Appendix E

Information Used in Cost Effectiveness Analysis And Example Calculation

This appendix contains information used in the cost-effectiveness analysis developed for this proposed regulation. Included in this appendix is information used to determine the costs for adding shore-power capability to ships and to berths, the hotelling times used in the analysis, and an example cost-effectiveness calculation.

Cost for Adding
Shore Power Equipment to Vessels
(cost per vessel)

Reported costs

- Container Vessels

- China Shipping (2004-2007)[1]:	$320,000
- NYK Atlas (2004)[2]:	$830,000
- Evergreen S Class (2005-2007)[3]:	$2,000,000
- NYK retrofit for 38 vessels[4]: (2007-2009)	$600,000
- K-line (2007-estimate for retrofit)	$150,000 to $500,000[5]

- Passenger Vessels

- Princess (2005-2007)[6]:	$500,000
- Norwegian Cruise Lines (2007)[6,7]:	$1,700,000

- Tankers

- BP diesel electric (retrofit 2 vessels)[8]:	$1,200,000

Notes

1) China shipping cost did not include cost for barge, which cost $2,000,000 and uses nine cables. If equipment on barge was installed on vessel, the cost would have been about $1,500,000. Power transfer process allows vessel to entirely lose power or go “black.” This shore power equipment setup will not be used for other shore power projects because the number of cables proved difficult to manage and labor cost were high.
2) Vessel uses 6.6 kV electrical system, which uses 2 cables that will be kept on vessel. (POLA, 2006)
3) Vessel uses 440 kV electrical system. Consequently, to use 6.6 kV power provided by port, system includes transformer. Cables also on vessel. Shore power transfer system highly automated. (Evergreen, 2005)
4) System uses a container, which holds the shore-power equipment, that can be moved from vessel to vessel. Consequently, the overall cost is lower since the main shore-power equipment is shared between the

vessels. NYK estimated the total cost to be $22,000,000 to add shore power equipment to 38 vessels (20 new vessels and 18 existing vessels) or about $600,000 per vessel. Cables are on the vessel. (NYK, 2007)

5) Ships being retrofitted as part of lease agreement with the port of Long Beach (SustainableShipping, 2007)
6) Vessel uses five cables and the cables are stored at the berth.
7) Cost provided by NCL (Norwegian, 2007)
8) Cost may not be representative for most tankers. These tankers are designed to operate in Alaska waters and consequently, many of the vessels systems have redundancy that added to the overall costs. Cables are part of shore infrastructure.

<u>Analysis</u>

Based on the above, the average cost for adding shore-power equipment to a vessel is about $1,100,000 for each container vessel and $1,000,000 for each passenger vessel. The average container vessel cost uses a cost of $1,500,000 for the China Shipping modifications. As shown by the above information, the cost for adding shore-power equipment to a vessel is variable, depending upon the specific considerations for the vessel (whether the vessel uses 6.6 kV or 440 v power—a vessel using a 440 v electrical system would need to be modified to use the 6.6 kV power that will be provided at the berth), whether the cables are located on the vessel (container and reefer vessels) or on shore (passenger ships), and the approach used to implement shore-power capability. In the cost-effectiveness analysis, staff used $1,500,000 as the cost to add shore-power equipment to each vessel, which is ¾ of highest reported cost. This represents a conservative estimate, as it is toward the higher end of the cost spectrum, and staff expects the cost per ship to decrease as new ships are built with shore-power capability instead of retrofitting existing vessels.

Cost for Adding
Shore Power Equipment to Berths

The cost below represents the costs to add shore-power equipment to a berth, including all modifications necessary within the port facility. These costs do not include costs associated with upgrading the utility system, which is outside the port facility. (These costs are included in the cost-effectiveness analysis as an additional capital expenditure.)

