European Commission Directorate General Environment

Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments

Task 2a – Shore-Side Electricity

Final Report

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Entec UK Limited

European Commission Directorate General Environment

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Report for

European Commission
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Directorate C - Unit C1

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Executive Summary

Introduction
This report forms part of the deliverables under Task 2 of the European Commission contract on Ship Emissions: Assignment, Abatement and Market-Based Instruments.

Task 2 requires an investigation of the costs, emission reduction potential and practicalities of ship emissions abatement technologies. The technologies to be considered are:

- Task 2a: The use of shore-side electricity (this report);
- Task 2b: NO_x abatement techniques (see separate report on NOx techniques);
- Task 2c: SO_2 abatement techniques with focus on sea water scrubbing (see separate report on SO_2 techniques).

This is the report for Task 2a on Shore Side Electricity in ports.

This report investigates the costs, emissions reductions and cost effectiveness of Shore-Side Electricity in ports.

Background
While in port, ships use their Auxiliary Engines (AE) to produce electricity for hotelling, unloading and loading activities.

One measure to reduce emissions from AEs while at berth is to provide electricity to the ships from the national grid. To provide ships with electricity, a shore-side electricity supply arrangement is required, also known as 'cold-ironing'.

The use of shore-side electricity allows the resulting emissions from ships' electricity use at berth to come from power generators supplying the national grid. These suppliers are likely to have lower emission factors per MWh of electricity, either due to the type of electricity production process (eg wind, hydro, nuclear etc) or the stringent emission controls imposed on land based power plants (eg through the European Union's Integrated Pollution Prevention and Control Directive and the Large Combustion Plant Directive).

There are currently only a limited number of examples of shore-side electricity in use around the world, for example:

- In 1991, the Pohang Iron and Steel Company (POSCO) in Pittsburg, California, established a shore-side electricity system as required by a local air permit.
- In 2002, five cruise vessels were converted to use shore-side electricity in Juneau, Alaska.
- In 1989, the Port of Gothenburg converted a terminal to service ferries with shore-side electricity. In 2003 an additional terminal was converted to use shore-side electricity, this time servicing roll-on-roll-off (RO-RO) vessels.
- The Port of Los Angeles has converted a terminal to use shore-side electricity.

- The Port of Lubeck in Germany is currently seeking to establish technical requirements for shore-side electricity in Baltic ports.
- The port of Pitea, Sweden, had plans to commission shore-side electricity servicing two RO-RO vessels.

Technical details

There are currently no existing standards for shore-side electricity, but a schematic diagram outlining the typical technical requirements and elements can be seen in Figure 2.1 of the main section of this report.

A brief summary of the elements that would be required in a shore-side electricity system include:

1. A connection to the national grid is needed carrying 20-100 kV electricity from a local sub-station where it is transformed to 6-20 kV.
2. Cables are then required to deliver the 6-20 kV power from the sub-station to the port terminal.
3. The electricity may then require power conversion. Electricity supply in Europe generally has a frequency of 50 Hz. A ship designed for 60 Hz electricity may be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating. However it could not use 50 Hz for the operation of motor driven equipment such as pumps, winches and cranes. Therefore, a ship using 60 Hz electricity will require 50 Hz electricity to be converted to 60 Hz by an electricity converter.
4. Electricity is then distributed to the terminal. Cables need to be installed underground within existing conduits or this may require new canalisation. Electricity is metered.
5. To avoid handling of high voltage cables, a cable reel system is suggested. A cable reel tower could be built on the berth supporting a cable reel, davit and frame. The davit and frame would be used to raise and lower the cables to the vessel. The cable reel and frame would be electro-mechanically powered and controlled.
6. Onboard the vessel a socket is needed for the connecting cable.
7. The ship then needs to transform the high voltage electricity to 400 V to be used onboard, by a transformer.
8. The electricity is then distributed around the ship, and the auxiliary engines are switched off.

Although port terminals will already have electricity connections, it is probable that in most cases these connections would need upgrading to support both existing terminal operations and shore-side electricity for ships. This may require new underground or overhead electricity lines and poles from the closest substation.

Ship Types and Docking Patterns

For the purposes of assessing practicality and applicability issues for ships, regular calling vessels can be broken into two useful categories:

- *No Cranes, Dock in same Position*. For tankers, RO-RO vessels, cruise ships, ferries and other vessels which dock in the same position each time at berth, fixed cable systems are possible which are relatively simple and cheap.

- *Container, Refrigerated Cargo (Reefers) and Dry bulk vessels*. Gantry cranes often run the full length of the wharf to unload container vessels, reefers and dry bulk vessels. The cranes may operate on fixed rails and require the full range of the wharf. This imposes an important restriction for an electrical connection to the ship at berth, as no fixed electrical transfer structures could be installed in the range of the crane. In addition, the vessels may dock at different positions along the same berth. Because of this, a fixed connection would restrict the terminal's operational flexibility. Therefore, the electrical connection required for ships which dock in various positions on the berth and use cranes will undoubtedly be more complex, and this is an area which needs further investigation which is outside the scope of this study. It is assumed in this report that the electrical connection could be made without a work barge (a relatively expensive system used in one application), but that terminal installation costs will be significantly higher than the case where ships dock in the same position.

Emissions reductions

Table 1 presents the estimated mid range values of emission reduction efficiencies of Shore Side Electricity considered in this study.

Table 1 Emission reduction efficiencies

Measure	% Emissions reduction (-) / increase (+) per vessel			
	NOx	SO_2	PM	VOC
Shore-Side Electricity (compared with 2.7% S Residual Oil (RO))	-97%	-96%	-96%	-94%
Shore-Side Electricity (compared with 0.1% S Marine Distillate (MD))	-97%	0%	-89%	-94%

Section 3.3 presents details of the impact of these measures on other emissions and noise.

Costs

The cost of supplying shore-side electricity infrastructure to a port varies widely from port to port. The major factors affecting costs include:

- whether the port infrastructure is existing and the installation is therefore retrofitted, or whether the infrastructure can be installed at the time of construction in a new build terminal/berth; and

- the electricity infrastructure near the port, including number of electrical substations which need upgrading to supply the additional electricity to the port.

Two case studies have been used to derive a range of the expected costs for shore-side electricity:

- Port of Gothenburg in Sweden. This port has installed shore-side electricity to two terminals. The port had spare capacity in existing conduits, which meant that cable installation was as cheap as that for a new build terminal. In addition only one of their two converted terminals required a new substation. These factors mean that the Port of Gothenburg incurred low capital and installation costs for the supply of high voltage electricity.
- Port of Long Beach in California. This port has undertaken a study into the likely cost for installing shore-side electricity. This identifies higher costs, for example it identifies that the port would require significant investment in the upgrade of substations to supply high voltage electricity to the site.

A third case study of the Port of Juneau was used to verify the derived cost range.

Table 2 presents the estimated mid range values (low fuel price of €250/tonne, no tax on electricity price) of cost-effectiveness of Shore Side Electricity, expressed in terms of €/tonne of each pollutant abated. For fuel prices above €450/tonne of substituted fuel Shore Side Electricity becomes a potentially financially attractive option under certain conditions. The associated uncertainty is considered in Section 1.3 and impacts of changing fuel prices and tax on electicity are discussed in section 4.5-4.7.

Table 2 Shore-side Electricity, Costs per tonne of emissions reduced, compared to engines using 2.7% RO (current average) (€/tonne pollutant) (Note 1)

Ship type	Emission	Small	Medium	Large
New	NOx	9,662	5,371	3,847
Retrofit	NOx	12,086	6,631	4,704
New	SO_2	9,889	5,498	3,937
Retrofit	SO_2	12,370	6,788	4,815
New	VOC	310,945	172,859	123,801
Retrofit	VOC	388,976	213,415	151,392
New	PM	152,631	84,850	60,769
Retrofit	PM	190,933	104,757	74,312

Note

1. The costs that are quoted assume an average of low and high port costs. In practice, it is possible for port costs to be even lower than this range if it only serves ships which use 50Hz power and not 60Hz (i.e. avoids need for power converter) and if ships dock at the same position and do not use gantry cranes.

More details of estimated costs, including estimated capital and operating costs for different size vessels and different types of ports, specific costs (€/kW capital, €/MWh operating) and total costs scaled up for all EU berths with EU-flagged vessels on regular service are given in Sections 4, 5 and 6.

Contents

1. Introduction

1.1 Background

While in port, ships use their Auxiliary Engines (AEs) to produce electricity for hotelling, unloading and loading activities. Main engines are usually switched off soon after berthing, however, most tankers and some bulk vessels use the main engine to generate power for pumps and other equipment for unloading the cargo. This usually means several hours of main engine running at berth for these vessels.

