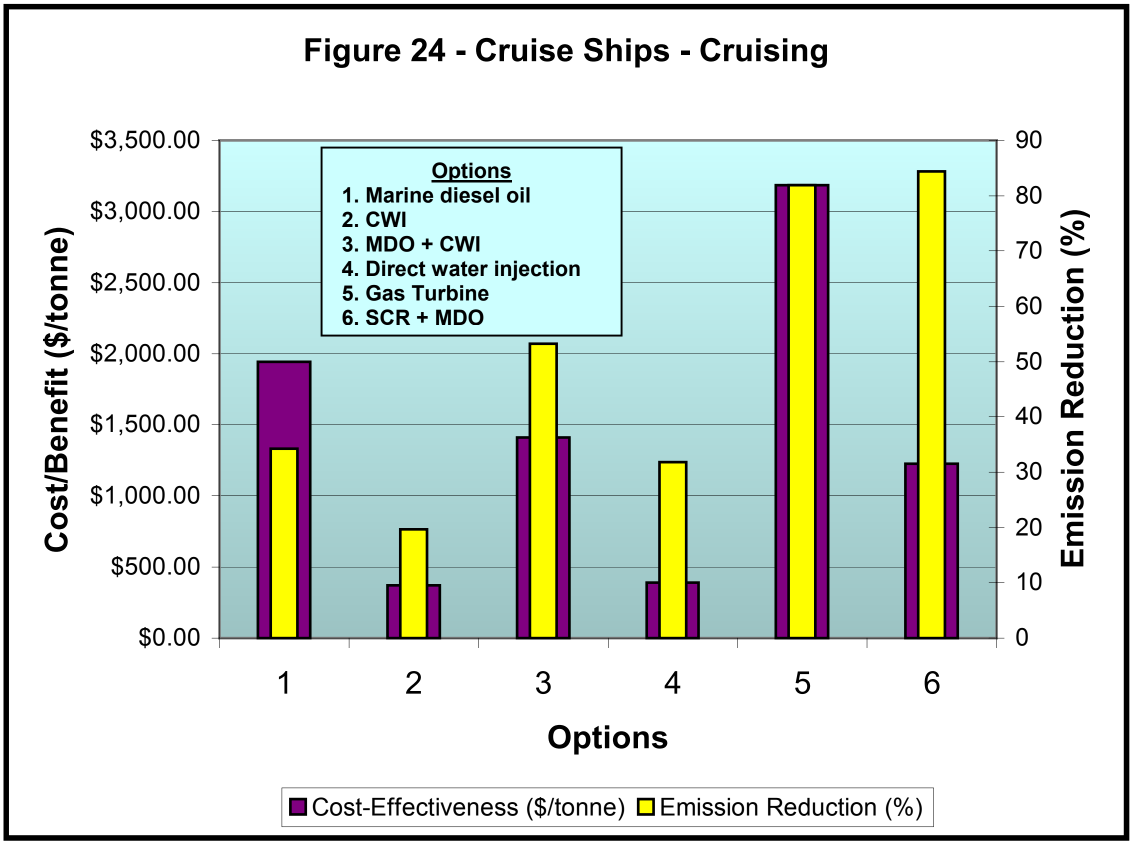


Vessel emissions while at dock could be controlled through differential port fees, which are an economic instrument, or through regulations imposed by local State air pollution regulatory bodies for stationary sources. Of these two options, the Swedish system of certification for fuel sulphur and machinery NOx emissions would be the easiest and least costly to implement. It would have to be implemented equally by all ports on the West Coast.

8.2 Cruise Ships

Cruise ships are becoming an increasingly significant fraction of the vessel fleet within the GB/PS area. During the year 2000 twenty-six separate cruise ships operated within the GBPS waters. Their emissions formed 13.8% of the total marine vessel emissions during 2000 – NOx emissions were 11,079 tonnes (12.3%), PM was 638 tonnes (14.3%) and SOx was 4,446 tonnes (19.5 %). Emissions while at dock form approximately 14% of the total cruise ship emissions within the GB/PS area.

Figure 24 shows the cost-effectiveness and reduction (%) for some of the emission reduction options that were studied for cruise ships.

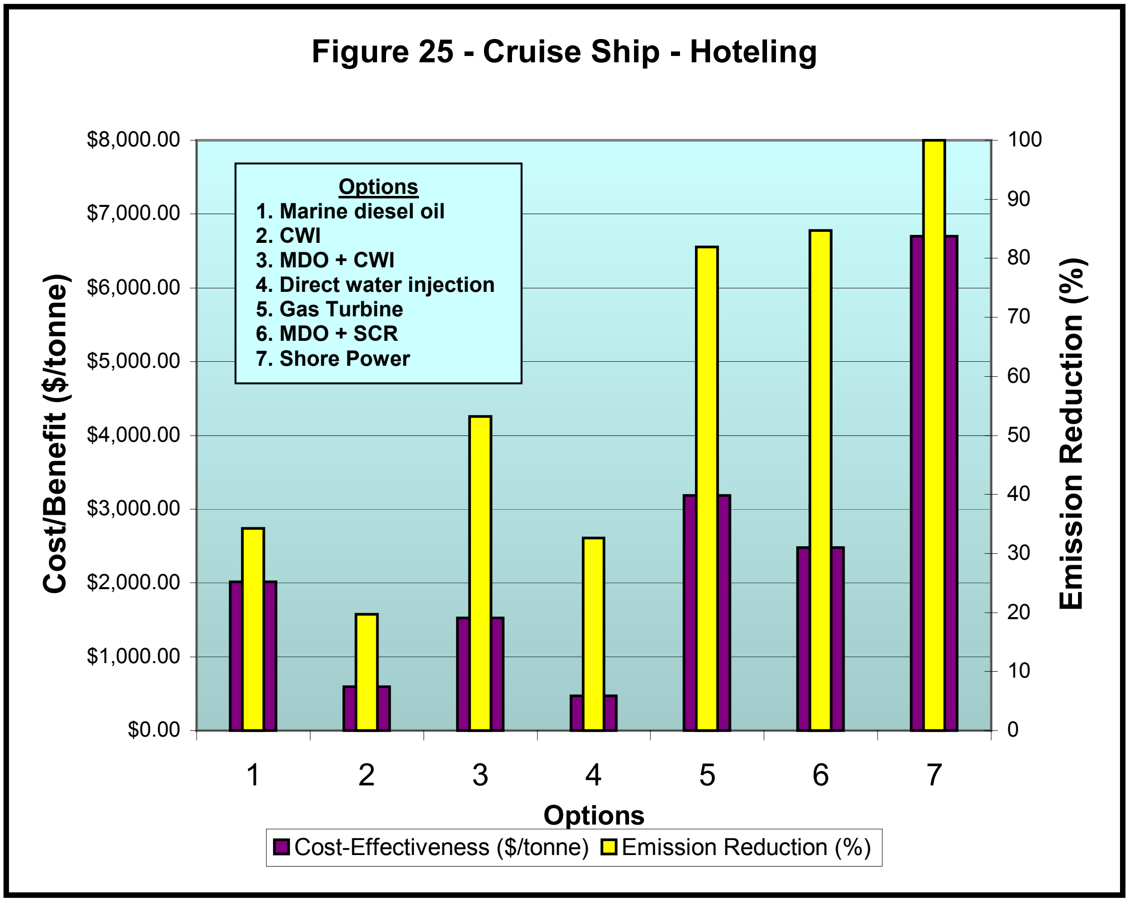


It can be seen that Option 2, CWI (continuous water injection) is one of the most cost-effective technologies but only reduces total ship emissions by about 20%. Option 6, SCR (selective catalytic reduction of NOx) plus MDO, results in the greatest emission reduction and is much more cost-effective than using gas turbines. However, gas turbines may have weigh and space saving credits as well as other advantages that have not been factored into the cost-effectiveness equation. Cruise ship companies are introducing vessels powered with gas turbines (e.g. Princess Cruises' *Coral Princess* is engined with a GE LM2500+ aeroderivative gas turbine), so the advantages must outweigh the operational cost penalty.

SCR is widely used in Scandinavia to reduce vessel emissions, the technology is mature and the costs are well known.

Implementation by the cruise ship industry, of emission reduction initiatives for vessels underway within the GB/PS region, could be voluntary or through differential port fees as discussed above in the section about large, ocean-going vessels. Presently most vessels voluntarily burn a lighter bunker (IFO 180) instead of a heavier but cheaper bunker (IFO 380) in order to reduce their emissions of visible smoke.

Figure 25 shows the cost-effectiveness and emission reduction (%) for some of the emission reduction options that were studied for cruise ships while they are at dock.



Option 4, direct water injection, is seen to be the most cost-effective option (mainly NOx and particulate reduction) while Option 7, shore power, results in the greatest reduction. Option 6, SCR (selective catalytic reduction of NOx) plus MDO, is almost as effective as shore power but at a much lower cost.

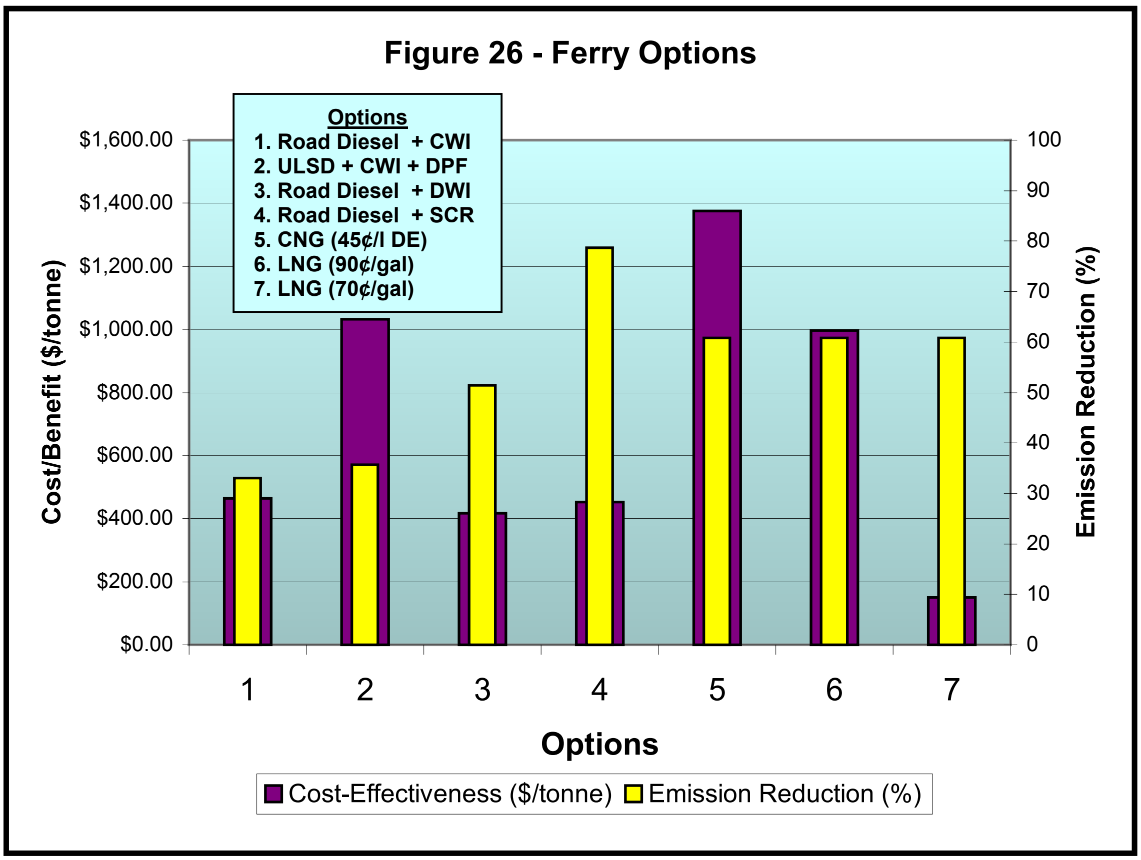
As previously discussed, SCR is widely used in Scandinavia and is proven technology. Shore power is coming into increasing favor within the cruise ship industry as a way of eliminating visible emission complaints while at berth. Princess Cruise has converted two of its vessels to shore power for berthing in Juneau, Alaska, where there are very stringent and expensive regulations concerning visible emissions.