- Container terminals

  - Long Beach and Oakland: $5,000,000 per berth

    - Estimate based upon bring power to all major berths at each port
    - Includes costs for infrastructure within port property, including costs for trenching, cables, 4 to 5 vaults per berth (where cables from vessels are plugged in), switchgear, and transformers to convert 33.6 kV power to 6.6 kV.
    - Based upon estimates for revisions necessary to use power from the utility grid

  China Shipping (POLA) $6,800,000

    - 1st installation of shore power at California port
    - One berth installation
    - Cost includes substantial retrofit of new terminal, including trenching and installation of additional transformer
    - Installation of seven vaults—more than necessary
    - Addition of power to second berth will be considerably less

    (POLA, 2006)

  Yusen (POLA) $1,200,000

    - Minimal modification necessary to terminal
    - Adequate power is available at the site
    - One vault installed

    (POLA, 2006)

  - Evergreen (POLA) $1,400,000

    - Estimated cost based on expected design

- Passenger Vessels
  - Seattle $2,000,000
    - Cables are located at the berth
  - Los Angeles Cruise Terminal $10,000,000
    - For two berths
    - Estimated cost based on expected design
    - Cables are located at the berth; cable system is moveable to accommodate the different locations where the cables will be attached to the vessel

<u>Analysis</u>

The cost for modifying each berth to add shore-power equipment will be site specific, depending upon power availability and amount of retrofit work necessary. China Shipping terminal's installation is not representative because of the unique design—the barge system which will not be used for other shore-power applications—and the over-engineering of certain aspects of the shore power equipment due to this terminal being the first ever shore-power installation for container vessels. Additionally, the costs to add shore power equipment to the Yusen terminal represents the low end of the range. The Yusen terminal represents a best case scenario because: 1) sufficient power was already available at the terminal; 2) minimal equipment modifications were necessary to existing shore-side electrical equipment; and 3) only one vault was installed. The vault is where the vessel would connect its cables to use shore power. For the Yusen terminal, only one vault was necessary. The berth is being configured to serve vessels for one company. Most berths would need to have multiple vaults to be able to service all vessel independent of the location of the cables on the vessel.

For the addition of shore power equipment to the shore-side, staff used $5,000,000 per berth for the cost effectiveness analysis. This cost provides a conservative estimate of the anticipated costs for adding shore power equipment to each berth—consistent with estimates for the container terminals at Long Beach and Oakland, and the cruise terminal at Los Angeles. As shown above, the costs may be lower in some applications. For example, the costs for the Yusen terminal is based upon the installation of one vault, which would reduce the cost for a berth by 30 percent as compared to the standard installation of four to five vaults per berth.

Hotelling Times Used in the Cost Effectiveness Analysis

In general, the hotelling times used for each vessel category is based upon wharfinger data provided by the ports. The wharfinger data provides, for each vessel visit, the time the vessel was tied to the berth (1st line on to last line off). The ports provided this wharfinger data for the years 2004 thru 2006. Staff assumed that the averages determined for passenger vessels and reefer vessels will not change substantially from the averages determined from the 2006 wharfinger data. The wharfinger data for 2004 thru 2006 indicated consistent hotelling times per visit for each of these vessel categories for the three year period. The following discussion provides more detail on the use of the wharfinger data to determine hotelling times for container vessels.

The table below provides the average hotelling times for container vessels, based upon the TEU capacity of the vessel. These hotelling times are based upon wharfinger data for 2006. Staff determined that the Wharfinger data for 2006 was more representative of current and future activities than a three year average.

2006 Hotelling Times for Container Vessels

TEU Capacity	Average berthing time for POLA/POLB	Range of berthing time for POLA/POLB	Average berthing time for Oakland	Range of berthing time for Oakland
<1000	24	21-47	15	15
1000-1999	25	10-48	17	10-21
2000-2999	40	8-51	23	12-33
3000-3999	45	19-65	19	9-24
4000-4999	42	11-78	16	9-27
5000-5999	66	26-92	24	14-30
6000-6999	64	52-81	21	8-26
7000-7999	69	60-74	18	13-35
> 8000	92	82-108	24	20-27

For the purposes of the cost-effectiveness analysis, whenever possible, hotelling times in the cost-effectiveness analysis are based on the specific hotelling times for a vessel size (e.g., Twenty Foot Equivalent Unit (TEU) capacity) and specific ship companies. If there is no specific company data, then the average hotelling time for the vessel size would be used.