One measure to reduce emissions while at berth is to provide electricity to the ships from the national grid instead of producing electricity by ship engines. To provide ships with electricity, a shore-side electricity supply arrangement is required, also known as ‘cold-ironing’.

The use of shore-side electricity allows the resulting emissions from ships’ electricity use at berth to come from power generators supplying the national grid. These suppliers are likely to have lower emission factors per MWh of electricity, either due to the type of electricity production process (e.g. wind, hydro, nuclear etc) or the stringent emission controls imposed on land based power plants (e.g. through the European Union’s Integrated Pollution Prevention and Control Directive and the Large Combustion Plant Directive).

Shore-side electricity has been used in the past for practical reasons. For example, electricity may be needed to power pumps to unload ships, and the electricity demand of the pumps may greatly exceed the capacity of the auxiliary engines. Other examples of use for practical reasons include the Muscat Cement Terminal at the Port of Los Angeles, the US Navy and the Sea-Launch LLP based at the Port of Long Beach (POLB, 2004).

More recently, shore-side electricity has been used specifically to reduce air emissions. There are a number of examples of shore-side electricity in use around the world (POLB 2004).

- In 1991, the Pohang Iron and Steel Company (POSCO) in Pittsburg, California, established a shore-side electricity system as required by a local air permit. Four dry bulk vessels travelling between South Korea and the San Francisco Bay area were converted to use shore-side electricity.

- In 2002, five Princess cruise vessels were converted to use shore-side electricity in Juneau, Alaska (POLB 2004). These vessels require 7 MW of auxiliary power. In 2004, a sixth Princess cruise vessel was built with shore-side electricity facilities, with an expected electricity power demand of 8-9 MW.

- In 1989, the Port of Gothenburg converted a terminal to service ferries with shore-side electricity. In 2003 an additional terminal was converted to use shore-side electricity, this time servicing roll-on-roll-off (RO-RO) vessels.

- The Port of Los Angeles has converted the China Shipping Terminal to use shore-side electricity. At the current time, the Port of Los Angeles and potential shippers are only considering shore-side electricity for new build vessels.

- The Port of Lubeck in Germany is currently seeking to establish technical requirements for shore-side electricity in Baltic ports. The Port of Lubeck is also planning to implement shore-side electricity for ferries and passenger terminals. The main impetus for this change is the SO_2 air quality exceedences experienced in winter. The Port plans to supply electricity from wind power generation. The City of Lubeck is also working on a more extensive shore-side electricity plan, called Plan Baltic 21, with all Baltic port cities.

- The port of Pitea, Sweden, had plans to commissioning of a 6,000 V terminal in November 2004 servicing two RO-RO vessels with an around 36 hour harbour stop (Ohman 2004).

1.2 This Report

This report forms part of the deliverables under Task 2 of the European Commission contract on Ship Emissions: Assignment, Abatement and Market-Based Instruments.

Task 2 requires an investigation of the costs, emission reduction potential and practicalities of ship emissions abatement technologies. The technologies to be considered are:

- Task 2a: The use of shore-side electricity (this report);
- Task 2b: NO_x abatement techniques (see separate report on NOx techniques);
- Task 2c: SO_2 abatement techniques with focus on sea water scrubbing (see separate report on SO_2 techniques).

This is the report for Task 2a on Shore Side Electricity in ports.

The purpose of this task is to determine the costs, emission reductions and cost effectiveness of shore-side electricity. The focus of the study is on nitrogen oxides (NOx), sulphur dioxide (SO_2), volatile organic compounds (VOC) and particulate matter (PM) emissions. Other emissions covered include carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), which are qualitatively assessed.

Capital and operating costs are quantified for different types of ports. Out of the four known cases of shore-side electricity installed for the purpose of reducing air emissions, data for three of these ports have been taken into account in this analysis. These include the Port of Gothenburg (Sweden), the Port of Long Beach (California) and the Port of Juneau (Alaska). Costs to ships were considered based on information from the Port of Gothenburg and the Port of Juneau.

In addition, practicality issues for ports and ships are also considered, covering electricity supply compatibility and the complexity of the electrical connections required for different types of ships.

1.3 Uncertainty of Results

The two key results of this study are the costs of a measure and the achieved emission reduction by this measure i.e.

$$Cost - Effectiveness_{measure\ i}(\ \ /\text{tonne of pollutant}) = \frac{\text{Cost of measure i (}\ \ \text{/year)}}{\text{Emission reduction (tonne of pollutant/year)}}$$

Costs of measures: It is estimated that the costs derived in this study are subject to a 50% uncertainty range compared to the best estimate cost figure which are quoted. The key contributors to the uncertainty in the above estimates include:

- Inherent variations in costs of installations at berth for shore-side electricity that depend heavily on the existing infrastructure;
- Inherent variations in costs of retrofitting abatement equipment at different ships due to ship specific factors; and
- Uncertainty in the system costs based on the ratio of converted berth to converted ships.

Emission reductions: It is estimated that the emission reduction derived in this study are subject to a 30% uncertainty range compared to the best estimate emission reduction figures which are quoted. This is caused by a number of factors including:

- Uncertainty of emissions produced without measure e.g. fuel usage at berth, baseline levels of emission factors, load factors; and
- Reduction effectiveness of measure depends on utilisation of converted berths and substituted fuel. Potentially large variations between different berths.

Based on these uncertainty ranges it can be estimated that the cost-effectiveness of measures derived in this study are subject to a 60% uncertainty range compared to the best estimate cost effectiveness figures which are quoted.

2. Technical Description

2.1 System Description

There are currently no existing standards for shore-side electricity, but a schematic diagram outlining the typical technical requirements and elements can be seen in Figure 2.1.

Elements of the system include as numbered in the figure:

1. A connection to the national grid is needed carrying 20-100 kV electricity from a local sub-station where it is transformed to 6-20 kV.

2. Cables are then required to deliver the 6-20 kV power from the sub-station to the port terminal.

3. The electricity may then require power conversion from the grid standard of 50Hz to 60Hz, depending upon whether the ship runs at 50 Hz or 60 Hz.

4. Electricity is then distributed to the terminal. Cables need to be installed underground within existing conduits or this may require new canalisation. Electricity is metered.

5. To avoid handling of high voltage cables, a cable reel system is suggested. A cable reel tower could be built on the berth supporting a cable reel, davit and frame. The davit and frame would be used to raise and lower the cables to the vessel. The cable reel and frame would be electro-mechanically powered and controlled.

6. Onboard the vessel a socket is needed for the connecting cable.

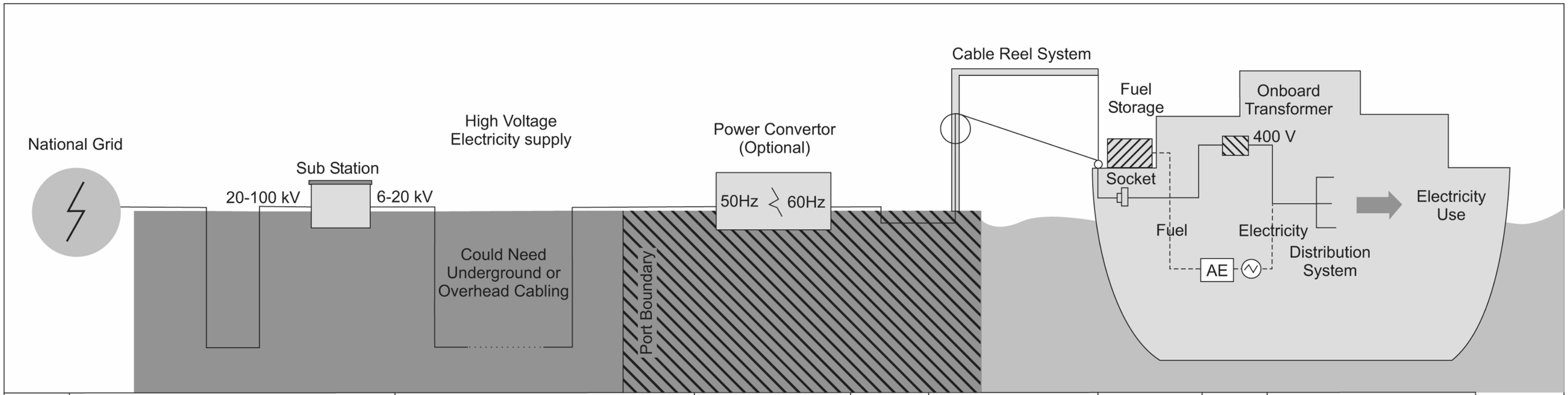
7. The ship then needs to transform the high voltage electricity to 400 V to be used onboard. This transformer is preferably located near the main switch board in the engine room.