Implementation of emission reduction measures for hoteling cruise ships could be carried out using differential port fees, through very stringent and expensive regulations concerning visible emissions as is done in Alaska, or via State emission limits for stationary sources. The differential port fees would be a logical strategy if already used to reduce under way emissions.

8.3 Ferries

There are a total of over 100 ferries operating within the GB/PS area. Total emissions during year 2000 were 15, 910 tonnes, or 13.6% of the total marine vessel emissions in this region. NOx emissions were 15,140 tonnes (16.85), PM emissions were 263 tonnes (5.9%) and SOx emissions were 507 tonnes (2.2%). Ferry emissions while at dock comprised 17.7% of the total ferry emissions in the GB/PS area.

Figure 26 shows the cost-effectiveness and percent emission reduction for the emission reduction options that were studied for ferries. ULSD is ultra-low sulphur diesel (< 15 ppm S), CWI is continuous water injection, DPF is catalytic diesel particulate filter, DWI is direct water injection and SCR is selective catalytic reduction of NOx. The CNG and LNG costs are based upon delivered prices by ENRG, which are highly sensitive to commodity prices.



It can be seen that the greatest emission reduction can be achieved using Option 4, SCR (Selective catalytic reduction) and low-sulphur road diesel (< 500 ppm S). This is also cost-effective compared to other options. Option 7, using LNG, is the most cost-effective if the price of LNG can be reduced through negotiations and long-term contracts.

LNG is presently being used the 100-car, 95-metre ferry *Glutra* entered service near the city of Molde, Norway in 1999. The ferry is refueled by tank truck at night. In Canada and in the USA the use of LNG would have to be approved by the Coast Guard. This may present problems but should not be insurmountable.

Ferry emission reduction implementations could be left to local state air pollution regulatory bodies in the form of some sort of phased-in emission regulations or emissions cap and trade. The cap and trade strategy is very effective in California for controlling air pollution. New stationary source owners have to buy offsets as required by district *New Source Review* programs. The 2001 average price paid for NOx was $27,100/ton, for PM10 was $46,150/ton and for SOx was $12,810 per ton.[58] As can be seen from Figure 26, the ferry operators could quickly recover the cost of their pollution control investments at these prices.

8.4 Work Boats

There are about 490 workboats (tugboats, tenders, etc.) and 45 government vessels that operate within the GB/PS area. Workboats generally use medium to high-speed diesel engines that burn regular diesel, or low sulphur diesel if that is all that is available.

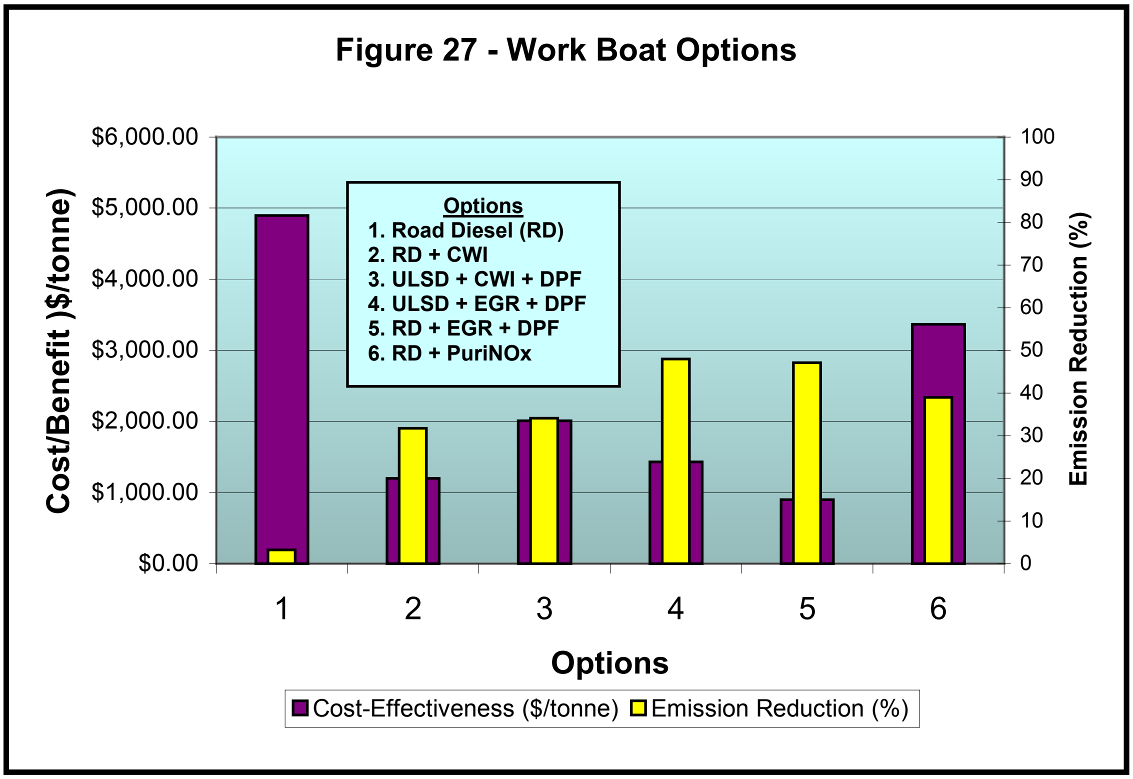
The workboats emitted 23,240 tonnes of NOx, PM and SOx during the year 200, or about 20% of the total marine vessel emissions. NOx emissions were 22,310 tonnes (24.8% of total NOx), PM was 249 tonnes (5.6% of total PM) and SOx was 681 tonnes (3.0% of total SOx).

The engines used in workboats are typically in EPA Category 1 and hence the engine manufacturers are subject to EPA Tier 1 and Tier 2 regulations. The latter will significantly reduce emission from new engines by the year 2004. However, the phase-in period for workboat engines is well in excess of 10 years, unless there is a government-subsidized engine replacement program such as California's Carl Moyer program. Therefore it may be desirable to implement other, more immediate, alternatives for reducing emissions from this class of vessels.

Figure 27 shows the cost-effectiveness and percent emission reduction for various emission reduction options for workboats. (CWI is continuous water injection; ULSD is ultra-low sulphur diesel (<15 ppm S), DPF is catalytically regenerated diesel particulate filter, EGR is exhaust gas recirculation, PuriNOx is a diesel-eater emulsion.)

Workboats, such as tugboats, in Canada are regulated by the Ship's Registry (Transport Canada) according to their size (volume). Increasing the boat size by installing a bulky exhaust-treatment system may bump the vessel into the next size category, resulting in different ship safety regulations and costs. The options shown in Figure 27 have been selected to minimize their impact upon vessel volume.

The greatest emission reductions are seen to be those using EGR (Options 4 & 5). These options are also cost effective. The EGR system that is the basis of the cost-effectiveness estimate is the Johnston-Matthey system. This system is compact and has been retrofitted to diesel buses[41]; therefore the space limitation that exists in workboats should not be a barrier to the use of this and similar compact technology.



Implementation of workboat options is best done through some sort of emission trading program, wherein existing operators are paid for their emission reductions and can therefore economically benefit by installing the controls.

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10.0 APPENDICES

Appendix 'A' - The Proposed Use of Natural Gas Technology in the British Columbia Ferry Fleet to Reduce Exhaust Emissions in the Georgia Basin – Puget Sound Area.

Appendix 'B' - SHORE POWER FOR CRUISE SHIPS AT THE PORT OF VANCOUVER BRITISH COLUMBIA.

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The Proposed Use of Natural Gas Technology in the British Columbia Ferry Fleet to Reduce Exhaust Emissions in the Georgia Basin – Puget Sound Area

INTRODUCTION

The use of dual fuel (natural gas/diesel) aboard the Translink (ex Highway) vehicle/passenger ferries, M.V. "KLATAWA" and M.V. "KULLEET" for operation on the Fraser River between Fort Langley and Albion, BC, has proven successful since their conversions in 1985 and 1988 respectively with a marked savings in fuel and maintenance costs plus an approximate 45% reduction in Nox emissions.

M.D.A. Marine Design Associates Ltd. were the Marine Consulting Group responsible for the dual fuel conversion designs to these ferries (also the original designs of the ferries built in 1972). It is their consideration that similar type dual fuel conversions to various vessels of the BC Ferry Fleet would realize similar dividends, noting that dual fuel conversion plans of the Century Class vessels (M.V. "Skeena Queen") are already approved by Transport Canada, Marine Safety and Lloyds Register of Shipping in London, England.

It is therefore the intent of M.D.A. within this emissions study paper to investigate the approximate costs and environmental benefits that could be achieved with a number of vessels in the BC Ferry Fleet operating on dual fuel. The study briefly examines the required CNG/LNG storage infrastructures at three of the B.C. Ferry Terminals, namely Tsawwassen, Horeshoe Bay and Swartz Bay and also on board the ferries under consideration for dual fuel operation.

Finally, the study will estimate the annual reduction in Nox and Particulate Matter (PM) from the selected B.C. Ferries operating on dual fuel (natural gas/diesel) and which will benefit the air quality in the Georgia Basin – Puget Sound area.

METHODOLOGY

Due to the limited time afforded the development of the specific amounts of natural gas/diesel required for each vessel on their schedule route(s) and areas of operation, it was necessary to establish from the BC Ferry records the Annual fuel oil consumption per each vessel, Table 1, plus number of round trips and thereafter calculate an average fuel oil consumption per day per vessel. Matching the vessels with their routes, M.D.A. then established the fuel oil requirements per terminal, these terminals being Tsawwassen, Horseshoe Bay and Swartz Bay. These figures are shown on Table 2.

In a dual fuel (natural gas/diesel) mode, a percentage of the fuel oil used in the present BC Ferries operation would be replaced with Compressed Natural Gas (CNG) or Liquified Natural Gas (LNG), the ratio of such relative to the route involved. Previous calculations (Appendix "A") on the Century Class (Skeena Queen) ferry indicate an approximate ratio of 73% natural gas to 27% diesel fuel whilst on the new 84 car ferry M.V. "Osprey 2000" for the Ministry of Transportation and Highways, the ratio was approximately 75% natural gas to 23% diesel. A ratio of 60% natural gas/40% diesel was used on the original duel fuel Highways ferries, "Klatawa" and "Kulleet" due to the short haul distance. In order to present conservative fuel savings and emissions on the BC Ferry fleet, the ratio of 60% natural gas/40% diesel is used in this Study. OF PRIME IMPORTANCE, TO THE FERRY OPERATOR, IS IF THE ON-BOARD SUPPLY OF NATURAL GAS IS SHUT-OFF BY REASON OF AN ALARM, THE ENGINES WILL AUTOMATICALLY REVERT TO DIESEL FUEL OPERATION. ALSO IN THE EVENT THE NATURAL GAS FROM SHORE SIDE IS INTERRUPTED, THE OPERATOR CAN CONTINUE THE VESSEL'S OPERATION SOLELY ON DIESEL FUEL.

Applying the 60% natural gas, 40% diesel ratio to each of the "converted" ferries and identifying their home terminals, the volume of natural gas both in a CNG and LNG form was calculated (see Table 2). Based on the known total horse power for each "converted" ferry at 85% power and the total annual sailing hours of each ferry, the annual reduction in Nox and PM was then estimated using the Wartsila 32DF dual fuel marine engine with water injection system as the basis for exhaust emission levels (see Table 3).

Some of the other dual fuel marine engines are the Nigata 8PA5LDF and the Ruston 6RKG engines. Clean Air Partners in San Diego also provide Caterpilla 3406 modified dual fuel engine as does Detroit Diesel-Allison and Cummins.

TYPICAL ON-BOARD NATURAL GAS SYSTEM

A typical on board natural gas system (CNG or LNG) would comprise the following equipment and components: -

- Storage cylinders (CNG) for the natural gas at 2,400 PSI in a number and capacity to suit the vessel operation and daily refueling requirements. Unlike the "Klatawa" and "Kulleet", the storage cylinders would be located underdeck in a gas tight compartment. Using a Liquified Natural Gas system, which accommodates more natural gas in a lesser volume, a Liquified Natural Gas storage tank complete with heat exchanger and liquid/vapour pressure control system would also be located underdeck in a designated gas tight compartment.

