Appendix J

Detailed Cost-Effectiveness Analysis of Tanker Ships

Detailed Cost-Effectiveness Analysis of Tanker Ships

This appendix contains a more thorough discussion of the cost-effectiveness analyses conducted for tanker ships than what was provided in Chapter VIII. For brevity and clarity, Chapter VIII addressed NOx emissions reductions for tanker ships burning 0.1 percent sulfur distillate fuel, with the necessary electrical transformer located on the shore—the most likely scenario. Appendix J further addresses the reduction of other pollutants, the use of 0.5 percent sulfur distillate fuel, and the construction of the electrical transformers on the ships.

Staff analyzed two types of crude-oil tankers and one type of product tanker. Because of the significant difference in power requirements for diesel-electric crude-oil tankers, this type of tanker was analyzed separately from the other crude-oil tankers. The tanker analyses are based upon the shipping activities at each of the California ports that tankers frequent.

Crude-Oil Tankers (Non-Diesel-Electric)

Tables J-1 through J-5 show the “all pollutants” cost-effectiveness values for crude-oil tankers using steam turbines for cargo pumping. The California ports visited by these tankers include Long Beach, El Segundo, Richmond, Benicia, and Martinez. As discussed in Chapter IV, the State Lands Commission Database did not accurately track the visits to the San Francisco Bay Area Ports. Bay Area ports identified in the State Lands Commission Database were Carquinez, Richmond, and San Francisco. Tanker traffic in Martinez and Benicia has been subsumed into one or more of these other designations.

As mentioned previously, about half of the crude-oil tankers that visited California in 2004 were steam ships, and, if cold-ironed, would provide minimal emissions reductions. Staff expects that these tankers will be replaced by ships whose auxiliary-power needs, except for cargo-pumping, will be provided by onboard generators. Because of federal requirement for double hulls, staff expects most of these tankers will be replaced by 2010. The analyses below for non-diesel-electric crude-oil tankers assume that the steam ships have been replaced.

As was done previously for other ship categories, for each port, cost-effectiveness values were determined for three scenarios: 1) all ships visiting the port are cold-ironed; 2) only ships that make three or more visits per year to a port are cold-ironed; and 3) only ships that make six or more visits per year to a port are cold-ironed. In addition, the cost-effectiveness scenarios consider whether the necessary electrical transformers are constructed at the port (shore-side) or on the ships (ship-side).

Table J-1: All Pollutants Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$140,000	$160,000
--shore-side transformer	$50,000	$57,000
Ships making 3 or more visits		
--ship-side transformer	$79,000	$90,000
--shore-side transformer	$31,000	$35,000
Ships making 6 or more visits		
--ship-side transformer	$60,000	$68,000
--shore-side transformer	$27,000	$31,000

Table J-2: All Pollutants Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at El Segundo (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$47,000	$53,000
--shore-side transformer	$27,000	$31,000
Ships making 3 or more visits		
--ship-side transformer	$29,000	$33,000
--shore-side transformer	$24,000	$27,000
Ships making 6 or more visits		
--ship-side transformer	$22,000	$25,000
--shore-side transformer	$24,000	$27,000

Table J-3: All Pollutants Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at Carquinez (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$83,000	$95,000
--shore-side transformer	$50,000	$57,000
Ships making 3 or more visits		
--ship-side transformer	$74,000	$84,000
--shore-side transformer	$55,000	$62,000
Ships making 6 or more visits		
--ship-side transformer	$66,000	$75,000
--shore-side transformer	$61,000	$70,000

Table J-4: All Pollutants Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at Richmond (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$43,000	$49,000
--shore-side transformer	$31,000	$36,000
Ships making 3 or more visits		
--ship-side transformer	$39,000	$44,000
--shore-side transformer	$32,000	$36,000
Ships making 6 or more visits		
--ship-side transformer	$41,000	$47,000
--shore-side transformer	$33,000	$38,000

Table J-5: All Pollutants Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at San Francisco (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$93,000	$110,000
--shore-side transformer	$63,000	$72,000
Ships making 3 or more visits		
--ship-side transformer	$79,000	$90,000
--shore-side transformer	$73,000	$83,000
Ships making 6 or more visits		
--ship-side transformer	$87,000	$99,000
--shore-side transformer	$96,000	$110,000

In general, the average cost-effectiveness values behave in a similar fashion to the other ship categories.