8. The electricity is then distributed around the ship, and the auxiliary engines are switched off.

High voltage electrical connections to ships are preferred over low voltage connections. A high voltage cable can make it possible to transfer, for example, 25 times more electricity than with a normal 400 V cable of the same dimension. High voltage connections have lower capital and maintenance costs than low voltage connections. High voltage cables are handy and simple, and being lighter, allow more flexible electricity connections (Jiven 2004).

Although port terminals will already have electricity connections, it is probable that in most cases these connections would need upgrading to support both existing terminal operations and shore-side electricity for ships. This may require new underground or overhead electricity lines and poles from the closest substation.

Figure 2.1 Overview of Shore-side Electricity Connection



Position	1	2	3	4	5	6	7	8	

2.2 Practicality and Applicability

2.2.1 Electricity Supply Compatibility

Frequency

The electricity frequency produced by the grid across the EU may not be compatible with the electricity required by ships. Electricity supply in Europe has a frequency of 50 Hz, however electricity frequency used aboard ships can be either 50 or 60 Hz. A ship designed for 60 Hz electricity may be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating. However it could not use 50 Hz for the operation of motor driven equipment such as pumps, winches and cranes. Electricity at 50 Hz would make these motors run at about 83% of their design speed, which is likely to have damaging effects on the equipment.

Therefore, a ship using 60 Hz electricity will require 50 Hz electricity to be converted to 60 Hz by an electricity converter. An electricity converter would raise the costs significantly. It is assumed in this study that roughly 50% of ships would require electricity conversion to 60 Hz (Jiven, 2004).

Voltage

The high voltage electricity supplied to the ships will need to be stepped down to the low voltage required on board by a transformer. However, while transformers are usually designed to take only one voltage level, different ports have access to different voltage levels from the electricity network. This means that the available voltages at ports vary. A transformer designed to take, for example, 6 kV cannot use 10 kV electricity without special arrangements. Such special arrangements will add additional costs.

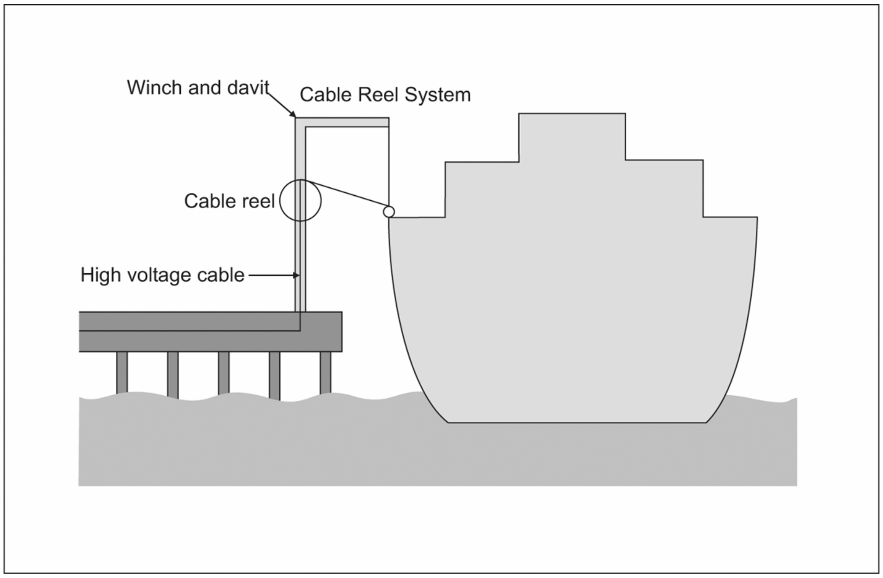
2.2.2 Electrical Connection

Safety in Handling High Voltage Cables

It is desirable to minimise the handling of high voltage cables to avoid wear on the cable creating safety hazards. For this reason it is likely that a fixed cable system would be more appropriate for use across the EU than a flexible cable.

This arrangement would involve a cable reel tower built on the berth supporting a cable reel, davit and frame, as illustrated in Figure 2.2. The davit and frame would be used to raise and lower the cables to the vessel. The cable reel and frame would be electro-mechanically powered and controlled (POLB 2004). It is likely that EU-flagged ships on regular service to the same port fleet would need only one cable reel.

Figure 2.2 Docking arrangements with cable reel system



Handling high voltage equipment carries a high potential hazard, and is likely to require trained operators to energise and de-energise the ship. The cost of an electrician's time is factored into the operating costs.

Ship Types and Docking Patterns

For the purposes of assessing practicality and applicability issues for ships, regular calling vessels can be broken into two useful categories as shown in Table 2.1. The docking arrangements for these groups of ships determine the ease with which the ships can be connected to shore-side electricity. Of particular importance is whether the ship always docks in the same position and whether the ship uses cranes to unload cargo.

Table 2.1 Ship Types and Docking Patterns

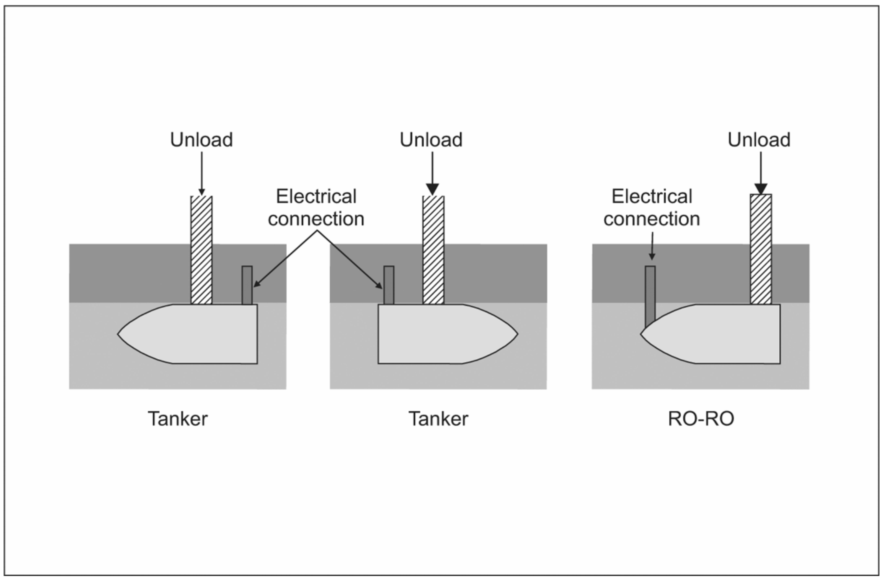
Category	Ship Type
1. No cranes, dock in same position (32% vessel calls to EU ports)	Tankers; RO-RO (Roll-on Roll-off) vessels; Cruise vessels; Ferry vessels; and Other vessels such as dredging, towing/pushing, fishing and research.
2. Use cranes, dock in various positions (68% vessel calls to EU ports)	Container vessels; Refrigerated vessels (reefers); and Dry bulk vessels.

1. No Cranes, Dock in same Position

Tankers and RO-RO vessels typically dock in the same position at the berth and do not often use gantry cranes. This means that the relatively simple and cheap wharf mounted electrical power infrastructure can be used. If the infrastructure is properly located, it will not impact upon operations (POLB 2004).

Tankers may discharge from either port or starboard. This means that the electrical connection must plug into sockets located at the centre of the stern. On the other hand, RO-RO vessels always unload vehicles from the stern with their starboard side against the wharf. This means the electrical connection would be located near the bow of the vessel and the sockets built into the starboard side (POLB 2004). Figure 2.3 illustrates the variety of docking arrangements for different tanker and RO-RO vessels.

Figure 2.3 Docking arrangements for tankers and RO-RO



For cruise ships, ferries and other vessels which dock in the same position each time at berth fixed cable systems are relatively simple and cheap. This is because the fixed cable system can use wharf mounted electrical power infrastructure.

