

Cold Ironing

Cost Effectiveness Study

Volume I - Report

Emulsified Diesel Fuel

ENVIRON



VOLUME I - REPORT

COLD IRONING COST EFFECTIVENESS
PORT OF LONG BEACH
925 HARBOR DRIVE
LONG BEACH, CALIFORNIA

Prepared for

Port of Long Beach
Long Beach, California

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A C R O N Y M S

A

ACFM	Actual Cubic Feet per Minute
AP-42	USEPA Compilation of Air Pollutant Emission Factors
AWMA	Air & Waste Management Association

B

BAAQMD	Bay Area Air Quality Management District
BACT	Best Available Control Technology
BTU	British Thermo Unit

C

CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CEMS	Continuous Emission Monitoring System
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CRC	Cryogenic Refrigerated Container

D

DCF	Discounted Cash Flow
DOT	Department of Transportation
DWI	Direct Water Injection
DWP	Department of Water & Power

E

EF	Emission Factor
EGR	Exhaust Gas Recirculation
EIA	Environmental Impact Assessment
EI	Emission Inventory
EIS	Environmental Impact Statement
ERC	Emission Reduction Credit

A C R O N Y M S (Continued)

F

FIP	Federal Implementation Plan
FR	Federal Register
FY	Fiscal year

G

GE	General Electric
----	------------------

H

HAM	Humid Air Motor
HAPs	Hazardous Air Pollutants
HC	Hydrocarbon
HFO	Heavy Fuel Oil
Hz	Hertz

I

IC	Internal Combustion
IFO	Intermediate Fuel Oil
ILWU	International Longshoremen's and Warehousemen's Union
IMO	International Maritime Organization
ISO	International Standard Organization

J

K

KV	Kilovolt
KVA	Kilovolt-amps
KW	Kilowatt
KW-hr	Kilowatts hour

L

LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas

A C R O N Y M S (Continued)

M

MARAD	Maritime Administration
MARPOL	The International Convention for the Prevention of Pollution of Ships
MATES	Multiple Air Toxics Exposure Study
MDO	Marine Distillated Oil
MGO	Marine Gas Oil
MSDS	Material Safety Data Sheet
MW	Megawatts
MW-hr	Megawatts hour

N

NAAQSs	National Ambient Air Quality Standards
NEPA	National Environmental Protection Act
NOx	Nitrogen Oxides
NPV	Net Present Value
NSR	New Source Review

O

O&M	Operating and Maintenance
OSHA	Occupational Safety and Health Administration

P

PAHs	Polycyclic Aromatic Hydrocarbons
PM ₁₀	Particulate Matter of 10 Microns in diameter or smaller
PMA	Pacific Maritime Association
PMSA	Pacific Merchants Shipping Association
POLA	Port of Los Angeles
POLB	Port of Long Beach
PPB	Parts per Billion
PPM	Parts Per Million
PTE	Potential to Emit

Q

A C R O N Y M S (Continued)

R

ROG	Reactive Organic Gases
RORO	Rolling-On and Rolling-Off
RPM	Revolutions per Minute

S

SCAQMD	South Coast Air Quality Management District
AQMP	Air Quality Management Plan
SCE	Southern California Edison
SCR	Selective Catalytic Reduction
SDCFM	Standard Dry Cubic Feet per Minute
SECA	Sulfur Oxides Emission Control Area
SIP	State Implementation Plan
SO ₂	Sulfur Dioxide
SOCAB	South Coast Air Basin
SOLAS	Safety of Life at Sea
SOPs	Standard Operation Procedures

T

TEU	Twenty-foot Equivalent Unit
TPD	Tons per Day
TPY	Tons per Year

U

UL	Underwriter's Laboratory
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency

V

VOC	Volatile Organic Compounds
-----	----------------------------

W

X

Y

Z

1.0 EXECUTIVE SUMMARY

This report presents an analysis of the feasibility of various types of emissions control technologies that may be available to the Port of Long Beach (POLB) to reduce air emissions from ocean going vessels while they are docked at the POLB. The study focuses on the feasibility of provision of shore side electricity to power the various activities performed on these vessels while they are at berth. This technique is often referred to as “cold ironing”, hence the title of this report. The report also considers the feasibility of using alternative approaches (e.g. cleaner diesel fuel, exhaust controls, and engine replacement), and a comparison is made of the cost effectiveness of the various approaches.

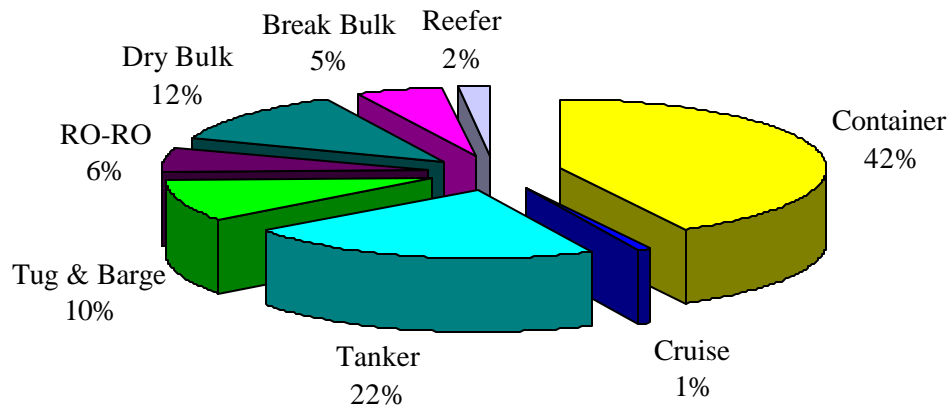
This report concludes that cold ironing is generally cost effective with vessels that spend a lot of time at the port, and therefore have high annual power consumption. Use of cold ironing for vessels that currently have high annual power consumption in the Port could cause a significant reduction in the overall annual emissions generated by docked vessels in the Port each year. The report also concludes that the availability of the various other types of emissions control technologies, while also potentially beneficial, is limited by a variety of implementation constraints that would slow their widespread application right away. Finally, the report concludes that the various technologies that are analyzed, including cold ironing, could have significant regulatory, legal, and logistical hurdles to overcome, particularly if the South Coast Air Quality Management District (SCAQMD) or other local agency wishes to mandate their use.

Between June 2002 and June 2003, 1,143 vessels made 2,913 calls at the Port of Long Beach, as shown on Table 1-1. As Figure 1-1 shows, container ships were the dominant vessel type in terms of vessel calls (1,231 calls) followed by tankers (635 calls), and dry bulk vessels (364 calls). These data (shown in Table 1-1 and Figure 1-1) do not include full operation by the cruise terminal on Pier G, which is projected to see more than 150 vessel calls per year or approximately 5% of calls.

Table 1-1. Frequency of Vessel Calls

Numbers of Calls per year	Number of Vessels	Percent of Total Vessels	Number of Calls	Percent of Total Calls
1 or more	1,143	100%	2,913	100%
2 or more	516	45%	2,286	78%
3 or more	302	26%	1,858	64%
4 or more	206	18%	1,570	54%
5 or more	158	14%	1,378	47%
6 or more	121	11%	1,193	41%
7 or more	97	8%	1,049	36%
8 or more	82	7%	944	32%
9 or more	60	5%	768	26%
10 or more	40	4%	588	20%

Figure 1-1. Vessel Calls at the Port of Long Beach



The frequency at which a given ship calls is particularly informative. As Table 1-1 shows, half of those vessels called only once, and less than 10 percent of the vessels called more than six times in a one-year period. These “frequent flyers”, however, accounted for more than 40 percent of all vessel calls.

While docked at the Port, the ocean-going cargo vessels shut off their propulsion engines, but they use auxiliary diesel generators to power refrigeration, lights, pumps, and other functions (activities commonly called “hotelling”). At present, the resultant air emissions -- nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), volatile organic compounds (VOC), and diesel particulate matter (PM) -- are largely not subject to emission controls. However, the SCAQMD Governing Board has identified port emissions as a major source of air pollution that warrants controls. Of particular interest are the diesel PM emissions, which have been declared by the California Air Resources Board (CARB) to be a toxic air contaminant that causes cancer. The latest available ocean-going vessel emission inventory for the San Pedro Bay ports (Port of Los Angeles and the Port of Long Beach combined) indicated that of the reported 33.0 tons per day (tpd) of NO_x in 2000 from vessel activity in ports, 11.0 tpd of NO_x were derived from vessel auxiliary engines operating in hotelling mode. The situation with respect to diesel particulates is similar.

One approach to reduce hotelling emissions is called cold ironing. Cold ironing is a process where shore power is provided to the vessel, allowing it to shut down its auxiliary generators. This technology has been used by the military at naval bases for many decades when ships are docked for long periods.

At present, there are currently no international requirements that would mandate or facilitate cold ironing of marine vessels, and very few that attempt to regulate vessel emissions in ports at all. Note that a recently proposed worldwide emission control mechanism, Annex VI of 1997 to MARPOL -- The International Convention for the Prevention of Pollution of Ships -- under the auspices of the International Maritime Organization (IMO) does seek to address emission controls for hotelling vessels, but it does not mention cold ironing. Annex VI would reduce NO_x, SO_x, and particulate matter emissions from international cargo vessels by imposing emission controls on diesel engines rated at more than 130 kW (~175 hp) manufactured after January 2000. This requirement covers main propulsion engines and most auxiliary generators, and is based on the quality of the fuel they burn, most notably on the sulfur content. This international agreement has yet to be ratified.

At the United States federal level, the United States Environmental Protection Agency (USEPA) has promulgated NO_x and PM emission standards based on the proposed Annex VI controls for new marine diesel engines, but those standards only apply to U.S.-flagged vessels, which only comprise a small fraction of the world’s fleet. The USEPA has stated its intent to work with IMO to tighten the Annex VI standards, because most ocean-going vessels calling on U.S. ports are foreign flagged.

At the state level, CARB believes it has the legal authority to regulate marine vessels. The SCAQMD considered a cold ironing regulation for vessels in the South Coast Basin in the late 1980's, but eventually terminated the rule-making process. SCAQMD now states, in the Final Program Environmental Impact Report for the 2003 Air Quality Management Plan (AQMP), "the SCAQMD does not have authority to directly regulate marine vessel emissions and the SCAQMD cannot require retrofitting, repowering or controlling emissions from marine vessels. However, CARB and the USEPA have authority to regulate these sources ..." Due to the high costs of cold ironing and the uncertainties in the legal framework, any regulation from environmental agencies that requires cold ironing is likely to meet with significant resistance and litigation.

Given the magnitude of vessel hotelling emissions and the uncertainty with regard to effective controls, the POLB commissioned this study of potential approaches available to the Port to reduce or eliminate hotelling emissions. The overall objective of the study is to provide the Long Beach Board of Harbor Commissioners with a summary of the technical feasibility, order-of-magnitude costs, potential emissions reductions, legal and institutional constraints and opportunities associated with each control strategy. The specific objectives of the study are:

- Assess opportunities and constraints associated with cold ironing and alternative emissions control measures;
- Identify vessel-side and land-side infrastructure requirements for cold ironing and other measures;
- Provide a conceptual cold ironing system design to estimate the cost of cold ironing;
- Evaluate the cost effectiveness of cold ironing and other emission control options; and
- Address potential labor, safety, legal and regulatory issues associated with the implementation of cold ironing and other control measures at the Port of Long Beach.

As of this writing, there is only one commercial cold ironing application of an appreciable size in actual operation (Section 3 of this report provides a more detailed analysis), and none of the other control technologies considered in this study are known to have been put into commercial operation. Accordingly, this study relies heavily upon reasonable assumptions and best professional judgments.

The first large-scale cruise vessel cold ironing installation in the world was in Juneau, Alaska, and, by the 2002 cruise season, five Princess Cruise vessels were using shore power when they docked in Juneau. This application serves the five Princess passenger vessels only; no cargo vessels use the facility. Princess spent approximately \$5.5 million to construct the shore side

facilities and to retrofit the vessels (about \$500,000 each). Princess estimates the cost of the shore power (which is about a third the cost of power in Southern California) to be approximately \$1,000 per vessel per day more than the cost of running the on-board diesel generators. No oceangoing commercial vessel cold ironing operations currently exist, although it is likely that in 2004 vessels operated by China Shipping will begin calling at Berth 100 in the Port of Los Angeles, where they will be required to use shore side electrical power.

The information gathered during this study including the recent vessel activity data from the Marine Exchange of Southern California, led to the selection of 12 vessels and associated berths at the Port of Long Beach for a detailed cost effectiveness study. The selected vessels (Table 1-2) represent a cross section of various vessel types, vessel ages, service routes, and Port call frequency, and provide useful surrogates for possible candidate vessels for cold ironing or other emission control strategies; their selection does not mean that those specific vessels should or should not be retrofitted.

Hotelling emissions were calculated based on the time at dock per call (hours), number of calls per year, generator load (kilowatts, denoted by the symbol kW), and the pollutant emissions factors of their auxiliaries (pounds per kilowatt-hour [lbs/kW-hr]). As Section 4 of this report shows, time at dock for the 12 study vessels ranged from 12 hours (Carnival's *Ecstasy*) to 121 hours (a large container vessel), calls per year ranged from 1 (a tramp bulk vessel) to 52 (*Ecstasy* for a partial year), and generator load from 300 kilowatts (a small coastal tanker) to 7,000 kilowatts (*Ecstasy*). This wide range of characteristics indicates the technical complexity of the hotelling emissions issue. Table 1-3 and Figure 1-2 show the results of the emissions calculations. These figures are the target of the various emissions control strategies and represent the theoretical maximum reduction that could be gained by eliminating all hotelling emissions from the study vessels.

Cost effectiveness estimates were calculated by developing conceptual designs for cold ironing installations at the various berths where the study vessels docked and for retrofitting the vessels to receive the shore side power, and by evaluating the application of the other emission control technologies considered to the study vessels. Conceptual designs for providing shore-side electrical power to the 12 study vessels (Section 5) included the needs and costs of upgrading Southern California Edison's (SCE) transmission and distribution infrastructure, constructing in-port and in-terminal facilities, retrofitting the vessels, and operating and maintaining the facilities. These figures were used to calculate the cost effectiveness of cold ironing (cost per ton of emissions reduction) for each study vessel. A similar approach was used to calculate the cost effectiveness of the other control technologies considered in this study. The cost effectiveness

calculations utilized standard SCAQMD methodologies and were based on a number of assumptions (Section 6 of this report), the most important of which were:

- Existing vessels and berths are retrofitted for shore side power or exhaust control/clean diesel technologies; the analysis did not consider the case of new terminals or new vessels, both of which cases would be more cost-effective and would avoid some of the operational, safety, and engineering challenges of retrofitting;
- Electricity would be purchased from SCE at its current TOU-8 tariff, which makes no allowance for any alternative pricing structure that SCE might develop for cold ironing;
- The life of the project over which costs are accumulated and amortized is assumed to be 10 years and the service life of all vessels is assumed to be 15 years; and
- The costs associated with the loss of service of a berth or vessel while it is being retrofitted were not included because no reliable figures are available. In the case of a berth, those costs could be several million dollars per retrofit.

It should be noted that all costs used in this study were estimated based upon the information available at the time of this report, were not reviewed by the stakeholders (i.e., vessel and terminal operators and SCE), and reflect technical assumptions that may not be valid for specific applications. However, SCE did provide the estimates of purchased power cost.

Table 1-2. Selected Vessels and Berths in the Study

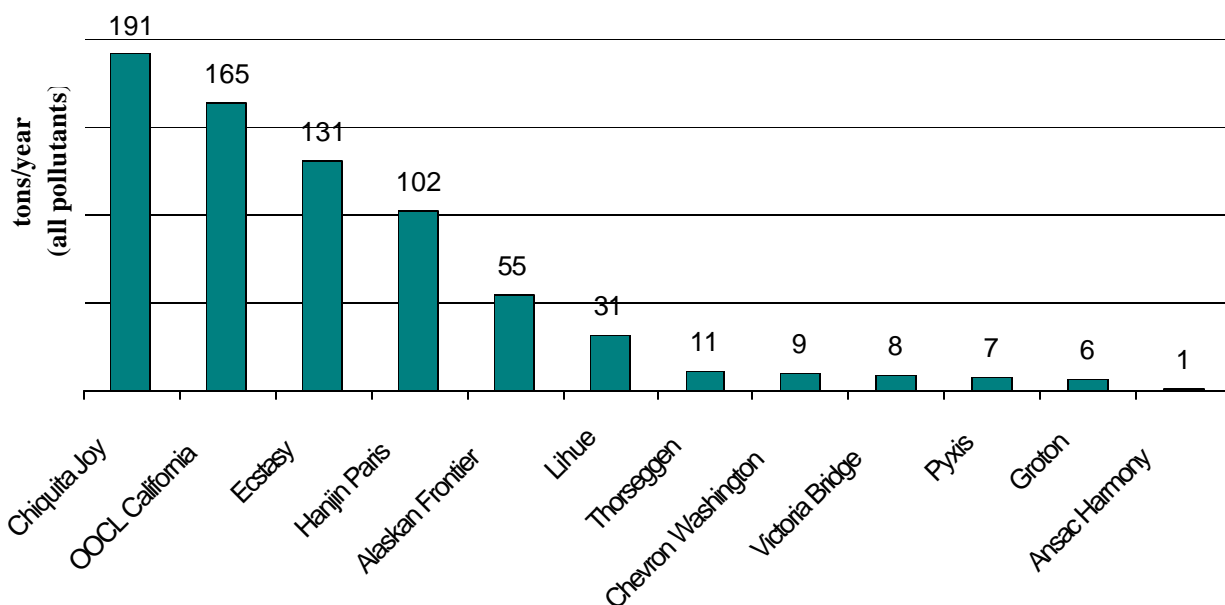
Vessel Type	Vessel Name	Vessel ID	Year Built	Vessel Operator	Usual Terminal & Berth	Terminal Operator	Average Berth Time (hrs/call)	Calls per Year
Container	<i>Victoria Bridge</i>	9184926	1998	K-Line	J232	International Transportation Services	44	10
Container	<i>Hanjin Paris</i>	9128128	1997	Hanjin	T136	Total Terminals	63	10
Container	<i>Lihue</i>	7105471	1971	Matson	C62	SSA Terminals	50	16
Container/Reefer	<i>OOCL California</i>	9102289	1996	OOCL	F8	Long Beach Container Terminal	121	8
Reefer	<i>Chiquita Joy</i>	9038945	1994	Inchcape/WD	E24	California United Terminals	68	25
Cruise	<i>Ecstasy</i>	8711344	1991	Carnival	H4	Carnival	12	52
Tanker	<i>Alaskan Frontier</i>	NA	2004	Alaska Tanker	T121	ARCO Terminal Services Corp	33	15
Tanker	<i>Chevron Washington</i>	7391226	1976	Chevron Texaco	B84	Shell	32	16
Tanker	<i>Groton</i>	7901928	1982	BP	B78	ARCO Terminal Services Corp.	56	24
Dry Bulk	<i>Ansac Harmony</i>	9181508	1998	Transmarine	G212	Metropolitan Stevedore	60	1
RO-RO	<i>Pyxis</i>	8514083	1986	Toyofuji	B83	Toyota	17	9
Break Bulk	<i>Thorseggen</i>	8116063	1983	Seaspan Shipping	D54	Forest Terminals	48	21

To estimate the net hotelling emission shown in Table 1-3, this study accounted for air emissions associated with shore-based power generation (Section 6) using USEPA standard emission factors, associated with berthing time and engine load derived from survey data.

Table 1-3. Annual Hotelling Emissions

Vessel Name	Emission (tons/yr)					
	VOC	CO	NO _x	PM ₁₀	SO _x	Combined
<i>Victoria Bridge</i>	0.0	0.7	3.8	0.43	3.5	8.4
<i>Hanjin Paris</i>	0.6	2.3	53.9	4.93	40.4	102
<i>Lihue</i>	0.1	0.4	4.1	3.64	22.8	31.1
<i>OOCL California</i>	0.7	13.7	73.5	8.36	68.4	165
<i>Chiquita Joy</i>	0.9	15.9	85.5	9.72	79.5	191
<i>Ecstasy</i>	0.8	2.9	69.3	6.34	51.9	131
<i>Chevron Washington</i>	0.1	0.1	7.4	0.29	1.5	9.4
<i>Groton</i>	0.1	0.6	4.3	0.10	0.4	5.5
<i>Alaskan Frontier</i>	0.4	1.4	25.3	2.98	24.4	54.5
<i>Ansac Harmony</i>	0.0	0.1	0.5	0.06	0.5	1.2
<i>Pyxis</i>	0.0	0.6	3.2	0.36	3.0	7.1
<i>Thorseggen</i>	0.1	1.6	8.6	0.15	0.6	11.0
Total	3.9	40.3	340	37.4	297	718

Figure 1-2. Annual Hotelling Emissions



Many emission control measures reduce only a single pollutant, such as nitrogen oxides (NO_x) or PM₁₀, but some reduce multiple combustion-generated pollutants. The cost effectiveness calculations considered the total quantity of criteria pollutant emission reductions, treating each pollutant as equally important. While there are varying health effects for each pollutant, there is no standard method for taking those differences into account in cost effectiveness evaluations. After estimating the cost of potential emission reductions, the total Net Present Value (NPV) of each control technology for each vessel was developed. Cost effectiveness was then calculated using the following formula. This formula has been used by SCAQMD in a multiple-pollutant rule development process.

$$\text{Cost Effectiveness} = \frac{\text{Total Net Present Value (\$)}}{\text{Total Emission Reduction of All Pollutants over the Project Life (tons)}}$$

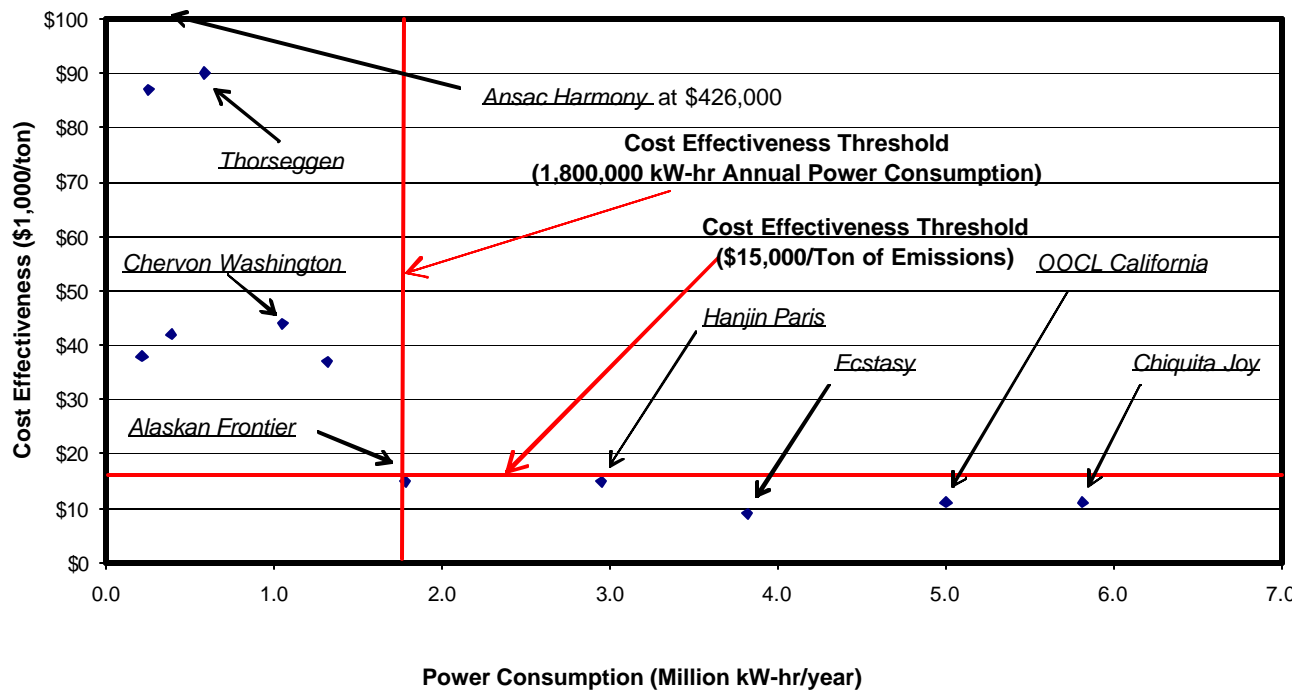
This method provides cost effectiveness values in dollar per ton of reduction and a ranking among the 12 vessels. There is no broadly accepted method for calculating a cost effectiveness threshold for control measures for multiple pollutants. The cost effectiveness values for the 12 vessels evaluated in this study have a significant break as shown on Figure 1-3, where the most cost-effective vessels have values less than \$15,000/ton, and the other vessels are far higher. This value is important because, for example, the SCAQMD Governing Board Policy for VOCs is not to adopt retrofit rules that cost more than \$13,500/ton unless special analyses are done. Moreover, the Carl Moyer program has a threshold for NO_x emissions of \$13,600/ton of NO_x for projects that use that funding mechanism. Based on the natural break that appears in the cold ironing values and the comparison with other cost effectiveness values and thresholds, the study selected \$15,000/ton of total pollutant removed as the threshold for cost effectiveness.

Based on this cost effectiveness criterion, this study found that five of the 12 study vessels – the cruise ship *Ecstasy*, the refrigerator vessels *Chiquita Joy* and *OOCL California*, the container ship *Hanjin Paris*, and the tanker *Alaskan Frontier* – would be cost-effective candidates for shore-side electrification, or cold ironing (Figure 1-3). These vessels share the characteristics of high hotelling power demand, frequent port calls, and, except in the case of the cruise ship, significant time at berth per call. These factors combine to result in significant annual energy consumption (kW-hr) and, therefore, greater potential for emissions reductions. As Table 1-3 shows, cold ironing those five vessels would eliminate about 90 percent of the emissions generated by the twelve study vessels. The remaining seven vessels do not meet the cost effectiveness criterion of approximately \$15,000 per ton of emissions reductions, primarily because of the combination of low power demand and fewer vessel calls.

Further, and upon close review of Figure 1-3, it becomes apparent that annual power consumption by a vessel at berth is the best single indicator of cost effectiveness. This analysis shows that cold

ironing is generally cost effective as a retrofit when the annual power consumption is 1,800,000 kW-hr or more (Figure 1-3). Table 1-4 shows the vessel calls, power consumption, and cost effectiveness for the 12 study vessels. For a new vessel with cold ironing equipment installed calling at a terminal with cold ironing capability installed during the construction of the terminal, cold ironing would generally be cost-effective if the vessel's annual power consumption exceeds 1,500,000 kW-hrs.

Figure 1-3. Cost Effectiveness vs. Annual Power Consumption



Section 7 evaluates the feasibility and costs of other emission control technologies as alternatives to cold ironing in vessel auxiliary generators with for reducing vessel hotelling emissions. Some more advanced concepts for emission control were not investigated in this study such as fuel-cell technology, non-thermal plasma technology, NO_x adsorbers, lean NO_x catalyst, battery-electric technology, and flywheel technology. At this time, there is not enough information about these technologies to assess their feasibility for marine vessel hotelling applications.

Further, based on low emission reductions, the questionable state of currently available equipment, inadequate fuel availability, and other specific constraints to implementation, the technologies in Table 1-5 were not considered feasible near-term (i.e., within the next ten years) alternatives for the POLB. Of particular concern is the fact that several technologies only address NO_x emissions and several of those actually increase diesel particulate emissions, whereas the reduction of diesel particulates is a key goal of any POLB emissions reduction strategy. Another concern with

Table 1-4. Vessel Calls, Power Consumption, and Cost Effectiveness

	<i>Victoria Bridge</i>	<i>Hanjin Paris</i>	<i>Lihue</i>	<i>OOCL California</i>	<i>Chiquita Joy</i>	<i>Ecstasy</i>	<i>Chevron Washington</i>	<i>Groton</i>	<i>Alaskan Frontier</i>	<i>Ansac Harmony</i>	<i>Pyxis</i>	<i>Thorseggen</i>
Total calls per year	10	10	16	8	25	52	16	24	15	1	9	21
Average Berth Time (hrs/call)	44	63	50	121	68	12	32	56	33	60	17	48
Average Power Demand at Berth (kW)	600	4,800	1,700	5,200	3,500	7,000	2,300	300	3,780	600	1,510	600
Total Annual Power Use (Million kW-hr)	0.3	3.0	1.3	5.0	5.8	3.8	1.1	0.4	1.8	0.0	0.2	0.6
Cost Effectiveness (\$1,000/ton)	\$87	\$15	\$37	\$11	\$11	\$9	\$44	\$42	\$15	\$426	\$38	\$90
Ranking	10	5	6	3	2	1	9	8	4	12	7	11
Cost-Effective (Yes/No)	No	Yes	No	Yes	Yes	Yes	No	No	Yes	No	No	No

technologies outlined in Table 1-5 (on the following page) is the potential that most of the cleanest diesel fuels cannot be used safely (per the International Convention for the Safety of Life at Sea [SOLAS] regulations) in marine vessels because their flash points and viscosities are much lower than those of the heavy fuel oil for which modern auxiliary marine diesel engines and fuel systems are designed and calibrated. Accordingly, none of these technologies were considered cost-effective and practical for application at the Port of Long Beach at this time.

Finally, several technologies for reducing hotelling emissions as alternatives to cold ironing were identified for examination in this report. These technologies fell into five basic categories:

- Engine Repowering (replacing auxiliaries with cleaner diesel engines [EPA Tier 2 standards] or natural gas engines);
- Clean Diesel Fuel (marine gas oil, CARB #2 diesel, emulsified diesel, Fischer-Tropsch diesel, bio-diesel);
- Combustion Management (injection timing delay, direct water injection, humid air motor technology, exhaust gas recirculation);
- Exhaust Gas Treatment (diesel oxidation catalysts with CARB #2 diesel, diesel particulate filters with CARB #2 diesel, selective catalytic reduction); and
- Cryogenic Refrigerated Containers (to reduce the electrical demand of refrigerated containers).

Note that most of these technologies are ship-based: little or no landside infrastructure would be required, although some provision might need to be made for additional fueling facilities.

Table 1-5. Not Practical Near-term Alternatives for POLB

Technology	Facts Considered
Injection Timing Delay	Increases PM, CO and VOC emissions
Exhaust Gas Recirculation	May increases PM, VOC and CO emissions
Direct Water Injection	Only reduces NO _x emissions
Humid Air Motor	Only reduces NO _x emissions
Selective Catalytic Reduction	Only reduces NO _x emissions
Repowering with EPA Tier 2 Engine	Only reduces NO _x emissions
Fischer-Tropsch Diesel	No adequate fuel supply available; Difficulty to distribute to vessels
Bio-Diesel (B100)	Increases NO _x emissions; Difficulty to distribute to vessels
CARB No. 2 Diesel Fuel	Flash point too low to be allowable under the Safety of Life at Sea (SOLAS) regulations.
Diesel PM Trap with CA On-road #2 Diesel	Flash point too low to be allowable under SOLAS regulations; Fuel distribution to vessels; no marine application yet.
Diesel Oxidation Catalyst with CA On-road #2 Diesel	Flash point too low to be allowable under SOLAS regulations; Fuel distribution to vessels; no marine application yet.
Cryogenic Refrigerated Container	Has not reached large scale application yet

Table 1-6 lists those technologies that have demonstrated potential benefits for overall emission reductions and potential applicability to marine vessels.