El Segundo (Table J-2) and Richmond (Table J-4) had the lowest average cost-effectiveness values because they receive the most visits. Note that for the six-visit scenario for San Francisco and El Segundo, the cost-effectiveness values for the shore-side transformer are higher than those for the ship-side transformer—an anomaly. This is due to the small number of tankers being cold-ironed (four). As a result, the shore-side infrastructure costs, allocated to so few ships, play a greater role in the overall cost-effectiveness assessment.

Similarly, Tables J-6 through J-10 show the NOx reduction cost-effectiveness values for non-diesel-electric tankers transporting crude oil to California ports. Note that the use of either distillate fuel results in the same cost-effectiveness values, as they have the same NOx emission factors. Again the average cost-effectiveness values were the lowest for El Segundo and Richmond.

Table J-6: NOx Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$170,000	$170,000
--shore-side transformer	$60,000	$60,000
Ships making 3 or more visits		
--ship-side transformer	$95,000	$95,000
--shore-side transformer	$37,000	$37,000
Ships making 6 or more visits		
--ship-side transformer	$72,000	$72,000
--shore-side transformer	$33,000	$33,000

Table J-7: NOx Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at El Segundo (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$56,000	$56,000
--shore-side transformer	$33,000	$33,000
Ships making 3 or more visits		
--ship-side transformer	$35,000	$35,000
--shore-side transformer	$29,000	$29,000
Ships making 6 or more visits		
--ship-side transformer	$26,000	$26,000
--shore-side transformer	$29,000	$29,000

Table J-8: NOx Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at Carquinez (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$100,000	$100,000
--shore-side transformer	$61,000	$61,000
Ships making 3 or more visits		
--ship-side transformer	$89,000	$89,000
--shore-side transformer	$66,000	$66,000
Ships making 6 or more visits		
--ship-side transformer	$80,000	$80,000
--shore-side transformer	$74,000	$74,000

Table J-9: NOx Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at Richmond (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$52,000	$52,000
--shore-side transformer	$38,000	$38,000
Ships making 3 or more visits		
--ship-side transformer	$47,000	$47,000
--shore-side transformer	$38,000	$38,000
Ships making 6 or more visits		
--ship-side transformer	$50,000	$50,000
--shore-side transformer	$40,000	$40,000

Table J-10: NOx Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at San Francisco (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$110,000	$110,000
--shore-side transformer	$76,000	$76,000
Ships making 3 or more visits		
--ship-side transformer	$96,000	$96,000
--shore-side transformer	$88,000	$88,000
Ships making 6 or more visits		
--ship-side transformer	$110,000	$110,000
--shore-side transformer	$120,000	$120,000

Tables J-11 through J-15 show the PM reduction cost-effectiveness values for non-diesel-electric tankers transporting crude oil to California ports. The cost-effectiveness values on a PM-reduction basis are substantial. Otherwise, the cost-effectiveness values exhibit the same trends as seen in the earlier analyses.

Table J-11: PM Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at POLB (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$6,300,000	$9,800,000
--shore-side transformer	$2,300,000	$3,500,000
Ships making 3 or more visits		
--ship-side transformer	$3,600,000	$5,600,000
--shore-side transformer	$1,400,000	$2,200,000
Ships making 6 or more visits		
--ship-side transformer	$2,700,000	$4,200,000
--shore-side transformer	$1,200,000	$1,900,000

Table J-12: PM Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at El Segundo (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$2,100,000	$3,300,000
--shore-side transformer	$1,200,000	$1,900,000
Ships making 3 or more visits		
--ship-side transformer	$1,300,000	$2,100,000
--shore-side transformer	$1,100,000	$1,700,000
Ships making 6 or more visits		
--ship-side transformer	$980,000	$1,500,000
--shore-side transformer	$1,100,000	$1,700,000