For the larger vessels, greater than 7000 TEU capacity, staff assumed the average hotelling time would be 70 hours per visit after 2014 for vessels visiting Long Beach or Los Angeles. Based upon the 2006 hotelling times, this would require a significant reduction in hotelling times for vessels greater than 8000

TEU. To achieve these shorter hoteling times, staff assumes that both the ports and terminals will install new equipment that will improve the efficiency of moving containers. This is borne out by the wharfinger data. During the time period between 2004 to 2006, the average hotelling times for the largest container vessels visiting Long Beach/Los Angeles, vessels with capacity larger than 7000 TEU, was 99 hours per visit for 2004. 2004 was the first year with significant visitation by these larger vessels. By 2006, the hotelling time per visit was reduced to 79 hours per visit in 2006. This reduction in average hotelling times was achieved largely with improved efficiency. Installation of new cranes would further improve efficiency—the terminals equipped with these newer cranes process these larger vessels 20 to 30 percent faster. Similarly, staff also assumed that the larger vessels visiting Oakland would be in port 25 hours per visit—which is consistent with current hotelling times for larger vessel visiting Oakland.

Example Cost Effectiveness Calculation

This example illustrates how the cost effectiveness analysis was done for a terminal. All the information in this appendix is for illustration purposes only and does not represent an actual terminal or fleet

Vessel Activity

The table below indicates which vessels will be affected by milestones of proposed regulation that visit Terminal 123. Terminal 123 has two berths. The information below provides the applicable data for the two fleets and specific vessel information for the 2006 baseyear.

For company ABC, the five vessels represent all the vessels that visit the port of Los Angeles. Each vessel makes 10 visits annually to the port. To achieve 50 percent milestone, Company ABC will need to add shore-power equipment to three of their vessels. Similarly, Company ABC will need to do a forth vessel by 2020 to comply with the 80 percent milestone. The fifth vessel is not affected.

2006 Vessel Activity for Vessels affected by 2014 and 2020 milestones

Ship Name	Company	Total visits 2006	TEU	Power Requirement (MW)	When subject to rule
ABC 1	ABC	10	5000	1.56	2014
ABC 2	ABC	10	5000	1.56	2014
ABC 3	ABC	10	5000	1.56	2014
ABC 4	ABC	10	5000	1.56	2020
Zip 1	ZIP	6	4000	1.46	2014
Zip 2	ZIP	6	4000	1.46	2014
Zip 3	ZIP	6	3000	1.16	2014
Zip 4	ZIP	2	5000	1.56	2014
Zip 5	ZIP	2	4000	1.46	2020
Zip 6	ZIP	5	6000	1.56	2020
Zip 7	ZIP	5	4000	1.46	2020
Zip 8	ZIP	4	6000	1.56	2020
Zip 9	ZIP	4	6000	1.56	2020

Company ZIP's vessels visit three different terminal at the ports of Long Beach and Los Angeles. The regulation affects ZIP's ships on a fleet basis, considering all visits by the fleet to both Long Beach and Los Angeles—the fleet requirement is not implemented on a per terminal basis. The company's fleet made 100 visits to Long Beach and Los Angeles during 2006, but only 53 of these visits were to terminal 123. Staff assumes that Company ZIP, in order to minimize the number of affected ships, would modify the ships that make the most frequent visits. ZIP 4, which made only two visits to Terminal 123, made 10 visits in total to both ports in 2006, eight of those visits to another terminal—one of the most frequent visitors from ZIP's fleet. Based on this premise, Company ZIP would modify ZIP 4 to use shore power even though it is not one of the most frequent visitors to Terminal 123. Finally, Company Zip has ten additional vessels that visit terminal 123 which are not affected by the proposed regulation—these vessels only made one or two visits during 2006 to Long Beach and Los Angeles.

The 2006 vessel activity is grown to 2014 and 2020 projected vessel activity. For container vessels, the vessels in 2014 are expected to be about 45 percent larger than the 2006 vessels and the vessels in 2014 also are projected to make 40 percent more visits. (Mercator, 2005)

In 2014, the vessel replacing ABC 1 will be 45 percent larger. ABC 1 is a 5000 teu container vessel. The replacement vessel is 45% larger or 5000 teu X 1.45 or 7250 teu vessel. The larger vessel will have higher power requirements, increasing from 1.56 to 1.76 MW average power needs. For the increase in visits, staff assumed that vessels would not make more visits to California—rather, the increase in overall visits is the result of more vessel being used to carry goods. Consequently, by 2014 Company ABC's fleet would grow from four vessels being affected to six vessels being affected and all the vessels would make 10 visits. This increase of two vessels represents a 40 percent increase. This methodology was also applied to Company Zip's vessels—resulting in one additional vessel making 6 visits. The table below indicates the final vessel statistics for the vessels affected by the 2014 milestone.