Table 1-6. Potential Alternatives to POLB

Technology	Potential Implementation Constraints	Average Cost Effectiveness	Cost-Effective Vessels
MGO Diesel	Design and operation of engine; Separate fuel system and delivery infrastructure	\$4,000/ton (No NO _x reduction)	All Vessels except for <i>Groton</i> , <i>Thorseggen</i> , and <i>Chevron Washington</i>)
Repowering with NG/Dual Fuel Engine	Safety concerns; fuel distribution system, separate on-board fuel system; in-use compliance if dual fueled engine	\$9,000/ton	All Vessels except for <i>Anzac Harmony</i>
Emulsified Diesel Fuel	Includes effectiveness of MGO use; Fuel distribution to vessels; design and operation of engine; separate fuel system; in-use compliance; loss of power; fuel phase separation.	\$42,000/ton	Seven Vessels (except <i>Groton</i> , <i>Anzac Harmony</i> , <i>Pyxis</i> , <i>Thorseggen</i> , and <i>Chevron Washington</i>)

However, they should not be considered readily available alternatives at this time until the identified implementation constraints are adequately addressed. A number of implementation issues would need to be investigated more thoroughly than the scope of this study permitted including safety, on-board fuel system and engine capabilities, and proven demonstrations on large vessels.

Several of the technologies have been demonstrated to reduce emissions and have potential feasible application to marine vessels (Table 1-6 above) although, as mentioned above, none (with the exception of low sulfur marine gas oil (MGO)) has actually been widely, if ever, applied to international cargo vessels. The use of other fuel types (natural gas, on-road diesel, and emulsified diesel) could have unforeseen issues with safety (most especially volatility and flammability), operation (such as fuel filter plugging, fuel pump or injector leakage, or compatibility with other marine fuels), and practical considerations including the construction cost and space limitations of maintaining separate fueling systems. After treatment devices, such as oxidation catalysts or especially particulate (PM) traps, have taken years of development to produce viable retrofits for use with on-road diesel engines, so application onto marine engines is likely to reveal additional implementation considerations.

There are many additional issues generally outside of the scope of this study that require more investigation, including safety of fuels and hardware, practical considerations of the size and cost of new and/or additional engines and fuel systems, compatibility of fuels and engines, and other issues that may be discovered only during the implementation of these alternative methods. In most cases, the measures reviewed below have not been widely, if at all, employed on large commercial vessels. Some of the more important of the issues are discussed below:

According to the ISO standards 8217 and 2719, marine fuel must have a flashpoint of a minimum of 60° C. According to SOLAS Chapter 11-2, part B, Regulation 4, no fuel oil with a flashpoint of less than 60°C shall be used. The flashpoint of MGO fuel is between 57°C and 69°C. This fuel should only be used if the flash point of the specific fuel is above 60°C. California on-road diesel No. 2 has a flash point less than 60°C, and so this measure along with other exhaust treatment devices such as diesel oxidation catalysts and diesel particulate filters that rely on this fuel were eliminated for safety reasons.

Other fuel switching alternatives have significant costs and uncertainties related to the availability of the fuel, the distribution systems for the fuel, on-board storage of the fuel, and the modifications required to burn the fuel in engines designed for other fuels. Another concern is related to the fact that some fuels are not broadly available, so that the vessels would have to incur additional costs to switch back and forth from the conventional fuels to the alternatives. The study did not evaluate the cost of making that switch.

Many regulatory, logistical, and labor relations issues could affect implementation of cold ironing. These are discussed in Section 8. There is no regulatory agency with the clear authority to require cold ironing or any of the alternative control measures discussed in this report.

All these possible control techniques have significant regulatory, legal, and logistical hurdles to overcome, particularly if the SCAQMD or other local agency wishes to mandate their use. Given such constraints, a voluntary program, or an incentive program may be the most productive means of reducing emissions from hotelling in the Port of Long Beach.

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2.0 INTRODUCTION

2.1 Background

International trade and commerce at the Port of Long Beach (the Port or POLB), which is currently ranked the second busiest container port in the United States, directly and indirectly supports approximately 30,000 jobs in the City of Long Beach¹. In the fiscal year 2002, 65.5 million metric tons of cargo with a total value of approximately \$100 billion was moved through the Port. As outlined in the Port's Facilities Master Plan, the Port is expecting to handle in excess of 16,638,500 twenty-foot-long cargo container units (TEUs) by the year 2020 at its container terminals, over three times its present activity. Significant increases of cargo movements are also predicted at non-container terminals in the Port.

While docked at the Port, cargo vessels shut down their propulsion engines but typically use auxiliary diesel engines to provide electrical power for refrigeration, lights, pumps, cargo handling gear, and other functions, a practice called "hotelling." The major emissions from those engines are nitrogen oxides (NO_x), sulfur oxides (SO_x), and diesel particulate matter (PM). These emissions are currently uncontrolled for most vessels. While the South Coast Air Basin currently meets the National Ambient Air Quality Standards for both NO₂ and SO₂, NO_x emissions combine with volatile organic compounds in the presence of sunlight to produce ozone, which has a number of adverse health effects. NO_x and SO_x emissions also contribute to particulate matter levels through the secondary formation of nitrates and sulfates. Diesel particulate matter contributes directly to particulate matter levels, which the California Air Resources Board (CARB) listed in 1998 as a cancer-causing toxic air contaminant.

The health effects of particulate matter include:

- Aggravated asthma;
- Increased respiratory symptoms, specifically coughing and difficult or painful breathing;
- Chronic bronchitis;
- Decreased lung function; and

¹ http://www.polb.com/html/2_community/economicImpacts.html

- Premature death

The toxic health risks of diesel particles have become better understood in the last ten to fifteen years. Hundreds of compounds have been identified as constituents of diesel particles. These compounds include polycyclic aromatic hydrocarbons (PAHs), formaldehyde, and 1,3-butadiene which have been associated with tumor formation and cancer. Diesel particles are microscopic; more than 90 percent of them are less than 1 micron in diameter; which allows them to penetrate deeply into the lung, where they may cause long term damage.

The South Coast Air Quality Management District's (SCAQMD) recent research project, the Multiple Air Toxics Exposure Study II (MATES II), concluded that diesel particulate matter is responsible for about 70 percent of the total cancer risk from all toxic air pollution in the South Coast Basin. Risk levels were higher in certain parts of the Basin, including areas around the Ports of Los Angeles and Long Beach.

Studies indicate that diesel emissions may also be a problem for asthmatics. Some studies suggest that children with asthma who live near roadways with high amounts of diesel truck traffic have more asthma attacks and use more asthma medication. Because of the quantity of emissions and the potential health impacts, the SCAQMD Governing Board has identified them as a source of air pollution warranting regulation.

Vessel call data, provided by Marine Exchange of Southern California, indicates that during the period of June 1, 2002 to May 31, 2003, a total 1,148 vessels made 2,913 calls at POLB. The primary types of vessels entering the POLB were container vessels with 1,231 calls, tankers with 634 calls, and dry bulk cargo vessels, with 364 calls. Table 2-1, a summary of NO_x emissions by mode for oceangoing vessels, is extracted from the latest emission inventory [Arcadis, 1999] for the San Pedro Bay ports (Port of Los Angeles and the Port of Long Beach combined). The report indicated that 33.0 tons per day (tpd) of NO_x from vessel approaching and within the ports used port, 11.0 tpd of NO_x were derived from vessel auxiliary engines operating in hotelling mode. The situation with respect to diesel particulates is similar.

**Table 2-1. Inventory Results for Oceangoing Vessels Calling at
San Pedro Bay Ports: 2000, NO_x tons per day**

Mode	In-Port NO _x emissions (tons/day)			
	Main Propulsion Engine	Auxiliary Engine	Auxiliary Boiler	Totals
Cruising	16.2	1.4	--	17.6
Maneuvering	2.0	0.7	0.1	2.8
Hotelling	0.7	11.0	1.0	12.7
Total	18.9	13.1	1.1	33.0

ENVIRON International Corporation (ENVIRON) was retained by the Port to conduct this cost effectiveness study of reducing air emissions from vessel hotelling. The study evaluated cold ironing (using shore generated electric power rather than running the vessel's auxiliary internal combustion engines) and other emissions reduction measures such as exhaust controls on auxiliary engines and/or using cleaner-burning fuels in the auxiliary engines. It should be noted that the scope of this report does not include evaluating alternative heating sources to replace the steam boilers that many vessels must operate while at berth. The report assumes that vessels' auxiliary boiler(s) would still provide steam for fuel heating, galleys, and comfort heating.

As an estimated one-third of in-port vessel emissions occur while the vessels are at berth, cleaning up the exhaust of auxiliary engines or replacing the engines with on-shore electric power could significantly reduce emissions. This study analyzed a range of factors such as vessel retrofit requirements, power demands, shore-side infrastructure needs, estimated costs, and potential emission reductions.

2.2 Previous Studies

Over the years, several studies, examples of which are described below, have been conducted to evaluate the cost-benefit of implementing cold ironing technology to reduce vessel hotelling emissions.

Feasibility Study. SCAQMD, 1987

The only pollutant considered in this study was NO_x. Total NO_x emissions from all vessels at berth were estimated at 9.0 tons per day. Total expected NO_x emission reductions from cold ironing were 4.7 tons per day. The SCAQMD estimated the cost effectiveness of reducing 4.7 tons NO_x per day for non-tanker motor vessels to be \$28,115/ton. The report cited advantages of cold ironing, which included reducing emissions of NO_x, SO₂ and PM; freeing vessel personnel assigned to operate power equipment for other work; providing time for inspection and small repairs; and reducing

noise levels on and near the vessel. Disadvantages were also identified. The United States Coast Guard and the Los Angeles Fire Department expressed concern over the safety of operations while vessels are being connected or disconnected from shore power, and the high cost and long lead times to engineer and retrofit power lines, substations and vessels. This study made several assumptions that compromised its accuracy, such as the assumption that the purchased power would have the same cost as running the vessel's engines. Purchased power in fact is likely to be over six times more expensive.

This study was part of the rule-making process for the proposed Rule 1165, Emissions of Oxides of Nitrogen from Ships at Berth. However, after a lengthy evaluation by both the District and the Ports of Los Angeles and Long Beach, the SCAQMD terminated the rule making process and did not adopt a cold ironing rule.

Port of Long Beach Electrification and Ship Emission Control Study, Southern California Edison, 1990

Under contract to SCE, the team of Bechtel Power Corporation, Moffatt & Nichol, Engineers, and Applied Utility Systems, Inc. examined the feasibility and cost of providing the shore-to-vessel power and infrastructure required for the Port of Long Beach. This study evaluated thirty vessels and twelve piers in the Port of Long Beach. The design electrical load associated with electrification was estimated to be approximately 40 MW, with an estimated average load of 15 MW. The maximum electric load by vessel type was 2.5 MW for a tanker. The study found that the present Edison Company electrical distribution facilities were not adequate to accommodate the added loads imposed by vessels at berth. The existing service system for most terminals was designed only for buildings, transit sheds, silos, cranes and lighting, and could not be utilized to supply vessel electrification requirements. New and separate electrical substations and vessel service connections would be needed. The total capital costs to the vessel operators associated with cold ironing were estimated at \$170.2 million, excluding land acquisition costs and interest during the construction, etc. Annual operating and maintenance (O&M) costs would be \$14.5 million, including the cost of electricity.

Control of Ship Emissions in the South Coast Air Basin, Port of Los Angeles and Port of Long Beach, 1994.

This report was generated in response to the proposed Federal Implementation Plan (FIP) released by the USEPA on February 15, 1994. The report evaluated cold ironing along with other NO_x control alternatives such as emission fees; retrofit technologies, and vessel speed reductions. The study concluded that shore-to-vessel electrification was feasible for small marine vessels, such as tugboats and workboats, because they have a home base where they always moor and their power demands are substantially lower than those of cargo vessels.

2.3 Objectives of the Present Study

The objectives of this cost effectiveness study is to:

- Assess and update opportunities and constraints associated with cold ironing and other potential emissions control measures;
- Identify vessel-side and land-side infrastructure requirements for cold ironing and other measures;
- Provide a conceptual cold ironing system design;
- Evaluate the cost effectiveness of cold ironing and other emission control options; and
- Address potential labor, legal and regulatory issues associated with the implementation of cold ironing and other control measures at the Port of Long Beach.

2.4 General Approach

Several information gathering meetings with various stakeholders were held as the initial step of performing this cost effectiveness study. The project team met with vessel operators, terminal operators, Southern California Edison, the United States Coast Guard, and regulatory agencies to obtain their views, concerns, and positions on cold ironing, barge-based clean fueling and other alternative control options. A report of findings from the information gathering meetings was submitted to the Port separately, and is included as Appendix A. Section 8 of this report presents an analysis of the legal and regulatory issues related to cold ironing.

This study is based on vessel call data obtained from the Marine Exchange of Southern California for the 12-month period of June 1, 2002 to May 31, 2003. The study then selected 12 vessels and associated berths for a detailed study. Vessels selected represent various vessel types, vessel ages, service routes, and port call frequencies. The vessels were selected based on the number of calls they make, the time at berth, and the size of auxiliary engine loads, with the goal of evaluating a range of candidates, from those that are most likely to be good candidates for cold ironing to those that are not. Table 2-2 lists the selected vessels and berths in this study.

The project team attempted to contact each selected vessel via telephone, fax, electronic mail, or personal visit. A survey questionnaire requesting information about the vessel's specific operating profile, fueling practices, and electrical system was provided to each vessel. In addition, the project team supplemented the survey data with information provided by Port staff, Lloyds Register, MarineData.com and the Clarkson Register. This data is included in Appendix B.

Table 2-2. Selected Vessels and Berths in the Study

Vessel Type	Vessel Name	Vessel ID	Year Built	Vessel Operator	Usual Berth	Terminal Operator	Average Time at Berth (hrs/call)	Calls per Year
Container	<i>Victoria Bridge</i>	9184926	1998	K-Line	J232	International Transportation Services	44	10
Container	<i>Hanjin Paris</i>	9128128	1997	Hanjin	T136	Total Terminals (TTI)	63	10
Container	<i>Lihue</i>	7105471	1971	Matson	C62	SSA Terminals	50	16
Container/Reefer	<i>OOCL California</i>	9102289	1996	OOCL	F8	Long Beach Container Terminal	121	8
Reefer	<i>Chiquita Joy</i>	9038945	1994	Inchcape/WD	E24	California United Terminals	68	25
Cruise	<i>Ecstasy</i>	8711344	1991	Carnival	H4	Carnival	12	52
Tanker	<i>Alaskan Frontier</i>	NA	2004	Alaska Tanker	T121	ARCO Terminal Services Corp	33	15
Tanker	<i>Chevron Washington</i>	7391226	1976	Chevron Texaco	B84	Shell	32	16
Tanker	<i>Groton</i>	7901928	1982	BP	B78	ARCO Terminal Services Corp.	56	24
Dry Bulk	<i>Ansac Harmony</i>	9181508	1998	Transmarine	G212	Metropolitan Stevedore	60	1
RO-RO	<i>Pyxis</i>	8514083	1986	Toyofuji	B83	Toyota	17	9
Break Bulk	<i>Thorseggen</i>	8116063	1983	Seaspan Shipping	D54	Forest Terminals	48	21

This study estimated power demand for the selected vessels based on survey responses. For the several vessels not responding to the survey, the installed generator capacity and number of engines were obtained from the Lloyd's Register; and the power demand was estimated based upon the requirements of similar vessels.

Vessel hotelling emissions from 12 study vessels were estimated as a function of time at dock (hours), average power demand (kilowatts or kW) (Section 4), and the pollutant specific emission factor (lbs/kW-hr). The emission factors for different types of engines and motors are described in Appendix D. Annual emissions are for all port calls throughout the year, therefore the number of calls per year is multiplied by the average emissions per call. Vessels with a large number of calls, long times at dock, and large electrical loads are more likely to produce higher emissions while at a dock. To account for air emissions associated with shore power generation, this study utilized emission factors derived from AP-42, assuming in-basin power generators are conventional natural gas fired steam plants with selective catalytic reduction (SCR) for NO_x control and no CO catalyst.

A conceptual engineering design was prepared based upon the requirements for cold ironing the 12 study vessels (Section 5). Engineering needs were identified as well as the financial requirements for improving Southern California Edison (SCE) power transmission, distribution infrastructure, constructing terminal facilities, and for vessel retrofitting.

This study provides a cost effectiveness analysis for cold ironing 12 study vessels (Section 6). Cost effectiveness is defined as the total cost of the control measure required to achieve a given emission reduction, and is presented as the net present value (NPV) in dollars per ton of emissions reduced. One time capital costs and the ongoing operating costs are combined to generate the NPV using the Discounted Cash Flow (DCF) method.

The following costs were applied to the cost effectiveness analysis for cold ironing and near-term control technologies:

- (1) One-time capital costs, including costs for improving the Southern California Edison (SCE) infrastructure, costs for constructing in-terminal facilities (e.g. substations, cable and hose handling gear, work-barges, fuel handling facilities, etc.) and costs for retrofitting vessels for cold ironing;
- (2) Operating and Maintenance (O&M) costs, including annual energy costs for purchasing electrical power from SCE, increased maintenance of emissions control equipment, and fuel cost savings generated by purchasing shore generated power instead of running auxiliary diesel engines.

This study also evaluated the feasibility and cost of the following near-term emission control technologies for reducing vessel hotelling emissions (Section 7):

(1) Engine Repowering or Replacement including

- Using USEPA Tier 2 Engines and
- Using natural gas (NG)/Dual-Fuel™ Engines

(2) Clean Fuel Strategy including

- Using marine gas oil (MGO);
- Using California #2 on-road diesel;
- Using emulsified diesel;
- Using Fischer-Tropsch diesel; and
- Using bio-diesel (B100)

(3) Combustion Management including

- Injection timing delay;
- Direct water injection (DWI);
- Humid air motor (HAM); and
- Exhaust gas recirculation (EGR)

(4) Exhaust Gas Treatment including

- Diesel oxidation catalyst with California #2 diesel fuel;
- Catalyzed diesel particulate filter with California #2 diesel fuel; and
- Selective catalytic reduction (SCR)

(5) Cryogenic Refrigerated Containers

The following key issues are among many factors considered in the evaluation of the proposed alternative technologies:

- Identification of technologies that reduce diesel particulate matter, a CARB listed air toxic;
- Availability of equipment and fuel associated with the technology;
- Extent of infrastructure impact on vessels and/or on land during implementation;
- Operational practicability, including operating safety issues

REFERENCES

ARCADIS, 1999. "Marine Vessels Emissions Inventory, UPDATE to 1996 Report: Marine Vessel Emissions Inventory and Control Strategies, Final Report" ARCADIS, 23 September 1999.

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3.0 CURRENT STATE OF COLD IRONING

The current applications of cold ironing around the world are summarized below.

3.1 Princess Cruise Vessels in Juneau, Alaska

The first cruise vessel cold ironing installation anywhere in the world was in Juneau, Alaska (R. Maddison, 2002). On July 24, 2001, the Princess Cruises vessel Dawn Princess operated completely on shore power for about 10 hours. By the 2002 cruise season, all five Princess Cruise vessels were converted to use shore power when they moored in Juneau. The Juneau project was initiated in order to comply with the local opacity standard. The application serves Princess passenger vessels only, no cargo vessel use the facility. Shore power is supplied by Alaska Electric Light & Power (AEL&P) from its local surplus hydroelectric power. The Juneau cold ironing system provides both electric power and steam, which is produced by an electric boiler. It should be noted that even at dock the vessel's boilers are run in a low-fire mode to prevent excessive smoking on start up.

Capital Costs

Princess Cruises provided \$5.5 million for the Juneau project to supply both electricity and steam. The \$5.5 million, \$4.7 million was spent to install the shore-side facilities (an onshore power distribution facility) and an average of about \$500,000 was spent per vessel for retrofitting. Significant cost (approximately \$150,000 each vessel) was incurred to modify the on-board power management software to synchronize the onboard power with the onshore supplied power. Each vessel was outfitted with a new door, an electrical connection cabinet, and the necessary equipment to automatically connect the vessel's electrical network to the local onshore electrical network. Each vessel's technical office area on deck 4 was used as the point of entry for the power connection. A 4- by 2.5-meter steel bulkhead was installed between adjacent steel decks to provide the A-0 fire class condition required to connect to a high voltage (6.6 KV) power source. The Sun Class vessels have four Sulzer 16ZAV40S engines driving four GEC generators delivering 6.6 KV, 3-phase, 60 Hz power. Each Sun Class vessel was originally constructed with one spare 6.6 KV breaker on its switchboard. The cable connection on the vessel is a traditional male/female plug and socket that was adapted from the American mining industry.

Operating Costs

Princess Cruises Sun Class vessels require about 7 MW of power at 6.6 KV, but the Grand Class will require 11 MW at berth. Princess Cruises estimated a cost of \$4,000 - \$5,000 per day for a Sun Class vessel to purchase power from AEL&P, compared to a cost of \$3,500 per day to run the diesel engines while in port at Juneau.

Operation

Electrical power is transmitted from a three-stage transformer onshore via four 3-inch diameter flexible cables that connect to the vessel. A special 135-foot long, 25-foot high gantry system was built into the dock to support the connecting equipment, connection cables, and plugs. This transmission equipment was designed to accommodate a 20-foot change in the tide level and to withstand 100 mile per hour winds. The cable connection and disconnection is performed by Princess Cruise crew, but the shore-side substation is operated by AEL&P personnel. Pulling the cables aboard, connecting them to the vessel controls and beginning to run the vessel on onshore power varies from 20 minutes up to two hours. The same amount of time is needed for disconnecting shore power. Process safety is addressed through personnel training and implementing process checklists.

The onboard power management system (PMS) software was modified to recognize the onshore power supply as an additional (the 5th) onboard power-generating unit. The software synchronizes the onboard power with the onshore supplied power, adjusts the onboard voltage until it matches the onshore supply and then regulates the onboard frequency and phase until they match the onshore supply characteristics.

Princess Cruise Line is near completion of cold ironing its newest vessel – *Diamond Princess* -- at the Port of Seattle. The newly built *Diamond Princess* will be delivered to Princess Cruise Line in April 2004. It has all of the equipment required for cold ironing installed during construction. Power demand at berth is expected between 8 to 9 MW.

3.2 POSCO Dry Bulk Vessels in Pittsburg, California

Pohang Iron & Steel Company (POSCO) charters four dry bulk vessels, from Pittsburg, California, for ocean shipments between South Korea and the San Francisco Bay Area (David Allen, 2003). The vessels are cold ironed at the POSCO Pittsburg docking facility. The four vessels were built in South Korea between 1991 and 1997, all with cold ironing capabilities. POSCO does not own these vessels but has long-term chartering contracts with the vessels' owners, HANJIN, Korean Shipping, and HYUNDAI. These ships are not dedicated to POSCO; however, the POSCO Pittsburg is the only place where they receive shore power. The first vessel connected to shore power at the POSCO Pittsburg berth was in 1991.

Cold ironing to supply shore generated electricity and steam was required by a local air permit. The permit condition was based upon the need to mitigate the cumulative impact of emission increases in accordance with the California Environmental Quality Act (CEQA).

The vessels typically have a capacity of 38,000 metric tons, and are about 180 meters long. Shore power is transmitted by two 440-volt cables. The total circuit is limited by an 800-amp breaker, which limits the load to about 0.5 MW. The vessels have an average of 48 hours in berth per visit. After a vessel docks, two vessel crewmembers pull the power cables on board, attach them to the vessel's circuits, and test the polarity. The POSCO terminal operator activates the circuit upon request by the vessel operator. It takes three people up to 20 minutes to complete the process. According to the operator, the power is synchronized without a blackout occurring.

3.3 Ferry Vessels at Port of Gothenburg, Sweden

The Port of Gothenburg has two passenger and Roll-on/Roll-off (RO-RO) ferry terminals equipped with electric connections for cold ironing (Port GOT, 2003). Vessels at the terminals have assigned locations and run on regular scheduled routes. Vessels are operated by DFDS Tor Line AB, which currently offers eight voyages per week between Gothenburg and Immingham, England, and six voyages per week between Gothenburg and Ghent, Belgium. The project was initiated in cooperation with Stora Enso, a Swedish paper manufacturer, who was interested in reducing its transport emissions in order to achieve ISO 14001 Environmental Management System goals.

The system has operated since the year 2000 without problems. It utilizes a 10 kV cable and transforms the electricity on-board to 400 volts DC. Shore-power is supplied by local surplus wind generated power. Terminal operators make the power connections and disconnections. It takes less than 10 minutes to complete the process. Vessels' hotelling power demand ranges from 1 to 1.5 MW. According to the Port of Gothenburg, cold ironing of the six weekly vessels led to reductions of 80 metric tons NO_x, 60 metric tons SO_x and 2 metric tons PM per year. Moreover, at current electricity price levels, the on-shore electricity is reportedly less expensive than the electricity generation on-board.

The Port of Gothenburg believes that more vessels would retrofit their vessels if more ports would offer a standardized on-shore electrical connection. Different electrical voltage, frequency, and safety issues pose challenges to the cold ironing concept.

It should be noted that ferry vessels have a low hotelling power demand: the vessels receive shore power only for lighting and ventilation purposes. In addition, ferry vessels have no cargo moving machinery and have little dockside activities. Therefore, the Gothenburg electrification process is much simpler than oceangoing cargo vessels that are the subject of this study.

3.4 China Shipping Terminal at the Port of Los Angeles

The Port of Los Angeles (POLA) is undertaking an alternative maritime power (AMP) project at the China Shipping terminal, at Berths 97 - 109. The terminal has been retrofitted with conduit, wiring, and a transformer. Ship calls are expected to begin in 2004. The Los Angeles Department of Water and Power (DWP) and POLA have standardized the shore-side part of the system. DWP input is at 14.5 KV, which will be stepped down to 6.6 KV and provided to cargo vessels. For vessels using 440V, another step-down transformer could be placed on shore, on a barge or on the receiving vessel. DWP has stated that there is sufficient system capacity for providing the power for shore-side electrification without the need for developing new supplies.

At this time, POLA and potential shippers examining shore-side electrification are considering only new vessel applications. China Shipping has agreed to install cold ironing capabilities on its new vessels as long as the POLA pays for the capital costs of engineering and construction. The comparative operating costs of producing power for hotelling are \$0.089 per kilowatt-hour (kW-hr) at DWP's industrial rate, \$0.045/kW-hr using Marine Diesel Oil (MDO) or Marine Gas Oil (MGO) in vessel auxiliary engines, and \$0.0333/kW-hr using residual fuel oil in vessel auxiliary engines. China Shipping has not yet used the new terminal facilities as of this report.

3.5 U.S. Navy

The U.S. Navy generally cold irons its vessels at its stations (Dames & Moore, 1994). It was reported that most of U.S. Navy vessels are built with cold ironing connectors, breakers, and controls and most of U.S. Naval stations have the electrified infrastructure to provide the power. However, it should be noted that naval vessels, have very low electrical power demand while hotelling. In contrast, an off loading tanker requires much more power while at berth than while underway. It should also be noted that the time at berth of commercial cargo vessels (ranging from 24 to 48 hours) is much shorter than the extended port stay of a Navy vessel (weeks or even months). Having such a long time in port makes cold ironing cost effective for the U. S. Navy.

3.6 Muscat Cement Terminal at the Port of Los Angeles

Only limited information is available on cold ironing at Muscat Cement Terminal. However, the Muscat Cement Terminal was designed for a specific vessel with standard electrical connections, and the vessel is permanently moored in port. Therefore using Muscat Cement terminal as example of successful cold ironing vastly oversimplifies the various technical, economical, and regulatory issues addressed in this study.

3.7 Plan Baltic 21

The Port of Lübeck, Germany, is currently seeking to establish standard technical requirements for cold ironing in Baltic ports and to implement cold ironing at the Port of Lübeck (Stefan Seum, 2003). The port plans a 10 kV on-shore connection for its ferry and passenger terminals. The city is adjacent to a town known for its health spa but SO₂ thresholds are exceeded in the winter, thereby risking the town's reputation. Surplus wind-powered energy in Lübeck would make on-shore electricity cost only one-fourth the price of on-board generation. The City of Lübeck is working on a more extensive cold ironing plan, called Plan Baltic 21, with all Baltic port cities.

3.8 Sea-Launch Assessment

Long Beach-based Sea-Launch LLP has recently completed a preliminary assessment on the cost effectiveness of cold ironing (Charles Bajza, 2003). Sea Launch has two foreign-registered, uniquely designed, and operated vessels: one launch platform and one assembly and command vessel. While at berth at Pier T in the POLB, the vessel's power-generating units provide hotelling power including support of operations unique to rocket and spacecraft assembly, test and preparation for launch. Assuming a basic cost of self-generation at \$0.07/kW-hr and an average SCE commercial rate at \$0.15/kW-hr, the added operating cost with shore power would be an average of \$930,631 per year for the assembly and commander vessel, and \$1,107,972 per year for the launch platform. The cost to upgrade and/or replace the power supplies and install the necessary distribution substation would be in addition to those operating costs.

REFERENCES

R. Maddison, 2002. "Going Cold Ironing in Alaska." 2003

Port GOT, 2003. "Shore-Connected Electricity Supply to Vessels in the Port of Göteborg", 2003

David Allen, 2003. Personal Communications between David Allen and ENVIRON.

Dames & Moore, 1994. "Control of Ship Emission in the South Coast Air Basin" Dames & Moore and Morrison and Foerster, August 1994.

Stefan Seum, 2003. "Summary Report on EU Stakeholder Workshop on Low-Emission Shipping, September 4-5, 2003". September 2003

Charles Bajza, 2003. Personal Communications between Mr. Charles Bajza and ENVIRON.

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4.0 SHIP CHARACTERIZATION AND HOTELLING EMISSION ANALYSIS

The first step in assessing the opportunity to reduce vessels hotelling emissions from deep draft (oceangoing) vessels was to review and characterize the vessel calls to the Port of Long Beach for a 12-month period to provide an understanding of the operations at the Port. Based upon these data and discussions with the Port and vessel agents/owners, a cross section of representative candidate vessels was selected to evaluate the use of the various emission control strategies listed in Section 7.

To identify candidate vessels, the study obtained data on vessels calling on the Port of Long Beach from the Marine Exchange of Southern California for the period June 1, 2002 to May 31, 2003. The data include arrival date and time, vessel number (unique to the vessel), vessel name (which can change), the shipping agent, the operator at the time of the call, vessel type code (described below), gross tonnage, and draft. The Marine Exchange collects data on all deep draft vessels entering San Pedro Bay ports, but there are two potential points of entry, one serving the Port of Los Angeles (Angel's Gate), the other the Port of Long Beach (Queen's Gate). In a few cases, vessels headed for Long Beach pass through Angel's Gate, so those port calls do not appear in this database and were not included in the analysis.

4.1 General Port Call Characterization

The study sorted the Marine Exchange data according to the vessel type codes shown in Table C-1 in Appendix C. Vessel types not considered in this work include tugs, fishing vessels, dredgers, cable layers, supply vessels, and various other smaller vessel types.

The port activity data provided by the Marine Exchange of Southern California indicated that there were 2,913 vessel calls by 1,143 vessels at the Port of Long Beach during the 12-month period ending May 31, 2003. As shown in Table 4-1, most vessels did not call more than two times – in fact, 55% of the vessels called Long Beach only once during the study period. However, 54% of port calls were by the 206 vessels that called four or more times during the study period.

Table 4-1. Frequency of Vessel Calls

Numbers of Calls per year	Number of Vessels	Percent of Total Vessels	Number of Calls	Percent of Total Calls
1 or more	1,143	100%	2,913	100%
2 or more	516	45%	2,286	78%
3 or more	302	26%	1,858	64%
4 or more	206	18%	1,570	54%
5 or more	158	14%	1,378	47%
6 or more	121	11%	1,193	41%
7 or more	97	8%	1,049	36%
8 or more	82	7%	944	32%
9 or more	60	5%	768	26%
10 or more	40	4%	588	20%

The study sorted the vessel data according to the vessel types considered to represent the most likely candidates for reducing hotelling emissions, (Table 4-2, and Figure 4-1). These candidate vessel types represented 2,630 of the vessel calls during the study period. The remaining 283 calls (10% of total vessel calls) were dominated by tug and barge craft that are generally significantly smaller than the deep draft oceangoing vessels described in Table 4-2. Of the candidate vessels, container vessels have the highest number of port calls. The lowest number of vessel calls was for cruise vessels, but that figure greatly underestimates the prospective cruise vessel traffic because the cruise vessel terminal only began operation during March 2003, two to three months before the end of the study period. Cruise vessels are expected to call at least 80 to 120 times in the coming 12 months.