- Fueling station with break-away disconnect in the case of CNG located on open deck in a location suited to docking end of vessel and shore side fueling station. Fill piping with associated valving is then led underdeck to the CNG cylinders or LNG storage tank.

- Exiting the CNG storage cylinders at 2,400 PSI the gas is pressure regulated down to suit the main and genset engines and in the case of the LNG operation the gas is led through a heat exchanger and liquid/vapour pressure control system prior to entry into the engines.

- Natural gas supply piping complete with necessary valving, etc., from the natural gas storage cylinders/LNG storage tank to the main/genset engines.

- A gas detection system complete with sensors and alarms including a 20% lower explosive limit detector with manual shut-off and a 40% lower explosive limit detector with an automatic shut-off.

- Conversion of the existing main/genset engines to dual fuel operation on existing vessels and new dual fuel engines on new vessels.

- New exhaust ventilation systems installed in the CNG gas bottle/LNG tank storage compartment and the main and genset engine room(s).

SHORE SIDE NATURAL GAS SUPPLY STATION

In the case of the Translink dual fuel operated ferries, “Klatawa” and “Kulleet” which used CNG, the shore installation comprised a three-stage compressor, inter-coolers, a self-contained radiator, a cascade of fifty bottles and electrical, operating and emergency controls all housed in a 20’-0” long trailer natural gas storage facility. Connections to the BC Gas (Utility) trunk pipeline and from the storage facility to dockside are also integral components of the shore installation. A pumping station is also provided for Ministry natural gas propelled highway vehicles.

Natural gas is supplied via the trunk pipeline at 120 PSI (873 KPa) and then compressed through three stages to a working pressure of 3,600 PSI (24.9 MPa). Following compression, the gas is stored in fifty 520 cubic foot (14.7 cubic meter) steel cylinders which provide a total storage capacity of 26,000 cubic feet (736.2 cubic meters) at 3,600 PSI (24.8 MPa) on shore. The bottles are connected in groups of three and piped to a main manifold which connects to the ferry containment system.

The design of this compressed gas station allows for a “quick fill” of the Klatawa/Kulleet natural gas storage cylinders, with a full charge design time of three to four minutes. From the shore cylinders the compressed gas passes through isolating valves, non-return valves and pressure regulators to a hose connection. At the end of the hose the gas passes through a “break-away disconnect” to the shipboard connection. Refueling follows a Transport Canada, Ship Safety Branch, approved procedure and is carried out under the supervision of the vessel’s Chief Engineer.

The supply of compressed natural gas by ENRG to the various ferries at the Tsawwassen, Horseshoe Bay and Swartz Bay terminals could be developed in a similar manner to that of Translink but on a much grander scale. Similarly the LNG would be supplied by ENRG.

NATURAL GAS COSTS

The natural gas, both CNG and LNG, delivered to the associated B.C. Ferry Terminals will be provided by ENRG (BC Gas), noting the supply of LNG to the Swartz Bay Terminal is not possible at this time as there is no LNG plant in that area.

The costs of the CNG and LNG provided by ENRG assume ENRG ownership of equipment (compressor station, etc.) and capital recovery for same and also includes the commodity costs. Please note all natural gas costs quoted herein are approximate and subject to change. Based on natural gas commodity costs of $3.00 per gigajoule (GJ) the delivered onboard ferry cost of LNG at Horseshoe Bay Terminal would be 69.9¢ per LNG gallon and at Tsawwassen Terminal would be 69.2¢ per LNG gallon. Based on natural gas commodity costs of $4.00 per GJ, the delivered on board cost of LNG at Horseshoe Bay Terminal would be 79.1¢ per LNG gallon and at Tsawwassen Terminal would be 78.4¢ per LNG gallon. In the event the ferries are fueled from tanker trucks directly, a reduction of approximately 15¢ per LNG gallon could be achieved.

For the purpose of this Study, the higher price of LNG based on a natural gas commodity cost of $4.00 per GJ will be used, which includes an allowance for terminal storage.

The cost of the compressed natural gas (CNG) delivered to the ferries at all three (3) terminals is 40¢ to 50¢ per diesel litre equivalent and is inclusive of the capital and maintenance costs of the terminal based natural gas compressor station. B.C. Ferry contractor price of diesel is 41¢ per litre.

Worth noting is that the Marine Branch of Ministry of Transportation and Highways are paying 52¢ per litre of marine diesel today noting the price of diesel fuel is on the increase.

For the purpose of this study, the price of diesel and that of CNG are assumed the same.

Also worthy of note is the engine maintenance and lube oil savings that can be accrued on a dual fuel operation noting the 60,000 hour run up on the Caterpillar Model 3406 main engines of the Translink ferry “Kulleet” before the engines were overhauled.

EXHAUST EMISSION REDUCTION ON DUAL FUEL

For the purpose of this study, the exhaust emissions addressed are those of Oxides of Nitrogen (NOx) and Particulate Matter (PM). Also, with there being eighteen (18) different B.C. Ferries with varying models of main engines, and a limited time frame and cost to prepare this study, the author uses the average emissions for the B.C. Ferry fleet calculated from a previous study. For NOx the base emission factor is 14.95g/kwh and for PM is 0.50/kwh whilst operating on diesel and on a 60% natural gas 40% diesel ratio the reduction in NOx is 58.5% of 14.95g/kwh equaling 8.75g/kwh and with PM the reduction is 72% of 0.50g/kwh.

These reductions in emissions multiplied by the ferry total Horsepower (kw) at 85% power and the annual sailing time in hours provide the estimated annual reductions in the NOx and PM exhaust emissions.

The results of the reduction in exhaust emission on dual fuel indicate an estimated NOx savings of 3,483.64 metric tons and a PM savings of 143.43 metric tons (see Table 3).

LNG INFRASTRUCTURE COST AT TERMINALS

The infrastructure costs of the LNG at each Terminal is factored into the cost of the LNG delivered by ENRG to each of the dual fuel “converted” ferries.

CNG INFRASTRUCTURE COST AT TERMINALS

The infrastructure costs of the CNG at each Terminal is factored into the cost of the CNG delivered by ENRG to each of the dual fuel “converted” ferries.

ESTIMATED COSTS OF CNG/LNG INFRASTRUCTURE ON BOARD B.C. FERRIES

These estimated costs are developed from the records of M.D.A. with regards the proposed dual fuel conversion of the B.C. Ferry Century Class ferry “Skeena Queen” and the Ministry of Transportation Highway Vessel, Province of British Columbia ferry “Osprey 2000”. Please note both ferries were designed to operate on dual fuel with CNG.

The infrastructure on both vessels included a gas bottle storage compartment, gas storage bottles, natural gas supply piping and valves, gas detection system including visual and audio gas alarms and shut downs, bunkering station, exhaust vent systems, water deluge and $C.O._2$ flooding system. Also included was the conversion of the main and genset engines to operate on dual fuel (natural gas/diesel).

The estimated cost for this infrastructure based on 1 fill per day on the “Skeena Queen” updated to the present is $1,400,000 whilst that of the “Osprey 2000” was $1,300,000. Based on the 4,178KW total Horse Power on the “Skeena Queen”, the dual fuel conversion cost factor equates to $1,400,000 divided by 4,178KW which provides a cost of $335.09 per KW main engine horse power.

Based on the 3,820KW total Horse Power on the “Osprey 2000”, the dual fuel conversion cost factor equate to 1,300,000 divided by 3,820 which provides a cost of $340.31 per KW main engine horse power.

Averaging the costs of dual fuel conversion on the “Skeena Queen” and the “Osprey 2000” this gives us a cost of $337.70 per KW for CNG. In the LNG infrastructure aboard each ferry, the main difference from that of CNG is that the gas storage bottles are replaced with a LNG storage tank and vaporizer unit with pressure regulator controls, the cost of such fairly similar to that of the CNG equipment and so the same figure of $337.70 per KW is used for LNG. We would again note the CNG/LNG infrastructure costs are based on one (1) refueling operation per day and these costs could be reduced by approximately 15% if the refueling process was performed four (4) times daily. However for this study we will assume filling to be once a day.

ESTIMATED FUEL & MAINTENANCE SAVINS ON DUAL FUEL

Fuel Savings

Based on the studies performed by M.D.A. to date, vessels operating on a dual fuel (natural gas/diesel) mode can generally achieve savings on fuel, maintenance and lub oil costs.

In the case of the "Osprey 2000" it was noted within the Economic Analysis Study on the vessel prepared by M.D.A. operating on dual fuel and based on a supply of CNG to the ferry at 28.5¢/litre diesel equivalent with diesel fuel at 30¢/litre the fuel cost savings per annum was $36,339.00 and with diesel fuel at 50¢ the annual savings was $520,860.00.

Diesel fuel prices fluctuate, based primarily on world supply and demand conditions and expectations concerning crude oil. The price of diesel fuel has varied in the past and will continue to fluctuate in the future noting however the world reserves of fuel oil are dwindling and therefore the need for alternative fuels.

Natural gas prices are not subject to the same influences as diesel oil prices. Some increase can be expected over the long term, but generally, natural gas prices are expected to remain stable. Any upward pressure on price is only expected over the medium to long term and would result from the commodity price the producers would negotiate. Historically, the price of natural gas has been usually less than that of diesel fuel.

From the estimated costs of compressed natural gas (CNG) provided by ENRG, which includes the cost of the compressor station, we assume the cost of diesel fuel at all three (3) terminals to be similar to that of compressed natural gas delivered to the "converted" ferries. However it is our consideration the price of the delivered CNG could be reduced under the terms of a long-term commodity contract which to quote ENRG would provide significant lower commodity prices.

With regards the supply of LNG by ENRG to the converted ferries, at the Tsawwassen and Horseshoe Bay Terminals there would be fuel savings based on the cost of diesel fuel being 52¢/litre and the LNG being 78.4¢ per LNG gallon at Tsawwassen and 79.1¢ per LNG gallon at Horseshoe Bay.

Therefor the annual fuel savings on LNG, factoring in the 1.7 LNG gallons to 1 gallon of diesel fuel, at the Tsawwassen Terminal with a diesel fuel requirement for 55,119,521 litres based on a diesel fuel cost of 52¢ per litre and a LNG cost of 78.4¢ per U.S. gallon would be as follows: -

= (55,119,521 litres @ 52¢) – (40% x 55,119,521 @ 52¢) + (14,853,886 @ 78.4¢)
= $28,662,151 – (22,047,808 @ 52¢) + 11,645,447
= $28,662,151 – ($11,464,860 + $11,645,447)
= $28,662,151 - $23,110,307
= **<u>$5,551,844</u>**

At the Horseshoe Bay Terminal the annual fuel savings on LNG with an annual total diesel fuel requirement for 35,094,891 litres based on a diesel fuel cost of 52¢ per litre and a LNG cost of 79.14¢ per U.S. gallon would be as follows: -

= (35,094,891 litres @ 52¢) – (40% x 35,094,891 @ 52¢) + (9,457,548 @ 79.14¢)
= $18,249,343 – (14,037,956 @ 52¢) + 7,484,703
= $18,249,343 – ($7,299,737 + $7,484,703)
= $18,249,384 - $14,784,440
= **<u>$3,464, 903</u>**

Engine Maintenance Savings

The extended length of service for marine engines operating on dual fuel has been demonstrated with the post dual fuel conversion performance of the Translink (ex Highway) ferries "Klatawa" and more specifically "Kulleet" (both initial and conversion designs by M.D.A.) with her main engines running up approximately 60,000 hours before rebuild. Based on this performance it is estimated that the B.C. Ferries converted to dual fuel operation will only need rebuild after approximately 57,000 hours of operation as opposed to the diesel only operation which like the Highways ferry "Omineca Princess" with its 600HP engines requires a rebuild after 35,000 hours of operation. Based on a 325 BHP engine rebuild cost of $35,000 for the "Klatawa" and "Kulleet" and a $60,000 rebuild cost on a 600HP main engine on the “Omineca Princess”, the estimated cost on the Highway ferry “Osprey 2000” for rebuild of each engine (955KW) is $90,000. This equates to $360,000 for the four (4) main engines.