2014 Vessel Activity For Affected Vessels

Ship Name	Company	Total visits 2006	TEU	Power Requirement (MW)
ABC 1	ABC	10	7250	1.76
ABC 2	ABC	10	7250	1.76
ABC 3	ABC	10	7250	1.76
ABC 4	ABC	10	7250	1.76
ABC 5	ABC	10	7250	1.76
ABC 6	ABC	10	7250	1.76
Zip 1	ZIP	6	5600	1.56
Zip 2	ZIP	6	5600	1.56
Zip 3	ZIP	6	4200	1.56
Zip 4	ZIP	2	7250	1.76
Zip 10	ZIP	6	5600	1.56

Similarly, vessel activity was grown from 2006 activity to 2020 ship activity. The factors used included an increase in size of 55 percent as compared to 2006 vessels, and a 75 percent increase in the number of visits. The table below provides information on the affected vessels for 2020.

2020 Vessel Activity For Affected Vessels

Ship Name	Company	Total visits 2006	TEU	Power Requirement (MW)
ABC 1	ABC	10	7,750	1.76
ABC 2	ABC	10	7,750	1.76
ABC 3	ABC	10	7,750	1.76
ABC 4	ABC	10	7,750	1.76
ABC 5	ABC	10	7,750	1.76
ABC 6	ABC	10	7,750	1.76
ABC 7	ABC	10	7,750	1.76
Zip 1	ZIP	6	6,200	1.56
Zip 2	ZIP	6	6,200	1.56
Zip 3	ZIP	6	4,650	1.56
Zip 4	ZIP	2	7,750	1.76
Zip 5	ZIP	2	6,200	1.56
Zip 6	ZIP	5	10,500	1.76
Zip 7	ZIP	5	4,650	1.56
Zip 8	ZIP	4	10,500	1.76
Zip 9	ZIP	4	10,500	1.76
Zip 10	ZIP	6	6200	1.56
Zip 11	ZIP	5	6200	1.56
Zip 12	ZIP	4	6200	1.56
Zip 13	ZIP	4	6200	1.56
Zip 14	ZIP	5	10,500	1.76
Zip 15	ZIP	5	10,500	1.76

<u>Emission Reductions</u>

Emission reductions were determined for each vessel with the following formula:

= Emission Factor (g/kW-hr) **X** 1 lb/454 g **X** ton/2000 lb **X** power (kW) **X** hoteling time **X** visits

The emissions for ABC 1 in 2020 is:

= 13.9 g/kW-hr **X** 1 lb /454 g **X** ton/2000 lb **X** 1,760 kW **X** (69 hr -- 3 hours) **X** 10 visits

= 17.8 tons per year

Summing up the reductions for each vessel for the two milestone years, about 143 tons of NOx reductions are achieved in 2020, and about 228 tons of NOx reductions are achieved in 2020.

Capital Costs

The following costs were used:

- $1,500,000 to add shore-power equipment to each vessel
- $5,000,000 to add shore-power equipment to each berth
- Utility upgrade cost for whole port is $15,000,000. Terminal 123's share of the utility cost is 1/8 (Terminal 123 is one of eight terminals) of this cost or $1,875,000.
- Assumed that electrical costs is offset by fuel savings

Capital costs for vessels in 2020

= 22 vessels **X** $1,500,000 = $33,000,000

About half of this cost will be used for satisfying the 2014 milestone and the other half will be used for satisfying the 2020 milestone. Note that ZIP 4 and ZIP 5 only make two visits to Terminal 123. These vessels actually visit another terminal more frequently. In this case, the $3,000,000 cost would actually be charged to the other terminal, and these vessels would be considered "free" at this terminal. Therefore, the overall cost is about $30,000,000

Capital costs for shore-side infrastructure in 2020

= $1,875,000 (utility upgrade) + 2 berths X $5,000,000

= $11,875,000

$6,875,000 will be spent to satisfy the 2014 milestone and $5,000,000 will be used to satisfy the 2020 milestone.