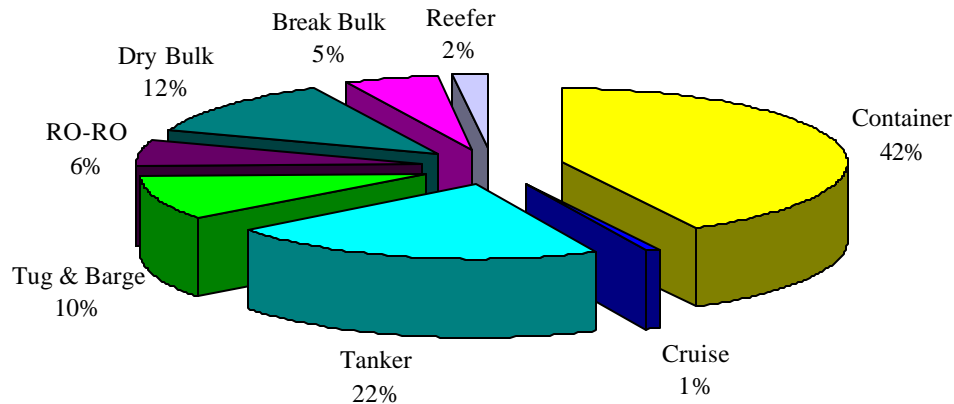
The best candidate vessels for reduced hotelling emission projects are likely to be those that call most often. The 21 vessels calling more than 12 times within the 12-month period ending May 31, 2003 are shown in Table 4-3. Of these, barges (either integrated or not) and tankers call most frequently. The two refrigerated vessels that predominately call at Long Beach do so quite often and are two of the top six vessels in terms of calls. Cruise vessels had only just begun calling at Long Beach during the study period, but the expectation is that in coming years cruise vessels will be the most frequently calling vessels, calling 80 or more times per year.

Table 4-2. Candidate Vessel Types, Codes, and Port Calls By Vessel Type

Vessel Type	Marine Exchange Code	Calls/yr	% of Calls	Avg. GWT (Call weighted)	Avg. GWT (Straight)
Container vessels	UCC	1,231	42%	43,400	43,338
Refrigerated vessels (Reefers)	GRF, UCR	59	2%	8,576	8,226
Cruise Vessels	MPR	20*	0.7%	70,375	70,379
Tankers	Any code starting with T	635	22%	54,281	49,599
Dry bulk	BBU, BCB, BOR, BWC	364	12%	28,029	28,560
Auto carrier or roll-on roll-off	URC, URR, MVE (vehicle carrier)	171 (100 MVE)	6%	44,691	42,347
Break bulk (General Cargo)	GGC	152	5%	21,025	20,871

* Port calls just began in March through the 12-month study period ending May 31, 2003.

Figure 4-1. Vessel Calls at the Port of Long Beach



Container vessels in general are the largest component of the vessel traffic, as seen in Table 4-3, but individual container vessels rarely call more than 12 times a year, most likely because of the transit times their routes entail.

Table 4-3. Most Frequently Calling Vessels

Vessel ID	Calls per Year	Vessel Name	Gross Tonnage	Type Code	Type Description
7611800	31	<i>Nehalem</i> (To: Navajo)	2,975	OBA	Tug and Barge
7702170	28	<i>Nestucca</i> (To: Natoma)	5,339	OBA	Tug and Barge
9189110	25	<i>Four Schooner</i>	40,037	TPD	Tanker
9038945	25	<i>Chiquita Joy</i>	8,665	GRF	Refrigerated
7901928	24	<i>Groton</i>	23,914	ITB	Integrated Tug and Barge
8917596	24	<i>Chiquita Brenda</i>	8,665	GRF	Refrigerated
8116063	21	<i>Thorseggen</i>	15,136	GGC	General Cargo (Break Bulk)
9035060	19	<i>Cygnus Voyager</i>	88,886	TCR	Tanker
9231626	19	<i>Ambermar</i>	23,843	TPD	Tanker
9051612	18	<i>Sirius Voyager</i>	88,886	TCR	Tanker
9533227	16	<i>NO NAME</i>	4,542	OBA	Tug and Barge
7391226	16	<i>Chevron Washington</i>	22,761	TPD	Tanker
24*	16	<i>Haleiwa</i> (To: Navajo)	4,586	OBA	Tug and Barge
8001189	16	<i>Baltimore</i>	23,913	ITB	Integrated Tug and Barge
7506039	15	<i>Denali</i>	94,647	TCR	Tanker
9633463	15	<i>NO NAME</i>	4,542	OBA	Tug and Barge
8414532	14	<i>S/R Long Beach</i>	94,999	TCR	Tanker
7708857	13	<i>CSL Trailblazer</i>	18,241	BOR	Dry Bulk
8711344	13	<i>Ecstasy</i>	70,367	MPR	Cruise vessel
7321087	12	<i>Lurline</i>	24,901	URC	Roll-on/Roll-off
9203904	12	<i>Tausala Samoa</i>	12,004	UCC	Container

* Not a Lloyd's Register number

Limited berth information was available in the Marine Exchange data because about 50% of the time (1,457 of the 2,913 calls to Long Beach) vessels were diverted to an anchorage point rather than proceeding to a specific berth upon entry to the port. In those cases, the Marine Exchange did not record the berth at which the vessel eventually docked. Accordingly, the berth information described below undercounts the number of calls to specific berths.

For the available berth information, Table 4-4 lists the berths with the highest number of calls. It is apparent that while the berth is commonly associated with the type of vessel (for example, Berth T121 services only tankers and Berth J245 services only container vessels), there are exceptions.

For instance, at Berth ‘B83’, 72 of the 84 calls were by roll on/roll off type vessels, but other types also call at that berth.

Table 4-4. Berths with Highest Number of Calls Where Data Was Available

Pier and Berth	Calls/yr	Primary Vessel		Secondary Vessel	
		Code	Vessel	Codes	Vessel
B83	84	MVE/URR	RO-RO	TCO/TPD/ITB	Tankers and Barges
T121	79	TCR/TPD	Tanker	---	---
J245	71	UCC	Container	---	---
A94	69	UCC	Container	---	---
J247	68	UCC	Container	---	---
A96	59	UCC	Container	GGC	General Cargo
J232	56	UCC	Container	---	---
E26	53	UCC	Container	GRF/GGC	Reefer/General Cargo
C62	50	UCC	Container	URC	RO-RO-Cargo
T122	47	OBA	Barge	OTB/TPD/GGC	Barge/Tanker/General Cargo
B77	40	ITB	Tug-Barge	TCO	Various Tankers
C60	38	UCC	Container	---	---
T140	37	UCC	Container	---	---
T138	35	UCC	Container	---	---
F8	34	UCC	Container	---	---
G229	33	UCC	Container	---	---
J270	32	UCC	Container	OBA	Barge
D44	32	OBA	Barge	---	---
T136	32	UCC	Container	BBU	Dry Bulk
G227	29	UCC	Container	---	---
J234	28	UCC	Container	BBU	Dry Bulk

4.2 Port Activities

4.2.1 Port Calls by Specific Container Vessels

Table C-2 of Appendix C lists the container vessels that called most frequently at the Port of Long Beach. Since these vessels currently dock at a number of different berths, implementation of an emissions control technology could involve any of the following considerations: scheduling vessels to particular berths with appropriate facilities, providing facilities at many berths, or applying the technology only to those vessels that primarily dock at a given berth.

4.2.2 Port Calls by Specific Refrigerated Vessels

Only two refrigerated vessels, *Chiquita Joy* and *Chiquita Brenda*, called at the Port of Long Beach more than once in the 12-month period studied. Table C-3 of Appendix C shows that berths E12, E24, and E26 handled most of the calls for these two vessels. As an anchorage area was listed as the destination for the remaining calls, these berths may have been the eventual berths for all of these calls. Although the *OOCL California* can handle refrigerated containers, it was classified as a containership.

4.2.3 Port Calls by Specific Cruise Vessels

Only two cruise vessels, *Ecstasy* and *Elation*, operated by Carnival Cruise Line, called at the Port of Long Beach in the 12-month period studied (Table C-4 of Appendix C). All calls docked at berth H4. These calls occurred during the last two to three months of the study period.

4.2.4 Port Calls by Specific Tankers

Tankers represented the most diverse vessel type in terms of product (crude oil, distilled petroleum oils, chemical products, food products, and others) and berth location (Table C-5 of Appendix C). Several berths handle tankers. Berth T121, in particular, handled much of the traffic. As with container vessels, many calls were listed as calls to anchorages instead of to the specific berth where they eventually docked.

4.2.5 Port Calls by Specific Dry Bulk Vessels

The only dry bulk vessel that called at Long Beach more than four times (*CSL Trailblazer*) always docked at berth B82 (Table C-6 of Appendix C).

4.2.6 Port Calls by Specific Vehicle Carriers and Roll-on/Roll-off Vessels

This group of vessels includes standard roll-on/roll-off (RO-RO) vessels and those dedicated to carrying finished vehicles. Table C-7 of Appendix C shows that the most frequently calling RO-RO vessels, primarily vehicle carriers, called at Berth B83.

4.2.7 Port Calls by Specific Break Bulk (i.e. General Cargo) Vessels

General cargo vessels, also called break bulk vessels, made many port calls during the study period. However, only one break bulk vessel, the *Thorseggen* (subject of the TRC 1989 emissions study), made more than four port calls (Table C-8 of Appendix C).

4.3 Vessel Characteristics for Selected Vessels

Twelve vessels that called at Long Beach relatively frequently and one vessel that called only once were selected for further evaluation. This selection was made to cover a range of vessel types and on-board electrical requirements. Table 4-5 presents a summary of these vessels and their berthing information.

Table 4-5. Selected Vessels for Shore Power Study

Vessel Type	Vessel Name	Vessel Type	Vessel ID	Gross Registered Tonnage	Calls per Year	Pier & Berth ¹	Terminal Operator
Container vessels	<i>Victoria Bridge</i>	UCC	9184926	47,541	10	J232	ITS
	<i>Hanjin Paris</i>	UCC	9128128	65,453	10	T136	TTI
	<i>Lihue</i>	UCC	7105471	26,746	8 (16) ²	C62	SSA
	<i>OOCL California</i>	UCC	9198109	66,046	8	F8	LBCT
Reefers	<i>Chiquita Joy</i>	GRF	9038945	8,665	25	E24	CUT
Cruise vessels	<i>Ecstasy</i>	MPR	8711344	70,367	(52) ³	H4	Carnival
Tankers	<i>Alaskan Frontier</i>	TCR	NA	185,000	15 ²	T121	ARCO
	<i>Chevron Washington</i>	TPD	7391226	22,761	16	B84	Shell
	<i>Groton</i>	TPD	7901928	23,914	24	B78	ARCO
Dry bulk	<i>Ansac Harmony</i>	BBU	9181508	28,527	1	G212	Metropolitan Stevedore
Auto carrier	<i>Pyxis</i>	MVE	8514083	43,425	9	B83	Toyota
Break bulk	<i>Thorseggen</i>	GGC	8116063	15,136	21	D54	Forest Terminal

1- Vessels are assumed to call at the designated pier/berth at all times in this study.

2- Expected annual number of calls for future scenarios based on recent activity.

3- Expected annual number of calls for this new vessel.

The information about each vessel (especially installed generators and generator capacity) was collected from; 1) survey responses by the owner/operator, 2) Lloyd's 2002 Registry of Vessels (hard copy edition), and 3) MarineData.com (<http://www.marinedata.com/>). The number of calls per vessel was taken from the Marine Exchange data as described above, and Captain John Z. Strong of Jacobsen Pilots provided the berthing time information. The detailed information for the selected vessels is given in Appendix B.

The most important data element for this study was the typical power requirements on board each vessel while docked. The estimates of power demand for the selected vessels (Table 4-6) were determined from survey responses.

The installed generator capacity and number of engines are also provided in Table 4-6 for reference. The generator load estimates for each vessel are described in more detail below.

Table 4-6. Estimated Average On-board Power Requirements for the Selected Vessels

Vessel Type	Vessel Name	Gross Registered Tonnage	Number of Generator Engines	Installed Generator Capacity (kW)	Average Load (kW)	Load Factor (% of capacity)
Container vessels	<i>Victoria Bridge</i>	47,541	4	5,440	600	11%
	<i>Hanjin Paris</i>	65,453	4	7,600	4,800	63%
	<i>Lihue</i>	26,746	2	2,700	1,700	63% ¹
	<i>OOCL California</i> ²	66,046	4	8,400	950	62%
Reefers	<i>Chiquita Joy</i>	8,665	5	5,620	3,500	62% ¹
Cruise vessels	<i>Ecstasy</i>	70,367	2	10,560	7,000	66% ¹
Tankers	<i>Alaskan Frontier</i>	185,000	4	25,200	3,780	15%
	<i>Chevron Washington</i>	22,761	2	2,600	2,300	89%
	<i>Groton</i>	23,914	2	1,300	300	23%
Dry bulk	<i>Ansac Harmony</i>	28,527	2	1,250	625	50% ¹
Auto carrier	<i>Pyxis</i>	43,425	3	2,160	1,510	70%
Break bulk	<i>Thorseggen</i>	15,136	3	2,100	600	29%

1- Estimated from a survey response for a similar vessel.

2- *OOCL California* reported load was lower than had been measured, and was likely the result of very few refrigerated containers, so a 62% load factor was assumed, similar to other reefers.

4.3.1 Container Vessels

Container vessels are the most frequent vessel type calling at the Port of Long Beach, but individual vessels do not call very often. The four vessels chosen cover a range of small, large, new, and old. Appendix B provides the information collected for each of 12 selected vessels. The activity (calls and berths) information for *OOCL California* was derived from data for *OOCL New York*, the vessel expected to be replaced by *OOCL California*. Because the *OOCL California* was designed as a container and refrigerated container vessel as well, an average load factor of 62% (of its total installed power generation capacity) was assumed in this study.

Because survey data were not available for the *Lihue*'s type of auxiliary engines, fuel, and typical port loads, assumptions were necessary to estimate the emissions and shore power requirements. The average in-use load at berth was assumed to be typically 63% (same as the *Hanjin Paris*), although it could be much higher because the generator capacity for this vessel is lower as a fraction of the vessel tonnage and propulsion power compared with other container vessels. The fuel type was considered to be heavy fuel oil (HFO), because all other container vessels use HFO in port. (IFO, intermediate fuel oil, is considered here to be equivalent of HFO because IFO fuels are a mix of HFO with a small amount, typically 10%, of middle distillate oil (MDO) which, like HDQ also contains high sulfur levels)

4.3.2 Tankers

The tankers in this study included 1) an old and relatively small (*Chevron Washington*) deep-draft tanker, 2) a tug and barge (*Groton*) of special integrated design, but likely typical of tug and barge traffic in general, and 3) a brand new, large, deep-draft tanker (*Alaskan Frontier*) to be launched in 2004. These tankers each have unique design features. The *Chevron Washington* uses gas turbines with very light diesel fuel, also referred to as Marine Gas Oil (MGO), for both propulsion and auxiliary power. The *Groton* may need separate auxiliary power on the barge and the associated tug for loading/unloading, but the survey response indicated load on a small diesel generator running a lower-sulfur diesel fuel. The *Alaskan Frontier* has a new and increasingly common design feature in which the propulsion transmission is diesel-electric. In this case, diesel engines power electrical generators rather than being directly geared to the propeller shaft, so propulsion and auxiliary power are generated from the same very large engines. Detailed vessel specifications are included in Appendix B.

4.3.3 Other Selected Vessels

The study selected one each of refrigerated (reefer), cruise, dry bulk, RO-RO, and general cargo vessel types for more detailed analysis. Information about the *Pyxis* (a RO-RO vessel) and the *Thorseggen* are in Appendix B. For the other three vessels, survey data was unavailable. Therefore, it was necessary to make the estimates described here to complete the analysis.

The two primary refrigerated vessels (*Chiquita Joy* and *Chiquita Brenda*) calling at the Port of Long Beach are nearly identical vessels, so the data provided in Appendix B are applicable to both. Survey data on the loads and engine type used for auxiliary power were not available for either vessel. The installed auxiliary generator capacity, available from the 2002 Lloyd's Registry of Vessels, did not describe the engine make or model. Because the *Hanjin Paris* was designed as a refrigerated vessel, the maximum load (63%) it reported, rounded to the nearest 100 kW, was used because this high loading occurs when refrigerated cargo is carried.

Cruise vessels had only just begun calling at the Port Long Beach, but the *Ecstasy* is expected to continue the activity that occurred in March - May 2003.

Loading information also was unavailable, but previous studies of similar sized cruise vessels in Alaska indicated that berthing loads of 7 MW are typical. The installed generator capacity was taken from the 2002 Lloyd's Registry of Vessels information. It should be noted that engines of this power (5,280 kW each) are likely of a different design than auxiliary generators found on most cargo vessels.

Accurate generator information was also unavailable for the dry bulk vessel *Ansac Harmony*, although the 2002 Lloyd's Registry of Vessels lists Akasaka as the make of the generator engines without indicating which model. An estimate of the auxiliary's capacity of 1,250 kW was derived from the auxiliary generator capacity for another dry bulk vessel, the *Zella Oldendorff*, prorated to estimate the *Ansac Harmony*'s installed generator capacity based on the tonnages and propulsion power of the two vessels. (Two Akasaka model T26R engines, with 23.4 l/cylinder displacements, would supply 1250 kW capacity, for example.) With such a low installed power level, an assumption of 50% load in port was used to estimate operation loads while berthed. This load factor could be too low if the vessel uses on board gear for loading or unloading or if the installed generator capacity was under estimated.

4.4 Berthing Times for Selected Vessels

Times at berth were determined from electronic data files that Jacobsen Pilots (John Z. Strong, October 9, 2003) provided. Time at berth was not available for those calls when the Marine Exchange information listed an anchorage point instead of an actual berth. Therefore, as shown in Table 4-7, berth times were determined from averages of the available data. The average time at berth for *OOCL New York*, (*OOCL California* was later substituted for this vessel in the analysis) was significantly longer than for other container vessels, but all 5 port calls reported by the pilots were greater than 115 hours. In addition, the time at berth for the new tanker *Alaskan Frontier* was assumed to be comparable to the other tankers in this study, although the *Alaskan Frontier* will be much larger than the other tankers reviewed here. Data were collected on a few other vessels besides the specific ones included in this study to allow a comparison to be made with other vessels of similar design. The times at berth shown in Table 4-7 are for non-bunkering calls, whereas the Arcadis (1999) report presented average hotelling (also called berthing) times by vessel type for 1997 for both bunkering and non-bunkering calls. Container vessels in this study had average berthing times similar (within the uncertainty of this limited sample) to the San Pedro ports average for container vessels derived by Arcadis (1999), except for the *OOCL New York*. Arcadis (1999) noted that approximately 15% of container vessels stayed at berth longer than 100 hours. The average time at berth for tanker calls presented by Arcadis (1999) was somewhat longer than for the tankers selected for this study.

Table 4-7. Available Berthing Time Summaries

Vessel	Vessel Type	GRT	N	Avg. Time	+/- at 90% Confidence	Avg. Time Arcadis (1999)
<i>Lihue</i>	Container	26,745	6	50.1	11.3	51.1
<i>Hanjin Paris</i>	Container	65,643	8	63.0	14.4	
<i>Victoria Bridge</i>	Container	47,541	7	44.3	11.7	
<i>OOCL New York</i>	Container	66,289	5	121.6	1.8	
<i>Chevron Washington</i>	Tanker	22,761	2	32.0	---	62.2
<i>Groton</i>	Tanker/Barge	23,914	13	55.7	9.1	
<i>Alaskan Frontier</i>	Tanker	185,000	---	33.0 est.	---	
<i>Thorseggen</i>	General Cargo	15,136	20	47.9	5.1	47.4
<i>Pyxis</i>	Car Carrier	43,425	6	17.4	6.5	26.4
<i>Ecstasy</i>	Cruise	70,367	13	12.0	0	9.5
<i>Chiquita Joy</i>	Reefer	8,665	16	67.9	7.6	38.5
<i>Ansac Harmony</i>	Dry Bulk	28,527	1	60	---	102.8

1 – *OOCL New York* was substituted by *OOCL California* per OOCL's suggestion. It was assumed that *OOCL California* has the same berthing time as *OOCL New York*.

4.5 Simultaneous Calls of Selected Vessels

Using the average berthing times and the number of calls over a 12-month period, an estimate was prepared of the number of times that two or more of the 12 selected study vessels are at berth simultaneously. The purpose of this exercise was to estimate the maximum electrical loads imposed by shore powering vessels at dock to allow designers to estimate the added capacity required to service these vessels.

There are a number of limitations to the analysis of the candidate vessels for the 12-month period, specifically because the 12-month period reviewed was not representative of the expected future activity rates. For the cruise vessels, the *Ecstasy* just began making calls at the Port of Long Beach in April, and the analysis period ended May 31, so the analysis includes less than two months of cruise activity. The data were not sufficient to determine if the cruise activity was or will be seasonally dependent. Also, the Matson vessel *Lihue* began calling at Long Beach in greater frequency beginning in January, so the number of calls for this vessel was less than that expected for the next 12-month period.

The number of simultaneous calls for the 12 selected vessels is shown in Table 4-8. This is important as it affects the maximum power demand for cold ironing. Because of a recent increase in the frequency of some vessels' calls, the 12-month totals are likely less representative than the most recent two months. For these 12 vessels, generally two vessels, and sometimes up to four

vessels, were docked simultaneously. Because the number of calls by the candidate vessels was lower than expected for a group of vessels that might actually be converted to cold ironing, the number of incidences of simultaneous calls by the candidate vessels is likely underestimated.

Table 4-8. Simultaneous Calls for the 12 Selected Vessels

Period	Total Calls	Incidences by the Number of Vessels Berthed at Once			
		2 or more	3 or more	4 or more	5 or more
12 months	160	87	27	7	0
Last 2 months	37	23	8	2	0

4.6 Emission Estimates for Selected Vessels

This section describes emission estimates to reduce emissions through the use of shore power rather than running on-board vessel service diesel generators while vessels are berthed. The emissions calculated here are for the typical diesel engine generators currently used by vessels while at berth.

Emissions per port call were estimated as a function of time at dock (hours), generator load (kilowatts or kW), and the pollutant-specific emission factor per kW-hr. The emission factors for different types of engines and motors are described in Appendix D. The average berthing time and engine load were described above and in the sections outlining the vessel characteristics and survey results. Annual emissions are for all port calls throughout the year, calculated as the number of calls per year multiplied by the average emissions per call. Vessels with large number of calls, long times at dock, and large electrical loads are more likely to produce higher emissions while at a dock.

$$\text{Emissions per port call} = (\text{Avg. Berthing Time}) \times (\text{Avg. Load, kW}) \times (\text{Emission Factor, g/kW-hr})$$

$$\text{Annual Emissions} = (\text{Emissions per port call}) \times (\text{Annual Calls})$$

The primary difference among engine types is in the NO_x emission rate. The primary auxiliary engine type for most merchant vessels is a Category 2 (with engine displacements of between 5 and 30 liters per cylinder) engine. Category 1 engines are smaller, with less than 5 liters per cylinder, and Category 3 engines are larger, with more than 30 liters per cylinder. Unless specific information was available for the auxiliary engine on each vessel, the Category 2 type was assumed.

Unusual vessels requiring exceptions be made include the following:

- (1) *Chevron Washington* has a gas turbine engine (less than half the NO_x emission rate of most diesel engines) supplying the auxiliary power.
- (2) *Groton* has Category 1 auxiliary engines of less than 1,000 kW.

- (3) *Alaskan Frontier* has diesel-electric drive system that uses the Category 3 engine useful for both propulsion and auxiliary power. This new vessel, due to be launched in 2004, is expected to meet the NO_x emissions limits in the MARPOL emission standard outlined in Appendix D. The MAN L48/60 engines on the *Alaskan Frontier* have rated speeds of 514 rpm, so NO_x emission rates of 12.9 g/kW-hr were used instead of 16.6 g/kW-hr for an uncontrolled Category 3 engine.
- (4) *Ecstasy* has two auxiliary engines rated at 5,280 kW, a high power rating more typical of a Category 3 engine.
- (5) *Hanjin Paris* has a Wartsila engine with a displacement of 28.1 liters per cylinder (under the Category 3 limit), but available emissions data for this specific engine model indicated NO_x emission rates were more typical of a Category 3 engine.
- (6) Data for the *Lihue* was unavailable, so the type of on-board auxiliary generators was not known. Because the vessel was known from Lloyd's data to be a steam vessel for propulsion power, the study assumed that the generator was driven by a steam turbine.

Emissions of PM and SO_x depend primarily on the sulfur content of the fuel used in the auxiliary engines. Three vessels in this study (*Chevron Washington*, *Groton*, and *Thorseggen*) operate their auxiliary engines on a light diesel fuel referred to here as marine gas oil (MGO). All other vessels either reported, or, if no information was provided, the study assumed, the use of heavy fuel oil (HFO) (including IFO-380, a mix of 90% heavy fuel oil and 10% middle distillate oil, both high in sulfur content).

Applying the emission factors to the vessel call activity levels provides an estimate of the emissions per port call. Annual emissions are then calculated based upon the number of calls expected over a 12-month period. One adjustment made to facilitate an accurate assessment of potential emissions benefits was that 1.5 hours (45 minutes on each end of each port call) was subtracted from the average berthing time to account for the time to transition to and from shore power. The emission results are provided here both as per port call and as an annual average to allow an understanding of the potential emissions for other vessels not subject to this analysis.

4.6.1 Container Vessels

The emissions for container vessels are shown by port call in Table 4-9 and for annual activity in Table 4-10. Of the container vessels, the *Hanjin Paris* and the *OOCL California* had the most potential for emission reductions through the use of shore power primarily because the auxiliary loads were estimated to be high because of the demands of refrigerated containers. The *Victoria Bridge* was not reported to carry refrigerated containers, so-in port loads were 20% or less than that of the *Hanjin Paris*, even though the installed auxiliary power for all three vessels is similar. To the

extent those vessels actually do carry refrigerated containers, their loads, and therefore emissions, will more closely resemble those of the *Hanjin Paris*. For *Lihue*, it was assumed that steam turbines are used for generating the electric power.

Table 4-9. Container Vessels Hotelling Emissions Per Call (tons per call)

Vessel	VOC	CO	NO _x	PM ₁₀	SO _x
<i>Victoria Bridge</i>	0.004	0.070	0.378	0.043	0.351
<i>Hanjin Paris</i>	0.065	0.227	5.393	0.493	4.036
<i>Lihue</i>	0.006	0.027	0.255	0.228	1.743
<i>OOCL California</i>	0.092	1.706	9.192	1.045	8.554

Table 4-10. Container Vessels Annual Hotelling Emissions (tons per year)

Vessel	Calls/yr	VOC	CO	NO _x	PM ₁₀	SO _x
<i>Victoria Bridge</i>	10	0.0	0.7	3.8	0.43	3.5
<i>Hanjin Paris</i>	10	0.6	2.3	53.9	4.93	40.4
<i>Lihue</i>	16	0.1	0.4	4.1	3.64	22.8
<i>OOCL California</i>	8	0.7	13.7	73.5	8.36	68.4

4.6.2 Tankers

The Alaskan Frontier was the highest emitting and largest tanker of those studied, as shown by the emissions per port call in Table 4-11 and by annual emissions in Table 4-12. However, no tanker in this study is entirely typical of tankers calling at the Port of Long Beach. The *Alaskan Frontier*, a new vessel, will be four times larger than the average tanker, and the same large engines will supply power for propulsion and auxiliary loads. The *Chevron Washington* is half the size of the average tanker and uses a gas turbine (with much lower NO_x emission rates) for auxiliary power. The *Groton* is an integrated tug and barge vessel more typical of other tugs and barges, where the auxiliary power demands are lower than for deep draft tanker vessels.

Table 4-11. Tanker Hotelling Emissions Per Call (tons per call)

Vessel	VOC	CO	NO _x	PM ₁₀	SO _x
<i>Chevron Washington</i>	0.005	0.007	0.463	0.018	0.091
<i>Groton</i>	0.005	0.027	0.179	0.004	0.016
<i>Alaskan Frontier</i>	0.026	0.092	1.690	0.199	1.628

Table 4-12. Tanker Annual Hotelling emissions (tons per year)

Vessel	Calls/yr	VOC	CO	NO _x	PM ₁₀	SO _x
<i>Chevron Washington</i>	16	0.1	0.1	7.4	0.29	1.5
<i>Groton</i>	24	0.1	0.6	4.3	0.10	0.4
<i>Alaskan Frontier</i>	15	0.4	1.4	25.3	2.98	24.4

4.6.3 Other Vessels

For other types of vessels, emission estimates are shown in Table 4-13 by port call and in Table 4-14 for the year. The refrigerated (*Chiquita Joy*) and cruise (*Ecstasy*) vessels produced higher annual and per-call emissions. The high annual emissions rates are only partly explained by the high number of port calls per year. Survey data on activity rates were limited for these two vessels, so the loads in port were derived from data available for similar vessel types, and may thus not be totally accurate. *Thorseggen* was the only vessel in this group that used MGO, a lower sulfur fuel, which explains its lower PM and SO_x emissions.

Table 4-13. Other Vessels Berthing Emissions per Call (tons per call)

Vessel	Type	VOC	CO	NO _x	PM ₁₀	SO _x
<i>Chiquita Joy</i>	Reefer	0.034	0.635	3.419	0.389	3.181
<i>Ecstasy</i>	Cruise	0.016	0.056	1.333	0.122	0.998
<i>Ansac Harmony</i>	Dry Bulk	0.005	0.100	0.537	0.061	0.500
<i>Pyxis</i>	RO-RO	0.004	0.066	0.354	0.040	0.329
<i>Thorseggen</i>	General Cargo	0.004	0.076	0.410	0.007	0.027

Table 4-14. Other Vessels Annual Berthing Emissions (tons per year)

Vessel	Calls/yr	VOC	CO	NO _x	PM ₁₀	SO _x
<i>Chiquita Joy</i>	25	0.9	15.9	85.5	9.72	79.5
<i>Ecstasy</i>	52	0.8	2.9	69.3	6.34	51.9
<i>Ansac Harmony</i>	1	0.0	0.1	0.5	0.06	0.5
<i>Pyxis</i>	9	0.0	0.6	3.2	0.36	3.0
<i>Thorseggen</i>	21	0.1	1.6	8.6	0.15	0.6

4.7 Emissions Associated with Shore Power Generation

To compare the emissions generated on-board, the study used an estimate of 0.11 lbs-NO_x/MW-hr as the average emission rate for electrical power generation to the grid. (0.11 lbs-NO_x/MW-hr equates to 0.045 g/kW-hr, which can be compared with a typical on-board auxiliary diesel engine emission rate of 13 g/kW-hr.)

Applying this factor to the electrical loads on board vessels indicates that, in most cases, the NO_x emission rate for shore power are typically at 0.3% of those uncontrolled on-board diesel generators. For lower emitting turbine and Category 1 diesel engines, the shore power could be as high as 0.8% of the emissions of on-board power emission rates. In any case, shore power should provide a NO_x emission reduction in excess of 99%. PM emission rates from shore-based generation are also estimated to be in a range between 3 to 17% of the on-board emission rates. The on-shore PM emissions are mostly from natural gas combustion, which have fewer toxic compounds than those from diesel combustion.