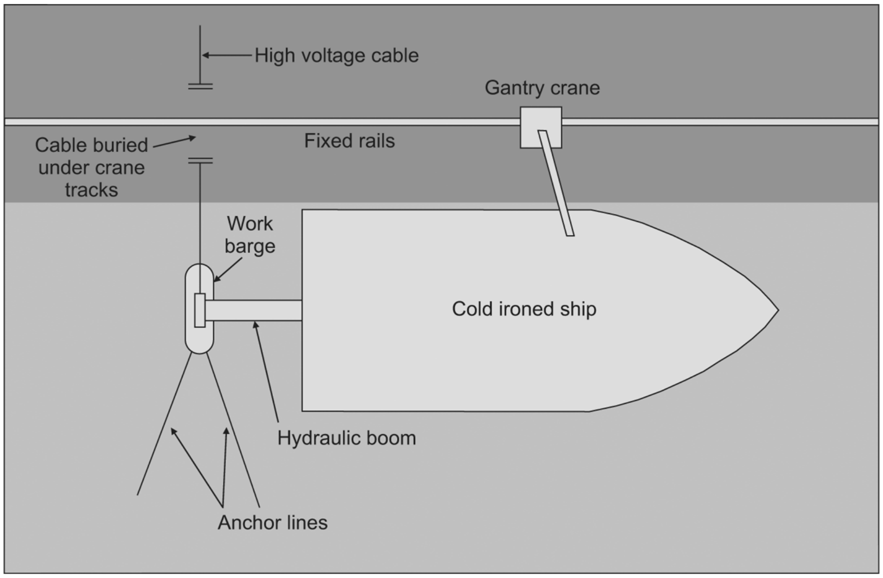
2. Container, Refrigerated (Reefers) and Dry bulk vessels

Gantry cranes often run the full length of the wharf to unload container vessels, reefers and dry bulk vessels. Although the crane may work in one area for an extended time period, the cranes may operate on fixed rails and require the full range of the wharf. This imposes an important restriction for an electrical connection to the ship at berth, as no fixed electrical transfer structures could be installed in the range of the crane (POLB 2004).

In addition, the vessels may dock at different positions along the same berth. Because of this, a fixed connection would restrict the terminal's operational flexibility (POLB 2004).

A study undertaken for the Port of Long Beach (POLB 2004) concluded that a ‘work barge’ concept was the most practical connection arrangement. This involves an anchored barge at the ship’s stern to connect the electricity cables from the shore to the ship. The barge would hold a cable reel, a hydraulic boom and possibly a transformer, as illustrated in Figure 2.4.

Figure 2.4 Docking arrangements with barge



The electrical cable would be connected from the shore-side to the cable reel on the work barge. The cable reel would be mounted to a turntable allowing it to swivel as much as 60 degrees, and it would be able to automatically adjust the tension to prevent sagging during tidal changes in the harbour. The cables would then be attached from the work barge along the hydraulic boom to the deck of the ship, where the cables would be connected to the ship. However, this is a complicated system with relatively high capital costs.

Operational costs for the work barge concept could also be significant. A two person crew would be needed to operate the work barge. These operators would:

- tend the conductor cables as the tide and vessel changes;
- monitor the electrical equipment; and
- re-position the work barge as needed.

A deckhouse would be needed to accommodate the crew for extended periods and to support the steering, reel and boom operations. The work barge would be moved away from the vessel during its docking and departure and brought alongside the wharf (POLB, 2004).

However this arrangement is unnecessarily complex for most cases (Spencer 2004, Driver 2004). The electrical connection required for ships which dock in various positions on the berth and use cranes will undoubtedly be more complex, and this is an area which needs further investigation which is outside the scope of this study. However it is assumed in this report that the electrical connection could be made without a work barge, but that terminal installation costs will be higher. A cost premium is taken into account for this connection type, but it is assumed that no additional operating costs are required (Spencer 2004, Driver 2004).

3. Emissions Reduction

3.1 Emission Factors

3.1.1 Emission Factors of Auxiliary Engines

The current mix of fuels used at berth has an assumed average sulphur content of 2.7%. The amended Directive 1999/32/EC as regards sulphur content of marine fuel will enforce vessels at berth to use 0.1% by mass sulphur marine fuels by 2010. Therefore emissions from the current use of 2.7% sulphur fuel, and the use of 0.1% sulphur fuel, are both relevant baselines for analysing the benefits of converting ships to using shore-side electricity. Using shore-side electricity will exempt ships from having to meet the 0.1% S fuel requirement under the directive, so it is useful to compare the cost-effectiveness of shore-side electricity to that of fuel switching. Table 3.1 depicts the emission factors used in the calculations for auxiliary engines at berth.

Table 3.1 Emission factors for AE at berth, g/kWh of electricity

	NOx (g/kWh)	SO_2 (g/kWh)	VOC (g/kWh)	PM (g/kWh)
Emission Factors from AE engines using 2.7% sulphur fuel (current average)	12.47	12.30	0.40	0.80
Emission Factors from AE engines using 0.1% sulphur fuel (EU 2010 limit)	11.8	0.46	0.40	0.30

3.1.2 Emission Factors for Electricity Generation in Europe

Based on EU25 emissions data from the RAINS model and EU25 electricity production data from the EC report on Energy and Transport Trends to 2030, average emission factors for electricity generation in 2010 were determined as shown in Table 3.2.[1] There is clearly a range of emissions factors higher and lower than this average value, depending on the method of electricity generation.

[1] The business as usual case CLE Aug 04 for EU 25 was used. Projections of electricity generation in 2010 for EU 25 were 3431 TWh (European Commission (EC) (2003)).

Table 3.2 Average emission factors for EU25 electricity production

	NOx (g/kWh)	SO_2 (g/kWh)	VOC (g/kWh)	PM (g/kWh)
Emission Factors	0.35	0.46	0.02	0.03

3.1.3 Comparison of Emission Factors

The emission factors from AEs (Table 3.1) were compared to those for shore-side electricity (Table 3.2) per kWh. Table 3.3 outlines that significant emissions could be reduced per kWh when shore-side electricity replaces AE electricity.

Table 3.3 Emissions reductions when using shore-side electricity instead of AE electricity, g/kWh

	NO_x (g/kWh)	SO_2 (g/kWh)	VOC (g/kWh)	PM (g/kWh)
Compared to 2.7% sulphur fuel (current average)	12.12	11.84	0.38	0.77
Compared to 0.1% sulphur fuel (2010 EU limit)	11.41	0.0	0.38	0.27

3.2 Emission Reductions per Berth

The reduction of emissions achieved by replacing AE generated electricity with shore-side electricity is shown in Table 3.3 per kWh. The absolute emission reduction depends upon the length of time which shore-side electricity substitutes for AE electricity generation, and the power level of electricity in kW. Emission reductions for the three different AE size categories were obtained by assuming a utilisation at berths of 70% of the time.

Table 3.4 and Table 3.5 show the emissions reduced per berth compared to engines using 2.7% sulphur Residual Oil (RO) (current average) and engines using 0.1% Marine Distillate (MD) (2010 EU limit).

Table 3.4 Emissions reduced per berth (t/year/berth) compared to engines using 2.7% sulphur RO (current average)

		Small (t/year)	Medium (t/year)	Large (t/year)
NOx	Baseline emissions	16.2	44.9	115.7
	Emissions reduced	15.72	43.63	112.41
	Reduction efficiency	97%	97%	97%
SO_2	Baseline emissions	15.96	44.29	114.10
	Emissions reduced	15.36	42.63	109.83
	Reduction efficiency	96%	96%	96%
VOC	Baseline emissions	0.52	1.44	3.71
	Emissions reduced	0.49	1.36	3.49
	Reduction efficiency	94%	94%	94%
PM	Baseline emissions	1.04	2.88	7.42
	Emissions reduced	1.00	2.76	7.12
	Reduction efficiency	96%	96%	96%

Table 3.5 Emissions reduced per berth (t/year/berth) compared to engines using 0.1% sulphur MD (2010 EU limit)

		Small (t/year)	Medium (t/year)	Large (t/year)
NOx	Baseline emissions	15.3	42.4	109.1
	Emissions reduced	14.81	41.09	105.86
	Reduction efficiency	97%	97%	97%
SO_2	Baseline emissions	0.62	1.72	4.44
	Emissions reduced	0.0	0.0	0.0
	Reduction efficiency	0%	0%	0%
VOC	Baseline emissions	0.52	1.44	3.71
	Emissions reduced	0.49	1.36	3.49
	Reduction efficiency	94%	94%	94%
PM	Baseline emissions	0.39	1.08	2.78
	Emissions reduced	0.35	0.96	2.48
	Reduction efficiency	89%	89%	89%

3.3 Other Emissions (CO, CO_2, CH_4, N_2O and Noise)

3.3.1 CO_2, CO, CH_4, N_2O

The net impact on emissions depends on the assumed methods of electricity production used to substitute for the AEs. Average emissions of CO_2, CO, CH_4 and N_2O were determined for electricity produced across the EU [2].