Over a 25 year period of operation the expenditure on main engine rebuilds on diesel is $1,800,000 as opposed to $1,080,000 on dual fuel. This represents a savings of $720,000, equaling $7.54/KW/year. Applying this figure to the “converted” B.C. Ferries, the results are outlined on the accompanying sheets.

The generators may also operate on dual fuel as was done on the “Klatawa” and “Kulleet” and rebuilding of the genset engines normally performed at eight year intervals on a diesel cycle was able to be extended to 12 year intervals and thus savings were achieved. However due to the limited time frame these are not factored into the cost savings in this study.

Lubricating Oil Savings

Based on the experience gained on the “Klatawa” and “Kulleet”, the lube oil changes to the engines were extended from 1,200 hours on diesel to 2,000 hours on dual fuel. On the “Osprey 2000” the annual cost savings for the lube estimated to be $18,000 which represents a savings of $4.75 per KW/year.

Regulatory Approvals

In 1984 during the development of the conversion design of the vehicle/passenger ferry “Klatawa” to operate on dual fuel (natural gas/diesel) the Ministry of Transportation and Highways, Province of British Columbia, Owners and Operators of the ferry were initially informed by Transport Canada, Marine Safety Branch in Vancouver, BC, that their department would not issue the vessel a certificate to operate on dual fuel because of their concern about the compressed natural gas on board the ferry and the inherent dangers associated with this medium. Needless to say this never occurred, and a certificate was issued but it still took over a year to obtain this approval thus making the “Klatawa” the first vehicle/passenger vessel in the world to be certificated to operate on dual fuel. The “Klatawa” sister vessel was similarly converted. To-date we have plan approval from Transport Canada, Marine Safety Branch, on three (3) other vehicle/passenger ferries to operate on dual fuel including the B.C. Ferry, “Skeena Queen” the latter also approved by Lloyds Register of Shipping in London, England to operate on dual fuel, another first in the world for this Classification Society.

However the approval of a dual fuel vehicle/passenger ferry using Liquified Natural Gas (LNG) as opposed to Compressed Natural Gas as the source of the natural gas supply on board the ferry is another question and in discussions with Transport Canada, Marine Safety Branch and also the United States Coast Guard (U.S.C.G.) it was intimated the approval of such medium aboard a passenger ferry could be a long uphill struggle to achieve approval.

From M.D.A. point of view, and now that LNG is more readily available than it was in 1985, the storage of natural gas aboard ferries in a LNG state would be more welcome than CNG this because of its larger storage volume in a lesser space and also from a weight point of view especially in vessels of limited displacement and stability. M.D.A. readily await clients who wish to incorporate LNG into their vessels.

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- *Midwest Power Products – Bryan Norrie & Charlie Duncan*

“appendix Aa”

CENTURY CLASS FERRY
SWARTZ BAY – FULFORD HARBOUR

4 – Mitsubishi Model S12R-MPTK Main Engines at 1,125 BHP at 190.65 litre/hour, and at 225 BHP at 45.70 litre/hour.

1 – Mitsubishi Model S6R2 Genset Engines at 127.2 litre/hour

Vessel operated 7 days/week with main engines and gensets 18 hour day.

Estimated total yearly consumption 4,475,061 litres.

20 minutes sailing time.

From 1988 calculations:

On diesel based on 18 hours day D.O. consumption of main engines and diesel gas = 12,804.12 litre/day

On dual fuel based on 18 hours day D.O. consumption of main and genset engines = 3,504.76 litre/day

∴ Reduction in use of .DO. = 72.63% using M.E. 88% / 12% N.G. ratio and genset 75% / 25% natural gas/diesel ratio.

∴ On a dual fuel operation the ratio of natural gas/diesel could be 72.63% / 27.37%.

"APPENDIX A-a"

Osprey 2000 – Kootenay Lake
Distance 8 kilometres

4 – Cat 3512B diesel Main Engines at 1,280 BHP each – 80% / 20%.

1 – Cat 3306TA diesel Genset Engines (190KW) 225 HP – 75% / 25%.

D.O. consumption on 5 months at 15 knots and 7 months at 12 knots, 360 day/year, 20 hour/day.

Total annual fuel consumption estimated at	3,255,446	litres
Savings on natural gas of	2,422,601	litres
∴ Diesel used on N/G	832,845	

∴ On a dual fuel operation overall ratio of natural gas/diesel could be 74.42% / 25.58%.

Klatawa/Kulleet

On dual fuel operation the average ratio of natural gas/diesel is taken as 60% / 40%. This reduced ratio is due to the short distance run where the maximum engine r.p.m. is only for about 8 – 10 minutes.

BC FERRY CORPORATION
2002 Fuel Consumption (Liters)
TABLE 1

	Sprit of BC	Spirit of Vancouver	Qn of Esquimalt	Qn New Westminster	Qn of Saanich	Qn of Vancouver	Qn of Alberni	Qn of Coquitlam
January	163,279	1,027,492	-	1,094,893	116,730	525,189	114,488	815,172
February	963,850	328,129	103,168	1,002,602	455,025	111,238	620,433	404,358
March	1,098,047	657,796	97,978	1,116,388	358,725	112,048	875,737	643,287
April	1,080,003	990,524	5,109	1,112,677	203,175	113,353	857,865	845,755
May	1,099,597	1,043,876	28,559	1,120,155	334,422	191,285	901,362	908,803
June	1,071,406	1,004,808	308,577	1,102,788	183,850	196,201	866,451	160,340
July	1,115,908	1,011,803	133,807	1,245,167	512,426	532,504	900,872	569,866
August	1,115,027	1,066,191	130,198	1,275,256	629,168	635,377	969,173	670,807
September	1,050,994	1,050,446	68,475	1,069,647	400,672	238,823	919,835	709,619
October	1,080,639	974,716	127,625	1,066,014	157,384	161,313	340,158	931,077
November	1,050,294	982,170	45,805	507,342	59,065	88,012	488,078	879,692
December	1,072,459	1,022,323	112,822	539,920	215,487	192,699	869,952	407,329
TOTAL	**11,961,503**	**11,160,274**	**1,162,123**	**12,252,849**	**3,626,129**	**3,098,042**	**8,724,404**	**7,946,105**

	Qn of Cowichan	Qn of Oak Bay	Qn of Surrey	Pacificat Explorer	Pacificat Discovery	Pacificat Voyager	Bowen Queen	Qn of Capilano
January	909,381	944,008	693,086	1,907	1,041	-	179,939	199,958
February	827,880	842,692	441,704	-	-	-	129,701	189,013
March	934,094	971,940	22,628	108,228	3,929	-	132,649	220,682
April	907,720	173,195	548,242	88,977	-	-	146,820	206,262
May	847,858	6,975	654,824	266,116	11,029	-	162,428	204,682
June	908,352	817,080	653,332	103,236	-	-	144,188	210,784
July	928,502	914,367	674,803	30,656	440	-	65,362	221,897
August	972,130	938,229	681,650	15,059	9,290	-	82,951	227,173
September	289,878	891,965	645,813	16,127	12,073	11,327	6,559	214,440
October	605,762	882,764	650,223	3,083	-	-	82,974	219,346
November	894,576	862,339	622,612	-	-	-	132,139	206,189
December	928,787	910,397	660,217	-	-	-	82,132	90,520
TOTAL	**9,954,920**	**9,155,951**	**6,949,134**	**633,389**	**37,802**	**11,327**	**1,347,842**	**2,410,946**

BC FERRY CORPORATION
2002 Fuel Consumption (Litres)
TABLE 1 (continued)

	Qn of Cumberland	Howe Sound Qn	Kahloke	Klitsa	Kwuna	Mayne Queen	Mill Bay Queen	Qn of Nanaimo
January	21,838	48,656	48,961	-	26,338	194,396	4,930	326,978
February	216,971	44,500	45,063	-	24,527	179,623	4,191	129,552
March	270,733	48,077	49,636	5,600	25,539	200,684	5,330	98,392
April	259,553	45,485	37,893	9,249	25,001	196,297	4,900	325,970
May	267,870	48,925	19,584	36,557	24,552	203,072	5,221	329,294
June	256,764	43,703	17,866	34,807	25,628	198,515	5,079	323,460
July	266,083	47,350	21,223	37,199	23,856	224,043	5,330	340,461
August	261,011	44,245	22,676	38,809	24,849	223,521	5,565	353,686
September	255,366	45,770	18,534	37,479	23,737	195,871	5,176	319,418
October	252,396	34,207	24,566	39,283	24,306	195,057	5,417	319,000
November	255,686	43,122	31,325	38,730	24,026	107,355	4,923	328,056
December	260,108	45,313	38,305	23,959	26,248	192,983	4,805	338,692
TOTAL	**2,844,379**	**539,353**	**375,632**	**301,672**	**298,607**	**2,311,417**	**60,867**	**3,532,959**
	Quinsam	**Skeena Queen**	**Qn of Burnaby**	**Qn of Chilliwack**	**Dogwood Princess**	**Charter Vessels**	**Nimpkish**	**North Island Princes**
January	86,655	155,730	331,121	280,314	11,071	-	25,085	72,963
February	11,964	135,763	316,570	294,966	9,597	-	30,074	67,496
March	-	150,818	335,205	318,123	2,658	6,985	28,703	75,560
April	44,152	118,062	187,759	306,405	9,395	1,521	9,742	73,130
May	81,815	5,457	165,437	207,685	11,415	-	5,341	74,539
June	100,344	36,562	315,508	185,458	3,664	6,361	-	70,096
July	96,514	188,453	338,823	220,929	-	12,333	-	72,583
August	97,796	193,687	346,817	250,610	9,176	4,429	-	69,999
September	87,901	177,497	319,330	94,806	10,460	-	-	68,537
October	89,222	180,511	199,094	154,796	10,176	-	-	72,800
November	93,108	169,404	14,813	296,636	10,076	-	-	74,670
December	86,700	176,231	306,502	317,920	10,176	-	-	79,820
TOTAL	**876,171**	**1,688,175**	**3,176,979**	**2,928,648**	**97,864**	**31,629**	**98,945**	**872,193**

BC FERRY CORPORATION
2002 Fuel Consumption (Litres)
TABLE 1 (Continued)

	Powell River Qn	Quadra Queen II	Quinitsa	Tachek	Tenaka	Qn of Tsawwassen	Qn of Prince Rupert	Qn of the North
January	102,647	79,594	40,810	26,990	16,590	78,272	508,900	-
February	91,080	70,796	36,850	23,816	2,000	140,722	462,000	-
March	102,024	79,649	43,258	27,742	9,752	203,713	509,700	219,000
April	94,931	75,419	40,072	25,074	40,210	110,051	-	573,020
May	97,782	77,324	39,855	-	40,640	249,810	226,200	792,000
June	94,071	74,298	34,826	-	37,732	269,728	335,100	934,000
July	97,421	75,636	36,579	-	40,536	280,127	365,900	960,000
August	98,125	77,237	40,600	-	40,174	287,347	388,700	966,018
September	93,832	7,400	38,237	62,192	38,596	275,704	358,900	936,293
October	51,846	34,961	25,623	50,477	39,228	276,349	450,500	74,690
November	60,928	70,925	-	26,896	40,612	257,420	482,300	45,000
December	104,883	71,602	26,850	28,813	40,535	35,417	484,000	-
TOTAL	**1,089,570**	**794,841**	**403,560**	**272,000**	**386,605**	**2,464,660**	**4,572,200**	**5,500,021**