More analysis of on shore power generating emissions is provided in Section 6, Cost Effectiveness Analysis.

5.0 ELECTRICAL POWER INFRASTRUCTURE CONCEPTUAL DESIGN

This section discusses the infrastructure needs and conceptual design for providing shore-based electrical power (cold ironing) to the 12 vessels evaluated in this study. In this report, the cost for transmission and distribution infrastructure is shared among the 12 vessels; therefore, a reduction in the number of vessels would increase the overall cost per vessel.

To properly account for the cost of cold ironing, the study assumed that all new power supply facilities would be constructed to and within the marine terminals, incurring a major capital cost. This assumption was made because, in most cases, the existing power for the terminals is inadequate to support both existing terminal operations and cold ironing. In any case, it is appropriate to assume that the entire cost of cold ironing would be borne by the project(s) rather than assuming that existing facilities and capacity would be available. This is a conservative assumption, as Southern California Edison (SCE) power rates do include a portion of the transmission facilities capital cost amortization. The exact breakdown of what is already included in the rates and what would increase the rates would be determined by negotiation with SCE, and is beyond the scope of this study.

Costs associated with the improvement of SCE power transmission and distribution infrastructure were estimated based on the engineering assumptions as described in Appendix H. The costs have not been reviewed by SCE.

5.1 Overview of Power Transmission/Distribution to the Vessels

This study assumes that power supplied by SCE would be transmitted by new overhead lines and poles from the Hinson Substation (located south of Interstate 405 and west of Santa Fe Avenue) to the SCE Pico Substation, which is south of Ocean Boulevard and east of Harbor Scenic Drive (transmission system). The voltage would then be stepped-down to 12.5 kV and run underground through street rights-of-way to the terminals (distribution system), where it would be metered. Figure 5-1 shows the location of the substations, the overhead transmission lines, the underground distribution routes to the subject terminals in the Port, and the points of connection to the meters.

The 12.5 kV high-voltage power brought underground into the terminals would again be reduced to 6.6 kV at an on-terminal substation and then run to the wharf.

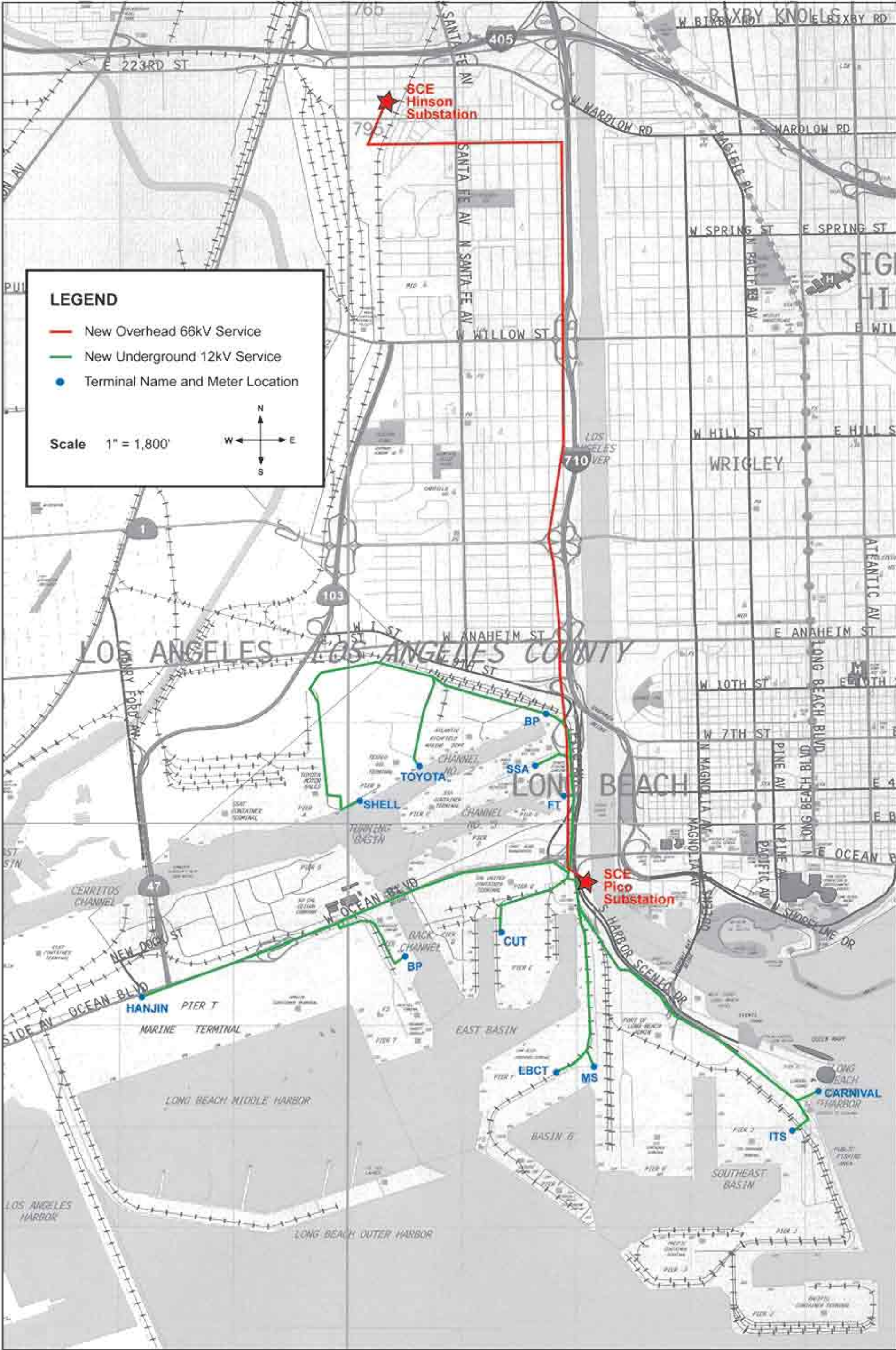
Two different methods for transferring the power from wharf-side to the vessel were evaluated, a work-barge and cable reel towers. These methods were selected because they would not adversely affect the berthing practices and/or cargo transfer operations. It should be noted that the work-barge method is used in this study to identify relative cost effectiveness for 12 selected vessels. The actual implementation of cold ironing at the POLB may use a different method, which would have somewhat different costs, but should not materially change the cost effectiveness. It is worth noting that the cost to provide the shore side infrastructure would be significantly lower if the facilities were installed when a terminal is being built or reconstructed as opposed to the retrofit situation that is the focus of this study.

5.1.1 Power Supply for Container, Reefer, and Dry Bulk Vessels

Gantry cranes that run the full length of the wharf unload all the container vessels, reefers, and dry bulk vessels in this study. The cranes operate on fixed rails and must have the full range of the wharf, although they typically operate at one station for an extended period before moving to the next station. Thus, no fixed electrical transfer structures could be constructed in their way, although a moveable, wheel-mounted system is theoretically possible. In addition, any given vessel may tie up at different positions along the same berth, so that the use of a fixed point for power transfer would reduce the terminal's operational flexibility.

The concept of outfitting the vessels with cable reels on the deck and feeding low voltage (440 to 480V) cables to the side of the wharf to be plugged into a newly constructed vault was found to have the following drawbacks.

- (1) Room would need to be made on the deck of the vessels for as many as 20 reels, each of which could be up to 10-feet in diameter. The reels might also displace cargo storage area. The cost per reel would be expected to be as much as \$65,000.
- (2) A berthed vessel can vary its orientation, which means cable reels would need to be installed on both the port and starboard sides of the deck. This would substantially increase the cost.
- (3) The reels could be installed on the stern of the vessel. However, some vessels are configured such that an extension of the cables directly to the wharf could interfere with the stern lines.
- (4) The outfitting of each vessel that might potentially call the berth with the cable reels is much more expensive than another concept in which cables are fed from shore and are plugged into the vessel.
- (5) Exposure to severe weather conditions in open sea could damage or affect the reliability of the cable reels. There is also a risk that cargo could be dropped on them.



Transmission and Distribution Routing FIGURE 5-1

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- (6) The wharf could require retrofitting or the installation of new fendering to provide adequate clearance between the vessel and wharf for the cables.
- (7) The number of conduits running underground to the new wharf vault from the new terminal substation would increase substantially, along with the cost.
- (8) The size of the new terminal substation would need to be increased to handle the electrical equipment for multiple conduits.

Outfitting the vessels with just one or two cable reels on the deck and feeding high voltage 6.6 kV cables to the side of the wharf to be plugged into a newly constructed vault was considered.

In addition to some of the drawbacks listed above, the primary difficulty is that there is no room on the vessels in this study with 440/460/480V for a new substation.

Because of the potential difficulties associated with using cable reels on the vessel, a work-barge concept to transfer the power from the wharf face to the stern of the vessel at centerline was selected for further evaluation. The work-barge supports the final substation by providing a location to step down the 6.6 kV to the typical 440-480V that the majority of the vessels currently use. The work-barge also houses cable reels, davits, and all necessary equipment to make the temporary connections to the vessels. In the event that a large container vessel with a 6.6 kV system arrives, the barge can still be used to connect the vessel directly to the wharf power, bypassing the on-board 6.6 kV/440V substation.

5.1.2 Power Supply for Tankers and RO-RO Vessels

The tankers and the roll-on/roll-off (RO-RO) vessel in the study do not utilize gantry cranes and they typically dock in the same position at every port call. Therefore, properly located, wharf-mounted facilities that have a minimal impact on operations can be utilized. A system consisting of a short tower to support electrical cable reel(s) and cables connecting to the vessel at the stern centerline was selected. The electrical cables would be positioned above the stern lines. A final substation may still be required to match the voltage(s) for the various vessels that call.

5.1.3 Power Supply for the Cruise Vessel

A large gangway mates up to the cruise vessel at its mid-section when at berth. The concept of having electrical cables carried underneath this gangway and connected into the side of the vessel was considered. Because the total amperage to be transferred is high, safety dictates not doing this. Therefore, the concept of an elevated platform on the pier deck supporting cable reels that would be either forward or aft of the gangway was considered for this study.

5.2 Method of Analysis of Energy and Transmission Distribution to Terminals

Since, the purpose of this analysis is to determine the approximate capital cost for providing cold ironing power to the terminals, typical facilities are assumed. For example, a 12.5 kV distribution system from the Pico substation to all terminals is assumed, even though actual distribution voltage may be different (e.g., the Pier T Terminal currently is served by 25 kV power).

5.2.1 Hinson Substation

A spare 66 kV feeder bay in the existing 66 kV ring bus structure would be used to extend another 66 kV transmission line from the Hinson Substation to the Pico Substation. This would require the addition of a 66 kV SF₆ circuit breaker, insulators and bus extension.

5.2.2 Transmission Line, 66 kV, Hinson Substation to Pico Substation

A 66 kV, overhead wood pole line with 336 ACSR conductors would be constructed from the Hinson Substation to the Pico Substation. This line would share the right-of-way with existing wood pole transmission lines. Wood poles would be guyed where required. As the existing transmission lines approach Pico Substation, the right-of-way crosses freeways and egress-ramps, where very tall wood poles, approximately 80 feet above finished grade, are used. The new line would do likewise. After crossing the freeways and egress ramps, the transmission line would terminate on a steel pole at the substation, as do the existing lines.

5.2.3 Pico Substation

Within the Pico Substation, a new low profile steel A-Frame structure would be built as the terminus of the 66 kV line from the Hinson Substation. This would include insulators, disconnect switches, and appurtenances to match the existing 66 kV line terminal structures. The 66 kV busing would be extended from the existing main and transfer buses to the vicinity of the new 66 kV, low profile structure. The new 66 kV line would connect to each of the 66 kV main and transfer buses after going through disconnects and SF₆ circuit breakers.

From the 66 kV main and transfer buses, 66 kV bus extensions would extend to a new 28 million volt-ampere (MVA), 66 kV to 12.47 (12.5) kV substation pad-mounted transformer. There appears to be adequate space at the north end of the substation yard to accommodate another substation transformer. One 12.5 kV bus extension with insulators and appurtenances would extend from the transformer's secondary side to a small 12.5 kV bus structure. 15 kV cable connected to the 15 kV bus via 15 kV cable terminations would extend underground in an existing utility trench to a new main and transfer bus scheme over near the existing 12.5 kV feeder take-off structures. There appears to be adequate room to install the new 12.5 kV feeder structure.

A new main and transfer bus open switchgear type structure would be built near the existing 12.5 kV feeder take-off structures. This would be an open-architecture steel structure with busing, insulators, a circuit breaker for each feeder and appurtenances.

5.2.4 12.5 kV Feeders

Although unconfirmed, SCE is thought to have a utility tunnel under the freeways adjacent to the Pico Substation. The study assumed that the utility tunnel would be extended from the Pico Substation to accommodate the following new cold iron loads. Appendix G describes the underground feeder routes to the terminals. Table 5-1 lists selected berths and their load values in kVA.

Table 5-1. Selected Berths Load

Vessel Name	Berth	Terminal Operator	Load (kVA)
<i>Victoria Bridge</i>	J232	ITS	0.9
<i>Hanjin Paris</i>	T136	TTI	6.0
<i>Lihue</i>	C62	SSA	2.1
<i>OOCL California</i>	F8	LBCT	6.5
<i>Chiquita Joy</i>	E24	CUT	4.4
<i>Ecstasy</i>	H4	CARNIVAL	8.8
<i>Alaskan Frontier</i>	T121	BP/ARCO	9.8
<i>Chevron Washington</i>	B84	SHELL	2.9
<i>Groton</i>	B78	BP/ARCO	0.4
<i>Ansac Harmony</i>	G212	MS	0.8
<i>Pyxis</i>	B83	TOYOTA	1.9
<i>Thorseggen</i>	D54	FT	0.8

5.2.5 Cost Estimate of SCE Infrastructure Improvements

Table 5-2 expresses cost estimates for the SCE infrastructure improvements by apportioning them to the various berths. Estimated costs include cutting asphalt or concrete, trenching, backfilling, and repairing pavement. The cable cost assumes using tri-plex cable. Table H-1 in Appendix H provides the cost by type of work.

Table 5-2. SCE Cost Distribution to Individual Berths

Vessel Name	Berth	Terminal Operator	Cost
<i>Victoria Bridge</i>	J232	ITS	\$944,000
<i>Hanjin Paris</i>	T136	TTI	\$3,039,000
<i>Lihue</i>	C62	SSA	\$941,000
<i>OOCL California</i>	F8	LBCT	\$761,000
<i>Chiquita Joy</i>	E24	CUT	\$977,000
<i>Ecstasy</i>	H4	CARNIVAL	\$2,323,000
<i>Alaskan Frontier</i>	T121	BP/ARCO	\$2,413,000
<i>Chevron Washington</i>	B84	SHELL	\$796,000
<i>Groton</i>	B78	BP/ARCO	\$495,000
<i>Ansac Harmony</i>	G212	MS	\$717,000
<i>Pyxis</i>	B83	TOYOTA	\$707,000
<i>Thorseggen</i>	D54	FT	\$567,000
	Total Cost:		\$14,681,000

5.3 Power Delivery within the Terminals

This section explains the assumptions made for locating the substations within the terminals, the underground electrical feeders, and the distribution runs to the berths. A limited description of the terminal cargo operations explains how decisions were made for locating the electrical equipment. Figures G-1 through G-4 in Appendix G show the assumed best locations of the SCE meters, new terminal substations, underground conduits runs, cable towers, and wharf vaults.

In each terminal, incoming 12.5 kV power would be stepped down in voltage at a new on-dock substation. The substation should be as close to the berth face as possible in order to reduce the need to carry high electrical loads far distances at lower voltages. However, 12.5 kV is not needed at the berth face. A small portion of the fleet could use 6.6 kV. The majority of the vessels considered in this study would use 440-480 kV. Thus, bringing 6.6 kV to the berth face is a suitable compromise.

5.3.1 Terminals Using a Work -barge

It should be noted that the work-barge method is used in this study to identify relative cost effectiveness for 12 selected vessels. The actual implementation of cold ironing at the POLB may use a different method, which would have somewhat different costs, but should not materially change the cost effectiveness values.

The routing of the underground conduit from the meter to the new substation is shown as one or possibly two straight segments, which assumes that there are no subsurface interferences requiring alternate routes. In practice, the route would probably be parallel to the existing high voltage feed to the substation. For reasons discussed below the new substation would be built nearby the existing one.

In a container terminal layout, the substation should be about 200 feet from the wharf face to be close to the gantry cranes, which are the primary power loads. 200 feet is also far enough away that there is no interference with the cranes and cargo movement on the wharf. To centralize operations, the terminal operations building is usually situated near the middle berth on the wharf, with the substation nearby. Vehicles and equipment also park around these structures. This arrangement leaves most of the remaining area of the terminal available for stacking containers in long rows, separated by lanes and high mast lights.

The secondary side power (6.6 kV) from the new substation would be delivered in a radial fashion to new electrical vaults constructed along the wharf face. Conduits would be constructed under the pavement until they could emerge under the concrete wharf deck. Supported by hangers, they would then run down the wharf face and feed into vaults, typically placed at 200-foot centers.

This spacing of vaults was chosen to allow for the various positions the vessel may berth along the wharf. There are a variety of factors affecting the berthing position including the number and size of vessels moored at the adjacent berth, other dockside work, crane repairs being performed, etc. The study assumed that five vaults spaced over 1,000 feet of wharf would provide sufficient flexibility for any berthing position.

Reinforced concrete vaults, approximately 4 feet wide, 3 feet deep, and 8 feet long, would be constructed under the wharf. They would have stainless steel junction boxes set into them with sockets to connect 6.6 kV cables to the work-barge. The highest amperage rating on a commercially available socket is 400A. Therefore, if the power demand from the vessel were greater than 2.64 kilovolt-amps (kVA), two sockets and two 6.6 kV cables would be needed. A 6.6 kV cable(s) from a cable reel(s) on the work-barge would be plugged into the socket(s) to feed the primary side of the transformer mounted on the work-barge. In the event that a 6.6 kV container vessel is at berth, the cables could be connected directly to the vessel.

After plugging in the vessel, the substation on the work-barge would be energized through the 6.6 kV cable(s) by closing the circuit breaker at the new terminal substation. Because energizing high voltage equipment can be dangerous, it is important that only someone who is qualified to switch high voltage open or close the breakers.

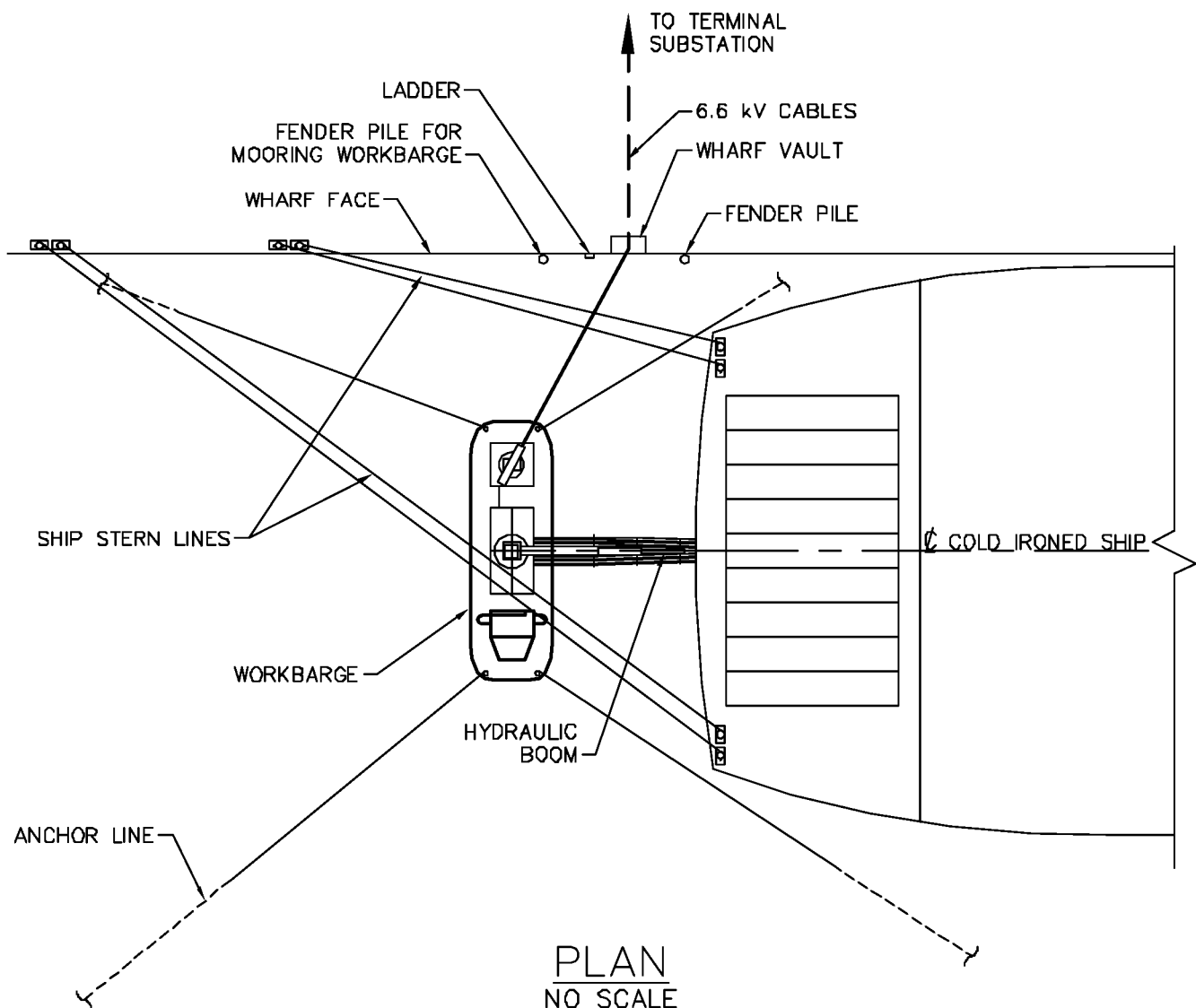
If two 6.6 kV cables were required, then two mono-spiral reels would be used. Tension on the cable(s) would be automatically adjusted to prevent sagging during tidal changes in the harbor. Any tension above a preset level would release more cable. The 10 to 11-foot diameter reel(s) would be elevated above the deck near the stern on a platform to provide deck clearance. The cable reel(s) would be mounted to a turntable allowing it to swivel as much as 60 degrees either side centerline of the work-barge. The work-barge and its layout in relation to the wharf and vessel during cold ironing are shown in Figures 5-2 through 5-4.

The lower voltage cables from the secondary side of the work-barge transformer would be extended by a hydraulic boom to the deck at the centerline of the cold-ironed vessel. The number of cables would vary with the amount of power required by the vessels. The vessel's crew would then connect the cables to the receptacles on the vessel to power the vessel.

The hydraulic boom would contain three or more telescoping tube steel sections. The boom would be capable of swiveling 360 degrees on its base. The cables on the telescopic boom would hang over saddles attached to arms connected to the outboard end of each boom section. With the boom retracted, the cables would loop below and between the saddles, much like a festoon system along an overhead crane runway. With the boom extended, the loops would straighten. At the end of the last boom section, the cables would dangle freely with enough length for the crew to reach them and plug them in the vessel's sockets. Because the change in the vessel's draft can be as much as 33 ft during container cargo operations, the boom would need to be frequently adjusted, probably on an hourly basis, to keep the cables in the correct position. Manual operation is possible, or an automatic system that would include a position sensor and controller could be installed.

Keeping the work-barge in a fixed position, centered with the stern of the vessel could best be done using two stern and two bow anchors. The work-barge would be moved away from the container vessel during its docking and departure. Conceivably, hauling the work-barge aside with the anchor lines could accomplish this. However, the work-barge might need to retrieve some or all of the anchors, depending on the specific situation. Other options for positioning the barge are possible.

A two-man crew would operate the work-barge to tend the conductor cables as the tide and vessel draft changes, to monitor the electrical equipment, and to reposition the work-barge as needed. Staggered 8-hour crew shifts could be arranged. The deckhouse would need to be large enough to comfortably accommodate the crew for extended periods during inclement weather and to support steering, reel(s), and boom operations. When not in service, the work-barge would be brought alongside the wharf and tied-off to fender piles.



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SCALE

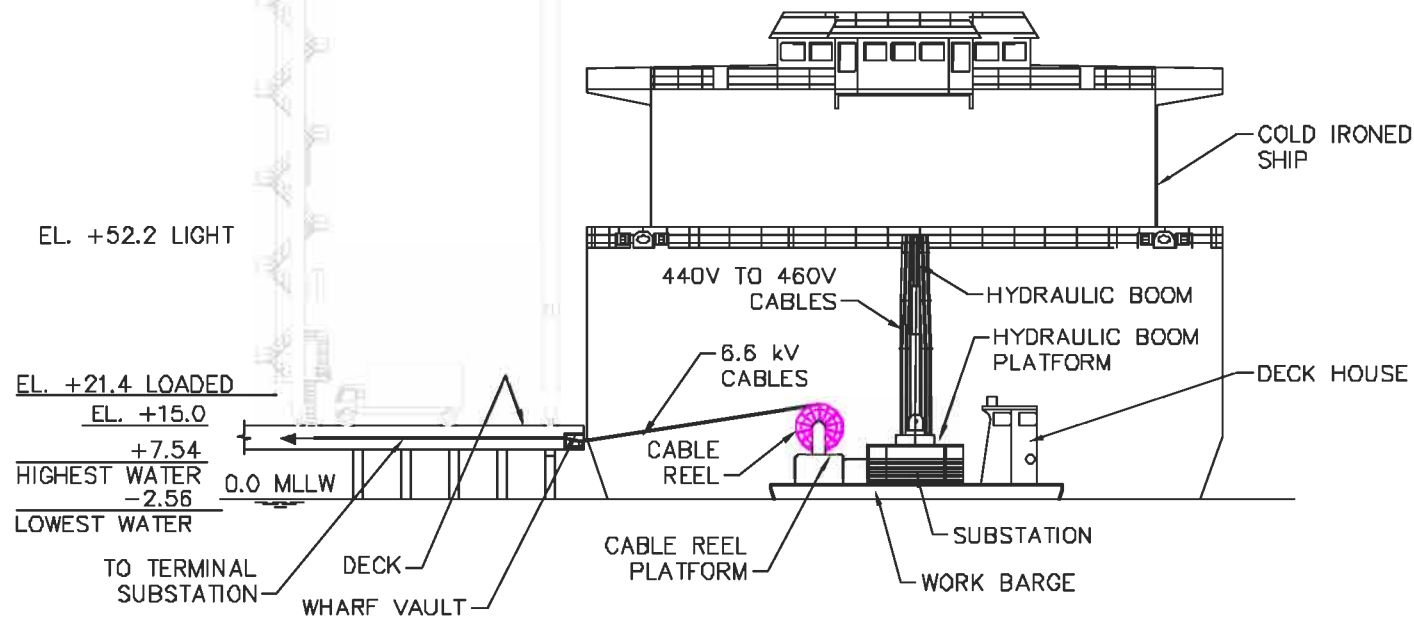
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FIGURE 5-2

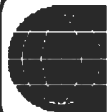
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- NOTES:
1. SHIP STERN LINES NOT SHOWN FOR CLARITY
 2. HANJIN PARIS CONFIGURATION SHOWN FOR ILLUSTRATIVE PURPOSE, OTHER SHIPS HAVE DIFFERENT CONFIGURATIONS.

STERN ELEVATION

NO SCALE



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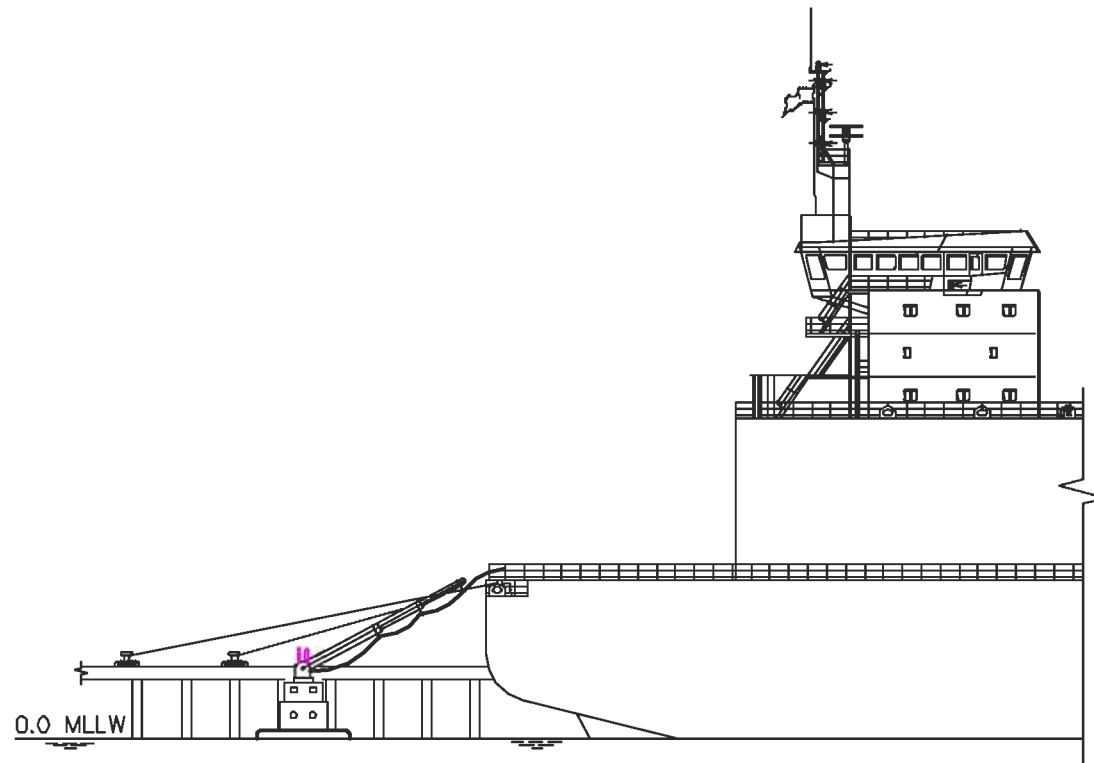
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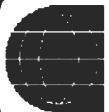
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STARBOARD ELEVATION
NO SCALE



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5.3.2 Work-barge Sizing

A new work-barge was conceptually sized at 76 ft x 30 ft by establishing a deck footprint to accommodate the substation equipment, an elevated rectangular platform to support the cable reel(s), a deckhouse, other equipment and working space. Detailed characteristics of the work-barge and cost estimates for barges to accommodate three different transformer sizes are provided in Appendix I.

5.3.3 Work-barge Cost Summary

Costs for three different sizes of work-barges to accommodate each size of substation are provided in Table I-2 in Appendix I. Data show there is only about a 3% cost difference in the construction of the work-barges when the cost of the substations is factored out.

The cost of converting existing barges was not considered feasible due to the shorter remaining life of used equipment compared to the expected service life of a new hull and the impracticality of if seven barges of the same size and in similar condition would be available.

5.3.4 Summary of Work-barge Annual Costs

Annualized recurring work-barge costs calculated for operations and maintenance are provided in Appendix I and are summarized in the Table 5-3 below.

5.3.5 Cost Associated with Loss of Operational Area

Revenue losses resulting from constructing a new substation in the facility would vary with the type of cargo operation. Removing cargo storage or parking areas to provide space for the substation could impact revenues. If there is no available land area for a substation, it may be necessary to construct the substation in an underground vault or on a platform over the water near the berth. These options are very expensive. The fenced area around the substations (having an oil filled transformer with a primary section and outdoor type secondary switchgear with a main breaker) would be sized as shown in Table 5-4.