The average CO2 emissions from electricity production across the EU can be estimated as around 330 g/kWh. Emissions of CO_2 for auxiliary diesel engines are on average around 690 to 720 g/kWh (Cooper 2004). Therefore, on average, the use of shore-side electricity rather than electricity generation from diesel engines will reduce CO_2 emissions by more than 50%.

The average CO emissions from electricity production across the EU can be estimated as around 0.0125 g/kWh. Emissions of CO for AE engines are in the range 0.9 to 1.3 g/kWh (Cooper 2004). Therefore, on average, the use of shore-side electricity rather than electricity generation from AE will reduce CO emissions by about 99%.

The average CH_4 emissions from electricity production across the EU can be estimated as around 0.028 g/kWh (gas power and leakage). Emissions of CH_4 for AE diesel engines are in the range 0.004 to 0.01 g/kWh (Cooper 2004). Therefore, on average, the use of shore-side electricity rather than electricity generation from diesel engines will increase CH_4 emissions by about four times, though the absolute emissions remain relatively small.

The average N_2O emissions from electricity production across the EU can be estimated as around 0.014 g/kWh. Emissions of N_2O for diesel engines are on average 0.031 g/kWh (Cooper 2004). Therefore, on average, the use of shore-side electricity rather than electricity generation from diesel engines will reduce N_2O emissions by more than 50%.

3.3.2 Noise

The dominant source of noise in diesel combustion is the sound associated with the combustion event itself. When a premixed charge of fuel and air ignites, the very rapid combustion leads to a sharp increase in pressure, which is easily heard and recognised as the characteristic sound of a diesel engine. In addition mechanical and exhaust noises are generated together with mechanical vibration.

An additional benefit from using shore-side electricity instead of onboard power generation is therefore the elimination of noise and vibration from the auxiliary engines whilst at berth. The greatest benefit is felt by the engineers working within the engine room environment, and this has been cited as a particular advantage by ships' engineers using shore-side electricity in the Port of Gothenburg.

In close proximity to the AEs, noise levels in the 90 - 120 dB interval can be reached[3] (Cooper 2004). All of this noise will be eliminated if shore-side electricity is used and AEs are switched

[2] CO2, CO, CH4 and N2O emissions were estimated for the EU25 energy sector by the UNFCC, *Greenhouse Gases Inventory*, http://ghg.unfccc.int/default.htf. EU25 electricity production data from the EC report on *Energy and Transport Trends to 2030*.

off. Even for other personnel working onboard the ships or involved in loading operations around the quay some positive noise reduction will be experienced. To our knowledge, however, no noise measurements have been undertaken of background levels experienced at the quayside, with and without shore-side power links in use (Lindeman, 2004).

[3] As a general guideline, maximum exposure time at 85 dB (A) is 8 hours while at 110 dB (A) this is reduced to ca. 1 ½ minutes. Noise levels above ca. 140 dB (A) can cause damage to hearing after just one exposure. Consequently engine room personnel regularly wear hearing protection.

4. Costs

4.1 Case Studies

It should be noted that although costs were based on case studies, additional assumptions were made to reflect the range of ports and ships serving regular ships in the EU.

The cost of supplying shore-side electricity infrastructure to a port varies widely from port to port. The major factors affecting costs include:

- whether the port infrastructure exists and the installation is therefore retrofitted, or whether the infrastructure can be installed at the time of construction in a new build terminal/berth; and
- the electricity infrastructure near the port, including number of electrical substations which need upgrading to supply the additional electricity to the port.

Two case studies are used to derive a range of the expected costs for shore-side electricity. These included the Port of Gothenburg in Sweden, which has installed shore-side electricity to two terminals (Jiven, 2004). Also, the Port of Long Beach in California has undertaken a study into the likely cost for installing shore-side electricity (POLB, 2004). A third case study of the Port of Juneau was used to verify the derived cost range.

The Port of Gothenburg had spare capacity in existing conduits, which meant that cable installation was as cheap as that for a new build terminal. In addition only one of their two converted terminals required a new substation. These factors mean that the Port of Gothenburg incurred low capital and installation costs for the supply of high voltage electricity (Jiven 2004 and Lindeberg 2004). Costs from the Port of Gothenburg study were quoted for two berths, and were therefore halved to arrive at costs per berth.[4]

On the other hand, a study undertaken on the cost of installing shore-side electricity at the Port of Long Beach (POLB) outlines costs for retrofitting a high voltage electricity connection into a port terminal (POLB, 2004). In addition, the POLB would require significant investment in the upgrade of substations to supply high voltage electricity to the site. The POLB study estimated costs in a very conservative manner and included a 30% contingency.[5] Therefore the costs from the POLB study are reduced by 30% to reflect pre-contingency cost estimations.

The third case study chosen was the Port of Juneau, Alaska, where five Princess cruise vessels were converted to shore-side electricity in 2001. Cost estimations from this third case study sit between the Port of Gothenburg and the Port of Long Beach pre-contingency costs.

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[4] Jiven (2004) outlines costs for a 1-10 MW connection. With average installed AE capacity ranging from about 0.5-4 MW for small to large ships, this means that about 2 berths could be served.

[5] The cost calculations included in the main body of the POLB (2004) report cite 30% contingencies, e.g. p66 costs for work-barge annual costs include 30% contingency.

Costs per ship are less varied than costs per port. Costs for ships were based on figures derived from Jiven (2004) and other experts.

4.2 Different Types of Ships

The cost of supplying shore-side electricity infrastructure to a port also varies depending upon the type of ship being served. The major factors affecting costs include:

- whether the ship using the electricity is a container, refrigerated cargo (reefer) or dry bulk vessel, and therefore requires a complex electrical connection; and
- the onboard electricity frequency (50/60 Hz) of the ships which will use the electricity, as this determines whether a electricity converter is required in the port.

Table 4.1 outlines the breakdown of ship types assumed in this study.

Table 4.1 Breakdown of ship types

Vessels	Assumed fraction of EU-flagged fleet[6]
Use cranes, dock in various positions i.e. Container, Reefers and Dry Bulk Vessels	68%
Ships using 60Hz electricity[7]	50%

4.3 Costs to Ports

The baseline for the cost estimates for ports are ports not currently equipped to provide shore-side electricity.

4.3.1 Cost Components

The costs are broken down to correlate with the positions described in the technical description and shown on Figure 2.1.

To derive annualised costs a discount rate of 4% is used.

Positions 1 and 2: Cost of Supplying High Voltage Electricity to the Terminal
The cost of supplying high voltage electricity to the port and then to the berth can vary significantly from one port to another. This is due primarily to variations in the distance to the nearest high voltage supply, and most significantly the number of transformer stations/connections that require upgrading. Other costs will depend on the local conditions,

[6] It can be assumed that the world fleet has a similar breakdown of ship type.

[7] Jiven 2004

which may include requiring additional overhead electricity lines and poles and running additional cables underground. In addition, the cost of retrofitting cables into a terminal is significantly higher than installing cables in a new build terminal. Therefore a cost range is used to reflect the large range in site-specific requirements.

The cost of connecting high voltage electricity to the Port of Gothenburg represents the lower end of possible costs.

The cost of supplying a new build terminal with 1-10 MW high voltage electricity connection can be estimated as:

High voltage electricity connection: €255,000 (Jiven 2004)

Number of berths served: 2

Life-span of high voltage connection: 30 years.

Table 4.2 depicts the annualised costs.

Table 4.2 Cost estimation to supply a new build terminal with a high voltage electricity connection (low costs)

Position 1+2 (low cost)	Cost including installation total (€)	Cost including installation per berth (€)*	Annualised Cost per Berth (€/year)
All engine sizes	255,000	127,500	7,400

* There are assumed to be two berths per terminal.

The cost of connecting high voltage electricity to a terminal quoted by the POLB study represents the higher end of possible costs.

Supply and installation of high voltage electricity to an existing terminal per berth: €532,000

Lifespan of high voltage connection: 30 years.

An average cost will be used in the cost calculations, as shown in Table 4.3.

Table 4.3 Estimation of cost to supply an existing terminal with a high voltage electricity connection per berth

Position 1+2 (high costs)	Cost including installation per Berth (€)	Annualised Cost per Berth (€/year)
All engine sizes	532,000	30,800

Position 3: Electricity Converter

Electricity supply in Europe has a frequency of 50Hz, however electricity frequency used aboard ships can be either 50 or 60Hz. A ship designed for 60 Hz electricity may be able to use 50 Hz electricity for some equipment, such as domestic lighting and heating, but could not use 50 Hz for the operation of motor driven equipment such as pumps, winches and cranes.