BC FERRY CORPORATION
Routes, Vessels & Fuel Consumptions
Year 2002
TABLE 2

Terminal	Route No.	Ferry	Route	Fuel per Round Trip (Litres)	No. of Round Trip/Year	Average Round Trip per Day	Annual Fuel Consumptn (Litres)	Daily Fuel Consumptn (Litres)	Remarks
Horseshoe Bay	2	Queen of Cowichan	Horseshoe Bay/Nanaimo	7,530	1,322	4	9,954,920	30,121	
Horseshoe Bay	2	Queen of Oak Bay	Horseshoe Bay/Nanaimo	7,462	1,227	4	9,155,951	29,848	
Horseshoe Bay	2	Queen of Coquitlam	Horseshoe Bay/Nanaimo	8,866	541	3.50	4,796,267	31,029	
Horseshoe Bay	2	Queen of Esquimalt	Horseshoe Bay/Nanaimo	7,189	33	4.71	237,221	33,891	
Horseshoe Bay	3	Queen of Surrey	Horseshoe Bay/Langdale	2,706	2,568	8	6,949,134	21,648	
Horseshoe Bay	3	Queen of Coquitlam	Horseshoe Bay/Langdale	3,286	351	5	1,153,310	16,429	
Horseshoe Bay	3	Queen of Esquimalt	Horseshoe Bay/Langdale	3,447	103	2	355,010	6,894	
Horseshoe Bay	8	Queen of Capilano	Horseshoe Bay/Bowen Island	446	5,408	16	2,410,946	7,133	
Horseshoe Bay	8	Bowen Queen	Horseshoe Bay/Bowen Island	268	307	15	82,132	4,013	
				41,200			**35,094,891**	**181,006**	
			Based on ratio 60% NG/40% diesel volume of Natural Gas						
			required in Litres =	24,720			21,056,935	108,604	
			required in S.C.F. =	954,192			812,797,691	4,192,115	
			volume of LNG (US gal) =				9,457,548		

BC FERRY CORPORATION
Routes, Vessels & Fuel Consumptions
Year 2002
TABLE 2 (Continued)

Terminal	Route No.	Ferry	Route	Fuel per Round Trip (Litres)	No. of Round Trip/Year	Average Round Trip per Day	Annual Fuel Consumptn (Litres)	Daily Fuel Consumptn (Litres)	Remarks
Swartz Bay	4	Skeena Queen	Swartz Bay/Fulford	715	2,351	8	1,688,175	5,720	
Swartz Bay	4	Bowen Queen	Swartz Bay/Fulford	564	656	7	369,823	3,946	
Swartz Bay	4	Mayne Queen	Swartz Bay/Fulford	2,546	88	3	224,043	7,638	
Swartz Bay	5	Mayne Queen	Swartz Bay/Gulf Islands	1,290	1,618	5	2,087,374	8,091	
Swartz Bay	5	Bowen Queen	Swartz Bay/Gulf Islands	1,364	324	4	441,779	5,456	
Swartz Bay	5	Queen of Cumberland	Swartz Bay/Gulf Islands	1,555	1,829	5.50	2,844,379	8,553	
				8,034			**7,655,573**	**39,404**	
			Based on ratio 60% NG/40% diesel						
			volume of Natural Gas						
			required in Litres =	4,821			4,593,344	23,643	
			required in S.C.F. =	186,091			177,303,079	912,620	
		*	volume of LNG (US Gal) =				2,063,062		

BC FERRY CORPORATION
Routes, Vessels & Fuel Consumptions
Year 2002
TABLE 2 (Continued)

Terminal	Route No.	Ferry	Route	Fuel per Round Trip (Litres)	No. of Round Trip/Year	Average Round Trip per Day	Annual Fuel Consumptn (Litres)	Daily Fuel Consumptn (Litres)	
Tsawwassen	1	Spirit of British Columbia	Tsawwassen/Swartz Bay	8,967	1,334	4	11,961,503	35,532	
Tsawwassen	1	Spirit of Vancouver Is.	Swartzbay/Tsawwassen	8,435	1,323	4	11,160,274	33,740	
Tsawwassen	1	Queen of Vancouver	Swartzbay/Tsawwassen	6,123	506	2.71	3,098,042	16,583	
Tsawwassen	1	Queen of Esquimalt	Swartzbay/Tsawwassen	6,538	150	1.33	980,826	8,696	
Tsawwassen	1	Queen of Saanich	Swartzbay/Tsawwassen	5,385	569	2.13	3,064,229	11,471	
Tsawwassen	30	Queen of New Westminster	Tsawwassen/Duke Point	9,724	1,260	4	12,252,849	38,896	
Tsawwassen	30	Queen of Alberni	Tsawwassen/Duke Point	7,687	1,135	4	8,724,404	30,747	
Tsawwassen	9	Queen of Nanaimo	Tsawwassen/S. Gulf Islands	3,900	906	3	3,532,959	11,699	
Tsawwassen	9	Queen of Tsawwassen	Tsawwassen/S. Gulf Islands	1,632	211	5	344,435	8,162	
				58,391			**55,119,521**	**195,526**	
			Based on ratio 60% NG/40% diesel volume of Natural Gas						
			required in Litres =	35,035			33,071,713	117,316	
			required in S.C.F. =	1,352,351			1,276,568,122	4,528,398	
		**	volume of LNG (US Gal) =				14,853,886		
			** 1 gallon diesel equals 1.7 LNG gallon						

BC FERRY CORPORATION
ESTIMATED EXHAUST EMISSIONS REDUCTION ON DUAL FUEL OPERATION
MARCH 2002
TABLE 3

Terminal	Route	Vessel	Total HP at 85% KW Power	Sailing Time per Round Trip Hrs	No. of Round Trips Per Year	Annual Sailing Time Hrs	Nox Reduction on Dual Fuel MT	PM Reduction on Dual Fuel MT	Remarks
Tsawwassen	Tsawwassen/ Swartz Bay	Spirit of British Columbia	11,560	3.17	1,334	4,229	427.77	17.60	48887240
Tsawwassen	Swartz Bay/ Tsawwassen	Spirit of Vancouver Island	11,560	3.17	1,323	4,194	424.22	17.46	
Tsawwassen	Swartz Bay/ Tsawwassen	Queen of Vancouver	5,278	3.17	506	1,604	74.08	3.05	
Tsawwassen	Swartz Bay/ Tsawwassen	Queen of Esquimalt	5,627	3.17	150	476	23.44	0.97	
Tsawwassen	Swartz Bay/ Tsawwassen	Queen of Saanich	5,670	3.17	569	1,804	89.51	3.69	
Tsawwassen	Stsawwassen/ Duke Point	Queen of New Westminster	10,649	4.00	1,260	5,040	469.63	19.33	
Tsawwassen	Stsawwassen/ Duke Point	Queen of Alberni	7,315	4.00	1,135	4,540	290.59	11.96	
Tsawwassen	Tsawwassen/ Gulf Island	Queen of Nanaimo	3,751	* 3.00	906	2,718	89.21	3.67	
Tsawwassen	Tsawwassen/ Gulf Island	Queen of Tsawwassen	5,671	* 3.00	211	633	31.41	1.30	
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Cowichan	7,315	3.17	1,322	4,191	268.25	11.04	
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Oak Bay	7,415	3.17	1,227	3,890	252.39	10.39	
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Coquitlam	7,315	3.17	541	1,715	109.77	4.52	
SUB-TOTAL							**2,550.27**	**104.98**	
** Estimated*									

BC FERRY CORPORATION
ESTIMATED EXHAUST EMISSIONS REDUCTION ON DUAL FUEL OPERATION
MARCH 2002
TABLE 3 (CONTINUED)

Terminal	Route	Vessel	Total HP at 85% KW Power	Sailing Time per Round Trip Hrs	No. of Round Trips Per Year	Annual Sailing Time Hrs	Nox Reduction on Dual Fuel MT	PM Reduction on Dual Fuel MT	Remarks
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Esquimalt	5,627	3.17	33	105	5.17	0.22	
Horseshoe Bay	Horseshoe Bay/ Langdale	Queen of Surrey	7,415	1.33	2,568	3,415	221.57	9.12	
Horseshoe Bay	Horseshoe Bay/ Langdale	Queen of Coquitlam	7,315	1.33	351	467	29.89	1.23	
Horseshoe Bay	Horseshoe Bay/ Langdale	Queen of Esquimalt	5,627	1.33	103	137	6.75	0.28	
Horseshoe Bay	Horseshoe Bay/ Bowen Island	Quee of Capilano	4,567	0.67	5,408	3,623	144.78	5.96	
Horseshoe Bay	Horseshoe Bay/ Bowen Island	Bowen Queen	2,452	0.67	307	206	4.42	0.19	
Swartz Bay	Swartz Bay/Fulford	Skeena Queen	3,551	1.17	2,351	2,751	85.48	3.52	
Swartz Bay	Swartz Bay/Fulford	Bowen Queen	2,452	1.17	564	660	14.16	0.59	
Swartz Bay	Swartz Bay/Fulford	Mayne Queen	2,452	1.17	2,546	2,979	63.91	2.63	
Swartz Bay	Swartz Bay/ Gulf Islands	Mayne Queen	2,452	* 3.00	1,290	3,870	83.03	3.42	
Swartz Bay	Swartz Bay/ Gulf Islands	Bowen Queen	2,452	* 3.00	1,364	4,092	87.79	3.62	
Swartz Bay	Swartz Bay/ Gulf Islands	Queen of Cumberland	4,567	* 3.00	1,555	4,665	186.42	7.67	
SUB-TOTAL							933.37	38.45	
SUB-TOTAL							2,550.27	104.98	
TOTAL							**3,483.64**	**143.43**	
** Estimated*									

Estimated Cost of CNG/LNG Infrastructure on board the Converted Ferries, Maintenance & lube Oil Savings (March 2002)
TABLE 4

Terminal	Route	Vessel	Total HP KW	CNG Infrastructure Cost $337.70/KW	LNG Infrastructure Cost $337.70/KW	Main Engine Maintenance Annual Savings	Lube Oil Annual Savings
Tsawwassen	Tsawwassen/ Swartz Bay	Spirit of British Columbia	13,600	$4,592,720	$4,592,720	$102,544.00	$64,056.00
Tsawwassen	Swartz Bay/ Tsawwassen	Spirit of Vancouver Island	13,600	4,592,720	4,592,720	102,544	64,056
Tsawwassen	Swartz Bay/ Tsawwassen	Queen of Vancouver	6,210	2,097,117	2,097,117	46,823	29,249
Tsawwassen	Swartz Bay/ Tsawwassen	Queen of Esquimalt	6,620	2,235,574	2,235,574	49,915	31,180
Tsawwassen	Swartz Bay/ Tsawwassen	Queen of Saanich	6,670	2,252,459	2,252,459	50,292	31,416
Tsawwassen	Stsawwassen/ Duke Point	Queen of New Westminster	12,528	4,230,706	4,230,706	94,461	59,007
Tsawwassen	Stsawwassen/ Duke Point	Queen of Alberni	8,606	2,906,246	2,906,246	64,889	40,534
Tsawwassen	Tsawwassen/ Gulf Island	Queen of Nanaimo	4,413	1,490,270	1,490,270	33,274	20,785
Tsawwassen	Tsawwassen/ Gulf Island	Queen of Tsawwassen	6,672	2,253,134	2,253,134	50,292	31,425
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Cowichan	8,606	2,906,246	2,906,246	64,889	40,534
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Oak Bay	8,724	2,946,095	2,946,095	65,779	41,090
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Coquitlam	8,606	2,906,246	2,906,246	64,889	40,534

BC FERRY CORPORATION
Estimated Cost of CNG/LNG Infrastructure on board the Converted Ferries, Maintenance & lube Oil Savings (March 2002)
TABLE 4 (Continued)

Terminal	Route	Vessel	Total HP KW	CNG Infrastructure Cost $337.70/KW	LNG Infrastructure Cost $337.70/KW	Main Engine Maintenance Annual Savings	Lube Oil Annual Savings
Horseshoe Bay	Horseshoe Bay/ Nanaimo	Queen of Esquimalt	6,620	$2,235,574	$2,235,574	$49,915	$31,180
Horseshoe Bay	Horseshoe Bay/ Langdale	Queen of Surrey	8,724	2,946,095	2,946,095	65,779	41,090
Horseshoe Bay	Horseshoe Bay/ Langdale	Queen of Coquitlam	8,606	2,906,246	2,906,246	64,889	40,534
Horseshoe Bay	Horseshoe Bay/ Langdale	Queen of Esquimalt	6,620	2,235,574	2,235,574	49,915	31,180
Horseshoe Bay	Horseshoe Bay/ Bowen Island	Queen of Capilano	5,373	1,814,462	1,814,462	40,512	25,307
Horseshoe Bay	Horseshoe Bay/ Bowen Island	Bowen Queen	2,885	974,265	974,265	21,753	13,588
Swartz Bay	Swart Bay/ Fulford	Skeena Queen	4,178	1,410,911	1,410,911	31,502	19,678
Swartz Bay	Swart Bay/ Fulford	Bowen Queen	2,885	974,265	974,265	21,753	13,588
Swartz Bay	Swart Bay/ Fulford	Mayne Queen	2,885	974,265	974,265	21,753	13,588
Swartz Bay	Swartz Bay/ Gulf Islands	Mayne Queen	2,885	974,265	974,265	21,753	13,588
Swartz Bay	Swartz Bay/ Gulf Islands	Bowen Queen	2,885	974,265	974,265	21,753	13,588
Swartz Bay	Swartz Bay/ Gulf Islands	Queen of Cumberland	5,373	1,814,462	1,814,462	40,512	25,307

Appendix ‘B’ - SHORE POWER FOR CRUISE SHIPS AT THE PORT OF VANCOUVER BRITISH COLUMBIA.