Determining the Cost Effectiveness In 2006 Dollars

2006 dollars

As shown below, all costs are brought back to 2006 dollars. For the shore side infrastructure, the total cost used to satisfy the 2014 milestone, as discussed above, is about $6,875,000. This amount is assumed to be spent in five installments between 2009 to 2013, or about $1,375,000 per year.

To convert the money spent in 2009 to 2006 dollars, the $1,375,000 is multiplied by the present worth factor. This factor for 2009 is 0.863 or the money spent in 2009, $1,375,000 is worth $1,187,000 in 2006. The present worth factor becomes smaller over time. For example, the $1,375,000 spent in 2019, the last year of such an expenditure, is worth $730,000 in 2006. Overall, the $11,875,000 spent for shore-side infrastructure is $9,400,000 in 2006 dollars. The table below summaries the expenditures projected for the shore-side infrastructure in actual costs and 2006 dollars

Shore-Side Infrastructure In Actual Costs And 2006 Dollars

Year	Actual costs	2006 dollars
2009	$1,375,000	$1,190,000
2010	$1,375,000	$1,130,000
2011	$1,375,000	$1,080,000
2012	$1,375,000	$1,030,000
2013	$1,375,000	$980,000
2015	$1,375,000	$890,000
2016	$1,375,000	$840,000
2017	$1,375,000	$800,000
2018	$1,375,000	$770,000
2019	$1,375,000	$730,000
Total	$13,750,000	$9,400,000

Similarly, for the vessels, 50 percent of the capital cost is spent in the five year period before 2014 and the other 50 percent is spent in the five year period before 2020. The vessel owners will spend $30,000,000 in total or about $20,000,000 in 2006 dollars. For container vessels, the cost-effectiveness analysis also factors in the costs for the additional container vessels that will need to be equipped with shore-power equipment as a result of an existing vessel being moved to another service. Staff assumes that the initial group of vessels will be entirely replaced over the period 2015 to 2030. For this example, the vessel owners will spend an additional $30,000,000 or about $11,700,000 in 2006 dollars. The major difference between the total funds spent and the 2006 dollars is a result of these funds being spent in future years.

Finally, the last cost to consider is the labor costs. Staff assumes that 3 longshoremen will be paid for eight hours for connecting and un-connecting the vessel from shore power. The labor cost was estimated at $100 per hour to perform this service. For 2014, there will be 86 visits affected by the proposed regulation and 139 visits affected by 2020, or the labor cost will be 340,000 per year for the period between 2014 and 2020 and $560,000 per year after 2020. Consequently, over the life of the regulation, the labor would account for $4,400,000.

NOx Emission Reductions

Finally, the emissions reductions resulting from implementing the proposed regulation would result in reductions of 143 tons per year from 2014 to 2020. After 2020, reductions would increase to 228 tons per year. The total reduction over the regulatory life of the regulation, or the period where capital funds are expended to achieve compliance with the regulation, is 3,366 tons.

Cost Effectiveness

The cost effectiveness is the total expenditures, both capital and recurring costs, in 2006 dollars divided by the total emissions. The total expenditures is the sum of the vessel and shore costs, which is the shore-side costs, $9,400,000, the vessel-side costs, $31,700,000, and the labor costs, $4,400,000 or a total of $45,500,000 in 2006 dollars.

Cost effectiveness	=	$45,500,000 / 3,400 tons of NOx
	=	$13,382 per ton of NOx reduced

REFERENCES:

Evergreen Marine Corporation. “Green ships for Evergreen.” March 23, 2005. (Evergreen, 2005)

Mercator Transport Group. *Forecast of Container Vessel Specifications and Port Calls Within San Pedro Bay*; February 2005. (Mercator,2002)

Norwegian Cruise Lines. Personal Communication. October 17, 2007. (Norwegian, 2007)

NYK Line. “NYK to Deploy Thirty Eight Containerships with Alternative Maritime Power Capability.” Press Release. April 26, 2007. http://www.nykline.co.jp/english/news/2007/0426_1/index.htm (NYK, 2007)

Port of Los Angeles. “Alternative Maritime Power Off and Running.” Faster Freight Cleaner Air Conference. Long Beach January 31 to February 1, 2006.

SustainableShipping. “K-line signs up for shore power.” Press Release. June 12, 2007. (SustainableShipping, 2007)