A ship using 60 Hz electricity will require 50 Hz electricity to be converted to 60 Hz by an electricity converter. The need for an electricity converter would add a significant additional cost. Costs for electricity converters in the electricity range suitable for shore-side electricity systems are:

Electricity converter cost:	€300,000 - €500,000 (Jiven 2004)
Installation cost:	75% of equipment cost
Number of berths served:	2
Electricity converter life-span:	20 years.

Table 4.4 outlines how these costs were scaled for berths serving different ship sizes.

Table 4.4 Cost estimation for Electricity Converter

Position 3	Converter Cost (€)	Installation Cost (€)	Total cost per berth* (€)	Annualised Cost per Berth (€/year)
Small	300,000	225,000	262,500	19,300
Medium	400,000	300,000	350,000	25,800
Large	500,000	375,000	437,500	32,200

* assumed two berths per electricity converter

Position 4: Cost of Supplying High Voltage Electricity in the Terminal

High voltage electricity supplied to the terminal then needs to be installed to the quay side in the terminal. The costs are likely to be significantly lower if the facilities were installed when a terminal is being built or constructed as opposed to a retrofit situation (POLB 2004).

Typical costs for high voltage cable installation for a new build terminal include (Jiven 2004):

Canalisation costs:	€125/m
High voltage cable (10kV) costs:	€12.5 /m
Distance from terminal high voltage electricity to quay side:	average of 250m
Lifespan:	40 years

These cost components are used to calculate cost estimations for berths, as shown in Table 4.5. As discussed in Section 4.1, costs quoted by Jiven (2004) are assumed to apply to two berths, which can be served by the size of electricity connection studied.

Table 4.5 Calculation of cost estimations for supplying high voltage electricity at the quay side for a new build terminal (Cable installation in terminal), depending on the position of the equipment as set out in Figure 2.1

Position		Units	All AE sizes[8]
Terminal cable installation costs:			
4	High voltage cable (10kV)	(€/m)	12.5
4	Canalisation costs	(€/m)	125
4	Distance from terminal to quay side	(m)	250
4	Metering equipment	(€)	9,120
4 and 5	Construction, installation, engineering costs (% of material costs)	(%)	100%
4 and 5	Total Terminal Installation Costs	(€)	86,990
4	Number of berths per port	(-)	2
4 and 5	Terminal cable installation costs per berth	(€)	43,495
	Annualised costs	(€/year)	2,200

Retrofitting high voltage cable installation in the terminal can significantly increase costs. This cost factor is unlikely to vary significantly with the size of the electricity supply. Estimated costs for high voltage cable retrofitting for an existing terminal are (POLB 2004):

Terminal cable installation per berth:	€182,000
Canalisation and cable life-span:	40 years
Annualised costs:	€9,200/y

[8] It is assumed that the cost of supplying high voltage connection to a port was the same for all ports and engines.

Comparing the annualised costs of cable installation for existing ports (€9,200) to that for new build terminals (€2,200), it has to be expected that retrofitting costs are about 4 times the costs of new build.

Position 5a: Electrical Connection to Ships Docking in Various Positions and Using Gantry Cranes

Section 2.2 discussed a potential practicality issue for ships which use gantry cranes and dock at different locations with each visit. These vessels include container, refrigerated and dry bulk ships. The crane tracks may restrict the space available at the quay side for an electrical connection. As explored in Section 2.2, the Port of Long Beach study suggests a 'work barge' solution to this problem, as shown in Figure 2.3. The costs involved in a work barge include (POLB 2004):

Approximate capital cost of 'work barge' for all connection sizes:	€ 1,010,000
Approximate operating cost of 'work barge' for all connection sizes per year:	€ 84,000 – 548,000

These costs would significantly increase the costs for shore-side electricity ships using gantry cranes such as container, refrigerated and dry bulk vessels. Since these vessel categories constitute a large fraction of the EU fleet, this issue will have an important impact on the feasibility of shore-side electricity in the EU. Although it is not in the scope of this report to arrive at a definitive answer to this practical issue, it seems possible that with further investigation there may be a more cost-effective arrangement.

For the purposes of this report, it will be assumed that ***the electrical connection could be made without a work barge***. Costs for this connection are estimated to be:

Position 5 special electrical connection:	€ 182,400

It is assumed that about 68% of the berths will need this special type of connection based on the fleet composition and that no additional operating costs would be required to connect ships using cranes.

Position 5b: Fixed Cable Reel System

It is assumed that handling of high voltage cables will be minimised to reduce electrical hazards Therefore a cable reel system is needed to connect the high voltage electricity from the shore to the ship. It is likely that EU-flagged ships on regular service to the same port would need only one cable reel. This arrangement is shown in Figure 2.3.

The costs for a cable reel system can be estimated as (POLB 2004):

Cost of cable reel system:	€152,000
Lifespan of cable reel system:	30 years
Annualised costs:	€8,800/y.

4.3.2 Calculation of Total Costs

Table 4.6 and Table 4.7 outline the total cost estimations for installing shore-side infrastructure to a low cost and high cost port. Table 4.8 outlines the cost for an extra low cost port, which can only serve:

- Ships which use 50 Hz power, not 60 Hz; and
- Ships which dock at the same position and do not use gantry cranes.

Table 4.6 Total costs per berth for a low cost port

	Vessels		
<u>Low cost port</u>	**Small**	**Medium**	**Large**
Pos. 4 Cable installation in the terminal capex (€)	43,495	43,495	43,495
Equipment lifespan (year)	40	40	40
Annualised costs (€/year)	2,198	2,198	2,198
Pos. 3 Power converter capex (€)	262,500	350,000	437,500
Equipment lifespan (year)	20	20	20
Annualised costs per berth serving ships with 60Hz (€/year)	19,315	25,754	32,192
Fraction of berths serving 60 Hz shipsn (%)	50%	50%	50%
Average annualised cost per berth (€/year)	9,658	12,877	16,096
Pos. 5a Additional capex for cable installation in the terminal for ships using cranes (€)	182,400	182,400	182,400
Equipment lifespan (year)	40	40	40
Annualised costs per berth using cranes (€/year)	9,215	9,215	9,215
Fraction of berths using cranes (%)	63%	63%	63%
Average capex per berth (€)	114,912	114,912	114,912
Average annualised cost per berth (€/year)	5,806	5,806	5,806
Pos. 1+2 HV connection from grid to terminal capex (€)	127,500	127,500	127,500
Equipment lifespan (year)	30	30	30
Annualised costs (€/year)	16,164	16,164	16,164
Pos. 5b Cable reel system capex (€)	152,000	152,000	152,000
Equipment lifespan (year)	30	30	30
Annualised costs (€/year)	8,790	8,790	8,790
<u>Total Capex per berth (€)</u>	**569,157**	**612,907**	**656,657**
***<u>Total Annualised Capex per berth</u>* (€/year)**	**42,615**	**45,834**	**49,053**
Capex per kW installed	1,076	418	174
O&M costs (€/year)	0	0	0
Total annual costs per berth (€/year)	**42,615**	**45,834**	**49,053**

Table 4.7 Total costs per berth for high cost port

	Vessels		
<u>**High cost port**</u>	**Small**	**Medium**	**Large**
Pos. 4 Cable installation in the terminal capex (€)	182,400	182,400	182,400
Equipment lifespan (year)	40	40	40
Annualised costs (€/year)	9,215	9,215	9,215
Pos. 3 Power converter capex (€)	262,500	350,000	437,500
Equipment lifespan (year)	20	20	20
Annualised costs per berth serving ships with 60Hz (€/year)	19,315	25,754	32,192
Fraction of berths serving 60 Hz ships (%)	50%	50%	50%
Average annualised cost per berth (€/year)	9,658	12,877	16,096
Pos. 5a Additional capex for cable installation in the terminal for ships using cranes (€)	182,400	182,400	182,400
Equipment lifespan (year)	40	40	40
Annualised costs per berth using cranes (€/year)	9,215	9,215	9,215
Fraction of berths using cranes (%)	63%	63%	63%
Average capex per berth (€)	114,912	114,912	114,912
Average annualised cost per berth (€/year)	5,806	5,806	5,806
Pos. 1+2 HV connection from grid to terminal capex (€)	532,024	532,024	532,024
Equipment lifespan (year)	30	30	30
Annualised costs (€/year)	30,767	30,767	30,767
Pos. 5b Cable reel system capex (€)	152,000	152,000	152,000
Equipment lifespan (year)	30	30	30
Annualised costs (€/year)	8,790	8,790	8,790
<u>***Total Capex per berth (€)***</u>	**1,112,586**	**1,156,336**	**1,200,086**
<u>***Total Annualised Capex***</u> **(€/year)**	**64,236**	**67,455**	**70,674**
Capex per kW installed	2,103	788	317
O&M costs (€/year)	0	0	0
Total annual costs (€/year)	**64,236**	**67,455**	**70,674**