SHORE POWER FOR CRUISE SHIPS AT THE PORT OF VANCOUVER BRITISH COLUMBIA

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Prepared by:

Colm D. Corcoran, P.Eng.

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(604) 986-0233

March 2003

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APPENDICES

SHORE POWER FOR CRUISE SHIPS

AT THE

PORT OF VANCOUVER, BRITISH COLUMBIA

1.0 INTRODUCTION

During the 2002 Alaska cruise ship season (from May to September) 27 ships operated by 13 companies docked a total of 342 times at Canada Place and Ballantyne Pier (see **Appendix 1** for detailed information downloaded from the Port of Vancouver's website). On-board generation of "hotelling power" which is the power required to maintain the lighting, heating, cooking, air conditioning systems, etc. while they are docked in port, results in the release of considerable airborne emissions. This report addresses the logistic, technical and economic issues related to providing shore power to eliminate the need to run one of the ship's engines to generate hotelling power while in port.

Alaska Electric Light and Power Company have constructed a shore-based infrastructure at Juneau to provide shore power for Princess Cruise Lines, which was put into service on July 24, 2001. Four of their vessels have currently been modified to accept shore power at Juneau and all of their future vessels will be constructed to accept shore power.

Studies are presently being conducted to provide shore power for container ships which dock in the Port of Los Angeles. Also, the United States Navy are currently utilizing shore power for some of their vessels.

2.0 TERMS OF REFERENCE

- Through talks with the cruise ship industry determine the hotelling power requirements for the various cruise ships that dock in the Port of Vancouver (i.e., maximum hotelling power, voltages, frequency, etc.).

- Obtain feedback from BC Hydro on the methodology and approximate costs of constructing the required shore-based infrastructure to provide power for a maximum of three cruise ships at Canada Place and one ship at Ballantyne Pier.

- Provide a technical overview and costs to convert the electrical systems on cruise ships to accept shore power from the BC Hydro grid, through discussions with Princess Cruise lines and Callenberg Engineering who converted four of their ships to accept shore power at Juneau, Alaska.

- Obtain technical details and costs from Alaska Electric Light and Power Company (AEL&P) for the shore power facility, which they constructed at Juneau, Alaska to provide shore power for Princess Cruise ships. Compare these costs to those from BC Hydro with consideration given to the difference in requirements and infrastructure required to supply shore power at the Port of Vancouver.

3.0 HOTELLING POWER REQUIREMENTS

Initial indications are that a guideline for the hotelling power required for the larger cruise ships, which would be utilized during the hottest days in summer when the air conditioning load is highest, would be 7 to 8 megawatts (MW). Shore power would be from a three-phase four-wire 60 cycle supply at 6.6 kv. Some of the very large ships will require an 11 kv supply and up to 10 megawatts power consumption.

In order to eliminate temporary shedding or short term outages of power on the ships, however brief, the modifications to the Princess Cruise ships required synchronization of the on-board generators to the AEL & P's shore power grid at Juneau, Alaska prior to transfer to shore power. Synchronization requires that the frequency, phasing and voltage of the shipboard generator be exactly matched to the shore supply before a "seamless" transfer of power is initiated. We assume that this would be a requirement of all the cruise line companies.

The vast majority of cruise ships dock in Vancouver at 7am and leave at 5pm, according to information provided by the Port of Vancouver. Assuming that it takes 30 minutes after docking to connect to shore power and 30 minutes before sailing to disconnect, this means that typically each cruise ship will require shore power for about nine hours while docked. For the 342 separate times that the cruise ships docked in Vancouver between May and September 2002, if we assume that the average power requirement per ship was 6 MW, the total shore power energy requirements for 2002 would have been 6 x 9 (hours docked) x 342 = 18,468 megawatt hours.

The 6 MW estimate is based on an average of the range of tonnages and passenger capacities of the ships, which will determine the shore power requirements for individual vessels.

Considerably more data is required to accurately determine the projected energy requirements, including tabulation of additional data to be obtained from the cruise line companies and other factors including fluctuating electrical load due to varying air conditioning requirements throughout the cruise ship season. The energy requirements will factor into economic feasibility studies by determining the net savings in energy to the cruise ship companies (to be offset against the capital costs of the electrical modifications to the ships and, presumably, the shipping lines share of the capital cost of the shore-based infrastructure). The projected energy consumption will also be factored into the amount of the capital cost of the shore-based infrastructure which will be borne by B.C. Hydro.

There are three docking berths at Canada Place, which vary in length from 276 to 507 metres. The north berth, which is 276 metres long cannot accommodate the largest ships, such as, the Star Princess which is a little more than 300 metres long. Because Canada Place cannot accommodate three of the largest ships at any one time, we would estimate that the total power required for all three berths would be approximately 25 MW with the largest ship requiring 10 MW.

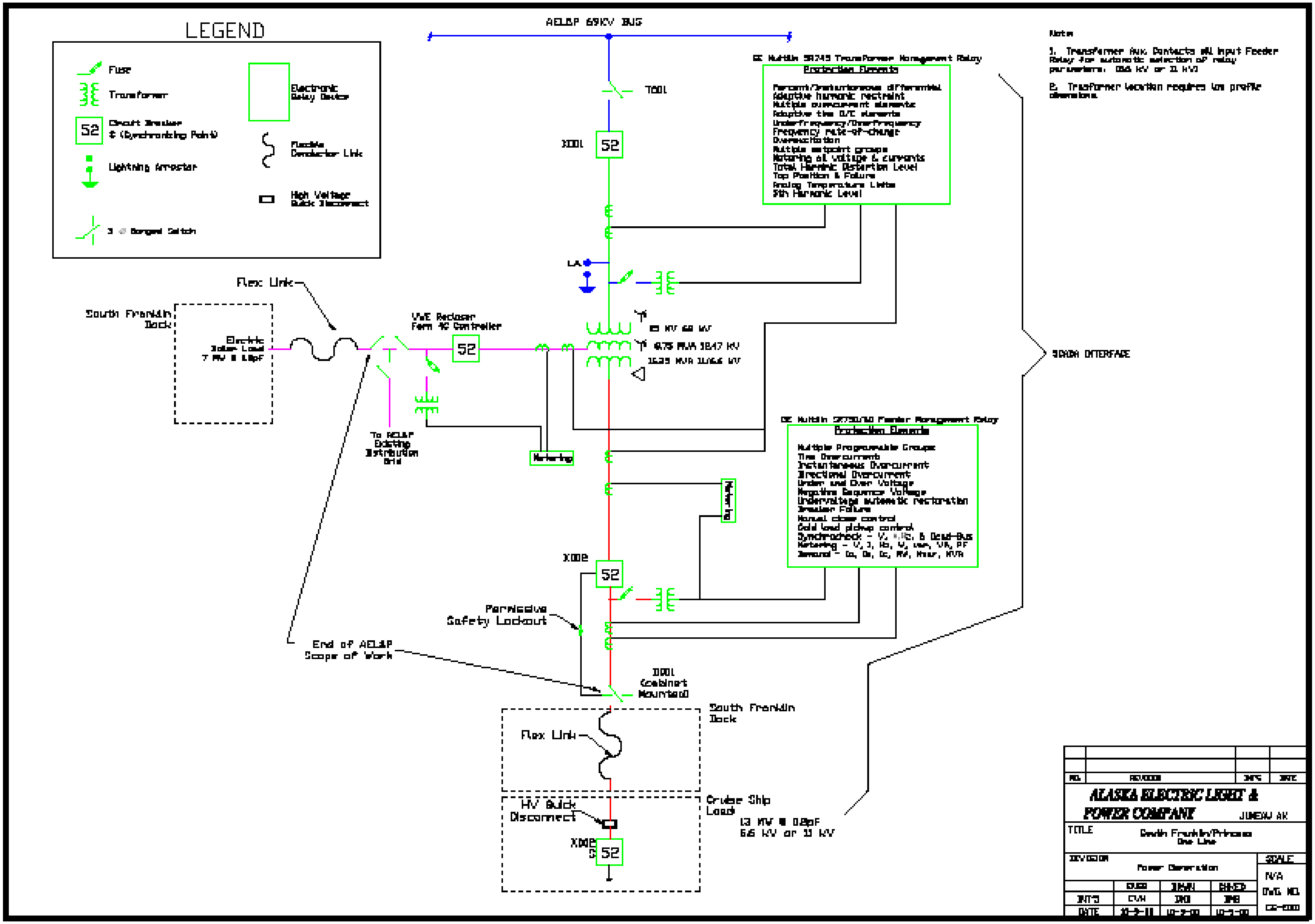
There are very few dockings at Ballantyne Pier such that the relative energy consumption would be small compared to Canada Place. For the purpose of preliminary discussions with BC Hydro, we have assumed a maximum shore power load of 10 MW for Ballantyne Pier.

4.0 SHORE-BASED INFRASTRUCTURE CONSTRUCTED FOR PRINCESS CRUISE LINES AT JUNEAU, ALASKA

Three-phase power from AEL&P's grid is fed to a substation, located across the street about 1,000ft. from the dock, at a primary voltage of 69 kv. The 25 megawatt transformer in the substation has three secondary voltages; 6.6 kv which is the shore power voltage required for most cruise ships, 11 kv which is required for some of the newer, larger ships and 12.5 kv which powers a shore based steam plant. The substation contains other electrical equipment including circuit breakers, potential and current transformers, protection and SCADA (supervisory control and data acquisition) equipment etc. The secondary 6.6 kv or 11 kv supplies are fed 1,000 ft. to a dock mounted disconnect/grounding switch.

The shore power is connected from the dock-mounted switch to the ship via four three-inch diameter electrical cables which hang from a special gantry on the dock, which is designed to accommodate a 20-foot variation in tides. The cable connection on the vessel is made via large male/female plugs and sockets, which are modified versions of connectors used in the mining industry. There is an additional smaller cable for carrying the SCADA interface information, metering, protection and control wiring between the vessel and the shore power substation.

It is understood from Mr. Corry Hildenbrand of AEL&P, that they are discussing the possible provision of shore power at Juneau with Holland America Cruise Lines. He has also forwarded an electrical schematic diagram for their shore power installation which is included on the next page. Additional information on the shore power installation at Juneau is included in **Appendix 2**.


LEGEND
Fuse
Transformer
52
Lightning Arrester
AEL&P 69KV BUS
52
Multiple Programmable Groups
Instantaneous Overcurrent
Directional Overcurrent
Under and Over Voltage
Total Harmonic Distortion Level
Frequency rate-of-change
Flex Link
South Franklin Dock
52
52
SCADA INTERFACE
Permissive Safety Lockout
End of AEL&P Scope of Work
South Franklin Dock
Flex Link
HV Quick Disconnect
52
Cruise Ship Load
ALASKA ELECTRIC LIGHT & POWER COMPANY
JUNEAU AK
TITLE
Power Generation
N/A

5.0 MODIFICATIONS MADE TO PRINCESS CRUISE SHIPS TO ACCEPT SHORE POWER AT JUNEAU

The power cables from the shore-based substation are fed via the male/female connectors into a receiving circuit breaker which is contained in an electrical room (together with ancillary metering, protection and control equipment) which is located behind a "shell door" constructed in the side of the vessel. Power cables are routed through the ship from the receiving breaker to another circuit breaker in the main electrical room which is used to transfer to shore power when the shipboard generator has been synchronized to the AEL&P power grid's frequency and voltage. After the initial safety checks, the transfer process, which is highly automated and utilizes sophisticated software especially developed to facilitate synchronization and a "seamless" transfer of power, takes about two minutes.