Table 5-3. Summary of Work-barge Annual Costs

	Vessel Name						
	<i>Victoria Bridge</i>	<i>Hanjin Paris</i>	<i>Lihue</i>	<i>OOCL California.</i>	<i>Chiquita Joy</i>	<i>Ansac Harmony</i>	<i>Thorseggen</i>
Workboat Substation Power (kVA)	2,000	7,500	5,000	2,000	5,000	2,000	2,000
Workboat Cost	\$1,805,000	\$2,216,000	\$2,048,000	\$1,805,000	\$2,048,000	\$1,805,000	\$1,805,000
Berth Calls/Year	10	10	16	8	25	1	21
Average Time at Berth (hrs)	44	63	50	121	68	60	48
Crew Time per Berth Call (hrs)	48	68	52	124	72	64	52
Fuel	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Parts	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000	\$6,000
Insurance	\$54,000	\$66,000	\$61,000	\$54,000	\$61,000	\$54,000	\$54,000
Drydocking	\$18,000	\$22,000	\$20,000	\$18,000	\$20,000	\$18,000	\$18,000
Small Craft	\$4,000	\$4,000	\$4,000	\$4,000	\$4,000	\$4,000	\$4,000
Marine Mechanic	\$9,000	\$9,000	\$9,000	\$9,000	\$9,000	\$9,000	\$9,000
Electrician	\$11,000	\$11,000	\$17,000	\$8,000	\$26,000	\$1,000	\$22,000
Crew	\$167,000	\$236,000	\$289,000	\$344,000	\$625,000	\$22,000	\$379,000
Total w/ 30% Contingency	\$350,000	\$462,000	\$530,000	\$578,000	\$979,000	\$150,000	\$641,000

Table 5-4. Fenced Footprint Around Substation

Power (kVA)	Fenced Footprint Around Substation	
	12.5 kV Primary & 6.6 kV Secondary	12.5 kV Primary & 440V Secondary
2,000	27' x 30'	27' x 36'
5,000	25' x 32'	25' x 38'
7,500	26' x 33'	26' x 43'
10,000	26' x 34'	26' x 52'
Power (kVA)	66 kV Primary & 6.6 kV Secondary	66 kV Primary & 440V Secondary
7,500	26' x 33'	26' x 43'
10,000	26' x 34'	26' x 52'

Container Operations

The lost operator revenue for a container facility due to the displacement of their yard space by a new substation is calculated as follows. The substation would be approximately 200 feet from the wharf. The estimated dwell time for a container near the wharf for a wheeled slot would be 2 to 3 days per week, average 2.5. During one year, a container would occupy this space $2.5 \times 52 = 130$ days. The gross revenue for a 40-foot container per day would be about \$5,000.

Therefore, assuming a 7.5% net profit the net revenue lost would be $130 \text{ days} \times \$5,000 \times .075 = \$48,750/\text{yr}$.

Tanker Operations

Tanker operations studied in this report have a roadway along the wharf area for equipment and vehicle access. An operations building, pumping equipment, and a substation dedicated to the cargo handling operations are set back from this frontage. The remaining available open area is limited, but it has been assumed for this study that there is sufficient room to construct a new substation. Therefore, it is assumed that there would be no net revenue loss to the tenant from handling their cargo. However, a new substation might intrude into fire clearance setbacks that may be required for the petroleum products handling.

In addition, the construction of a new substation may reduce the available area available for future expansion of the facility if additional pumping or product storage equipment is needed.

Vehicle Unloading Operations

The Toyota wharf, which is about 100 feet wide, appears to have enough room for a substation in its northwest corner, which would be near the bow of the vessel. Unloading cars occurs only through the stern. The unloaded cars are driven immediately to a nearby lot for storage and are

not parked on the wharf. However, the remaining wharf area, which does not handle the traffic from the unloading of cars, from about amidships eastward, may be used to temporarily store equipment or supplies for the vessel. This study assumed that this was a practical location for a substation, out of the way of operations. Thus, no foreseeable net revenue loss would be attributable to its construction.

Break Bulk Operations

The terminal substations would be shoe-horned into the Metropolitan Stevedore operations area, which is already congested with conveyor systems and heavy equipment. It is not known at this time what financial impact it would have on their operations.

The Forest Terminals substation would need to be located in the parking lot southeast of the warehouse. This would eliminate parking and cargo space. The extent of the potential financial impact is not known at this time.

Cruise Vessel Terminal

This area has practically no open space for a substation. It was assumed that the area near the fire station would be available. If no space is available, then the substation could be put either underground, or on a new pile platform over the water. Either option would be very expensive, with the platform costing the most.

5.3.6 Shore Side Power Delivery for RO-RO, Breakbulk Vessels and Tankers

The RO-RO, breakbulk vessel, and tankers would be supplied power from a cable reel tower that would be located close to the face of the wharf or pier. The 6.6 kV cable reel(s) would be the same type used for a work-barge. Since a tanker may discharge from either port or starboard, the cable(s) would need to plug into sockets located at the center of the stern. The RO-RO unloads vehicles from the stern with its starboard side always against the wharf. Therefore, the cable reel tower would be located near the bow of the vessel and the sockets would be built into the starboard side. Three tankers berth in the same position each time in order to discharge through pipe connections and manifolds that are located in the middle third of the pipe rack on the pier. The cable reel tower would be located at the stern of the vessel.

For all three types of vessels, the 6.6 kV cable reel would be the same as used for the work-barge. The number of cable reels needed would depend on the potential amperage. The tanker *Alaskan Frontier* would require one reel; but the *Chevron Washington*, and the *Groton*, 2 reels. Toyota's RO-RO, *Pyxis*, and the breakbulk vessel *Thorseggen*, would require one reel.

The 6.6 kV feed to the cable reel tower would run underneath the wharf or dock in the same manner as in the work-barge scenario. The tower would be a 30-inch diameter steel pipe with the cable reel attached on one side, or one on each side if two reels were needed. Near the base of the cable reel tower would be an electrical pull box for both the high voltage feed and the low voltage feed for the tower's electrical motors. The reel tower would be supported on a new foundation built into the wharf or pier deck. The bottom of the reel would be about 7 feet above the deck to provide clearance, and the tower would be set far enough back to clear the hull of the vessel. Atop the tower would be a steel davit with an electric winch and steel cable to control a sling to move the 6.6 kV cable(s) vertically. The davit would also be on an electrically powered, geared turntable to enable it to rotate away from the vessel. This concept is illustrated in Figure 5-5.

After the vessel berths, an operator would use a pendant control, either from the dock or on the vessel, to lower the 6.6 kV cable(s) to the deck of the vessel to be plugged in. Then the electrician at the substation would energize the power. The reverse procedure would be used when the vessel departs.

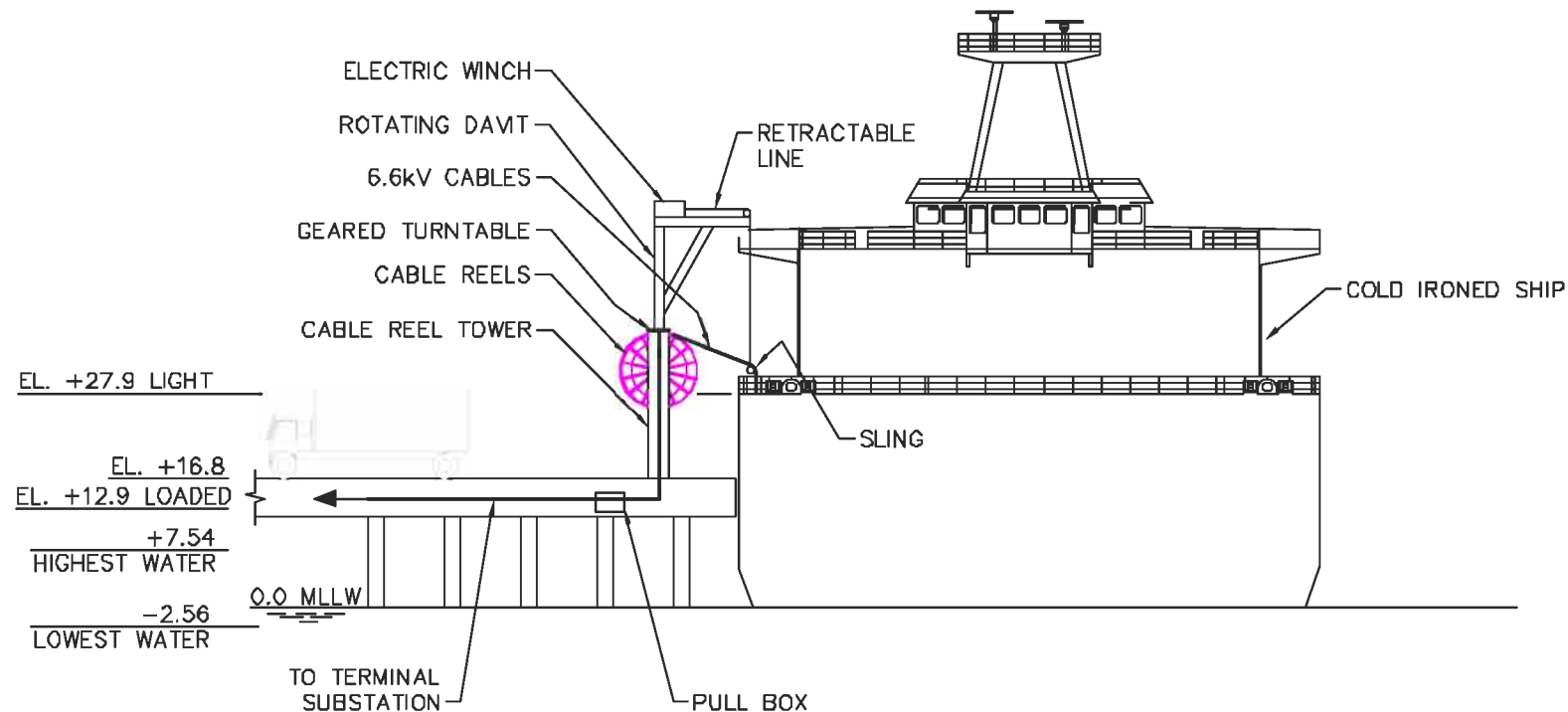
5.3.7 Shore Side Power Delivery for Cruise Vessel

The existing Carnival *Ecstasy* electrical system would require three 6.6 kV lines. The vessel berths in relatively the same position during each call to connect to the passenger gangway system on the pier. A large steel frame supports the gangway allowing it vertical and horizontal movement along the pier. There is room on the north side of the gangway to install two cable reel towers. One tower would support a single reel and the other tower, a double reel. The towers would support a davit and frame, which would be used to raise and lower the cables to the vessel. Cable reels and the frame would be electro-mechanically powered and controlled. Cable movement would be pendant controlled from either the pier or the vessel. An electrician at the substation would energize and de-energize the power.

5.3.8 Summary of Terminal Infrastructure Costs for Work-barges and Cable Reel Towers

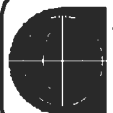
Table 5-5 summarizes annual labor costs for the work-barge and cable reel towers concepts. Cost breakdowns for individual items are provided in Appendix I.

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- NOTES: 1. SHIP STERN LINES NOT SHOWN FOR CLARITY
 2. CHEVRON WASHINGTON CONFIGURATION SHOWN FOR ILLUSTRATIVE PURPOSE, OTHER SHIPS HAVE DIFFERENT CONFIGURATIONS.

ELEVATION
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Table 5-5. Summary of Terminal Infrastructure Costs for Work-barges and Cable Reel Towers

Vessel Name	Terminal	Meter to Terminal Substation Run	Substation	Terminal Substation to Wharf Run	Run Under the Wharf	Wharf Vaults	Fender Piles	Wharf Ladder	Single Cable Reel Towers (6.6kV)	Double Cable Reel Towers (2x6.6kV)	Combo Single and Double Reel (3x6.6kV)	Total
<i>Victoria Bridge</i>	ITS	\$15,471	\$57,973	\$13,326	\$103,318	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$402,000
<i>Hanjin Paris</i>	TTI	\$15,471	\$112,390	\$13,326	\$6,078	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$360,000
<i>Lihue</i>	SSA	\$134,085	\$107,344	\$115,495	\$6,078	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$575,000
<i>OOCL California</i>	LBCT	\$15,471	\$57,973	\$13,326	\$6,078	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$305,000
<i>Chiquita Joy</i>	CUT	\$39,194	\$107,344	\$33,760	\$103,318	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$496,000
<i>Ecstasy</i>	Carnival	\$59,822	\$143,636	\$51,528	\$32,211	\$0	\$0	\$0	\$0	\$0	\$468,455	\$756,000
<i>Alaskan Frontier</i>	BP	\$49,508	\$143,636	\$42,644	\$27,957	\$0	\$0	\$0	\$0	\$378,690	\$0	\$1,642,000 ⁽¹⁾
<i>Chevron Washington</i>	Shell	\$11,346	\$107,344	\$9,773	\$6,078	\$0	\$0	\$0	\$0	\$378,690	\$0	\$513,000
<i>Groton</i>	BP	\$150,587	\$57,973	\$129,709	\$6,078	\$0	\$0	\$0	\$247,845	\$0	\$0	\$592,000
<i>Ansac Harmony</i>	MS	\$20,938	\$57,973	\$18,035	\$103,318	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$413,000
<i>Pyxis</i>	Toyota	\$2,063	\$57,973	\$1,777	\$6,078	\$0	\$0	\$0	\$247,845	\$0	\$0	\$316,000
<i>Thorseggen</i>	FT	\$36,925	\$57,973	\$31,805	\$97,240	\$163,367	\$23,725	\$25,188	\$0	\$0	\$0	\$436,000

Note: (1) One million dollars were added for a dolphin system at the Terminal T121.

5.3.9 Summary of Reel Tower Annual Labor Costs

Table 5-6 summarizes annual labor costs associated with energizing and de-energizing the high voltage from the terminal substation to the vessel. The hourly rate for the electrician to perform this is the same used for the work-barge scenario.

Table 5-6. Summary of Reel Tower Annual Labor Costs

		Vessel Name				
		<i>Ecstasy</i>	<i>Alaskan Frontier</i>	<i>Chevron Washington</i>	<i>Groton</i>	<i>Pyxis</i>
Berth Calls		52	15	16	24	9
Electrician		\$55,000	\$16,000	\$17,000	\$25,000	\$10,000
Contingency	30%	\$16,000	\$5,000	\$5,000	\$8,000	\$3,000
Total		\$71,000	\$21,000	\$22,000	\$33,000	\$13,000

5.4 Vessel Conversion Analysis

5.4.1 Method of Analysis

This analysis evaluates the cost impacts associated with conversion of vessel-board power distribution systems to permit a complete shutdown of the vessel's electrical power generating plant while using shore facility power to supply all in-port electrical needs. Most vessels currently in service are designed with a shore power capability that is only intended to support an extended berthing period. During such a time, only hotel loads and support services deemed necessary to ensure personnel safety and equipment protection are considered to be in operation. This limited capability cannot accommodate operating propulsion equipment and auxiliaries or equipment associated with cargo handling operations.

The study examined several types and sizes of vessels, and considered the pier-side operations conducted, and the configuration of the platform. Typical vessels of each type were selected based on reported power requirements received from the vessel owners. In cases where no owner input was received, power loads were estimated based on comparison with similar vessels, judgment, and experience. Conceptual designs for supplying shore power to the existing vessel service switchboard were developed. Costs to supply and install such a shore power feed system were then estimated. It must be noted that the cost estimates are a rough order of magnitude budgetary figures, not prepared with the benefit of vessel arrangement drawings or site surveys. This study made assumptions that may not reflect the most appropriate solution or may not be possible in any actual individual situation.

Each specific vessel must ultimately be evaluated based on an on-vessel survey to determine the validity of the assumptions made and to establish the most effective and efficient method for implementing the intended result. This evaluation must include confirmation of:

- (1) electric power requirements;
- (2) location of shore power connection boxes;
- (3) establishment of cable routing between the shore power connection box and the switchboard;
- (4) evaluation of the existing switchboard design and the feasibility of modifying the switchboard in order to accept a large capacity shore power feed;
- (5) identification of specific structural modifications associated with installation of the shore power receptacles, cables and switchboard modifications; and
- (6) requirements of the specific Classification Society for the vessel.

The general standards and requirements of the United States Coast Guard (US Coast Guard) and American Bureau of Shipping (ABS) applied to all 12 vessels in the analysis. The evaluation of individual vessels is presented in Appendix F.

5.4.2 Vessel Analysis Cost Summary

Table 5-7 is a summary of the vessels, shore power requirements, and costs. Appendix F provides a detailed cost breakdown for each of the evaluated vessels.

Table 5-7. Vessel Analysis Cost Summary

Vessel	KW	Volts	Amperes	Cost
<i>Victoria Bridge</i>	700	450	1120	\$296,000
<i>Hanjin Paris</i>	4800	450	7700	\$1,106,000
<i>Lihue</i>	1700	450	2800	\$452,000
<i>OOCL California</i>	5200	450	8300	\$977,000
<i>Chiquita Joy</i>	3500	450	5600	\$751,000
<i>Ecstasy</i>	7000	6600	765	\$574,000
<i>Alaskan Frontier</i>	7800	6600	850	\$457,000
<i>Chevron Washington</i>	2300	4160	400	\$380,000
<i>Groton</i>	300	450	480	\$202,000
<i>Ansac Harmony</i>	600	450	960	\$296,000
<i>Pyxis</i>	1500	450	2420	\$414,000
<i>Thorseggen</i>	600	450	960	\$236,000

5.5 Conclusions and Overall Cost Summary

The analysis of electrical power infrastructure design provided in this study was predicated on bringing a total of 40 kVA of new electrical power to 12 terminals to cold iron vessels that would call to selected berths. This included new overhead SCE transmission lines and poles from an existing substation about four miles from the Port, associated equipment, underground distribution lines to the limits of each terminal, metering, underground distribution lines in the terminal, terminal substations, wharf vaults, a wharf side method to deliver power to the vessel, and vessel electrical retrofitting. The wharf side methods to deliver vessel power included work-barges and cable reel towers, mounted either on the existing wharf structure or on a dolphin.

The breakdown costs for these improvements are summarized in Table 5-8.

Table 5-8. Overall Cost Summary

Vessel Name	Vessel side (\$)	SCE (\$)	Terminal (\$)	Work-barge (\$)	Terminal O&M (\$/yr)	Workboat O&M (\$/yr)
<i>Victoria Bridge</i>	\$296,000	\$944,000	\$402,000	\$1,805,000	\$49,000	\$350,000
<i>Hanjin Paris</i>	\$1,106,000	\$3,039,000	\$360,000	\$2,216,000	\$49,000	\$462,000
<i>Lihue</i>	\$452,000	\$941,000	\$575,000	\$2,048,000	\$49,000	\$530,000
<i>OOCL California</i>	\$977,000	\$761,000	\$305,000	\$2,216,000	\$49,000	\$6,000,000
<i>Chiquita Joy</i>	\$751,000	\$977,000	\$496,000	\$2,048,000	\$49,000	\$979,000
<i>Ecstasy</i>	\$574,000	\$2,323,000	\$756,000	\$0	\$71,000	\$0
<i>Alaskan Frontier</i>	\$457,000	\$2,413,000	\$1,642,000	\$0	\$21,000	\$0
<i>Chevron Washington</i>	\$380,000	\$796,000	\$513,000	\$0	\$22,000	\$0
<i>Groton</i>	\$202,000	\$495,000	\$592,000	\$0	\$33,000	\$0
<i>Ansac Harmony</i>	\$296,000	\$717,000	\$413,000	\$1,805,000	\$49,000	\$150,000
<i>Pyxis</i>	\$414,000	\$707,000	\$316,000	\$0	\$12,000	\$0
<i>Thorseggen</i>	\$236,000	\$567,000	\$436,000	\$1,805,000	\$49,000	\$641,000

6.0 COLD IRONING COST EFFECTIVENESS ANALYSIS

6.1 Methodology and Assumptions

This section provides a cost effectiveness analysis for providing shore based electrical power (cold ironing) to 12 selected vessels calling at the Port of Long Beach (Table 6-1). Cold ironing would greatly reduce emissions from vessels while they are hotelling (i.e., operating diesel-fired generators while at berth). Cost effectiveness of a proposed control measure is the cost of the control measure required to achieve a given emission reduction. Costs, expressed as Net Present Value (NPV), consist of the one-time capital costs of construction and the present value of ongoing operating and maintenance costs. This study applied the Discounted Cash Flow (DCF) method, as recommended by the South Coast Air Quality Management District (SCAQMD) in its Best Available Control Technology (BACT) Guidance (SCAQMD, 2000).

Table 6-1. Selected Vessels and Berths in the Study

Vessel Type	Vessel Name	Vessel ID	Year Built	Pier & Berth	Average Power Demand at Berth (kW)	Average Berth Time (hrs/call)	Calls per Year
Container	<i>Victoria Bridge</i>	9184926	1998	J232	600	44	10
Container	<i>Hanjin Paris</i>	9128128	1997	T136	4,800	63	10
Container	<i>Lihue</i>	7105471	1971	C62	1,700	50	16
Container/Reefer	<i>OOCL California</i>	9102289	1996	F8	5,200	121	8
Reefer	<i>Chiquita Joy</i>	9038945	1994	E24	3,500	68	25
Cruise	<i>Ecstasy</i>	8711344	1991	H4	7,000	12	52
Tanker	<i>Alaskan Frontier</i>	NA	2004	T121	3,780	33	15
Tanker	<i>Chevron Washington</i>	7391226	1976	B84	2,300	32	16
Tanker	<i>Groton</i>	7901928	1982	B78	300	56	24
Dry Bulk	<i>Ansac Harmony</i>	9181508	1998	G212	1,250	60	1
RO-RO	<i>Pyxis</i>	8514083	1986	B83	1,510	17	9
Break Bulk	<i>Thorseggen</i>	8116063	1983	D54	600	48	21

The following assumptions were applied in order to complete cost effectiveness calculations for cold ironing:

- (1) All vessels are able to dock at the designated pier and berth listed in Table 6-1 every time they call at the Port²;
- (2) Electrical power is purchased from SCE at its current TOU-8 Tariff;
- (3) Air emissions from work-barge during vessels berth time are negligible and therefore are not counted in the calculation of net emission reductions;
- (4) A real interest rate is four percent (4%). The real interest rate is the difference between market interest and inflation, which typically remains constant at 4% (SCAQMD, 2000);
- (5) Cold ironing has 10 years project life as the standard used in SCAQMD cost effectiveness evaluation;
- (6) All vessels have 15 years of service life. If a vessel was over 15 years old already in 2003, it is assumed that it has additional 5 years in service. It is also assumed that at the retirement of the current vessels that would occur before the end of the 10 year project life, the shipping line would retrofit another identical vessel for cold ironing and this vessel would call at same pier and berth for the rest of the project life;
- (7) All particulate matter emissions from vessel auxiliary generators are smaller than or equal to 10 microns or micrometers (PM₁₀); and all hydrocarbons (HC) emitted from vessel auxiliary generators are Volatile Organic Compounds (VOCs); and
- (8) Costs for terminal business interruption due to terminal facility construction are not considered but were discussed.

Many emission control measures reduce only a single pollutant, such as nitrogen oxides (NO_x) or PM₁₀, but some reduce multiple combustion-generated pollutants. The cost effectiveness calculations considered the total amount of criteria pollutant emission reductions, treating each pollutant as equally important. While there are varying health effects for each pollutant, there is no standard method for taking those differences into account in cost effectiveness evaluations.

After emission reductions and the total NPV of cold ironing for each vessel at the designated berth were estimated, cost effectiveness was first calculated via the formula used by SCAQMD in a multiple pollutant rule development process:

$$\text{Cost Effectiveness (\$/ton)} = \frac{\text{Total Net Present Value (\$)}}{\text{Total Emission Reduction of All Pollutants over the Project Life (tons)}}$$

6.2 Potential Emission Reductions from Cold Ironing

Cold ironing a vessel by shutting down its auxiliary diesel generators at berth would achieve significant emission reductions³ (see Section 4 of this report).

The use of shore generated electrical power for cold ironing would increase air emissions from power plants in the region. To account air emissions associated with shore power generation, this study utilized emission factors derived from AP-42 by assuming in-basin power generation are conventional natural gas fired steam plants with selective catalytic reduction (SCR) for NO_x control and with no CO catalyst. Table 6-3 provides emission factors for criteria pollutants from natural gas fired steam power plants. The study assumed that all power used for cold ironing was generated from steam power plants within the South Coast Air Basin (SCAB), but to the extent that the power would be generated by other means and/or at plants outside the SCAB, these estimates may be conservative.

Table 6-3. Emission Factors for Natural Gas Steam Power Generation

Air Pollutant	Emission Factor		
	lbs/MMcf	lbs/MMBtu ¹	lb/MW-hr ²
NO _x	10	0.0095	0.11
CO	84	0.0800	0.96
PM (assumed PM ₁₀)	7.6	0.0072	0.087
SO ₂	0.6	0.0006	0.0069
VOC	5.5	0.0052	0.063

1- heating value of natural gas = 1,050 Btu/scf

2- power generation heat rate = 12,000 Btu/kW-hr

Comparing these factors to the vessels' electrical generation emissions indicates that shore power would reduce NO_x emissions by 99% and PM emission rates by 83% to 97%. Based on emissions data from the California Office of Environmental Health Hazard Assessment (OEHHA), PM emissions from diesel engines are more detrimental to human health than PM emissions from natural gas combustion. Table 6-4 presents emission reductions from cold

² Some vessels currently call at multiple berths. If the assumption used cannot be accommodated, the cost effectiveness value will increase due to the need to provide shore-side electrical facilities at multiple berths.

³ One and one half hours (45 minutes on each end of each port call) was subtracted from the average time at berth time to account for the time to transition to and from shore power, when the ships' generators would still be operating. The actual transition time will vary.

ironing, after subtracting associated shore power generating emissions; note that using shore generated power could increase CO emissions for *Chevron Washington* (gas turbine powered) and *Lihue* (steam turbine powered). Also as stated, work-barge emissions are not considered in the calculation of net emission reduction.

Table 6-4. Potential Net Emission Reduction from Cold Ironing

Vessel Name	Potential Net Emission Reductions (tons/yr)					
	VOC	CO	NO _x	PM ₁₀	SO _x	Combined
<i>Victoria Bridge</i>	0.0	0.6	3.8	0.4	3.5	8.3
<i>Hanjin Paris</i>	0.6	0.9	53.8	4.8	40.4	100.3
<i>Lihue</i>	0.1	-0.2 ⁽¹⁾	4.0	3.6	22.8	30.2
<i>OOCL California</i>	0.6	11.3	73.3	8.1	68.4	161.6
<i>Chiquita Joy</i>	0.7	13.1	85.1	9.4	79.5	187.9
<i>Ecstasy</i>	0.7	1.1	69.1	6.2	51.9	129.0
<i>Chevron Washington</i>	0.1	-0.4 ⁽¹⁾	7.4	0.2	1.5	8.7
<i>Groton</i>	0.1	0.5	4.3	0.1	0.1	5.3
<i>Alaskan Frontier</i>	0.3	0.5	25.3	2.9	24.4	53.4
<i>Ansac Harmony</i>	0.0	0.1	0.5	0.1	0.5	1.2
<i>Pyxis</i>	0.0	0.5	3.2	0.4	3.0	7.0
<i>Thorseggen</i>	0.1	1.3	8.6	0.1	0.6	10.7
Total	3.2	29.1	338.2	36.4	296.7	703.6

As described earlier, cost effectiveness is function of total NPV and potential emission reduction of all pollutants over the 10 years project life. Combined emission reduction in tons per year, calculated by adding the 5 individual pollutants, and multiplied by the project life, gives the potential emission reduction of all pollutants over the 10 year project life.

6.3 Initial Capital Investment for Cold Ironing

The one-time initial capital investment for cold ironing consists of the following costs:

Table 6-5 summarizes costs for improving Southern California Edison (SCE) infrastructure and to provide terminal substations as described in Section 5 of this report.

Table 6-5. Power Infrastructure Cost By Individual Berth

Pier Berth	Vessel Selected	Terminal Operator	SCE System	Terminal Substation	Total
J232	<i>Victoria Bridge</i>	ITS	\$944,000	\$402,000	\$1,346,000
T136	<i>Hanjin Paris</i>	TTI	\$3,039,000	\$400,000	\$3,498,000
C62	<i>Lihue</i>	SSA	\$941,000	\$575,000	\$1,516,000
F8	<i>OOCL California</i>	LBCT	\$761,000	\$305,000	\$1,066,000
E24	<i>Chiquita Joy</i>	CUT	\$977,000	\$496,000	\$1,473,000
H4	<i>Ecstasy</i>	CARNIVAL	\$2,323,000	\$1,531,000	\$3,855,000
T121	<i>Alaskan Frontier</i>	ARCO	\$2,413,000	\$1,642,000	\$4,055,000
B84	<i>Chevron Washington</i>	SHELL	\$796,000	\$513,000	\$1,309,000
B78	<i>Groton</i>	ARCO	\$495,000	\$592,000	\$1,087,000
G212	<i>Ansac Harmony</i>	MS	\$717,000	\$413,000	\$1,129,000
B83	<i>Pyxis</i>	TOYOTA	\$707,000	\$316,000	\$1,023,000
D54	<i>Thorseggen</i>	FT	\$567,000	\$436,000	\$1,003,000
--	--	Total	\$14,681,000	\$7,582,000	\$22,263,000

- (1) The study assumed (Section 5) that work-barges would be required for container vessels, due to the difficulty of using land-based electrical supplies. Costs to fabricate work-barges were estimated for all vessels except *Ecstasy*, *Chevron Washington*, *Groton*, *Alaskan Frontier*, and *Pyxis*. It should be noted that new fabricated work-barges would not have to be dedicated to a specific vessel; making them available to serve other vessels would make cold ironing more cost effective. The estimated work-barge costs are listed in Table 6-6.

Table 6-6. Work-barge Capital Cost

Pier and Berth	Vessel Selected	Terminal Operator	Cost
J232	<i>Victoria Bridge</i>	ITS	\$1,805,000
T136	<i>Hanjin Paris</i>	TTI	\$2,216,000
C62	<i>Lihue</i>	SSA	\$2,048,000
F8	<i>OOCL California</i>	LBCT	\$2,216,000
E24	<i>Chiquita Joy</i>	CUT	\$2,048,000
H4	<i>Ecstasy</i>	CARNIVAL	Work-barge is not required
T121	<i>Alaskan Frontier</i>	ARCO	Work-barge is not required
B84	<i>Chevron Washington</i>	SHELL	Work-barge is not required
B78	<i>Groton</i>	ARCO	Work-barge is not required

Table 6-6. Work-barge Capital Cost

Pier and Berth	Vessel Selected	Terminal Operator	Cost
G212	<i>Ansac Harmony</i>	MS	\$1,805,000
B83	<i>Pyxis</i>	TOYOTA	Work-barge is not required
D54	<i>Thorseggen</i>	FT	\$1,805,000

(2) Some cold-ironed vessels would incur costs for retrofitting replacement vessels when they retire or are removed from POLB service. The study assumed that shipping lines would spend the same amount of money to retrofit a vessel for replacement at the time the retirement or removal from POLB service of the current vessel. This assumption may be conservative because retrofitting a future vessel for cold ironing would cost more comparing to order future vessels with cold ironing capability already installed. To calculate the net present value of costs for retrofitting replacement vessels, the study applied a future-to-present value factor, at 4% interest rate and current vessel remaining service life. The replacement vessel for *Lihue*, which is a steamship, would more likely be a diesel motor ship than a steamship. However, due to a lack of new vessel specifications, this study assumed an identical vessel would be retrofitted for cold ironing. Table 6-7 presents the initial capital cost, converted as net present value, for retrofitting the replacement vessels.