Table J-13: PM Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at Carquinez (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$3,800,000	$5,900,000
--shore-side transformer	$2,300,000	$3,500,000
Ships making 3 or more visits		
--ship-side transformer	$3,400,000	$5,200,000
--shore-side transformer	$2,500,000	$3,800,000
Ships making 6 or more visits		
--ship-side transformer	$3,000,000	$4,700,000
--shore-side transformer	$2,800,000	$4,300,000

Table J-14: PM Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at Richmond (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$1,900,000	$3,000,000
--shore-side transformer	$1,400,000	$2,200,000
Ships making 3 or more visits		
--ship-side transformer	$1,800,000	$2,700,000
--shore-side transformer	$1,400,000	$2,200,000
Ships making 6 or more visits		
--ship-side transformer	$1,900,000	$2,900,000
--shore-side transformer	$1,500,000	$2,300,000

Table J-15: PM Reductions Cost Effectiveness for Cold-Ironing Crude-Oil Tankers at San Francisco (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$4,200,000	$6,600,000
--shore-side transformer	$2,900,000	$4,500,000
Ships making 3 or more visits		
--ship-side transformer	$3,600,000	$5,600,000
--shore-side transformer	$3,300,000	$5,200,000
Ships making 6 or more visits		
--ship-side transformer	$4,000,000	$6,100,000
--shore-side transformer	$4,300,000	$6,700,000

Crude-Oil Tankers (Diesel-Electric)

Diesel-electric tankers are better candidates for cold-ironing because electrical power is used to drive the cargo pumps; therefore, total hotelling power requirements are significantly greater.

Currently, only five diesel-electric crude-oil tankers visit California, and two more are under construction. Of these seven, only two are expected to make frequent trips to California, visiting the Port of Long Beach at least six times annually. If this scenario situation changes—for example, diesel-electric tankers begin to frequent Bay Area tanker terminals—then the cost-effectiveness analysis for cold-ironing diesel-electric tankers needs to be revisited.

Table J-16 provides the "all pollutants" cost-effectiveness values for this analysis.

Table J-16: All Pollutants Cost Effectiveness for Cold-Ironing Diesel Electric Crude-Oil Tankers (Dollars/ton)

Port	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
POLB	$9,000-38,000	$10,000-43,000

The average cost-effectiveness values are considerably lower than for non-diesel-electric crude-oil tankers; however, the range is substantial and is dependent upon the number of visits to the port. If the company operating the cold-ironed tankers commits the ships to bring crude oil to the Port of Long Beach exclusively, the tankers can make as many as 22 annual visits, resulting in very attractive cold-ironing economics. Conversely, if the cold-ironed tankers are not dedicated to Long Beach, but are operated as members of a West Coast fleet, they may not visit Long Beach more than six times annually, resulting in the higher cost-effectiveness values.

Because of the large power demands needed for the cargo pumps, and the relatively low number of port visits, the electrical cost for these two ships represents a substantial part—over 50 percent—of the overall cost. Utility rates average between 18 - 47 cents per kW-hr. As has been mentioned earlier in this report, high, but infrequent, electrical usage is expensive. Average electrical rates are lower for more consistent, sustained use, i.e., greater berth utilization.

Table J-17 below shows a similar wide range of cost-effectiveness on a NOx-emissions-reduction only basis, again based on ship visits.

Table J-17: NOx Reductions Cost Effectiveness for Cold-Ironing Diesel-Electric Crude-Oil Tankers (Dollars/ton)		
Port	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
POLB	$10,000-45,000	$11,000-45,000

Finally, Table J-18 below shows the PM reduction cost effective values. As with other ship categories and previous tanker analyses, PM-only emissions reductions result in very high average cost-effective values.

Table J-18: PM Reductions Cost Effectiveness for Cold-Ironing Diesel-Electric Crude Oil Tankers (Dollars/ton)		
Port	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
POLB	$430,000-1,800,000	$660,000-2,800,000

Product Tankers

Product tankers are smaller than crude-oil tankers, and they carry various types of finished petroleum products and chemicals. Since they may carry several products at the same time, their berthing times are usually short, and they may move around to several berths within a port. The major ports that product tankers visit include the San Pedro port complex of Los Angeles/Long Beach, El Segundo, Richmond, and Bay Area tanker ports, including the ports of Richmond, Benicia, and Martinez.