In the case where the on-shore BC Hydro infrastructure and substations will be required to provide power to a wide range of ships manufactured by different companies, it will be necessary to standardize the SCADA interface and protection and control systems through discussions with the various cruise lines and ship manufacturers. It will also be necessary to standardize the male/female power connectors to the ships.

6.0 On-shore Infrastructure to Provide Shore Power from the BC Hydro Grid

Provision of shore power from the BC Hydro grid to Canada Place and Ballantyne Power is much more complex and costly than AEL & P's installation at Juneau, Alaska for the following reasons.

8. The supply voltage to the shore power substation at Juneau is 69 kv which is provided by an overhead pole line at a cost of only US$55,000.

   B.C. Hydro have advised us that it is impractical for them to supply 69 kv service to Canada Place and Ballantyne Pier because the costs would be prohibitive due to substantial infrastructure additions.

   Power to the downtown area of Vancouver is currently provided by underground cables at 12 kv. Each 12 kv circuit is only capable of carrying about 6.5 MW which is very much less than the capacity of the single 69kv feed at Juneau which powers a 25 MW transformer.

9. Supply to Canada Place would require four separate 12kv underground cable circuits from Cathedral Square substation and two circuits from Murrin substation to Ballantyne Pier to provide the required power capacities. Installation of underground cables is also very expensive.

10. There are technical issues pertaining to paralleling the 12kv circuits at the dockside substations because of the resultant high ground fault currents. It may be necessary to provide three separate substations at Canada Place to supply each docking berth.

11. Land or available space is at a premium and may require taking space from the parking or other currently utilized areas at Canada Place. It is not possible to assess detailed substation area requirements or costs at this time until further studies are conducted.

7.0 Budgetary Estimates

7.1 Cruise Ship Modifications

Four of the Princess Cruise Line ships were modified to accept shore power at Juneau by Callenberg Engineering of Miami, Florida at a cost of US$500,000 per ship.

Corry Hildenbrand of AEL & P provided a very rough estimate that, even for small cruise ships requiring less power, similar modifications to those made to Princess Cruise vessels would probably not cost less than US$300,000 per ship.

We assume that, in time, modification costs to cruise ships would decrease somewhat because of lower design and software development costs and installation of the shore power modifications during the construction of new vessels. Corry Hildenbrand also provided a very rough estimate that, if some of the smaller ships did not require synchronization to the shore power grid, the modification costs could decrease by US$60 – 70,000.

Corry Hildenbrand also said me that there are plans to provide shore power at Victoria shipyards where their vessels are maintained. Currently, only limited power is supplied utilizing a 480 volt three phase supply. Additional power supplied at 6.6 or 11 kv will lessen the time required in dry dock resulting in more cruise ship passenger revenue and elimination of the expense of shore-based accommodation for the crew while in dry dock.

7.2 Shore-based Infrastructure at Juneau, Alaska

The approximate costs for construction of the shore power infrastructure at Juneau, which were provided by AEL & P, are as follows:

69 kv overhead supply line:-	US $55,000.00
Substation alone:-	US$1,300,000.00
Substation cabling to dockside disconnect switch:-	US $300,000.00
Disconnect switch to ship cable and delivery system:-	US $600,000.00
TOTAL COST:	**US$2,255,000.00**

7.3 Shore-based Infrastructure at the Port of Vancouver

Because of the technical complexity of providing shore power from the B.C. Hydro grid to Canada Place and Ballantyne Pier, further studies are required in order to design and estimate the costs of the shore-based infrastructure. For the purpose of this preliminary study, we have extrapolated the following cost guestimates from information provided by AEL & P on the Juneau installation and input from B.C. Hydro:

Canada Place (25 MW)

Four 12 kv feeders from Cathedral Square substation	$3,000,000
Maximum of three substations at an average cost of $1,500,000 per substation	$4,500,000
Cabling and infrastructure from substations to three vessels at $1,000,000 per berth	$3,000,000
TOTAL	**$10,500,000**

Ballantyne Pier (10 MW)

Two 12 kv feeders from Murrin substation	$1,500,000
One substation	$1,500,000
Cabling and infrastructure from substation to one vessel	$1,000,000
TOTAL	**$4,000,000**

The above very rough estimates for four docking berths at Vancouver approximately correlate to the US$50 – 60,000,000 estimate for providing power to up to 20 cargo-containing ships simultaneously at the Port of Los Angeles (i.e., C$3,625,000 per berth at Vancouver versus C$4,125,000 per vessel at Los Angeles).

B.C. Hydro may absorb some of the capital costs to construct the 12kv supply circuits, but none of the capital cost to construct the dockside substations and cable connections to the ships.

7.4 Energy Costs

Please refer to **Appendix 4** for information on B.C. Hydro's rate schedule #1211. We have been verbally advised by Mr. Harold Nelson of B.C. Hydro's Customer Projects organization that this rate schedule is based on normal year-round energy consumption, whereas, shore power for the cruise ships will only be required for the five month cruise season.

However, for the purpose of calculating a preliminary rough estimate of energy costs, we have utilized schedule #1211, which is comprised mainly of energy costs and demand charges.

Demand charges are designed to recover B.C. Hydro's total infrastructure costs to supply power and are a function of the maximum power to be supplied irrespective of energy consumption. In the case of providing our estimated shore power and energy requirements, the demand charges are actually higher than the energy costs.

For preliminary budgetary purposes, we have estimated an energy cost, including demand charges of approximately 8 cents (Canadian) per kilowatt-hour utilizing rate schedule #1211.

This estimate is based on demand charges of $6.12 per kilowatt for the power requirements and 3.07 cents per kilowatt-hour for the energy charges as shown on B.C. Hydro's rate schedule.

Based on our 18,468 megawatt-hours estimate of the total energy required for all of the 27 cruise ships which docked in Vancouver in 2002, the total cost of energy would be $1,477,440 or an average of $54,720 per vessel, per cruise ship season.

The actual energy costs would be based on future discussions and negotiations with B.C. Hydro.

8.0 SHORE POWER INITIATIVE AT THE PORT OF LOS ANGELES

The Port of Los Angeles, the mayor of Los Angeles and the Los Angeles Department of Water and Power have initiated a program entitled “Alternative Maritime Power Research and Development Program” to supply shore power to commercial “in-service container” vessels which dock at the Port of Los Angeles. The document in **Appendix 3** gives a brief outline of the philosophy and objectives of the program which is the first of its kind for supplying shore power to cargo container ships.

There were approximately 2,200 cargo ship visits to the Port of Los Angeles in 2001, with an average length of stay of two days. Construction of the on-shore infrastructure to supply shore power at the Port of Los Angeles is expected to cost $50-60 million US over about 10 years.

The shore power infrastructure will ultimately be capable of providing power simultaneously for up to twenty cargo container ships at docking berths which can accommodate up to three vessels.

The philosophy of the program is based on achieving a nett savings for the container cargo shipping companies (seven companies have signed an agreement to participate in the program) taking into account the savings in cost of shore power energy and the eventual recovery of the capital cost to convert the ships and construct the on-shore infrastructure.

Note that the energy savings for container ships utilizing shore power would be several more times than with cruise ships because they spend considerably more time in port (two days compared to ten hours for cruise ships). The energy savings would obviously vary with the power requirements for individual ships whereas the cost of shipboard modifications per megawatt are expected to increase with ships requiring less shore power.

The above information was provided verbally by Mr. Randy Howard of the Los Angeles Department of Water and Power who said that there was a workshop in Los Angeles in the first week of March pertaining to issues related to their shore power program. He will provide information on the workshop and other future developments which we will forward to Genesis Engineering and Environment Canada.

9.0 Conclusions

5. In the year 2002, 27 cruise ships operated by 13 companies docked a total of 342 times at Canada Place and Ballantyne Pier during the Alaska cruise season. Most of the ships dock at 7am and leave at 5pm such that they could be connected to shore power for about 9 hours allowing for one hour to connect and disconnect the shore power supply. The larger ships require approximately 7-8 MW of hotelling power to be supplied at 6.6 kv. Some of the very large ships will require as much as 10MW and an 11kv supply voltage.

6. Shore power has been successfully implemented by Princess Cruise Lines in Juneau, Alaska since July 24, 2001. In order to eliminate temporary shedding or short term outages of power on the ships, the modifications to the cruise ships required synchronization of the on-board generators to the shore power grid. Synchronization requires that the frequency, phasing and voltage of the shipboard generator be exactly matched to the shore supply before a "seamless" transfer of power is initiated. We assume that this would be a requirement of all of the cruise ships companies.

7. Modifications to accept shore power at Juneau were made to four of the Princess Cruise ships by Callenberg Engineering of Miami, Florida. The total cost was US$500,000 per ship. The shore-based infrastructure was constructed by Alaska Electric Light and Power for a total cost of US$2,255,000.

8. Provision of shore power from the BC Hydro grid to Canada Place and Ballantyne Pier will be much more technically complex and expensive to provide than the 69kv overhead conductor supply at Juneau for the following reasons:

   a) B.C. Hydro has advised us it is impractical to supply 69 kv service because the costs would be prohibitive due to substantial infrastructure additions.

   b) Power to the Vancouver downtown area is currently provided by 12kv underground circuits which can carry only about 6.5 MW per circuit such that four circuits would be required to provide the estimated 25 MW at Canada Place and two circuits to provide the estimated 10 MW load at Ballantyne Pier. There are also technical issues related to paralleling the circuits at the dockside substations. In may be necessary to provide separate substations at Canada Place to supply each of the three docking berths.

c) The cost of installing underground cable is very much higher than overhead lines.

d) Land or available space is at a premium and may require taking space from parking or other currently utilized areas at Canada Place. It is not possible to assess detailed substation area requirements at this time until further studies are concluded.

For preliminary budgetary purposes, we estimated the following costs to provide shore power from the B.C. Hydro grid:

Canada Place $10,500.00
Ballantyne Pier $4,000,000
Energy Costs .... 8 cents per kilowatt-hour
Estimated average electrical energy costs per ship, per cruise ship season $54,720

12. The US Navy has implemented shore power for their ships. Information on their shore installations and shipboard modifications has not been included in the scope of this report. We have included some preliminary information in this report on an initiative to provide shore power for <u>container</u> ships in the Port of Los Angeles. It should be noted that one factor to be included in any economic analysis pertaining to shore power is the length of time that the ships will be utilizing the less expensive energy provided by shore power while in dock. The cruise ships typically dock for about 10 hours, the container ships for two days and the US Navy ships could be docked for some weeks at the same location.

13. In order to construct a shore-based infrastructure at the Port of Vancouver, which will be compatible with a wide variety of cruise ships, it will be necessary to develop a high degree of standardization for the modification to the ships. Standardization will include the male/female power connectors and the SCADA (supervisory control and data acquisition) and other protection and metering interface systems between the ship and shore electrical systems in addition to providing the required power and voltages.

14. In general, provision of shore power is technically complex and expensive and will require extensive co-operation from the shipping lines, power utilities, government agencies, etc.

10.0 Recommendations

d) Additional information is required from the cruise ships companies to fine-tune the shore power, voltage and energy consumption of the cruise ships. We will forward any detailed information which we requested from the North West Cruise Ship Association on the power and voltage requirements for the cruise ships that dock in Vancouver when it is received.

e) In order to provide a more accurate budgetary estimate for a shore-based infrastructure and energy costs at the Port of Vancouver further studies and negotiations with B.C. Hydro will be required.

f) On-going feedback should be obtained from the shore power studies for container ships at the Port of Los Angeles with particular reference to the discussions with the shipping lines pertaining to standardization of the shipboard modifications and shore-based infrastructure to accept shore power.