Table 6-7. Cost for Retrofitting Replacement Vessels at the Retirement of Current Selected Vessels

Vessel Name	Service Years Left	Initial Retrofit Cost (\$)	Future-to-Present Factor	Retrofit NPV for Replacement Vessel (\$)
<i>Victoria Bridge</i>	10	\$296,000	0 ¹	0
<i>Hanjin Paris</i>	9	\$1,106,000	0.7026	\$777,000
<i>Lihue</i>	5	\$452,000	0.8219	\$372,000
<i>OOCL California</i>	8	\$977,000	0.7307	\$714,000
<i>Chiquita Joy</i>	6	\$751,000	0.7903	\$594,000
<i>Ecstasy</i>	3	\$574,000	0.8890	\$510,000
<i>Chevron Washington</i>	5	\$380,000	0.8219	\$312,000
<i>Groton</i>	5	\$202,000	0.8219	\$166,000
<i>Alaskan Frontier</i>	15	\$457,000	0 ¹	0
<i>Ansac Harmony</i>	10	\$296,000	0 ¹	0
<i>Pyxis</i>	5	\$414,000	0.8219	\$340,000
<i>Thorseggen</i>	5	\$236,000	0.8219	\$194,000

1 – If a vessel's remaining service life is greater than 10-year project life, there will be no replacement vessel

For the *Hanjin Paris*, the retrofit cost was based on a load of 4,800 kW as reported by the vessel (which includes 3,015 kW for refrigerated containers). This load is higher than the other three container vessels (700 kW for *Victoria Bridge*, 1,700 kW for *Lihue*, and 5,200 kW for *OOCL California*). In order to satisfy this load the number of cables and circuit breakers required on *Hanjin Paris* are proportionately higher than on the other three vessels and the estimated cost for installation accordingly higher. A comparison was made on cost per kW capacity. It shows that *Hanjin Paris* at \$230/kW would be lower than the *Lihue* at \$266/kW, the *OOCL California* at \$190/kW, and the *Victoria Bridge* at \$423/kW.

6.4 Operating and Maintenance Costs

Ongoing operating and maintenance (O&M) costs for cold ironing consist of the following:

(1) Purchased Power Costs.

SCE estimated annual purchased power cost for the 12 selected vessels based on the vessels' port call activities and assumed time-of-use profiles. Current SCE TOU-8 primary rate schedule was applied for calculating the power cost for all vessels except for *Hanjin Paris*. Because of the existence of 66KV substation at Terminal T, TOU-8 Sub-transmission Voltage Service rate schedule was applied for that terminal. Appendix K of this report shows the details of the estimates. Table 6-8 summarizes the annual energy cost for the 12 selected vessels.

Table 6-8. Annual Purchased Power Cost

Vessel Name	Vessel Operator	Annual Purchased Power Cost (\$)	Effective Power Price (\$/kW-hr)
<i>Victoria Bridge</i>	K-line	\$79,000	\$0.3073
<i>Hanjin Paris</i>	HANJIN	\$485,000	\$0.1644
<i>Lihue</i>	Matson	\$329,000	\$0.2490
<i>OOCL California</i>	OOCL	\$1,203,000	\$0.2404
<i>Chiquita Joy</i>	Great White	\$1,069,000	\$0.1837
<i>Ecstasy</i>	Carnival	\$1,052,000	\$0.2752
<i>Chevron Washington</i>	Chevron Texaco	\$302,000	\$0.2872
<i>Groton</i>	BP	\$85,000	\$0.2162
<i>Alaskan Frontier</i>	Alaska Tanker	\$504,000	\$0.2823
<i>Anzac Harmony</i>	Transmarine	\$24,000	\$0.6856
<i>Pyxis</i>	Toyofuji	\$109,000	\$0.5060
<i>Thorseggen</i>	Seaspan	\$132,000	\$0.2257

(2) Fuel Cost Savings

Vessels would receive a fuel cost benefit by purchasing shore generated power instead of running auxiliary diesel engines. Table 6-9 gives the estimated fuel savings for each vessel based on the fuel consumption rates while hotelling (Table 7-4 of Section 7) and recent snapshot prices for MGO and HFO diesel fuels of \$303 and \$163 per metric ton, respectively.

Table 6-9. Annual Fuel Savings

Vessel Name	Fuel Type	Fuel Savings	
		(metric tons/yr)	(\$/yr)
<i>Victoria Bridge</i>	HFO	57	\$9,000
<i>Hanjin Paris</i>	HFO	655	\$106,000
<i>Lihue</i>	HFO	371	\$60,000
<i>OOCL California</i>	HFO	1,111	\$181,000
<i>Chiquita Joy</i>	HFO	1,291	\$210,000
<i>Ecstasy</i>	HFO	842	\$137,000
<i>Chevron Washington</i>	MGO	330	\$100,000
<i>Groton</i>	MGO	87	\$26,000
<i>Alaskan Frontier</i>	HFO	397	\$64,000
<i>Ansac Harmony</i>	HFO	8	\$1,000
<i>Pyxis</i>	HFO	48	\$8,000
<i>Thorseggen</i>	HFO	130	\$39,000

(3) Landside Facility Operating and Maintenance Costs

Landside facility O&M costs, including work-barge costs, were estimated in Section 5.5 of this report, and summarized in Table 6-10.

Table 6-10. Landside Facility O&M Costs

Pier and Berth	Terminal Operator	Cost (\$/year)
J232	ITS	\$399,000
T136	TTI	\$511,000
C62	SSA	\$579,000
F8	LBCT	\$649,000
E24	CUT	\$1,028,000
H4	CARNIVAL	\$71,000
T121	ARCO	\$21,000
B84	SHELL	\$22,000

Table 6-10. Landside Facility O&M Costs

Pier and Berth	Terminal Operator	Cost (\$/year)
B78	ARCO	\$33,000
G212	MS	\$199,000
B83	TOYOTA	\$12,000
D54	FT	\$690,000

6.5 Cost Effectiveness of Cold Ironing

Tables 6-11 and Figure 6-1 present the cost effectiveness of shore-side power using techniques described above; detailed calculations are included in Appendix J.

In Table 6-11, cost effectiveness equals the total Net Present Value (\$) divided by the combined emission reduction of all pollutants over the 10-year project life. The most cost-effective vessels were *Ecstasy*, *Chiquita Joy*, *OOCL California*, *Alaskan Frontier*, And *Hanjin Paris*. The least cost-effective vessel was the *Ansac Harmony*. The Table 6-11 also gives the average cost effectiveness of the 12 selected vessels at \$69,000 per ton, and the weighted average (total cost for all 12 vessels divided by the total emission reduction) at \$16,000/ton. These two figures could be used to represent cold ironing technology in comparing with other control measures.

6.6 Candidate Vessels and Berths for Cold Ironing

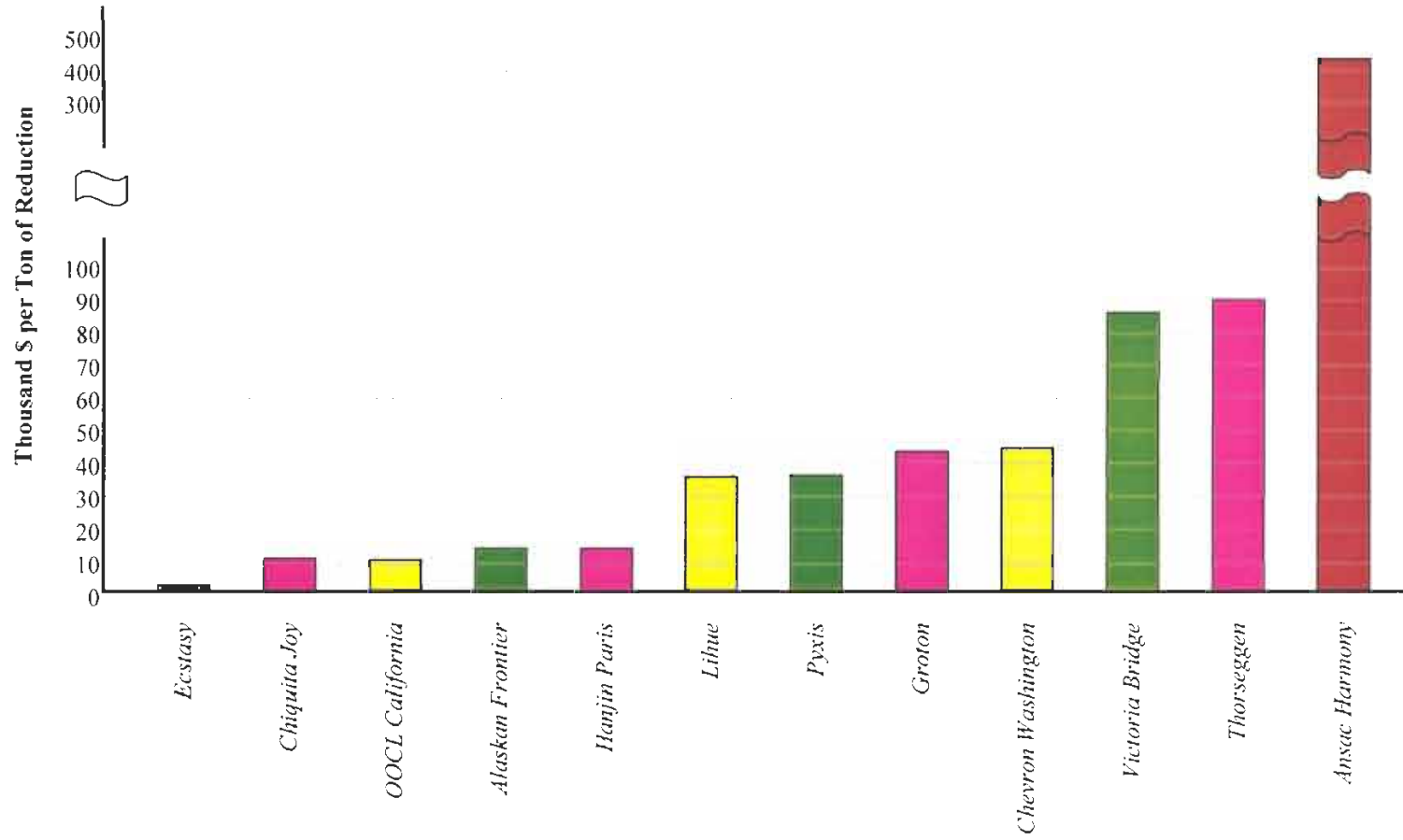
Five vessels, based on the cost effectiveness values presented in Table 6-11, are considered cost-effective for cold ironing at the Port. Of the 12 vessels studied, these five vessels represent the best candidates for cold ironing. Table 6-12 lists these candidate vessels and associated piers and berths.

Comparing with other vessels, these five vessels have significantly higher hotelling power demand, longer berth time, and relatively frequent port calls. These factors contribute to significant energy consumption (kW-hr) and therefore offer a greater potential for achievable emission reductions. The emission data in Table 6-4 indicates that cold ironing these five of 12 vessels would achieve 90% of the emission reduction for all pollutants that emitted from all 12 vessels. These vessels have been evaluated as representative of the classes of vessels, and this result does not necessarily mean that these particular vessels should be retrofitted for cold ironing.

Table 6-11. Cost Effectiveness Data and Results

Vessel Name	Vessel Operator	Vessel Type	Pier and Berth	Combined Emission Reduction (tons/yr)	Total NPV (\$)	Cost Effectiveness (\$/ton)	Rank
<i>Victoria Bridge</i>	K-line	Container	J232	8.3	\$7,251,000	\$87,000	10
<i>Hanjin Paris</i>	HANJIN	Container	T136	100.3	\$14,717,000	\$15,000	5
<i>Lihue</i>	Matson	Container	C62	30.2	\$11,266,000	\$37,000	6
<i>OOCL California</i>	OOCL	Container	F8	165	\$18,527,000	\$11,000	3
<i>Chiquita Joy</i>	Great White	Reefer	E24	187.9	\$20,155,000	\$11,000	2
<i>Ecstasy</i>	Carnival	Cruise	H4	129.0	\$12,160,000	\$9,000	1
<i>Chevron Washington</i>	Chevron Texaco	Tanker	B84	8.7	\$3,817,000	\$44,000	9
<i>Groton</i>	BP	Tanker	B78	5.3	\$2,202,000	\$42,000	8
<i>Alaskan Frontier</i>	Alaska Tanker	Tanker	T121	53.4	\$8,251,000	\$15,000	4
<i>Ansac Harmony</i>	Transmarine	Dry Bulk	G212	1.2	\$5,032,000	\$426,000	12
<i>Pyxis</i>	Toyofuji	RO-RO	B83	7.0	\$2,693,000	\$38,000	7
<i>Thorseggen</i>	Seaspan	Break Bulk	D54	10.7	\$9,589,000	\$90,000	11
Average of All Vessels				59.0	\$9,638,000	\$69,000	
Total of All Vessels				698.3	\$108,409,000	\$16,000	

Figure 6-1. Cost Effectiveness of Cold Ironing



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Table 6-12. Candidate Vessels and Berths for Cold Ironing

Vessels Name	Vessel Type	Vessel Operator	Pier and Berth	Terminal Operator	Cost Effectiveness (\$/ton)
<i>Ecstasy</i>	Cruise	Carnival	H4	Carnival	\$9,000
<i>Chiquita Joy</i>	Reefer	Great White	E24	CUT	\$11,000
<i>OOCL California</i>	Container/ Reefer	OOCL	F8	LBCT	\$11,000
<i>Alaskan Frontier</i>	Tanker	Alaska Tanker	T121	BP/ARCO	\$15,000
<i>Hanjin Paris</i>	Container	HANJIN	T136	TTI	\$15,000

6.7 Discussion on Cold Ironing Cost Effectiveness

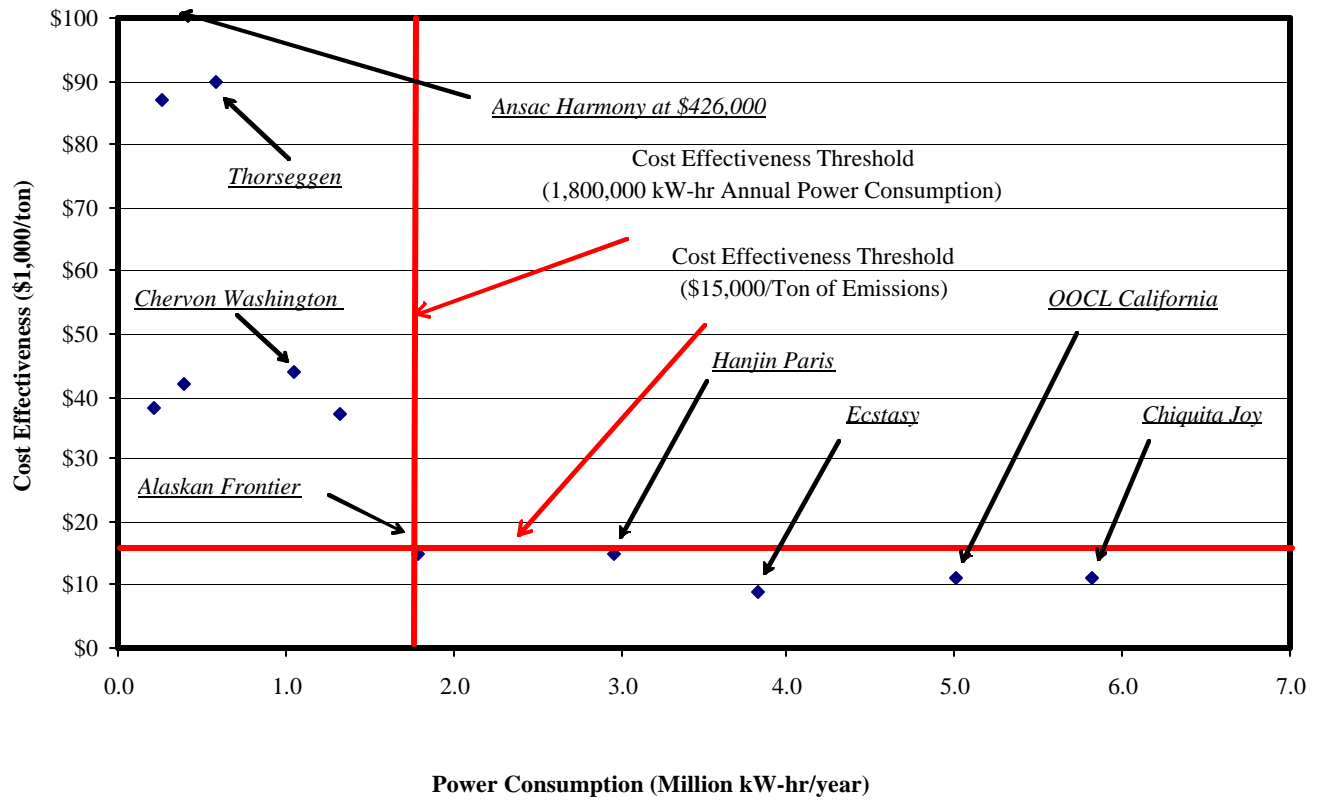
This study evaluates the cost effectiveness of cold ironing on 12 vessels currently in service and their associated berths. Building new vessels and new terminals with cold ironing capabilities will improve cold ironing cost effectiveness and will avoid some of operational, engineering, and safety problems associated with the process of retrofitting in use vessels.

The cost effectiveness of cold ironing is based on the assumption that all construction of landside facilities at a specific berth, including SCE transmission and distribution infrastructure improvement, to serve a single selected vessel. If more vessels were to use the cold ironing facility, the cost effectiveness would be improved.

It is desirable to use a well-accepted cost effectiveness standard and to compare cold ironing technology to other off-road multi-pollutant control measures. California's Carl Moyer program targets NO_x emission reductions, and often is used to retrofit in use diesel engines. It has a limit of \$13,600 per ton of NO_x reduction. After consulting with the SCAQMD, this study evaluates cold ironing cost effectiveness by adding all pollutants together to form an over all emission reduction. It gives each pollutant an equal weight in the cost effectiveness value. This method has been used by the SCAQMD in a multiple pollutant rule development process.

The study evaluated the parameters that affect cost effectiveness. The evaluation shows that annual power consumption by the ship while hotelling shows the best correlation with cost effectiveness (Figure 6-2). This analysis shows that cold ironing is cost effective as a retrofit when the annual power consumption is one point eight million (1,800,000) kW-hr or more. For a new constructed vessel with cold ironing equipment installed calling at a new terminal with the needed power facilities, it would be cost-effective if the annual power consumption is greater than one point two million (1,500,000) kW-hrs.

Figure 6-2. Cost Effectiveness vs. Annual Power Consumption



REFERENCES

SCAQMD, 2000. "Best Available Control Technology Guidelines" South Coast Air Quality Management District. August 17, 2000

7.0 ALTERNATIVE CONTROL TECHNOLOGIES

In recent years, concerns about air pollution in and around the ports of the U.S. have focused on controlling emissions from marine vessels. Since most marine vessels are equipped with uncontrolled diesel auxiliary engines that often burn high-sulfur heavy fuel oil, the exhaust emissions from these diesel engines are substantial, especially for nitrogen oxides (NO_x), particulate matter (PM), and sulfur oxides (SO_x).

This section presents the potential emission reductions benefits and associated capital and operating costs, as well as cost effectiveness values, of several alternative emission control technologies (i.e. other than “cold ironing”) for reducing emissions from on-board diesel generators of the twelve representative marine vessels while hotelling in the Port of Long Beach. These vessels were selected to represent a broad cross section of the ocean going vessels that call at the POLB, and their selection does not mean that those specific vessels should or should not be retrofitted.

In an early effort to control emissions from marine vessels, the International Maritime Organization (IMO), as part of the International Convention for the Prevention of Pollution from Ships (MARPOL), adopted in 1997 the international protocol of Annex VI entitled “Regulations for the Prevention of Air Pollution from Ships” (IMO, 1997). The MARPOL’s Annex VI regulates main engine NO_x levels, shipboard incinerators, fuel sulfur content and fuel quality, tanker vapor emission controls, and ozone depleting substances. The MARPOL Annex VI NO_x standards for new engines, which were to have gone into effect in the year 2000, are shown in Table 7-1.

Table 7-1. MARPOL's ANNEX VI NO_x Emission Standards.

Engine Speed (n)	NO _x (g/kW-hr)
n ≥ 2000 rpm	9.8
130 rpm ≤ n < 2000 rpm	4.5 x n ^{-0.2}
n < 130 rpm	17.0

In December 1999, the United States Environmental Protection Agency (USEPA) adopted a set of federal marine diesel engine emission standards (the so-called Tier 2 standards) for Category 1 and Category 2 marine engines (USEPA, 1999-1). These standards apply to new commercial engines, both propulsion and auxiliary, rated at or above 37 kilowatts but displacing less than 30 liters per cylinder that are installed on U.S.-flagged vessels. In February 2003, the USEPA adopted a federal

marine diesel emission standard for engines displacing 30 liters or greater per cylinder, the so-called Category 3 marine engines, which is similar to the MARPOL's Annex VI. NO_x limit for marine vessel engines (USEPA, 2003-1)⁴. Table 7-2 summarizes the USEPA federal marine diesel standards.

Table 7-2. USEPA Marine Emission Standards

Category	Displacement (liters per cylinder)	Starting Date	NO _x + HC	PM	CO
			(g/kW-hr)		
1	Disp. < 5.0	2004 - 2007	7.2 – 7.5	0.20 - 0.40	5.0
2	5.0 ≤ Disp. < 30	2007	7.8 - 11.0	0.27 - 0.50	5.0
3	Disp. ≥ 30	2004	MARPOL NO _x Standards		

7.1 Characteristics and Emissions of Selected Marine Vessels

Emissions and fuel consumption estimates for the selected marine vessels are required to develop the cost effectiveness values for potential emission control technologies. Section 4 discusses the characteristics of these selected marine vessels in detail. Table 7-3 presents the key parameters used in the cost effectiveness analyses.

Table 7-3. Key Parameters of the Selected Marine Vessels

Vessel Name	Calls per year	Service Years Left (yr)	Time at Berth (hrs)	Load Factor	Generator (kW)	Fuel Type	Fuel Sulfur %	Engine Category
<i>Victoria Bridge</i>	10	10	44	11%	5,440	HFO	2.8	2
<i>Hanjin Paris</i>	10	9	63	63%	7,600	HFO	2.8	3
<i>Lihue</i>	16	5	50	63%	2,700	HFO	2.8	Steam
<i>OOCL California</i>	8	8	121	62%	8,400	HFO	2.8	2
<i>Chiquita Joy</i>	25	6	68	62%	5,620	HFO	2.8	2
<i>Ecstasy</i>	52	3	12	66%	10,560	HFO	2.8	3
<i>Chevron Washington</i>	16	5	32	89%	2,600	MGO	0.2	Gas turbine
<i>Groton</i>	24	5	56	23%	1,300	MGO	0.2	1
<i>Alaskan Frontier</i>	15	15	33	15%	25,200	HFO	2.8	3
<i>Ansac Harmony</i>	1	10	60	50%	1,250	HFO	2.8	2
<i>Pyxis</i>	9	5	17	70%	2,160	HFO	2.8	2
<i>Thorseggen</i>	21	5	48	29%	2,100	MGO	0.2	2

⁴ Note that these standards apply only to U.S. flagged vessels which represent a small fraction of the vessels that call at Long Beach; foreign-flagged vessels are governed by the MARPOL standards.

Table 7-4 presents estimated annual emissions, electric power usage, and fuel consumption while hotelling for these selected marine vessels. The study calculated the power consumption in MW-hr per year from the average load shown in Table 4-6 in Section 4.

Table 7-4. Annual Hotelling Emissions and Fuel Consumption for Selected Marine Vessels

Vessel Name	VOC	CO	NO _x	PM	SO _x	Fuel Usage	Power Usage
	(Short Tons/yr)					(Metric Tons/yr)	(MW-hr/yr)
Victoria Bridge	0.04	0.7	3.8	0.4	3.5	57	257
Hanjin Paris	0.65	2.3	53.9	4.9	40.4	655	2,952
Lihue	0.10	0.40	4.10	3.64	22.8	371	1,324
OOCL California	0.70	13.7	73.5	8.36	68.4	1,111	5,003
Chiquita Joy	0.86	15.9	85.5	9.7	79.5	1,291	5,815
Ecstasy	0.83	2.9	69.3	6.3	51.9	842	3,795
Chevron Washington	0.09	0.1	7.4	0.3	1.5	330	1,123
Groton	0.12	0.6	4.3	0.1	0.4	87	391
Alaskan Frontier	0.39	1.4	25.3	3.0	24.4	397	1,786
Ansac Harmony	0.01	0.1	0.5	0.1	0.5	8	37
Pyxis	0.03	0.6	3.2	0.4	3.0	48	217
Thorseggen	0.09	1.6	8.6	0.1	0.6	130	585

7.2 Alternative Emission Control Technologies

This study evaluated the following emission control technologies for reducing hotelling emissions from the marine vessel diesel generators:

(1) Engine repowering or replacement, including

- Repowering with US EPA Tier 2 Engines and
- Repowering with LNG/Dual-FuelTM Engines.

(2) Clean fuel strategy, including

- Marine Gas Oil (MGO) Fuel;
- California on-road #2 diesel fuel;
- Emulsified diesel fuel;
- Fischer-Tropsch diesel fuel; and

- Bio-diesel fuel (B100).

(3) Combustion management, including

- Injection timing delay;
- Direct water injection (DWI);
- Humid air motor (HAM); and
- Exhaust gas recirculation (EGR).

(4) Exhaust gas treatment, including

- Diesel oxidation catalyst with California on-road #2 diesel;
- Catalyzed diesel particulate filter with California on-road #2 diesel; and
- Selective catalytic reduction (SCR).

(5) Cryogenic refrigerated containers (CRC).

Some more advanced concepts for emission control were not investigated in this study such as fuel-cell technology, non-thermal plasma technology, NO_x adsorbers, lean NO_x catalyst, battery-electric technology, and flywheel technology. At this time, there is not enough information about these technologies available to assess their feasibility for marine vessel hotelling applications.

The feasibility of many near-term (i.e., within the next ten years) technologies for marine applications or stationary diesel generators has been investigated and discussed elsewhere (BAE 2000, CALSTART 2002, CEC 2001, ENVIRON 2003, US EPA 1999-2, US EPA 2003-2, JJMA-BAH 2002, MAN-B&W 2002, NESCAUM 2003, SIEMENS 2002, Ricardo 2002, Seaworthy 2002, Starcrest 2002). This section discusses the general operating principles, costs and practical application of each of the near-term control technologies, and presents the cost effectiveness values of these technologies for reducing hotelling emissions for the selected marine vessels. There are many additional issues outside of the scope of this study that require more investigation including safety of fuels and hardware, practical considerations of the size and cost of new and/or additional engines and fuel systems, compatibility of fuels and engines, and other issues that may be discovered only during the implementation of these alternative methods. In most cases, the measures reviewed below have not been employed on large commercial vessels.

The following key issues are among many factors considered in the evaluation of the proposed alternative technologies:

- Identification of technologies that reduce diesel particulate matter, which is a California Air Resources Board (CARB) listed toxic air contaminant;
- Availability of equipment and fuel(s) associated with the technology;
- Extent of infrastructure impact on vessels and/or on land during implementation; and
- Operational practicability, including safety issues.

The following assumptions were made in order to complete cost effectiveness analyses for the alternative technologies:

- (1) The real interest rate is 4% and the project life is 10 years. The real interest rate is the difference between market interest and inflation, which typically remains constant at 4% (SCAQMD, 2000);
- (2) All vessels have 15 years of service life. If a vessel is already more than 15 years old, it is assumed to have an additional 5 years in service.
- (3) All particulate matter emissions from vessel auxiliary generators are smaller than 10 microns or micrometers (PM₁₀) and all hydrocarbons (HC) emitted from vessel auxiliary generators are Volatile Organic Compounds (VOCs); and
- (4) The cost for the time out of service due to vessel retrofitting was not included in this study.

Many emission control measures reduce only a single pollutant, such as nitrogen oxides (NO_x) or PM₁₀, but some reduce multiple combustion-generated pollutants. The cost effectiveness calculations considered the total quantity of criteria pollutant emission reductions, treating each pollutant as equally important. While there are varying health effects for each pollutant, there is no standard method for taking those differences into account in cost effectiveness evaluations. After estimating potential emission reductions and the total NPV of each control technology for each vessel, cost effectiveness was calculated using the following formula, which has been used by SCAQMD in a multiple pollutant rule development process.

$$\text{Cost Effectiveness} = \frac{\text{Total Net Present Value (\$)}}{\text{Total Emission Reduction of All Pollutants over the Project Life (tons)}}$$

This method provides cost effectiveness values in dollar per ton of reduction and a ranking among the 12 vessels. There is no broadly accepted method for calculating a cost effectiveness threshold

for control measures for multiple pollutants. The cost effectiveness values for cold ironing the 12 study vessels have a significant break as shown on Figure 1-3, where the most cost-effective vessels have values less than \$15,000/ton, and the other vessels are far higher than that value. For comparison, the SCAQMD Governing Board Policy for VOC is not to adopt retrofit rules that cost more than \$13,500/ton unless special analyses are done. The Carl Moyer program has a threshold for NO_x emissions of \$13,600/ton of NO_x for projects that use that funding mechanism. Table 7-5 shows selected cost effectiveness values. Based on the break in the cold ironing values and the comparison with other cost effectiveness thresholds, \$15,000 /ton of total pollutant removed was selected as the cost effectiveness threshold for other alternative control measures as well.

Table 7-5. Selected Cost Effectiveness Values (\$/ton Reduced)

Pollutant	Carl Moyer Threshold	SCAQMD AQMP Values for School Buses	SCAQMD Board VOC Retrofit Threshold	SCAQMD BACT Threshold
NO _x	\$13,600			\$18,300
PM ₁₀		\$15,000 – \$110,000		\$4,300
SO ₂				\$9,700
CO				\$380
ROG (equal to VOC)			\$13,500	\$19,400

7.2.1 Repowering with NG/Dual-Fuel™ Engines

This strategy repowers or replaces older, uncontrolled diesel generator engines in the marine vessels with natural gas (NG) or Dual-Fuel engines. This strategy would require a natural gas refueling infrastructure in sufficient locations to supply the fuel demands globally, and on-board storage for natural gas fuel; therefore, it would require a substantial capital cost.

Emissions data for NG marine engines provided in the CALSTART 2002 study indicate that NG marine engines would reduce NO_x emissions by 90%, PM emissions by 94%, and SO_x emissions by 99% (CALSTART, 2002). The CALSTART study estimated the capital cost for an NG engine and its refueling infrastructure to be about \$165 to \$202 per kilowatt. The same study also estimated the fuel cost penalty to be 30% based on the differential in fuel consumption and fuel costs per British Thermal Unit (BTU)⁵. While NG/Dual Fuel engines have been used in many applications, including automotive, transit and stationary generators, there have been few uses of these engines in marine applications as either propulsion, auxiliary or generator engines. This is mainly due to fuel storage and safety issues, as natural gas would have to be stored in high-pressure cylinders as

⁵ The CALSTART study estimated that the MGO fuel cost was \$1.08/gallon and the CNG fuel cost was \$1.40/gge.

compressed natural gas or in cryogenic tanks as liquid natural gas. The application constraints associated with this technology are primarily the absence of fueling facilities, the current limited availability of natural gas at the POLB, the lack of on-board fuel storage, and operating safety. As the POLB is currently evaluating a major liquefied natural gas (LNG) receiving terminal, the availability condition may change. Also, as with any marine engine replacement, there could be significant problems installing and fitting the engine and fuel system in the available engine compartment.