Table 4.8 Total costs, Extra low cost port

	Vessels		
Extra low cost port	Small	Medium	Large
Pos. 4 Cable installation in the terminal capex (€)	43,495	43,495	43,495
Equipment lifespan (year)	40	40	40
Annualised costs (€/year)	2,198	2,198	2,198
Pos. 1+2 HV connection from grid to terminal capex (€)	127,500	127,500	127,500
Equipment lifespan (year)	30	30	30
Annualised costs (€/year)	16,164	16,164	16,164
Pos. 5b Cable reel system capex	152,000	152,000	152,000
Equipment lifespan (year)	30	30	30
Annualised costs (€/year)	8,790	8,790	8,790
***Total Capex per berth* (€)**	**322,995**	**322,995**	**322,995**
***Total Annualised Capex* (€/year)**	**27,151**	**27,151**	**27,151**
Capex per kW installed	611	220	85
O&M costs (€/year)	0	0	0
Total annual costs (€/year)	**27,151**	**27,151**	**27,151**

4.3.3 Comparison of Total Port Costs to a Third Case Study

These cost estimations were verified with a third case study. A shore-side electricity facility for five Princess Cruise Vessels was installed in Juneau, Alaska in 2001. The ships use 60 Hz electricity which does not need an electricity converter since grid frequency in Alaska is 60Hz. The ships would also have simple electrical connections since the ships would dock in the same position and not use cranes.

The ships' installed AE capacity is 7 MW, which is twice the size of the average capacity of the EU regular fleet's largest ship category. Therefore the cost estimations made above were extrapolated to reflect costs to a 7 MW ship.

The cost of installing the high voltage shore-side electricity facilities totalled €3.76 million ($4.7 million) (POLB 2004). Assuming that five berths were converted to supply electricity to service the five ships, this equates to around €0.75 million per berth, or €105/kW installed. These costs are broadly similar to the estimate in Table 4.8 for extra low cost ports of €85/kW installed.

4.3.4 Operational Costs

It is assumed that the cost of electricity and system maintenance would be directly passed onto the ships using the electricity. The port may decide to add a premium to the electricity cost to repay investment costs of providing the electricity infrastructure. However, for the purposes of this report, it is assumed that electricity will be supplied to ships at standard non-residential rates plus maintenance costs.

4.4 Costs to Ships - Capital Costs

The baseline for the capital costs estimates for ships are ships not currently equipped to use shore-side electricity.

4.4.1 Cost Components

Position 7a Existing auxiliary engines

Ships will still need to retain and maintain AEs even if the ship is constantly using shore-side electricity at berth. This is because some ships use AEs for electricity generation at sea, and all ships equipped for shore-side electricity will need AEs in case of onshore electricity failure, or if the ship calls at a port without shore-side electricity facilities. Therefore the capital cost for AEs is excluded from the cost calculations, as there are no capital cost savings available or additional capital expenditure required.

Position 7b Onboard Transformer

For the large majority of ships, a transformer is required onboard to convert 6-20 kV electricity to the 400 V used onboard. Some ships use high voltage electricity, but this is unlikely to constitute a significant fraction of the regular service EU fleet (Spencer 2004). Typical costs for onboard transformers with installation costs are shown in Table 4.9 (Jiven 2004, Driver 2004).

Table 4.9 Transformer cost estimations

Equipment Type	Estimation
Onboard transformer (0.5-4 MW):	€40,000 – 106,400;[9]
Installation cost, new build:	75% of equipment cost;[10]
Retrofitting installation:	150% of equipment cost;
Transformer lifetime:	10 years in a marine environment;
Unsheltered transformer:	10% equipment cost premium;
Unsheltered transformer lifetime:	10 years in a marine environment;
Multiple supply voltage transformer	50% equipment cost premium;
Multiple supply voltage transformer lifetime:	10 years in a marine environment.

The cost of installing a transformer to an existing ship is expected to be significantly higher than installing a transformer on a new ship. The estimated lifespan of a transformer in a marine environment is lower than an on-shore transformer in a well protected environment, due to

[9] Jiven (2004) quotes €40,000 to €70,000 for 0.5-2MW. These figures are linearly extrapolated to represent the 4MW for large auxiliary engines.

[10] Jiven (2004) outlines an installation cost of 50% to 100% of equipment capex for new build ships. An average of 75% is used in this study. Driver (2004) estimates that retrofitting may require double the installation costs on new build ships.

exposure of the marine transformer to vibrations, and because maintenance is likely to be less frequent.

A transformer may be located in a sheltered or unsheltered position. A transformer would need a suitable watertight enclosure with cable access via a watertight door in the topside. This is estimated to cost 10% of the equipment cost for a sheltered transformer. It is estimated that the life-span of a transformer designed for an unsheltered position will not be shorter than a sheltered transformer.

Different ports have access to different voltage levels, meaning that the available voltages at ports vary. A transformer designed to take, for example, 6 kV cannot use 10 kV electricity without special arrangements, at an additional cost. Transformers which can use a range of supply voltages are available, and the estimated price premium is estimated for a transformer with up to 3 different supply voltage connections. Assumptions were made about the fraction of ships with shelter for transformers, those requiring multi-voltage transformers and the premium for installation (Driver 2004).

Table 4.10 Calculation of transformer costs for new build ships.

New build ships	Small	Medium	Large
Onboard transformer (€)	40,000	59,200	106,400
Unsheltered onboard transformer (€)	44,000	65,120	117,040
Multi-voltage transformers (€)	60,000	88,800	159,600
Fraction of ships without shelter room for transformer (%)	40%	30%	20%
Fraction of ships needing a multi-voltage transformer	5%	5%	5%
Weighted average transformer cost (€)	44,600	65,416	116,508
Construction, installation and engineering costs (% of equipment)	75%	75%	75%
Transformer equipment and installation costs (€)	78,050	114,478	203,889
Annualised costs (€/year)	**9,623**	**14,114**	**25,138**

Table 4.11 Calculation of transformer cost for retrofitting on existing ships.

Retrofitting	Small	Medium	Large
Weighted average transformer cost (€)	44,600	65,416	116,508
Construction, installation and engineering costs (% of equipment)	150%	150%	150%
Transformer equipment and installation costs (€)	111,500	163,540	291,270
Annualised costs (€/year)	**13,747**	**20,163**	**35,911**

Position 8 Connection to Electrical Distribution System

Costs involved with connecting the electrical supply to the ship's electricity distribution system depend upon the practicalities and distances for cable installation. Estimations for cable costs and distances include:

Low voltage cable (400V): €12.5 /m

Average distance of cable required: 125 m

Life-span of low voltage cable: 25 years.

These cost components are then calculated as shown in Table 4.12.

Table 4.12 Capital cost estimation for connection to electrical distribution system ships.

	New ships all AE sizes	Retrofitting all AE sizes
Low voltage cable (400V) (€/m)	12.5	12.5
Average distance from transformer to distribution system (m)	125	125
Construction, installation and engineering costs (% of equipment costs)	75%	150%
Total cable installation cost (€)	2,740	3,900
Lifespan (years)	25	12.5
Annualised costs (€/year)	**175**	**403**

4.4.2 Calculation of Total Capital Cost Estimation

Table 4.13 outlines the estimated costs of converting a ship to use shore-side electricity for new ships and retrofitting on existing ships.