APPENDIX 1

Cruise Ship Information Downloaded From Port of Vancouver Website

2002 Cruise Season

Line	Vessel
Carnival	Carnival Spirit
Celebrity Cruises	Infinity Mercury Summit
Cruise West	Spirit of Oceanus
Crystal Cruises	Crystal Harmony
Holland America	Amsterdam Ryndam Statendam Veendam Volendam Zaandam
Norwegian Cruise Lines	Norwegian Sky Norwegian Wind
Mitsui O.S.K. Lines	Nippon Maru
Peace Boat	Olvia
Princess Cruises	Dawn Princess Ocean Princess Sea Princess Star Princess Sun Princess
Radisson Seven Seas	Seven Seas Navigator
Royal Caribbean	Legend of the Seas Radiance of the Seas Vision of the Seas
Seabourn Cruise Line	Seabourn Spirit

World Explorer Universe Explorer

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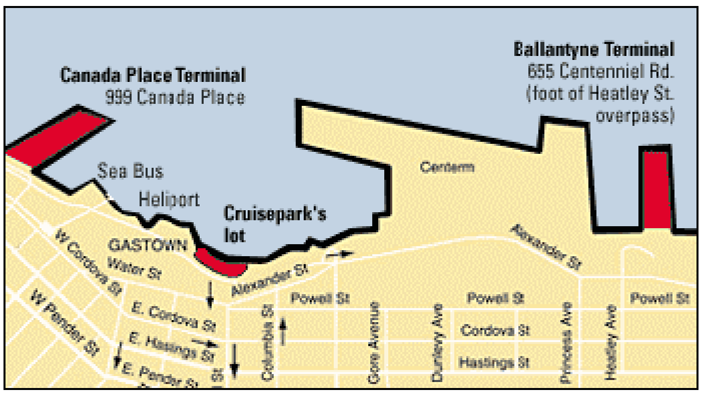
Canada Place | Ballantyne

Vancouver's cruise ship terminals, Canada Place and Ballantyne, offer all the modern conveniences and services for a positive and safe cruise experience. Canada Place is located in the city centre. Ballantyne is east of the city centre and close to Canada Place. In 2002, the port hosted 342 sailings carrying more than one million revenue passengers.



You can use Map Quest to find your way there

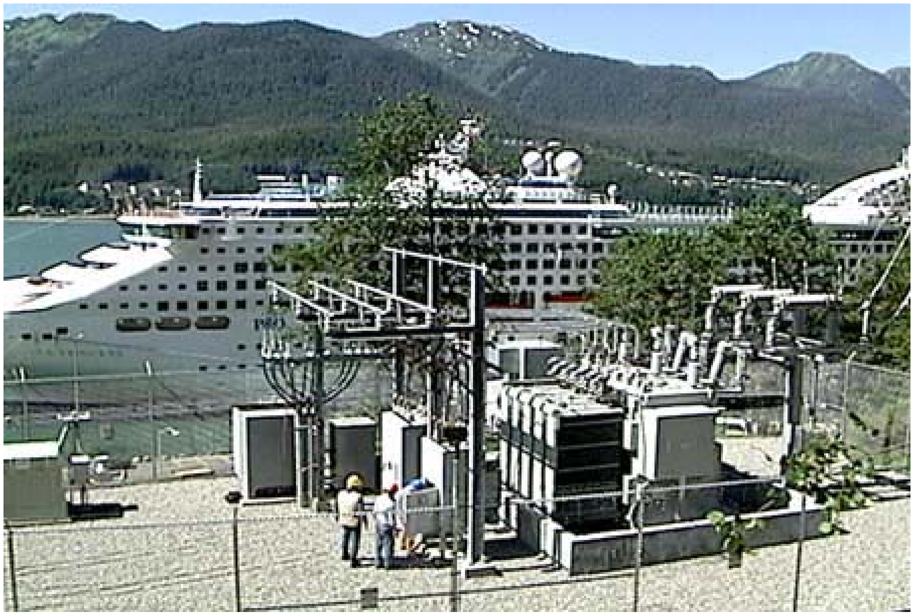
New Third Berth at Canada Place

The Vancouver Port (VPA) Authority developed a new third cruise berth at Canada Place for the 2002 cruise season and beyond. The VPA provided the $89 million (Canadian funds) in funding required for the project with support from the cruise industry. Construction began in February, 2000 and was completed one season ahead of schedule.

Canada Place was extended, creating a new cruise berth and additional space for passengers. Passenger and baggage loading and unloading were expanded from 133,000 sq. ft. to 189,000 sq. ft., with an enlarged passenger-level area, as well as enhanced truck, bus and taxi access from 63,000 to 100,000 sq. ft. Canada Place is now home to three berths: one at 1,600 feet, a second at 1,070 feet and a third at 900 feet.

APPENDIX 2

Description of Shore Power Installation at Juneau, Alaska



Following a July 17 ceremony aboard the cruise ship **Dawn Princess** in Juneau, Princess Tours President Charlie Ball threw a switch to symbolically begin a process which will have local residents breathing a lot easier about their environment.

Reacting to complaints from Juneau residents concerning visible smoke emissions from visiting cruise ships, AEL&P and Princess Cruises joined forces to construct a shore-side power station on the South Franklin docks. The $4.5 million power facility allows cruise ship engineers to shut down their diesel generators which power the ship while it's docked in Juneau. Engineers now connect four large power cables from the shore facility to the ship, giving passengers and crew up to 13 megawatts of clean hydroelectric power produced by AEL&P.

Corry Hildenbrand, AEL&P's Project Manager, says the project will also lighten electric bills for area residents. He says revenues generated from Princess Cruises for the use of shore power will be placed in a fund that will help offset a Cost of Power Adjustment currently paid by Juneau customers.

Currently, Princess Cruises has converted the power plants of four liners that make regular stops in Juneau, with a fifth ship expected to join the shore-power fleet for the 2002 season.

Shore Power Connection

Shore Power Connection Launched for Princess Ships

Innovative Program Demonstrates Company's Commitment to Local Concerns

JUNEAU, Alaska July 25, 2001

The use of shore power by Princess Cruises was officially begun yesterday in Juneau, marked by a special ceremony launching this innovative, first-of-its-kind project.

Demonstrating its commitment to help clear the air of visible smoke emissions, Princess Cruises is turning off the diesel engines of its ships when they dock at the Franklin Street Dock this summer. The first program of its kind in the world, the project required an investment by Princess of $4.5 million, and the coordination of a complex array of technical resources around the world as well as in Juneau.

”This unprecedented program sends a strong message that Princess cares deeply about the local concerns regarding visible haze accumulation in Juneau," said Charlie Ball, president of Princess Tours. “Because we want to continue to be welcomed as a responsible summer visitor, we've committed significant financial and technical resources to this complex engineering challenge."

Ball explained that Princess recognized that Juneau's unique climatic condition and geography help contribute to the accumulation of haze and smoke, and that only extraordinary measures would resolve the problem.

Four of the five Princess ships this summer are using the South Franklin Street Dock, where a sophisticated power distribution system has been built, enabling the ships to connect to local surplus hydroelectric power provided by Alaska Electric Light & Power (AEL&P).

As a complex and successful testing process concludes, the ships' diesel engines will be shut down upon arrival in Juneau, and power from a special transformer installed ashore will be used to supply electric power for the running of all onboard services during the day-long calls.

Each Princess ship has been outfitted with a new hull door, a custom-built state-of-the-art electrical connection cabinet with equipment that automatically connects the ship's electrical network to the local electrical network ashore. The electrical power is transmitted from the transformer ashore to the vessel via four 3 and 1/2-inch diameter flexible electrical cables that hang festooning-style on a special gantry system built on the dock.

The gantry and the festooning equipment have been designed to accommodate the 20 feet rise and fall of the tide and withstand the 100 mph winds during the winter. The actual cable connection on the vessel is a traditional, though quite large, male/female plug and socket, adapted from the American mining industry.

In the future, to ensure that visible emissions are minimized, Princess will also be shutting down each ship's oil-fired steam boiler even though the amount of emissions from these are quite small. The steam will be produced by a shoreside electric boiler, currently being installed.

The City and Borough of Juneau has allocated $300,000 from the 2001 Cruise Passenger Fees as a contribution to the cost of the shore power installation.

”That makes the community of Juneau a partner in this effort," said Ball.

As part of the agreement with Princess, AEL&P was not required to pay the capital cost of the service connection, and the amount Princess pays AEL&P for the surplus hydroelectric power will go into a special fund that would contribute to deferring the cost of diesel-generated power required during the winter months.

”This was an incredibly challenging project because it was the first of a kind and there was no existing blueprint we could use. Thanks to the efforts of a worldwide team of technical contractors, suppliers and consultants, including many here in Juneau, we now have a program in place that we believe will make a difference here, and will show the residents we care about the environmental issues that are important to all of us," said Ball.

Next summer, all five of Princess' ships will connect to shore power at the Franklin Street Dock, including the company's new Star Princess, which is in the final phase of construction and is being outfitted with the special connection equipment.

All Princess Cruises can be booked by calling **Lighthouse Travel at 800-719-9917.**

APPENDIX 3

Overview of the Shore Power Initiative for Container Ships at the Port of Los Angeles

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ALTERNATIVE MARITIME POWER

RESEARCH AND DEVELOPMENT PROGRAM

- Groundbreaking clean air research program, aimed at reducing emissions from commercial "in-service container" vessels docked at the Port of Los Angeles
- First program of its kind in the world for container vessels
- When implemented, vessels will turn off diesel engines and plug into Los Angeles Department of Water and Power shore-side electric power sources
- How it works:
  - Vessels would be retrofitted or built with systems to accommodate electric generators to power systems while docked in port
  - LADWP would build dockside power substations
- Los Angeles is partnering with the shipping industry to change the standards for vessels docked at port
- Reinforces Mayor Hahn's pledge of "no net increase" policy for emissions at the Los Angeles Harbor
- Complements Port of Los Angeles' innovative environmental initiatives to improve air quality
- Within the shipping industry, seven firms have signed AMP MOU agreements:
  - P & O Nedlloyd, Nippon Yusen Kaisha Line, Mitsui O.S.K. Lines Ltd., China Shipping, Orient Overseas Container Line Ltd., Yang Ming Line and Evergreen Marine Corp.

APPENDIX 4

B.C. Hydro Rate Structure

British Columbia Hydro and Power Authority
Electric Tariff
Twenty-second Revision of Page C-15
Effective: 1 April 1996

SCHEDULES 1200, 1201, 1210, 1211

GENERAL SERVICE (35 kW and over

Availability: For all purposes. Supply is 60 hertz, single or three phase at secondary or primary potential. The Authority reserves the right to determine the potential of the service connection.

Applicable in: Rate Zone 1.

Rate: Basic Charge $4.15 per month

Demand Charge

First 35 kW of billing demand per month Nil
Next 115 kW of billing demand per month @ $3.32 per kW
All additional kW of billing demand per month @ $6.37 per kW

plus

Energy Charge

First 14800 kW.h per month @ 6.49¢ per kW.h
All additional kW.h per month @ 3.12¢ per kW.h

Discounts

1. A discount of 1½% shall be applied to the above rate if a customer's supply of electricity is metered at a primary potential.

2. A discount of 25¢ per kW of billing demand shall be applied to the above rate if a customer supplies transformation from a primary potential to a secondary potential.

3. If a customer is entitled to both of the above discounts, the discount for metering at a primary potential shall be applied first.

British Columbia Hydro and Power Authority
Electric Tariff
Twenty-second Revision of Page C-15
Effective: 1 April 1996

SCHEDULES 1200, 1201, 1210, 1211

GENERAL SERVICE (35 kW and over (Cont'd

Billing Codes:	Schedule 1200	applies if a customer's supply of electricity is metered at a secondary potential and the Authority supplies transformation from a primary potential to a secondary potential.
	Schedule 1201	applies if a customer's supply of electricity is metered at a primary potential and the Authority supplies transformation from a primary potential to a secondary potential.
	Schedule 1210	applies if a customer's supply of electricity is metered at a secondary potential and the customer supplies transformation from a primary potential to a secondary potential.
	Schedule 1211	applies if a customer's supply of electricity is metered at a primary potential and the customer supplies transformation from a primary potential to a secondary potential.

Monthly Minimum Charge:

The greater of:

1. Twelve dollars and twenty-two cents ($12.22) per month, or

2. 50% of the highest maximum demand charge billed in any month wholly within an on-peak period during the immediately preceding eleven months. For the purpose of this provision an on-peak period commences on 1 November in any year and terminates on 31 March of the following year.