Tables 7-6 and Table 7-7 present the potential emissions reductions and cost effectiveness values for the selected marine vessels using this (NG) or Dual-Fuel engine strategy, respectively. As shown in Table 7-7, repowering with NG/Dual Fuel engines is cost effective in reducing hotelling emissions from these vessels except for the *Ansac Harmony*. Detail cost effectiveness calculations are included in Appendix L.

Table 7-6. Potential Emission Reductions for Repowering with NG/Dual Fuel™ Engines

Vessel Name	NO _x	PM	SO _x
	Short Tons/yr		
<i>Victoria Bridge</i>	3.40	0.40	3.48
<i>Hanjin Paris</i>	48.54	4.64	39.96
<i>Lihue</i>	3.69	3.42	22.57
<i>OOCL California</i>	66.90	7.86	67.75
<i>Chiquita Joy</i>	76.92	9.13	78.73
<i>Ecstasy</i>	62.40	5.96	51.37
<i>Chevron Washington</i>	6.67	0.27	1.44
<i>Groton</i>	3.87	0.09	0.38
<i>Alaskan Frontier</i>	22.81	2.81	24.18
<i>Ansac Harmony</i>	0.48	0.06	0.49
<i>Pyxis</i>	2.86	0.34	2.93
<i>Thorseggen</i>	7.74	0.14	0.57

Table 7-7. Cost Effectiveness of Repowering with NG/Dual Fuel™ Engines

Vessel Name	Capital Cost (\$)	Fuel Cost Increase (\$/year)	Total NPV Cost (\$)	Cost Effectiveness (\$/ton)	Cost-Effective? (Yes/No)
<i>Victoria Bridge</i>	998,240	2,778	1,021,000	14,000	Yes
<i>Hanjin Paris</i>	1,394,600	31,944	1,682,000	2,000	Yes
<i>Lihue</i>	495,450	18,086	576,000	4,000	Yes
<i>OOCL California</i>	1,541,400	54,161	1,906,000	2,000	Yes
<i>Chiquita Joy</i>	1,031,270	62,937	1,361,000	1,000	Yes

Table 7-7. Cost Effectiveness of Repowering with NG/Dual Fuel™ Engines

Vessel Name	Capital Cost (\$)	Fuel Cost Increase (\$/year)	Total NPV Cost (\$)	Cost Effectiveness (\$/ton)	Cost-Effective? (Yes/No)
<i>Ecstasy</i>	1,937,760	41,068	2,052,000	6,000	Yes
<i>Chevron Washington</i>	477,100	29,959	610,000	15,000	Yes
<i>Groton</i>	238,550	7,869	274,000	13,000	Yes
<i>Alaskan Frontier</i>	4,624,200	19,330	4,849,000	10,000	Yes
<i>Ansac Harmony</i>	229,375	396	233,000	22,000	No
<i>Pyxis</i>	396,360	2,344	407,000	13,000	Yes
<i>Thorseggen</i>	385,350	11,790	438,000	10,000	Yes

7.2.2 Low-Sulfur Marine Gas Oil (MGO) Diesel Fuel

The MGO Diesel Fuel strategy assumes the use of MGO diesel fuel, which has a sulfur content of 0.2%, in those marine vessels that use Heavy Fuel Oil (HFO) diesel fuel, which has a sulfur content of 2.8%. Using MGO diesel fuel instead of HFO diesel fuel will reduce PM and SO₂ emissions by about 85% and 90%, respectively (see Appendix D), but would not reduce emissions of NO_x, CO or VOC. This study assumed that there would be a one-time capital cost of about \$50,000 to clean the main fuel tank, service tank, and fuel supplying system, to replace fuel filters etc. in order to switch from HFO to MGO diesel fuel. The only other cost associated with this strategy is the incremental fuel cost⁶.

The potential emission reductions and cost effectiveness values for the use of MGO diesel fuel for the selected marine vessels are presented in Table 7-8 and Table 7-9, respectively. Except for three vessels already using the MGO fuel, use of MGO is considered cost effective and provides significant PM and SO_x emission reductions.

One challenge of this control strategy would be to develop an in-use compliance mechanism to ensure that MGO fuel is actually used in the generators while these vessels are hotelling at the berths.

According to the ISO standards 8217 and 2719, marine fuel must have a flashpoint of a minimum of 60°C. According to SOLAS Chapter 11-2, part B, Regulation 4, no fuel oil with a flashpoint of less than 60°C shall be used. The flashpoint of MGO fuel is between 57°C and 69°C. A specific MGO should be used only if its flash point is greater than 60°C.

⁶ Snap-shot prices of the recent MGO and HFO diesel fuels of \$303 and \$163 per metric ton, respectively, were used in the cost effectiveness analyses (see footnotes 2 and 3).

Table 7-8. Emission Reductions from the Use of MGO Diesel Fuel

Vessel Name	PM	SO _x
	Short Tons/yr	
<i>Victoria Bridge</i>	0.36	3.16
<i>Hanjin Paris</i>	4.19	36.3
<i>Lihue</i>	3.09	20.5
<i>OOCL California</i>	7.11	61.59
<i>Chiquita Joy</i>	8.26	71.6
<i>Ecstasy</i>	5.39	46.7
<i>Chevron Washington</i>	NA	NA
<i>Groton</i>	NA	NA
<i>Alaskan Frontier</i>	2.54	22.0
<i>Ansac Harmony</i>	0.05	0.45
<i>Pyxis</i>	0.31	2.67
<i>Thorseggen</i>	NA	NA

Table 7-9. Cost Effectiveness of MGO Diesel Fuel

Vessel Name	Capital Cost (\$)	Fuel Cost Increase (\$/year)	Total NPV Cost (\$)	Cost Effectiveness (\$/ton)	Cost-Effective? (Yes/No)
<i>Victoria Bridge</i>	50,000	8,000	115,000	3,000	Yes
<i>Hanjin Paris</i>	50,000	92,000	732,000	2,000	Yes
<i>Lihue</i>	50,000	52,000	281,000	2,000	Yes
<i>OOCL California</i>	50,000	156,000	1,097,000	2,000	Yes
<i>Chiquita Joy</i>	50,000	181,000	997,000	2,000	Yes
<i>Ecstasy</i>	50,000	118,000	377,000	2,000	Yes
<i>Chevron Washington</i>	NA	NA	NA	NA	NA
<i>Groton</i>	NA	NA	NA	NA	NA
<i>Alaskan Frontier</i>	50,000	56,000	500,000	2,000	Yes
<i>Ansac Harmony</i>	50,000	1,000	59,000	12,000	Yes
<i>Pyxis</i>	50,000	7,000	80,000	5,000	Yes
<i>Thorseggen</i>	NA	NA	NA	NA	NA

7.2.3 Emulsified Diesel Fuel

This control strategy assumes that MGO or HFO would be replaced by emulsified diesel fuel in the auxiliary generators. Emulsified diesel fuel consists of regular diesel fuel to which water and stabilizing surfactants have been added. A similar measure that is likely more cost effective is to mix the fuel and water in the fuel line just prior to injection into the engine. This avoids the need to store and agitate emulsified fuel on the vessel. Emulsified fuels have been used in stationary, low-speed, diesel engine since the 1980's. The NO_x emission reductions are achieved by the lower peak combustion temperature provided by the cooling effect of the water in the fuel, and it is theorized that the PM reductions are achieved through fuel drop shattering when the water in the fuel drop spontaneously boils during combustion. Similar measures such as direct water injection or humidification of the inlet air would likely reduce NO_x emissions without affecting PM emission rates.

Typically, 15% of the volume of emulsified diesel fuels is water, which lowers the energy content of the fuel. Two emulsified fuel suppliers, Lubrizol and Aquazole, are currently supplying emulsified diesel fuels in the California market. CARB has verified that Lubrizol's PuriNO_x emulsified diesel fuel can produce emission reductions of about 14% NO_x, 63% PM, and 25% VOC.

The study assumed that switching HFO/MGO diesel fuel to emulsified diesel fuel would incur a one-time cost of about \$50,000 per vessel to replace seals, pumps, lines, and filters, and to modify the fuel supply system to provide the fuel switching capability (i.e. installing a switching valve in the fuel line and other associated connections). In addition, supplying emulsified diesel fuel would require the use of either a service barge or an off-shore refueling station. An average capital cost of \$450,000 is used in the cost effectiveness analysis to account either a service barge or an off-shore refuel station. Thus, the total capital cost for this strategy would be \$500,000. This is conservative, as the cost of on-board emulsification would be much lower, assuming adequate water making capacity.

The other costs associated with this strategy are the incremental cost of the fuel and the fuel energy content penalty. Emulsified diesel fuel costs about \$0.20 to \$0.30 more per gallon relative to MGO. Combining the incremental fuel cost and cost associated with the fuel efficiency penalty, it is estimated that emulsified diesel fuel would cost about 35 to 50% more than regular fuel (Starcrest, 2002). For vessels currently operating on HFO, the cost and benefits of switching to MGO were also included.

The potential emission reductions and cost effectiveness values for the use of emulsified MGO diesel fuel instead of MGO or HFO fuel for the selected marine vessels are presented in Table 7-10 and Table 7-11, respectively.

There are issues related to this strategy:

- The need for an in-use compliance mechanism to ensure the use of the emulsified diesel fuel in the generators while these vessels are at the berths;
- The uncertainty for supply of emulsified diesel fuel due to current limited production volume and supply infrastructure;
- Possible problems with long-term storage of the emulsified diesel fuel due to the separation of water and diesel fuel; and
- Effects on the engine including durability and lube oil changes.

If Lubrizol and Aquazole were to supply emulsified diesel fuels in California for the 6 vessels for which this strategy is cost-effective, it would require over 6,000 tons per year of emulsified diesel delivered to POLB. Fuel availability is considered a major constraint to this alternative. Because the *Lihue* is a steamship, it is not a suitable candidate for use of emulsified diesel fuel, as the study found no instances where it has been used in a boiler.

Table 7-10. Potential Emission Reductions from the Use of Emulsified Diesel Fuel and MGO Substitution

Vessel Name	HC	NO _x	PM	SO _x
	Short Tons/yr			
<i>Victoria Bridge</i>	0.01	0.53	0.41	3.16
<i>Hanjin Paris</i>	0.16	7.55	4.66	36.33
<i>OOCL California</i>	0.19	10.30	7.90	61.59
<i>Chiquita Joy</i>	0.21	11.96	9.18	71.57
<i>Ecstasy</i>	0.21	9.71	5.99	46.70
<i>Chevron Washington</i>	0.02	1.04	0.18	-
<i>Groton</i>	0.03	0.60	0.06	-
<i>Alaskan Frontier</i>	0.10	3.55	2.82	21.98
<i>Ansac Harmony</i>	0.00	0.08	0.06	0.45
<i>Pyxis</i>	0.01	0.45	0.34	2.67
<i>Thorseggen</i>	0.02	1.20	0.09	-

Table 7-11. Cost and Cost Effectiveness Values of the use of Emulsified Diesel and MGO Substitution

Vessel Name	Capital Cost (\$)	Fuel Cost Increase (\$/yr)	Total NPV Cost (\$)	Cost Effectiveness (\$/ton)	Cost-Effective? (Yes/No)
<i>Victoria Bridge</i>	500,000	7,000	559,000	14,000	Yes
<i>Hanjin Paris</i>	500,000	84,000	1,257,000	3,000	Yes
<i>OOCL California</i>	500,000	142,000	1,462,000	2,000	Yes
<i>Chiquita Joy</i>	500,000	166,000	1,370,000	2,000	Yes
<i>Ecstasy</i>	500,000	108,000	801,000	4,000	Yes
<i>Chevron Washington</i>	500,000	42,000	689,000	111,000	No
<i>Groton</i>	500,000	11,000	550,000	159,000	No
<i>Alaskan Frontier</i>	500,000	51,000	913,000	3,000	Yes
<i>Ansac Harmony</i>	500,000	1,000	508,000	87,000	No
<i>Pyxis</i>	500,000	6,000	528,000	31,000	No
<i>Thorseggen</i>	500,000	17,000	574,000	87,000	No

7.2.4 Repowering with US EPA Tier 2 Engines

Repowering (i.e., replacing older, uncontrolled diesel with lower-emitting USEPA Tier 2 marine engines) is a widely employed strategy to reduce emissions from marine vessels. The California Carl Moyer program has funded several projects over the past 3 years to repower more than 190 marine engines at a total cost of about 14 million dollars. Unit costs ranged from \$7,500 to \$310,000 with the average cost of - \$75,000⁷. Since the Tier 2 marine engine regulation is a NO_x control regulation, the Tier 2 engines would reduce NO_x emissions without significantly affecting other criteria emissions, including diesel particulates.

This technology is more appropriate for small marine vessels such as tugboats, barges, or ferryboats rather than for oceangoing cargo vessels. It is therefore not effective for the POLB or shipping lines to implement.

7.2.5 Injection Timing Delay

The injection timing delay strategy is used to control NO_x emissions from diesel engines by retarding the injection of the fuel into the combustion chamber, which results in a lower peak combustion temperature, and reduced emissions. However, retarding the injection timing generally

⁷ <http://www.arb.ca.gov/msprog/moyer/appa.pdf>

increases PM and HC emissions, smoke production, and fuel consumption. The CALSTART study reported that the NO_x reduction range for the injection timing delay strategy was 10 to 30%, with an average reduction of 19%, and the fuel penalty was about 4% (CALSTART, 2002). In addition, CALSTART estimated that the HC, CO, and PM emissions would increase by about 11% (CALSTART, 2002).

Because injection-timing delay unacceptably increases HC, CO and PM emissions, this strategy was eliminated for further consideration.

7.2.6 California On-Road Diesel (Diesel #2)

The California On-Road Diesel #2 fuel strategy assumes the use of this fuel instead of HFO or MGO diesel in selected vessels' auxiliary engines. The California On-Road Diesel #2 fuel has much lower sulfur content (about 0.3% or 300 ppm) and aromatic content compared to HFO or MGO fuels. Using California On-Road Diesel #2 fuel instead of MGO or HFO fuel would reduce NO_x emissions by about 6%⁸, PM by about 87%, and SO₂ emissions by about 90% (see Appendix D). Some short haul marine applications, such as ferries and tug boats in California and Texas, and stationary diesel generators in California that are similar to the diesel generators in the studied vessels, are running on on-road diesel fuels, including California On-Road Diesel #2 and ultra low sulfur diesel fuel.

Past California experience has shown that switching between fuel types with significantly different fuel properties, such as cetane number, sulfur, and aromatic contents, could cause major fuel leakage due to oil-seal-related problems in diesel engines in use.

As with the MGO diesel fuel strategy, an issue with the use of California On-Road Diesel #2 Fuel would be to develop an in-use compliance mechanism to ensure the use of the correct fuel in the generators while these vessels are hotelling at the berths. There are several additional considerations with this lighter fuel including, availability, timely delivery of the fuel, and compatibility of the fuel and engine such as injector tolerances.

According to the ISO standards 8217 and 2719, marine fuel must have a flashpoint of a minimum of 60°C. According to SOLAS Chapter 11-2, part B, Regulation 4, no fuel oil with a flashpoint of less than 60°C shall be used. The flashpoint of California On-Road Diesel #2 Fuel is between 52°C and 60°C. Therefore this fuel should not be used with current formulations for hotelling operations in the Port of Long Beach.

⁸ "Input Factors For Large CI Engine Emission Inventory," ARB Mail Out MO99_32.3, California Air Resources Board, Sacramento, California, 1999.

7.2.7 Fischer-Tropsch Diesel Fuel

The Fischer-Tropsch Diesel Fuel strategy assumes the use of Fischer-Tropsch diesel fuel instead of MGO or HFO diesel fuel in the selected marine vessels' auxiliary engines. Fischer-Tropsch diesel fuel, also referred to as gas-to-liquid or GTL diesel fuel, is a synthetic liquid fuel made from natural gas, coal, or biomass. This synthetic liquid fuel has no aromatics or sulfur, a low specific gravity, and an extremely high cetane level. Because of these properties, Fischer-Tropsch diesel fuel provides considerable reductions in PM, SO_x, and VOC emissions, and a minor NO_x emission reduction, compared to conventional diesel fuels. For example, compared to California on-road diesel #2 fuel, the Fischer-Tropsch diesel fuel provides reductions of about 23% in HC emissions, 39% in CO emissions, 5% in NO_x emissions, and 30% in PM emissions (JMA&BAH, 2002). Compared to MGO and HFO diesel fuels, the PM emission reductions can be about 13% and 87%, respectively (see Appendix D). Since its sulfur content is extremely low (0 to 5 ppm), using Fischer-Tropsch diesel fuel essentially eliminates SO_x emissions.

As with the other fuel strategies, it was assumed that switching HFO/MGO diesel fuel to Fischer-Tropsch diesel fuel would incur an one-time fuel switching cost of about \$50,000 per vessel to replace seals, pumps, lines, filters, and to modify the fuel supply system to provide the fuel switching capability (i.e. installing a switching valve in the fuel line and other associated connections). In addition, supplying Fischer-Tropsch diesel fuel would require the use of either a service barge or an off-shore refueling station at the port. The California Energy Commission indicated that although the nearest current GTL supplier is the 2,400 barrels per day Shell-Malaysia, Bintulu MSD plant in Malaysia, discussions are underway to develop a GTL production facility in Alaska capable of initially producing 40,000 barrels per day and with a goal of 300,000 barrels per day¹⁹.

There are issues related to this strategy:

- The need for an in-use compliance mechanism to ensure the use of the emulsified diesel fuel in the generators while these vessels are at the berths;
- The need for careful logistical planning due to the uncertainty of supply of Fischer-Tropsch diesel fuel as a result of current limited production volume and supply infrastructure; and
- The lack of known applications for marine propulsion, auxiliary or generators even though Fischer-Tropsch diesel fuel has been used as automotive diesel fuel and used in some stationary diesel generators.

- There are several additional considerations with this lighter fuel including the flammability and volatility, availability or timely delivery of the fuel, and compatibility of the fuel and engine such as injector tolerances.

Thus, the Fischer-Tropsch diesel fuel technology is not a near term alternative for POLB.

7.2.8 Bio-Diesel Fuel

The Bio-Diesel Fuel strategy assumes the use of bio-diesel fuel instead of MGO or HFO diesel fuel in the marine vessels. Bio-diesel, chemically known as methyl or ethyl esters, is produced from vegetable oils or animal fats through a process known as "transesterification" with alcohol (methanol or ethanol) and catalysts. It yields a lower viscosity compound (methyl or ethyl esters) than the parent fats and oils by converting triglyceride compounds to glycerol (a by-product of the process) and removing the glycerol and the fatty acids. Methyl ester is produced when methanol is used in the transesterification process, and ethyl ester is produced when ethanol is used.

A USEPA report indicated that the use of 100% bio-diesel (B100) reduced PM emissions by about 50%, but increased NO_x emissions by about 10%, compared with standard diesel fuels (US EPA, 2002). Since there is no sulfur in the fuel, using B100 fuel essentially eliminates SO_x emissions.

A study for the San Francisco Bay Area Water Transit Authority reported that using bio-diesel reduced PM emissions by 30% and eliminated the SO_x emissions, but increased NO_x emissions 13%, compared to on-road diesel fuel (JJMA-BAH, 2002). The PM emission reductions are about 87% and 13%, respectively, compared to HFO and MGO diesel fuels (see Appendix D). This technology is eliminated from further evaluation because it unacceptably increases NO_x emissions. Besides increasing NO_x emissions, Bio-diesel is not available to meet substantial demand that would be posed by marine vessels.

7.2.9 Direct Water Injection

Direct water injection (DWI) technology involves introducing water into the combustion chamber of a diesel engine during the combustion process either directly or indirectly through the air intake manifold. Similar to emulsified diesel fuel, adding water into the combustion chamber during the combustion process reduces the peak combustion temperature, thus reducing the NO_x emissions. Since the injection is controlled electronically, the DWI system provides greater flexibility in term of optimizing emission reductions while minimizing fuel penalty compared to emulsified diesel fuel. A major technical issue with the DWI system is the need to supply water, and thus water storage or increased load on the vessel water making capacity.

A study for the Port of New York & New Jersey reported that using the DWI system reduced NO_x emissions by 40 to 50% (Starcrest, 2002). The capital cost of a DWI system was estimated to be

\$15 to \$40 per kilowatt, which equates to \$75,000-\$200,000 for a large vessel with 5,000 kW of installed generator power, and the operational cost was estimated to be \$1.30 to \$3.40 per 1000 kilowatt-hours (Starcrest, 2002). DWI is clearly a cost-effective approach to controlling NO_x emissions, but since it has no benefits in terms of PM or SO_x, it is a less attractive approach. Therefore no further evaluation was performed.

7.2.10 Humid Air Motor (HAM)

The humid air motor (HAM) is another NO_x emission reduction technology involving introducing humidified air into the combustion chamber to reduce the peak combustion temperature and the NO_x emissions. The humid air motor requires the evaporation of water to humidify the intake air so that extra water can be introduced into the combustion chamber. The HAM technology has the similar effect on reducing NO_x emissions as the emulsified diesel fuel or DWI system, but to a lesser extent as the amount of water that can be added is limited by the water vapor saturation point.

Similar to the direct water injection (DWI) technology, the humid air motor only reduces NO_x emissions. As there is no reduction of other pollutants, including diesel particulate, this technology is not a candidate for the POLB or shipping lines.

7.2.11 Exhaust Gas Recirculation (EGR)

Exhaust gas recirculation (EGR) is an effective NO_x emission reduction technology. Many heavy-duty diesel engine manufacturers in the U.S. have adopted EGR technology to meet the on-road 2007 emission standards. Similar to the effect of adding water into the combustion chamber, introducing a portion of the exhaust gas into the combustion chamber reduces the peak combustion temperature through heat absorption (i.e. due to the higher specific heat capacities of the exhaust gases mostly nitrogen, CO₂ and vapor water). Displacing some intake air with exhaust gases reduces the oxygen concentration of the combustion air, thus also reducing the peak combustion temperature. The drawbacks with the EGR technology include some fuel penalty and increases in the PM, VOC, and CO emissions. Studies have showed that reducing NO_x emissions by 20 to 30% may be achieved with a slight increase in the PM emissions. However, there is a substantial PM emission increase with NO_x emission reduction of more than 30% via EGR (Starcrest, 2002). The estimated capital cost for an EGR system was about \$20,000 per engine (Starcrest, 2002). The increasing PM, HC and CO emissions make this technology unfeasible for the POLB.

7.2.12 Diesel Oxidation Catalyst (DOC) with California On-road #2 Diesel Fuel

The diesel oxidation catalyst (DOC) promotes oxidation of CO, HC, toxic air compounds that are HCs, and the soluble organic fraction (SOF) of the PM in the diesel exhaust. In general, DOCs could effectively reduce 90% of the CO and HC emissions, and about 20% of PM emissions for diesel engines that use on-road diesel fuel. The use of DOC with non-road diesel fuel or marine

diesel fuels, which have much higher sulfur contents, might actually increase the PM emissions due to the formation of sulfates from the oxidation of SO₂ emissions.

For that reason, this strategy combines the use of DOCs with the use of low sulfur content California Diesel #2 fuel. By so doing, the PM emissions could be reduced by more than 85% and HC, CO and SO₂ emissions could be reduced by about 90% (see Appendix D). The use of California on-road #2 diesel may have insignificant reduction of NO_x emissions (~6%). The cost for a DOC system is estimated to be about \$6 per kilowatt (Starcrest, 2002).

Although a DOC system is a mature technology widely used in stationary diesel engines, and on-road and off-road applications, including marine applications, it is essential to investigate the feasibility of retrofitting a DOC system in a specific vessel due to differences in engine operating and exhaust temperature conditions, and space constraints in engine and exhaust compartments. Not only must the device fit in the exhaust ducting, but it must be accessible for servicing by the engineering staff. Often insulation must be added for safety and to maintain catalyst temperatures. Because the *Lihue* is a steamship and the *Chevron Washington* is powered by a gas turbine, they are not suitable candidates for DOCs. In addition, according to the ISO standards 8217 and ISO 2719 marine fuel must have a flashpoint of a minimum of 60°C. According to SOLAS Chapter 11-2, part B, Regulation 4, no fuel oil with a flashpoint of less than 60°C shall be used. The flashpoint of California On-Road Diesel #2 Fuel is between 52°C and 60°C. Therefore, this fuel combination with DOC should not be used with current formulations and would not be feasible for hotelling operations in the Port of Long Beach.

7.2.13 Catalyzed Diesel Particulate Filter with California On-road #2 Diesel Fuel

Many engine and/or vehicle manufacturers are using or will be using exhaust after-treatment devices, such as diesel particulate filters (DPFs), to reduce PM emissions from on-road diesel vehicles. In addition, with the implementation of the statewide CARB Diesel Risk Reduction Program²⁰, many existing on-road vehicles and off-road vehicles or engines will be required to retrofit DPFs to reduce PM emissions.

While some DPFs use filter media such as fiber wound, woven fiber and sintered metallic materials, most DPFs in the market use ceramic monolithic cells or honeycomb structures. A ceramic monolithic DPF has a honeycomb structure with canals that are alternatively closed at each end in a checkerboard pattern. With this arrangement, the DPF forces diesel exhaust gas to flow through the ceramic monolithic cells, and thus, traps the solid PM and other particles as the exhaust leaves the DPF. Most ceramic monolithic DPFs have PM control efficiencies of 90% or more.

As the PM starts to build up in the DPF, the filter must be cleaned by burning or otherwise removing the PM, which is commonly known as regeneration. If it is not regenerated, the DPF will

eventually plug with PM and create unacceptable backpressure levels for the engine. The regeneration process can occur continuously within the DPF (such as passive-catalyzed DPFs and active DPFs that require external induced heat) or by physically removing the DPF for cleaning or purging. While self-regenerating DPFs are capable of burning off trapped PM while in operation, inorganic ash will plug the filter and most, if not all, of these DPFs will eventually plug due to accumulation of high ash PM loading and/or insufficient exhaust temperature to promote the catalytic reaction that provides heat for regeneration. Therefore, even self-regenerating DPFs ultimately need to be physically removed and cleaned in order to be usable again.

With high sulfur diesel fuels, such as the non-road diesel fuel or marine diesel fuels, the use of the catalyzed DPFs might actually increase the PM emissions due to the formation of sulfates resulting from the oxidation of SO₂ emissions. For that reason, this strategy combined the use of catalyzed DPF and low sulfur California #2 diesel fuel. With the use of both technologies, the PM, VOC, CO and SO₂ emissions could be reduced by about 90%, and the NO_x emissions could be slightly reduced by about 3% (CALSTART, 2002). The capital cost for a catalyzed DPF is reported to be about \$20 per kilowatt, and the operating cost is reported to be about \$18 per kilowatt-hour (CALSTART).

While DPFs have been widely used in stationary diesel engines, and on-road and off-road applications, it is essential to investigate the feasibility of retrofitting a DPF system in a oceangoing cargo vessel due to differences in engine operating and exhaust temperature conditions, and space constraints (similar to those described with DOC) in engine and exhaust compartments. Those uncertainties may prevent this technology from being a readily practicable alternative for POLB. Because the *Lihue* is a steamship and the *Chevron Washington* is powered by a gas turbine, they are not suitable candidates for DPFs. In addition, according to the ISO standards 8217 and ISO 2719 marine fuel must have a flashpoint of a minimum of 60°C. According to SOLAS Chapter 11-2, part B, Regulation 4, no fuel oil with a flashpoint of less than 60°C shall be used. The flashpoint of California On-Road Diesel #2 Fuel is between 52°C and 60°C. Therefore this fuel combination with DOC should not be used with current formulations and would not be feasible for hotelling operations in the Port of Long Beach.

7.2.14 Selective Catalytic Reduction (SCR)

Selective catalytic reduction (SCR) is another technology for reducing NO_x emissions from diesel engines by catalytic means. In the SCR process, a reducing agent, ammonia or urea, is injected directly into the exhaust gas stream before the SCR catalyst to reduce the NO_x emissions to N₂ and H₂O.

SCR technology has been used for many years in stationary and marine diesel applications, with a NO_x emission reduction potential of 90% to 99%, with an average value of 95%.

In its Regulatory Support Document for the Category 3 Marine Engine Regulation, EPA provided lists of the marine applications that were equipped with SCR systems. The marine applications ranged from ferries, “RO-ROs”, RoPaxs, and vessel propulsion, main, and auxiliary engines with capacity ranging from 900 to 7,000 kW (EPA, 2003).

The capital cost for a SCR system was reported to be about \$71 per kilowatt, the operating cost was reported to be about \$21 per kilowatt-hour, and the urea cost was estimated to be equivalent to about a 2% increment of the fuel cost (CALSTART, 2002).

SCR does not reduce PM or SO₂ emissions. Therefore, SCR is not an appropriate candidate for hotelling emissions reductions in the POLB.

7.2.15 Cryogenic Refrigerated Container (CRC)

During the past decade, a new type of refrigerated container – a cryogenic refrigerated container or CRC - has been introduced to ocean shipment. Cryogenic refrigerated containers utilize food grade dry ice (CO₂) as the refrigerant to maintain sub-zero (°C) temperatures in the containers. As CRCs do not require any kind of mechanical device or electrical power to keep the cargo refrigerated, they could be shipped on many modes of transportation without the concern for an outside power source or a mechanical breakdown. The use of dry ice in CRCs does not generate any air emissions. However, it should be noted that making dry ice takes a significant amount of energy, which could have significant emissions impacts, depending on the technology.

Container Service Company (CSC), a Portland, Oregon based cryogenic refrigerated container manufacturer and operating company, currently operates 30 CRCs for moving frozen foods between Portland/Seattle and Japan (CSC, 2003). CSC placed its first CRC unit in commercial cargo operation 5 years ago. CSC is negotiating a sales contract with a European client to sell them 260 CRCs. CSC also sells its CRC units to trucking companies for inland transportation. Other issues associated with CRCs include:

(1) Temperature Management

At the present time, cryogenic refrigerated containers are only good for cargo shipments in a sub-zero environment. A temperature management technology for a “mid-low” temperature (~15-20 °C) condition is under development but is not yet commercially available.

(2) O₂ and CO₂ levels in the container

During shipment the O₂ level inside the container is near zero. When the doors of a CRC are opened, a sublimated CO₂ cloud that is heavier than air will flow out of the container. It takes only a few minutes to vent all the CO₂, but the process must be carried out in a safe manner to

avoid asphyxiating nearby people. The CRC operator must pass safety certification tests established by the US Department of Transportation (DOT). The European Union has a similar program to manage the safe operation of CRCs.

(3) Long Shipping Hours

Single charged CRCs could maintain the temperature at the desired level for up to 30 days. It is long enough to accommodate virtually all ocean shipment (20 days) and inland transportation times (10 days).

(4) Operating Costs

According to CSC, 250 pounds of dry ice (CO₂) is needed for a 40-foot ISO container each day. The total CO₂ usage for a 30 days charge is about 7,500 pounds. Liquid CO₂ is commercially available at \$50 to \$120 per ton depending on purchase quantity, and market conditions. The CO₂ cost for a 30 day charge would be \$190 to \$450 per 40-foot ISO container.

(5) CO₂ Charge Station

It would be financially feasible for CSC to set up a CO₂ charge station anywhere the demand is greater than charging 6 cryogenic refrigerated containers per day.

(6) Space Requirements

Dry ice compartments in cryogenic refrigerated container take out space normally used for freight. 7,500 pounds of dry ice would take 80 cubic feet of space, which is about 3% of the volume of a 40-foot ISO container. This would increase the cost of freight shipment by at least 3%.

While the CRC strategy is included in this section, the cost effectiveness of this strategy was not assessed. At the present, the CRC technology has not yet reached a scale needed for significant emission reduction in marine vessels calling at the POLB. Furthermore, as CRC technology is only relevant to refrigerated containers it would not address other hotelling demands, which, in the case of tankers and passenger vessels, are substantial.

7.2.16 Summary

A summary of emission reductions reported by other studies is summarized in Table 7-12.