Staff made several assumptions about product tankers. First, the analyses assume that separate shore infrastructure would be required for crude-oil tankers and product tankers. Second, the cost-effectiveness values assume that all product tankers can be cold-ironed. Staff understands that some product tankers use either direct-drive pumps or hydraulic pumps that would not be amenable to cold-ironing. Consequently, the average cost-effectiveness values in the table are probably lower than if each individual product tanker could be fully analyzed. Finally, staff assumed that the cargo pumps would operate 60 percent of the time the product tankers were in port. The other 40 percent of the time, the product tankers would be receiving product via shore-based cargo pumps.

Tables J-19 thru J-26 show the "all pollutants" cost-effectiveness values for product tankers visiting California ports. Based on the State Lands Commission designations, these ports include: Carquinez, El Segundo, Hueneme, POLA/POLB, Richmond, San Diego, San Francisco, and Stockton.

As was done previously for other ship categories, for each port, cost-effectiveness values were determined for three scenarios: 1) all ships visiting the port are cold-ironed; 2) only ships that make three or more visits to the port are cold-ironed; and 3) only ships that make six or more visits to the port are cold-ironed. In addition, the cost-effectiveness scenarios consider whether the necessary electrical transformers are constructed at the port (shore-side) or on the ships (ship-side). Finally, for San Diego, none of the ships made more than 2 visits, and for Hueneme, none of the ships made more than 3 visits.

Table J-19: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at San Diego (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$380,000	$430,000
--shore-side transformer	$320,000	$360,000

Table J-20: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at Hueneme (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$240,000	$270,000
--shore-side transformer	$200,000	$220,000
Ships making 3 or more visits		
--ship-side transformer	$360,000	$410,000
--shore-side transformer	$340,000	$380,000

Table J-21: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at Stockton (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$150,000	$170,000
--shore-side transformer	$74,000	$83,000
Ships making 3 or more visits		
--ship-side transformer	$110,000	$120,000
--shore-side transformer	$88,000	$100,000
Ships making 6 or more visits		
--ship-side transformer	$96,000	$110,000
--shore-side transformer	$110,000	$120,000

Table J-22: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at POLA/POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$180,000	$210,000
--shore-side transformer	$90,000	$100,000
Ships making 3 or more visits		
--ship-side transformer	$110,000	$120,000
--shore-side transformer	$91,000	$100,000
Ships making 6 or more visits		
--ship-side transformer	$110,000	$100,000
--shore-side transformer	$130,000	$150,000

Table J-23: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at El Segundo (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$62,000	$67000
--shore-side transformer	$40,000	$43,000
Ships making 3 or more visits		
--ship-side transformer	$36,000	$38,000
--shore-side transformer	$39,000	$42,000
Ships making 6 or more visits		
--ship-side transformer	$30,000	$33,000
--shore-side transformer	$44,000	$47,000

Table J-24: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at Carquinez (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$110,000	$120,000
--shore-side transformer	$45,000	$50,000
Ships making 3 or more visits		
--ship-side transformer	$43,000	$48,000
--shore-side transformer	$40,000	$45,000
Ships making 6 or more visits		
--ship-side transformer	$44,000	$50,000
--shore-side transformer	$63,000	$71,000

Table J-25: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at Richmond (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$70,000	$77,000
--shore-side transformer	$28,000	$30,000
Ships making 3 or more visits		
--ship-side transformer	$32,000	$34,000
--shore-side transformer	$19,000	$21,000
Ships making 6 or more visits		
--ship-side transformer	$22,000	$22,000
--shore-side transformer	$19,000	$20,000

Table J-26: All Pollutants Cost Effectiveness for Cold-Ironing Product Tankers at San Francisco (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$95,000	$110,000
--shore-side transformer	$39,000	$44,000
Ships making 3 or more visits		
--ship-side transformer	$74,000	$84,000
--shore-side transformer	$47,000	$53,000
Ships making 6 or more visits		
--ship-side transformer	$110,000	$130,000
--shore-side transformer	$160,000	$180,000

In general, the average cost-effectiveness values behave in a similar fashion to the other ship categories. The cost-effectiveness values were the lowest for El Segundo and Richmond because they received the most ship visits. The cost-

effectiveness values were the highest for the ports receiving few ships: San Diego and Hueneme.