Table 7-12. Emission Reductions from Alternative Technologies

Technology Evaluated	Reported Emission Reduction (%)				
	PM ₁₀	NO _x	SO ₂	CO	VOC
Repowering with NG/Dual Fuel Engine	~94%	~90%	~99%		
Diesel PM Trap & CA On-road #2 Diesel	~90%	~3%	~90%	~85%	~92%
California On-road #2 Diesel	13-87%	~6%	~90%		
Fischer-Tropsch Diesel	13-87%	~5%	~99%	~39%	~23%
Diesel Oxidation Catalyst & CA On-road #2 Diesel	~87%	~6%	~90%	~90%	~90%
MGO Diesel ⁽¹⁾	0-85%		0-90%		
Emulsified Diesel Fuel	~63%	~14%	15-20%		~25%
Bio-Diesel (B100)	13-87%	Increase	100%	~50%	~93%
Selective Catalytic Reduction		~95%			
Direct Water Injection		40-50%			
Humid Air Motor		~28%			
Repowering with EPA Tier 2 Engine		18-46%			
Injection Timing Delay	Increase	10-30%		Increase	Increase
Exhaust Gas Recirculation	Increase	20-30%		Increase	Increase
Cryogenic Refrigerated Container	100%, except for air emissions from making dry ice				

Note: (1) 0% associated with vessels already using MGO (marine) diesel in on-board generators.

Based on emission reduction benefits, current equipment and/or fuel availability, and other uncertainties associated with implementation of some technologies, the technologies listed in Table 7-13 are not practical near-term alternatives for POLB.

Table 7-13. Not Practical Near-term Alternatives for POLB

Technology	Facts Considered
Injection Timing Delay	Increases PM, CO and VOC emissions
Exhaust Gas Recirculation	May increases PM, VOC and CO emissions
Direct Water Injection	Only reduces NO _x emissions
Humid Air Motor	Only reduces NO _x emissions
Selective Catalytic Reduction	Only reduces NO _x emissions
Repowering with EPA Tier 2 Engine	Only reduces NO _x emissions

Table 7-13. Not Practical Near-term Alternatives for POLB

Technology	Facts Considered
Fischer-Tropsch Diesel	No adequate fuel supply available; Difficulty to distribute to vessels
Bio-Diesel (B100)	Increases NO _x emissions; Difficulty to distribute to vessels
CARB No. 2 Diesel Fuel	Flash point too low to be allowable under SOLAS regulations.
Diesel PM Trap with CA On-road #2 Diesel	Flash point too low to be allowable under SOLAS regulations; Fuel distribution to vessels; no marine application yet.
Diesel Oxidation Catalyst with CA On-road #2 Diesel	Flash point too low to be allowable under SOLAS regulations; Fuel distribution to vessels; no marine application yet.
Cryogenic Refrigerated Container	Has not reached the large scale application yet

Table 7-14 lists those technologies that have demonstrated potential benefits for overall emission reductions and potential applicability to marine vessels. However, they should not be considered readily available alternatives to POLB until the identified implementation constraints could be adequately addressed.

Table 7-14. Potential Alternatives to POLB

Technology	Potential Implementation Constraints	Average Cost Effectiveness over 12 Vessels (\$/ton)	Cost-Effective Vessels
MGO Diesel	Design and operation of engine; Separate fuel system and delivery infrastructure	\$4,000 (No NO _x reduction)	All Vessels except for <i>Groton</i> , <i>Thorseggen</i> , and <i>Chevron Washington</i>)
Repowering with NG/Dual Fuel Engine	Safety concerns; fuel distribution system, separate on-board fuel system; in-use compliance if dual fueled engine	\$9,000	All Vessels except for <i>Anzac Harmony</i>
Emulsified Diesel Fuel	Includes effectiveness of MGO use; Fuel distribution to vessels design and operation of engine; separate fuel system; in-use compliance; loss of power; fuel phase separation.	\$42,000	Seven Vessels (except <i>Groton</i> , <i>Anzac Harmony</i> , <i>Pyxis</i> , <i>Thorseggen</i> , and <i>Chevron Washington</i>)

REFERENCES

- IMO, 1997. "Regulations for the Prevention of Air Pollution from Ship: Annex VI – the Protocol of 1997," International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), International Maritime Organization, London, United Kingdom, 1997.
- USEPA, 1999-1. "Control of Emissions of Air Pollution from New Marine Compression-Ignition Engines at or Above 37 kW," Final Rule, Federal Register: December 29, 1999 (Volume 64, Number 249), pages 73299-73373, Environmental Protection Agency, Washington, DC, December 29, 1999.
- USEPA, 1999-2. "Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engine," EPA 420-R99-026, Environmental Protection Agency, Ann Arbor, MI, November 1999.
- USEPA, 2003-1. "Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder," Final Rule, Federal Register: February 28, 2003 (Volume 68, Number 40), pages 9745-9789, Environmental Protection Agency, Washington, DC, February 28, 2003.
- USEPA, 2003-2. "Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder," EPA 420-R-03-004, Environmental Protection Agency, Ann Arbor, MI, January 2003.
- ENVIRON, 2003. "Air Quality Technology Development Needs: Diesel NO_x Emission Reduction Technologies," Final Report to the Texas Council on Environmental Technology, Austin, TX, ENVIRON International Corporation, Novato, CA, and Southwest Research Institute, Austin, TX, May 2003.
- CEC, 2001. "Emission Reduction Technology Assessment for Diesel Backup Generators in California," Consultant Report P500-01-028, California Energy Commission, Sacramento, CA, December 2001.
- CSC, 2003. Personal communications between Mr. Steve Fulton of CSC and ENVIRON.
- BAE, 2000. "Guide to Exhaust Emission Control Options," BAE Systems, Land & Sea Systems, Bristol, United Kingdom, March 2000.
- CALSTART, 2002. "Passenger Ferries, Air Quality, and Greenhouse Gases: Can System Expansion Result in Fewer Emissions in the San Francisco Bay Area?" Report to Gas Technology Institute and Brookhaven National Laboratory, Department of Energy, CALSTART, California, July 23, 2002.

- JJMA-BAH, 2002. “New Technologies and Alternative Fuels: Working Paper on Alternative Propulsion and Fuel Technology Review,” Report to San Francisco Bay Area Water Transit Authority, John J. McMullen Associates, Inc, and Booz Allen Hamilton, May 2, 2002.
- JJMA, 2004. Phone conversation with Allen Bozzuffi, a marine engineer of John McMullen Associates, Inc., January 2004.
- Starcrest, 2002. “Emission Reduction Strategies Findings Report for New York/New Jersey Harbor Navigation Project,” Report to the Port Authority of New York & New Jersey, Starcrest Consulting Group, LLC and Allen King Rosen & Fleming, Inc., November 15, 2002.
- SIEMENS, 2002. “NO_x Reduction for Marine Diesel and Heavy Fuel Oil Engine,” Presentation to the Maritime Working Group Meeting, Oakland, CA, by SIEMENS, July 26, 2002.
- MAN-B&W, 2002. “Emission Reduction Methods, Theory, Practice and Consequences,” Presentation to the Maritime Working Group Meeting, Oakland, CA, by MAN B&W, July 26, 2002.
- NESCAUM, 2003. “Stationary Diesel Engines in the Northeast: An Initial Assessment of the Regional Population, Control Technology Options, and Air Quality Policy Issues” Northeast States for Coordinated Air Use Management, Boston, MA, June 2003.
- Ricardo, 2002. “Engine Manufacturers meet New Energy and Air Quality Challenges,” Presentation to the Maritime Working Group Meeting, Oakland, CA, by Ricardo, July 26, 2002.
- Seaworthy, 2002. “The Future of Practical Exhaust Emissions Control for Marine Diesel Engines,” Presentation to the Maritime Working Group Meeting, Oakland, CA, by Seaworthy Systems, Inc., July 26, 2002.
- USEPA, 2002. “A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions,” EPA420-P-02-001, Environmental Protection Agency, Ann Arbor, MI, October 2002.
- CARB, 2000. “Diesel Risk Reduction Plan, Appendix 9,” California Air Resources Board, Sacramento, CA, 2000.

8.0 POLITICAL AND TECHNICAL ISSUES

8.1 Legal Authority/Current and Future Regulatory Requirements

Cold ironing and/or other air pollution controls for marine vessels while they are hotelling at the Port of Long Beach could potentially be required by four different levels of government: international (by international treaty), Federal (United States Environmental Protection Agency), state (California Air Resources Board) and local (South Coast Air Quality Management District).

8.2 International Level

Background

The United States is a signatory to the International Convention for the Prevention of Pollution from Vessels, the global agreement to control accidental and operational discharges of pollution from vessels. The original 1973 treaty, together with an important protocol added in 1978, are referred to as "MARPOL."

Under the auspices of the International Maritime Organization (IMO), an agency of the United Nations, the signatory countries adopted Annex VI to MARPOL in 1997 to reduce worldwide NO_x emissions from vessels by about 20 to 30 percent. These limits apply to diesel engines with a power output of more than 130 kW manufactured after January 1, 2000 and require the use of readily available emission control technology. The regulation covers propulsion engines and most auxiliary engines. (As described more fully below, Annex VI does not address shore side electrification as a means to reduce vessel emissions – it is focused solely on engine and fuel technology.) Although the Annex has not yet entered into force and is not yet legally binding, it is widely recognized that the vast majority of marine diesel engines manufactured and installed after January 1, 2000 meet the requirements of the Annex.

Annex VI also controls emissions of sulfur oxides by imposing a global cap of 4.5% sulfur (45,000 ppm) on the sulfur content of fuel oil used on ships for combustion. The annex also contains a provision for the establishment of special "SO_x Emission Control Areas (SECAs)". The sulfur content of fuel used by ships operating in these areas must not exceed 1.5% (15,000 ppm). Alternatively, a ship can use an exhaust gas cleaning system to limit the SO_x emissions. To date, only the Baltic Sea has been designated as a SECA.

Annex VI will be legally binding at the point when at least 15 nations with at least 50 % of the gross tonnage of the world's merchant shipping have ratified the annex. It is expected that this threshold should be met in 2004. The President of the United States has submitted Annex VI to the U. S. Senate for its advice and consent to ratification.

Current Regulatory Requirements and Future Directions

Presently, there are no international requirements that would mandate or facilitate cold ironing of marine vessels. With regard to other alternative control technologies evaluated in this report, establishment of a SECA would be one mechanism for implementing low sulfur diesel fueling. Current international requirements would not likely affect the other alternatives. However, negotiations will begin soon under the IMO umbrella to tighten the NO_x emission limits that could result in engine modifications and/or control technology to reduce NO_x emissions from ship hotelling in future years.

While not an international requirement, it should be noted that the European Union has introduced a 0.2% (2,000 ppm) sulfur limit for fuel used by seagoing vessels at berth in EU ports and by inland vessels, with the limit dropping to 0.1% in 2008. Should the proposal become a final rule, such an EU requirement could have a practical effect on low sulfur fueling strategies in the United States by setting a precedent. It would also facilitate the availability of such fuels in U.S. ports because a vessel traveling to European ports would likely need to bunker and start using low sulfur residual fuel upon leaving a port in the U.S. in order to be in compliance upon arrival in EU waters.

8.3 Federal Level

Background

At the federal level, USEPA regulates emissions from new marine diesel engines, on vessels that are flagged or registered in the United States, under Section 213 of the Clean Air Act. This provision required USEPA to determine whether non-road engines and vehicles, including marine vessel engines, contribute significantly to ozone and CO concentrations in more than one nonattainment area and/or significantly contribute to air pollution that may reasonably be anticipated to endanger public health or welfare. EPA made such a finding in 1994 and subsequently promulgated NO_x and PM emission standards for new marine diesel engines with in-cylinder displacement of less than 30 liters (Category 1 and 2) and NO_x emission standards for new engines with displacement greater than 30 liters (Category 3). Generally, auxiliary engines on large marine vessels fall into Category 1 and 2, while main propulsion engines are Category 3. The Category 1 and 2 standards become effective between 2004 and 2007, depending on exact engine size, while the Category 3 standards are effective in 2004. USEPA intends to adopt a further tightening of the standards by 2007. These standards are at least as stringent as the current Annex

VI international standards, so that engines complying with the Federal standards will comply with Annex VI.

Most ocean-going vessels calling on U.S. ports are foreign flagged. USEPA specifically considered but ultimately deferred application of these standards to such vessels. The agency has stated its intent to work with IMO to tighten the Annex VI standards as the preferred method to regulate emissions from foreign flagged vessels.

USEPA has also proposed that starting in 2007, fuel sulfur levels in non-road diesel fuel would be limited to a maximum of 500 ppm, the same as for current highway diesel fuel. This limit also covers fuels used in many marine applications (though not to the marine residual fuel typically used by propulsion engines and many auxiliary engines on ocean-going vessels). The agency has also requested comment regarding further reducing the sulfur limit to 15 ppm in 2010 for marine vessels.

Current Regulatory Requirements and Future Directions

Presently, there are no Federal requirements that would mandate or facilitate cold ironing of marine vessels. During the public comment period for setting Category 3 standards, many commenters insisted that the Federal government should establish a national policy or regulation addressing hotelling emissions from marine vessels. However, USEPA has determined that the Clean Air Act only gives the agency authority to set emission standards for new marine engines, leaving the regulation of the use and operation of marine engines to state and local government.

With regard to the other alternative control technologies evaluated in this report, establishment of a SECA under Annex VI would be one mechanism for implementing low sulfur diesel fueling (1.5% S). USEPA is currently preparing a strategy to develop a proposal to IMO to establish SECA's for the East, West and Gulf Coasts. Likewise, to the extent that non-residual diesel fuels used by marine vessels are refined or imported into the United States, a low-sulfur diesel fueling strategy could be enhanced by the proposed Federal 500 ppm and 15 ppm future sulfur-in-fuel limits.

The Category 1, 2 and 3 engine emission standards for NO_x and PM could result in the application of the other alternative control techniques such as engine modifications and/or exhaust treatment. Such controls could reduce NO_x emissions from ship hotelling in future years, at least for vessels constructed after the effective date of the regulations. The contemplated further tightening of these standards by USEPA in 2007 could further require these control technologies in the 2010 - 2020 timeframe.

8.4 State Level

Background

At the state level, the California Air Resources Board believes it has the legal authority to regulate marine vessels. On October 23, 2003, CARB adopted the State and Federal Strategy for the California State Implementation Plan, including revisions to State commitments to adopt and implement additional statewide measures to achieve emission reductions. The legal authority discussion in the Strategy states: “California has concurrent authority to regulate some non-road engines or vehicles including marine vessels. However, as a practical matter adoption of separate, California-only standards for national transportation sources (e.g. heavy duty trucks or marine vessels) is not a fully effective means of controlling emissions from these sources.” The state’s position is more fully explained in the June 1984 Report to the California Legislature on Air Pollutant Emissions from Marine Vessels. This report includes a detailed legal analysis prepared by CARB staff.

As part of the State and Federal Strategy, CARB has included the following elements that it recommends USEPA include in evaluating Long-Term Advanced Technologies for marine vessels:

- Further tightening of the both the Annex VI and USEPA Category 1,2 and 3 standards;
- Operational controls;
- Cleaner fuels in California waters;
- Incentive programs to encourage cleaner vessels;
- Opacity limits within California coastal waters; and
- Cold ironing.

The Board adopted the so-called Burke amendment to the State and Federal Strategy during the October 23, 2003 hearing. Among other commitments, the amendment included an increase to the near-term State commitment by an additional 97 tons per day, ROG and NO_x combined, in the South Coast Air Basin in 2010. This commitment includes a possible measure for “cold ironing for ships calling on the Ports of Long Beach and Los Angeles”.

The State and Federal Strategy and the 2003 South Coast Air Quality Management Plan (AQMP) will be submitted to the USEPA as a formal revision to the California State Implementation Plan. USEPA would then review, propose action (approval or disapproval), receive public comment and then take final action on the submittal. Upon approval, the revision would become enforceable by both the USEPA and citizens under the Clean Air Act. The Burke Amendment, in particular, may raise approvability issues for EPA because, in contrast to long-term measures, near-term measures for extreme ozone nonattainment areas have traditionally been required to be individually described

with scheduled adoption dates and emission reductions. Because the Burke amendment gives a broad commitment to tons with an as-yet not firmly defined set of measures, full approval may be problematic.

Current Regulatory Requirements and Future Directions

While cold ironing had been identified as a long-term measure for the State and Federal Strategy, as noted above, the Burke amendment specifically listed “cold ironing for ships calling on the Ports of Long Beach and Los Angeles” as one of the possible items that may be included by CARB in achieving the 97 tons per day near-term State commitment. However, since the amendment specifies that “CARB commits to achieve, at minimum, the ROG and NO_x reduction target in this control measure through adoption and implementation of any combination of feasible control strategies affecting on-road and off-road mobile sources and consumer products”, it is not certain that cold ironing will be one of the measures ultimately adopted to meet the 97 ton commitment.

At the December 3, 2003 Maritime Air Quality Technical Working Group meeting, CARB staff presented a more detailed schedule regarding their intended evaluation of cold ironing for ships that frequently visit South Coast ports. Specifically, they intend to complete an evaluation in by 2004 and adopt a measure (if feasible) by 2005.

With regard to the other alternative control technologies evaluated in this report, low-sulfur fueling strategies are receiving increasing attention from CARB. At the December 3, 2003 Maritime Air Quality Technical Working Group meeting, CARB presented a detailed schedule for reducing emissions from auxiliary engines on ships while hotelling: They anticipate a completed evaluation in 2004 and adoption of a measure(s) by 2006. They also presented the following regulatory concepts:

- On-board generators burning cleaner fuel at dockside or in California Coastal Waters;
- Marine gas oil (MGO) with sulfur cap or EPA/CARB on-road diesel in main propulsion engines;
- Allow cold ironing or add-on controls as an alternative to burning cleaner diesel;
- Special provisions for vessels calling on California ports several times per year; and
- Encourage western states/Canada to adopt similar program.

CARB staff also identified the following key issues that they will examine as part of their evaluation:

- Cost impacts;
- Fuel switching procedures;

- Additional tanks and piping needed;
- Engine compatibility;
- Availability of cleaner fuels;
- Safety issues/flash point;
- Cost benefits of cold ironing for frequent flyers; and
- Port impacts.

In addition to actively considering mandating the use of low sulfur distillate fuels while marine vessels are hotelling, CARB is also actively working with other West Coast states in supporting EPA in the establishment of a SECA under Annex VI of MARPOL (discussed above). In the event that a distillate strategy is not adopted, the 1.5% sulfur limit in a SECA would establish lower sulfur fueling for ships that are currently burning high sulfur residual in their auxiliary and propulsion engines. In addition, the add-on control technology alternatives evaluated elsewhere in this report could be encouraged if CARB adopts a provision as part of a clean fuel strategy to allow ships to install add-ons in lieu of burning lower sulfur fuel.

During information meetings with the Pacific Merchant Shipping Association (PMSA) and the Pacific Maritime Association (PMA), they expressed the view that the legal authority of the SCAQMD, CARB and even the Federal Government to require cold ironing of ships is questionable. In particular, they pointed to a court decision "Intertanko v. Locke" that restricted the ability of a state to regulate marine vessels. In this March 2000 decision, the United States Supreme Court granted certiorari and addressed the question of whether the State of Washington regulations, which placed restrictions on oil tankers that entered state waters, were preempted by congressional acts that had the same or similar regulations. The Court held that federal law preempted four of the Washington regulations. The Court also remanded the case in order for the lower court to determine if any of the other provisions of the Washington regulation were preempted. It should be noted that at the appeal stage, the United States intervened on Intertanko's behalf, contending that the District Court's ruling failed to give sufficient weight to the substantial foreign affairs interests of the Federal Government. It would appear that the effect of this court decision would need to be evaluated by the regulatory agencies as they evaluate cold ironing and other hotelling strategies.

8.5 Local Level

Background

The South Coast Air Quality Management District previously considered a cold ironing regulation for ships in the South Coast Basin in the late 1980's. However, after a lengthy evaluation by both the District and the Ports of Los Angeles and Long Beach, the SCAQMD terminated the rule

making process and did not adopt a cold ironing rule. Apparently, a primary deciding factor not to proceed with a regulation was the position of the U.S. Coast Guard that such a rule would conflict with USCG safety requirements that vessels be able to be underway within thirty minutes in case of a safety or security emergency. The USCG was especially concerned about steamships, which take longer than diesel engine marine vessels to power up from a cold state. At that time, the percentage of steamships compared to diesel engine vessels was much higher than today.

Although it was never consummated, the historical development of a cold ironing rule would indicate that the SCAQMD believed at the time that they had the legal authority for regulating marine vessels at the South Coast ports. That view now appears to have changed: in the Final Program Environmental Impact Report for the 2003 Air Quality Management Plan (AQMP), Chapter 4 states that “the SCAQMD does not have authority to directly regulate marine vessel emissions and the SCAQMD cannot require retrofitting, repowering or controlling emissions from marine vessels. However, CARB and the U.S. EPA have authority to regulate these sources ...”

The SCAQMD Governing Board adopted the 2003AQMP on August 1, 2003. CARB staff reviewed that plan, which the CARB board then approved by on October 23, 2003. As discussed above, the AQMP will be submitted with the State and Federal Strategy as a formal revision to the California SIP for review and approval by the USEPA. The AQMP contains several provisions that could affect the implementation of cold ironing and other alternative control technologies for marine vessels.

On May 11, 2001, the South Coast District adopted Rule 1632, Pilot Credit Generation Program for Hotelling Operations. Under this rule, NO_x credits can be generated when vessels near ports use electrical power supplied by fuel cells. The Rule envisions that fuel cells would be located on a mobile barge that could move to individual vessels. To date, credits have not been generated under Rule 1632. Even if they were, minimal emission reductions would be generated from Rule 1632 because any emission reductions achieved would be used to generate credits to allow inland sources such as power plants to increase their emissions (less a 10 percent “discount” retired for the benefit of the environment).

Current Regulatory Requirements and Future Directions

SCAQMD’s Board also adopted the environmental community’s suggested Attachment 2C, “SCAQMD’s Action Plan to Expedite Implementation of Long Term Measures”. This attachment included several proposed strategies for ships in ports, including cold ironing and low-sulfur diesel fueling. Feasibility studies are to be completed for these two strategies in 2004 and if found to be feasible and within the SCAQMD’s legal authority for implementation, rules would then be proposed for the Governing Board’s adoption in 2005. Presumably, the feasibility studies will be coordinated with CARB’s evaluation and adoption schedule for cold ironing and emission reduction

strategy for auxiliary engines on ships while hotelling, as described above. At this writing, it is unclear which agency would actually be adopting a rule if the strategies are found to be feasible.

Finally, the 2003 AQMP includes Attachment 2B, “Suggested Control Concepts for the State and Federal Element,” prepared by SCAQMD staff. One of the suggested measures is to require retrofits of auxiliary engines on ships with existing technology such as diesel oxidation catalysts and diesel particulate filters. While not a binding commitment, CARB will likely consider this suggested measure as part of its evaluation of hotelling strategies, specifically a provision for allowing add-on controls in lieu of burning low-sulfur diesel fuel.

8.6 Operational Flexibility

Vessel operators, PMSA, and PMA were surveyed to determine the possible impacts of cold ironing on their operational flexibility. They expressed the following major concerns:

- Retrofitting ships for cold ironing would constrain company planning because it would limit the ships that come into the Port of Long Beach. If cold ironing is required at all terminals in the Port, only ships retrofitted for cold ironing would be able to call, and if only certain berths have cold ironing capabilities, retrofitted ships would have to dock only at those berths. With the exception of container lines, which do not shift their berths very often, ships may go to different berths on different runs and may go to more than one berth during a single port call. An example of in-port movement is transferring tankers and bulk loaders from a deepwater berth to a shallow-water berth to maximize use of the deepwater berths.
- Many shipping lines operate with chartered ships rather than with their own ships. Charter ship contracts are based on market condition and ship availabilities, and many are negotiated on a short-term basis. In addition, shipping alliance members share berths at terminals and are assigned space on an as-needed basis. It would be difficult for shipping lines to charter exclusively cold ironing-ready ships and to send them only to cold ironing-ready berths.
- Fleet turnover and ship deployment are driven by market conditions. In the case of container ships, a common practice is apparently to place newer, larger ships in the Asian and European routes. The older vessels are then transferred to trans-Pacific service, which brings them to the Port of Long Beach. Finally, as they age and are supplanted by even larger vessels, they will be placed on different routes that will not call at Long Beach. Oceangoing vessels typically have approximately 15 years of useful life because many customers do not allow use of older ships in order to limit their liabilities. The average geographic placement cycle is about two to three years. It is very unlikely that a ship would call at the same port for its entire service life.

A requirement to burn low sulfur diesel fuel in California coastal waters or ports may also affect operational flexibility. Not all vessels may be able to burn low sulfur fuel. In addition, ships that can burn low sulfur fuel may need to be retrofitted with dual tank fuel storage systems. Such retrofitting may be problematic on certain vessel designs because of space limitations or safety issues. In addition, unavailability of low sulfur fuel in certain foreign ports may constrain routing, if vessels entering California waters have not been able to refuel their auxiliary tanks with low sulfur fuel at their last port of call.

A requirement for application of other alternative control techniques such as engine modifications and/or exhaust treatment could also affect operational flexibility. Many engines cannot be modified because of fundamental design considerations. Likewise, space limitations and technical problems will likely prohibit the use of add-on treatment systems on many marine vessels.

8.7 Safety and Other Liabilities

Vessel operators, PMSA, and PMA were also surveyed to determine possible safety issues regarding implementation of cold ironing: They expressed the following major concerns:

- Currently, ship operators lack personnel with the special training or possible certification to perform power connection and disconnection. Personnel working on a vessel with cold ironing capability would require new training to perform such tasks.
- Jurisdictional issues were also raised regarding worker safety. CAL-OSHA has regulatory responsibility for safety for landside operations that affect the ILWU, while vessel crews are covered by the regulations of the country in which the vessel is flagged. Federal OSHA may also have some jurisdiction for some activities not covered by CAL-OSHA.
- Process safety is definitely a critical issue for shore-side electrification. If electrical service was interrupted and the ship's generators did not start up quickly, the navigation systems on some ships could take 4 to 6 hours to come back online once power is restored. However, many ships can tolerate short blackouts during the switch to and from shore power.

The U.S. Coast Guard was also contacted regarding USCG safety and security requirements that might affect the feasibility of cold ironing. The Eleventh District representatives expressed the following concerns:

- The USCG does not believe the 30-minutes notice requirement described earlier is applicable to all types of ships.
- The USCG Eleventh District is developing an Area Maritime Security Plan (AMSP) and a Port Safety Plan (PSP). These plans may establish a series of emergency scenarios in which ships could be asked to leave their docks in intervals ranging from immediate to up to 12

hours depending on level of security, degree of emergency and weather conditions. When these plans are established, they will act as guidance, not rules. The USCG is interested in information on how long a marine vessel would take to prepare to get underway when cold ironed, particularly if it would be longer than at present.

- The USCG does not require the exclusion of specific cargoes from cold ironing. Safety issues and personnel training should be addressed according to California or Federal Occupational Safety and Health Administration (OSHA) regulations and associated industrial standards. For example, chemical tankers must maintain the minimum inert gas concentration.
- Besides keeping the waterway clear for ship traffic and meeting the safety requirements imposed by other regulations, the USCG has no objections to utilizing a clean fuel barge as an alternative to control hotelling emissions.
- The USCG does not require a review of system design and the USCG is not responsible for approving or disapproving any engineering design. However, the USCG would expect any shore-side electric distribution facility to meet the location, distance and security requirements set forth in the associated classification society standards.

8.8 International Cooperation and Interstate Coordination

Port competitiveness is an important issue to be considered in designing strategies for reducing hotelling emissions. Were cold ironing to be required at South Coast Basin ports and not others on the West Coast, many shipping lines, especially auto movers, could send their ships to other ports where cold ironing is not required. However, shippers that might leave the Port for a while due to cost impacts may eventually return because other West Coast ports could likely not provide the intermodal infrastructure found in the San Pedro Bay ports for shipping goods eastward. In addition, approximately half of the goods arriving at the Ports of Long Beach and Los Angeles are destined for delivery in the Basin itself. The regulatory agencies have recognized the importance of this issue. As noted at the December 3 Maritime Air Quality Working Group meeting, CARB and USEPA are actively working with other western states and Canada to harmonize and coordinate hotelling emission reduction strategies. Ideally, IMO would address such strategies in order to facilitate compatible worldwide requirements.

PMA and PMSA representatives believe there is strong need for standardization of any cold ironing equipment requirements. They believe it would be best for IMO or some other national or international body or government to establish design standards so that ships calling at multiple ports would have the ability to have one set of plug ins (analogous to the plug ins that aircraft have when converted to local power at airports). They are concerned that if POLB or POLA independently

establish cold ironing requirements, the equipment installed on vessels for POLB may not work in other ports.

8.9 Labor Issues

Many labor issues would need to be addressed if cold ironing were implemented. Ship owners may want to retain the responsibility for "plugging in" to be reserved for the ship crews and not be considered an activity under the purview of the ILWU. However, the ILWU may believe that the connection is a landside activity covered by union contracts. Vessel operators may be concerned about the additional costs for dedicated crews, safety training and technical training if the ILWU were responsible for the connection and disconnection. Existing responsibilities for bunker fueling and fresh water hookups could also provide useful precedents in resolving labor and union issues regarding cold ironing hookups.

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9.0 CONCLUSIONS

Cold ironing is a process to reduce emissions by using shore generated electrical power instead of operating a vessel's on-board diesel-fired generators. The cost of cold ironing the 12 studied vessels on a Net Present Value (NPV) basis is a composite of many expenditures, including:

- Power purchased from Southern California Edison (SCE) (25% after the small fuel savings);
- Landside operating costs (30%);
- Landside capital costs, primarily SCE and terminal electrical distribution infrastructure (20%);
- Vessel retrofit costs (5%); and
- Work-barges needed for some vessels (20%).

None of these costs is dominant, but all are important. The cost of purchased power is estimated to be 6.2 times the value of the fuel savings. If new vessels had cold ironing capability installed at the time of construction, some costs would be saved, but the overall cost effectiveness would not change significantly. However, if more vessels use the berths that are capable of cold ironing, the cost effectiveness would improve significantly. This is because the amount of emissions reduced would increase without significant additional capital costs. The unit cost of the purchased power would also decrease if the berths were used more often.

The study evaluated the parameters that affect cost effectiveness. Of those parameters, annual power consumption by the vessel while hotelling shows the best correlation. This analysis shows that cold ironing is cost effective as a retrofit when the annual power consumption is one point eight million (1,800,000) kW-hr or more. For a new vessel with cold ironing equipment installed calling at a new terminal with the needed power facilities, it would be cost-effective if the annual power consumption is greater than one point two million (1,500,000) kW-hrs.

Among the 12 selected study vessels, the study shows that five vessels are cost-effective candidates for cold ironing, although some other emission control techniques are even more cost-effective. Some ships, particularly those that do not call often, are very poor, non-cost-effective candidates for cold ironing or most other control technologies.

There are many alternatives to cold ironing for reducing hotelling emissions. They include alternative fuels, alternative engines, tailpipe controls such as diesel oxidation catalysts, and fuel additives or mixtures. Some of the feasible alternatives are more cost-effective than cold ironing, although in some cases they have lower emissions reductions or achieved single pollutant reduction, and many have unresolved technical obstacles.

All of the possible control techniques have significant regulatory, legal, and logistical hurdles to overcome, particularly if the SCAQMD or other agency wishes to mandate their use. These hurdles are at the local, State, Federal, and international levels. Given those constraints, a voluntary program or an incentive program may be the most productive means of reducing emissions from hotelling in the Port of Long Beach.