Tables J-27 through J-34 show the NOx reduction cost-effectiveness values for product tankers visiting California ports.

Table J-27: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at San Diego (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$450,000	$450,000
--shore-side transformer	$380,000	$380,000

Table J-28: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Hueneme (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$280,000	$280,000
--shore-side transformer	$230,000	$230,000
Ships making 3 or more visits		
--ship-side transformer	$430,000	$430,000
--shore-side transformer	$400,000	$400,000

Table J-29: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Stockton (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$180,000	$180,000
--shore-side transformer	$88,000	$88,000
Ships making 3 or more visits		
--ship-side transformer	$130,000	$130,000
--shore-side transformer	$110,000	$110,000
Ships making 6 or more visits		
--ship-side transformer	$110,000	$110,000
--shore-side transformer	$130,000	$130,000

Table J-30: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at POLA/POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$220,000	$220,000
--shore-side transformer	$110,000	$110,000
Ships making 3 or more visits		
--ship-side transformer	$130,000	$130,000
--shore-side transformer	$110,000	$110,000
Ships making 6 or more visits		
--ship-side transformer	$140,000	$140,000
--shore-side transformer	$160,000	$160,000

Table J-31: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at El Segundo (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$71,000	$71,000
--shore-side transformer	$45,000	$45,000
Ships making 3 or more visits		
--ship-side transformer	$40,000	$40,000
--shore-side transformer	$44,000	$44,000
Ships making 6 or more visits		
--ship-side transformer	$35,000	$35,000
--shore-side transformer	$49,000	$49,000

Table J-32: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Carquinez (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$130,000	$130,000
--shore-side transformer	$53,000	$53,000
Ships making 3 or more visits		
--ship-side transformer	$51,000	$51,000
--shore-side transformer	$47,000	$47,000
Ships making 6 or more visits		
--ship-side transformer	$53,000	$53,000
--shore-side transformer	$75,000	$75,000

Table J-33: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Richmond (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$81,000	$81,000
--shore-side transformer	$32,000	$32,000
Ships making 3 or more visits		
--ship-side transformer	$36,000	$36,000
--shore-side transformer	$22,000	$22,000
Ships making 6 or more visits		
--ship-side transformer	$23,000	$23,000
--shore-side transformer	$20,000	$20,000

Table J-34: NOx Reductions Cost Effectiveness for Cold-Ironing Product Tankers at San Francisco (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$110,000	$110,000
--shore-side transformer	$46,000	$46,000
Ships making 3 or more visits		
--ship-side transformer	$89,000	$89,000
--shore-side transformer	$56,000	$56,000
Ships making 6 or more visits		
--ship-side transformer	$140,000	$140,000
--shore-side transformer	$190,000	$190,000

As with previous analyses, the cost-effectiveness values were the lowest for El Segundo and Richmond and the highest for San Diego and Hueneme.

Tables J-35 thru J-42 show the PM reduction cost-effectiveness values for product tankers visiting California ports.

Table J-35: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at San Diego (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$18,000,000	$29,000,000
--shore-side transformer	$15,000,000	$24,000,000

Table J-36: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Hueneme (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$11,000,000	$18,000,000
--shore-side transformer	$9,500,000	$15,000,000
Ships making 3 or more visits		
--ship-side transformer	$18,000,000	$27,000,000
--shore-side transformer	$16,000,000	$26,000,000

Table J-37: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Stockton (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$7,100,000	$11,100,000
--shore-side transformer	$3,600,000	$5,600,000
Ships making 3 or more visits		
--ship-side transformer	$5,300,000	$8,200,000
--shore-side transformer	$4,300,000	$6,700,000
Ships making 6 or more visits		
--ship-side transformer	$4,700,000	$7,300,000
--shore-side transformer	$5,100,000	$8,000,000

Table J-38: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at POLA/POLB (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$8,800,000	$14,000,000
--shore-side transformer	$4,400,000	$6,800,000
Ships making 3 or more visits		
--ship-side transformer	$5,100,000	$8,000,000
--shore-side transformer	$4,400,000	$6,900,000
Ships making 6 or more visits		
--ship-side transformer	$5,500,000	$8,600,000
--shore-side transformer	$6,500,000	$10,000,000

Table J-39: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at El Segundo (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$4,200,000	$6,700,000
--shore-side transformer	$2,700,000	$4,300,000
Ships making 3 or more visits		
--ship-side transformer	$3,000,000	$4,800,000
--shore-side transformer	$3,300,000	$5,300,000
Ships making 6 or more visits		
--ship-side transformer	$2,600,000	$4,200,000
--shore-side transformer	$3,700,000	$5,900,000

Table J-40: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Carquinez (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$5,200,000	$8,100,000
--shore-side transformer	$2,200,000	$3,400,000
Ships making 3 or more visits		
--ship-side transformer	$2,100,000	$3,200,000
--shore-side transformer	$1,900,000	$3,000,000
Ships making 6 or more visits		
--ship-side transformer	$2,100,000	$3,300,000
--shore-side transformer	$3,000,000	$4,700,000

Table J-41: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at Richmond (Dollars/ton)

Description	Distillate Fuel (0.5% Sulfur)	Distillate Fuel (0.1% Sulfur)
All Ships		
--ship-side transformer	$4,500,000	$7,100,000
--shore-side transformer	$1,800,000	$2,800,000
Ships making 3 or more visits		
--ship-side transformer	$2,700,000	$4,400,000
--shore-side transformer	$1,600,000	$2,600,000
Ships making 6 or more visits		
--ship-side transformer	$3,800,000	$6,500,000
--shore-side transformer	$3,300,000	$5,700,000

Table J-42: PM Reductions Cost Effectiveness for Cold-Ironing Product Tankers at San Francisco (Dollars/ton)		
Description	**Distillate Fuel (0.5% Sulfur)**	**Distillate Fuel (0.1% Sulfur)**
All Ships		
--ship-side transformer	$4,600,000	$7,200,000
--shore-side transformer	$1,900,000	$3,000,000
Ships making 3 or more visits		
--ship-side transformer	$3,600,000	$5,600,000
--shore-side transformer	$2,300,000	$3,600,000
Ships making 6 or more visits		
--ship-side transformer	$5,500,000	$8,600,000
--shore-side transformer	$7,800,000	$12,000,000

The cost-effectiveness values were the lowest for Carquinez, Richmond, and El Segundo, and highest for San Diego and Hueneme, although in all cases, the cost-effectiveness values exceeded $1,000,000 per ton of diesel PM.

The prior analyses have all addressed *average* cost effectiveness. When cold-ironing all ships, these average values include many ships that visit a few times and a few ships that visit many times. The following analysis will address the cost effectiveness of cold-ironing an incremental ship if the shore-side infrastructure is already in place.

Tables J-43 and J-44 provide incremental cost-effectiveness values for NOx reductions only, PM reductions only, and "all pollutants" for crude-oil (non-diesel electric) and product tankers. These values are based on 0.1 percent sulfur distillate, and a transformer located on shore.

Table J-43: Incremental Cost Effectiveness for Crude-Oil Tanker Using Distillate Fuel (0.1 percent sulfur) (Dollars/Ton)			
Visits	**NOx**	**PM**	**All Pollutants**
1	$200,000	$11,000,000	$190,000
3	$67,000	$3,900,000	$63,000
5	$40,000	$2,300,000	$38,000
7	$28,000	$1,700,000	$27,000

Table J-44: Incremental Cost Effectiveness for Product Tanker Using Distillate Fuel (0.1 percent sulfur) (Dollars/Ton)

Visits	NOx	PM	All Pollutants
1	$170,000	$11,000,000	$160,000
3	$56,000	$3,500,000	$53,000
5	$33,000	$2,100,000	$31,000
7	$24,000	$1,500,000	$22,000

Not surprisingly, the incremental cost-effectiveness values drop significantly with more visits made by a ship. The incremental cost-effectiveness values approach the average cost-effectiveness values discussed earlier for some ports at about 3-5 visits. More than likely, however, a crude-oil tanker visiting a port that many times would have been factored into the original assessment to cold-iron at that port.