Table 4.13 Estimated capex costs per ship

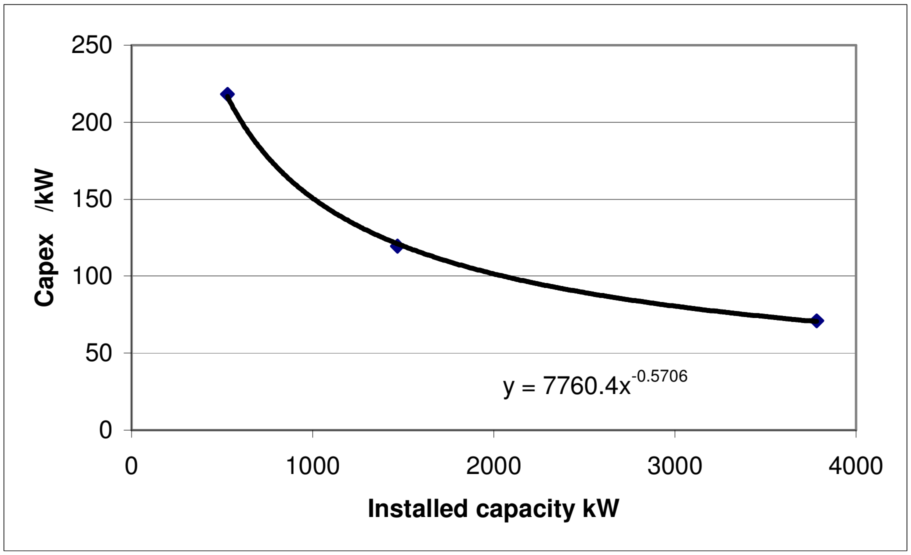
New build capex	Small	Medium	Large
Transformer capex (€)	78,050	114,478	203,889
Equipment lifespan (year)	10	10	10
Annualised costs (€/year)	9,623	14,114	25,138
Cable installation capex	2,740	2,740	2,740
Equipment lifespan (year)	25	25	25
Annualised costs (€/year)	175	175	175
Total Capex new build (€)	**80,790**	**117,218**	**206,629**
Annualised capex costs new build (€/year)	**9,798**	**14,289**	**25,313**
Capex per kW AE installed (€)	153	80	55
Retrofit capex (€)			
Transformer capex (€)	111,500	163,540	291,270
Equipment lifespan(year)	10	10	10
Annualised costs (€/year)	13,747	20,163	35,911
Cable installation capex (€)	3,906	3,906	3,906
Equipment lifespan (year)	12.5	12.5	12.5
Annualised costs (€/year)	403	403	403
Total Capex retrofit (€)	**115,406**	**167,446**	**295,176**
Annualised capex costs retrofit (€/year)	**14,150**	**20,566**	**36,314**
Capex per kW AE installed (€)	**218**	**114**	**78**

4.4.3 Comparison of Total Ship Costs with a Third Case Study

It is useful to compare these cost estimations to a third case study. Five Princess Cruise Vessels based in Juneau, Alaska were retrofitted to use shore-side electricity in 2001. The ships' installed AE capacity is 7 MW, which is twice the size of the average capacity of the largest ship category. Therefore the cost estimations from this study were extrapolated to reflect a 7 MW AE ship.

The capex cost of retrofitting the Princess cruise vessels totalled €0.4 million ($0.5 million), or €57/kW installed (POLB 2004). Extrapolating the retrofitting capex costs derived in this study to represent a 7MW vessel, using the trend-line shown in Figure 4.1, show almost identical specific costs of €55/kW. This indicates that the cost estimations in this study are likely to be a realistic reflection of costs.

Figure 4.1 Trend-line for specific Capex as a function of the installed AE capacity



4.5 Cost to Ships – Operating Costs

The baseline for the operating costs estimates for shore-side electricity are ships using marine distillate (MD) at berth instead of shore-side electricity. The presented operating costs are therefore the additional costs incurred for switching from MD to shore-side electricity.

4.5.1 Costs Saved: AE Fuel

The major operating cost for AEs is the cost of fuel. Although fuel prices vary across the EU and the world, a good estimation of fuel prices can be made from bunker fuel prices in Rotterdam, since Rotterdam is the second largest port in the world after Shanghai. The reference year of this study was 2000. Average prices over the period December 2003 to June 2004 for 0.2% sulphur marine distillate (MD) from the Port of Rotterdam are around (Jiven 2004):

Marine Diesel (MD) (0.2% sulphur): €227 /tonne[11].

€227 per tonne is regarded as a representative figure over recent years and therefore the cost of 0.2% sulphur MD was set at €227 per tonne for this study.

This study compares the use of shore-side electricity to the use of 0.1% sulphur MD. It is assumed that the cost of reducing 0.2% sulphur to 0.1% sulphur demands a 10% cost premium. Therefore the cost of 0.1% sulphur MD fuel is assumed to be:

Marine Distillate (MD) (0.1% sulphur): €249 /tonne (low fuel price).

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[11] Although fuel prices rose for the remainder of the study in 2004 and 2005, for example, the cost of 0.2% sulphur MD in June 2004 was €325 per tonne and www.bunkerworld.com quotes €540/tonne MGO on September 1st 2005, such high prices are not expected to last but the prices could stay above the used prices in this study making options based on substitutions financially more attractive.

To assess the impact of potentially higher fuel prices on the cost results the calculations are also done with a fuel price of €500/tonne (high fuel price).

Specific fuel consumption for engines using MD is assumed to be:

Specific fuel consumption (MD): 217g/kWh.

Table 4.14 outlines the fuel consumption for ships at berth and outlines the fuel costs saved for ships converting to shore-side electricity.

Table 4.14 Fuel consumption for ships at berth in AEs (t/year/ship)

	Small	Medium	Large
Fuel Saved per ship (t/year/ship)	32	89	230
Cost per tonne 0.1% MD (€/tonne), low / high fuel price	249 / 500	249 / 500	249 / 500
Fuel costs saved (€/year/ship), low / high fuel price	8,000 / 16,000	22,300 / 44,500	57,400 / 115,000
Fuel Saved per berth (t/year/berth) (70% berth utilisation)	282	781	2,013

4.5.2 Costs Saved: Maintenance Costs

Other operating costs include investment and maintenance costs. Ships would need to retain their AEs in case of electricity supply failure or berthing at ports without shore-side electricity facilities. Therefore investment costs are required whether the ship is shore-side electricity or not, and therefore are not included. However it is likely that investment costs may be reduced by shore-side electricity, since the expected equipment life may increase.

Engine maintenance costs may also be reduced by shore-side electricity. Ships using shore-side electricity will still need a low level of routine maintenance for AEs, but this will be significantly lower than maintenance required by ships not using shore-side electricity. Engineers aboard ships using shore-side electricity in Gothenburg have cited that a significant advantage of the system is that shutting the engine down while at berth allows routine maintenance to take place much more regularly and in a cleaner, quieter environment than if the engine is left running.

Maintenance costs vary with engine type, for example, two or four stroke, engine brand and size. Engine age and running hours per year will also affect maintenance costs. A general maintenance cost can be estimated as (Jiven, 2004):

Maintenance costs for engines: €1.6 /running hour

Maintenance costs saved for AEs: €1,100/year/ship

4.5.3 Costs of Electricity

The operating cost of shore-side electricity will be due primarily to the electricity cost. The cost of electricity will depend upon the country and the electricity supply contract. An average industrial electricity price across the EU15 for the year 2000 was used, as shown in Table 4.15 (European Commission (EC) (2003)).

The cost estimates were compiled without taking into account any taxes. This was to enable analysis of the factors which affect the cost effectiveness of shore-side electricity systems.

If electricity taxes are applied, the operating costs increase. Electricity costs are a significant proportion of the costs of this measure. A tax on electricity has a major direct impact on the cost effectiveness of shore-side electricity. Therefore shore-side electricity is most cost effective where electricity is cheapest, and/or where fuel costs are highest.

In contrast, marine fuels are not generally subject to taxation, so the extra cost of tax on electricity is a potential disincentive for ships to use a shore-side electricity system. However EC Directive 2003/96 on taxation of energy products does include the possibility for individual countries to allow electricity tax exemptions on environmental grounds. It would be open to Member States to apply to the Commission for such an exemption for shore-side electricity used by ships.

Another political cost factor to bear in mind is that ships' emissions of CO_2 and air pollutants are not currently included in EU countries' emissions targets under the Kyoto Protocol and National Emissions Ceilings directive. Emissions from electricity generation are included, so ships switching to shore-side electricity could have a minor impact on national emissions.

An estimation of the port's operating costs for the electricity installation is made. A shore-side electricity port's operating cost of 0.0065 €/kWh was estimated by Jiven (2004). It is assumed that the port does not mark up the grid price on supplying electricity to ships. Therefore the EU average cost of electricity to ships is estimated as €0.0715 / kWh as shown in Table 4.15.

Table 4.15 Estimated electricity costs for shore-side electricity across the EU

Cost Element	€/kWh
Average EU electricity cost (Note 1)	0.0650
Operating cost	0.0065
Total Electricity Cost (excluding taxes)	0.0715
Range of industrial electricity prices taxes in EU countries 2004[12]	0-50%
Average tax rate on industrial electricity prices in EU countries 2004[13]	15%

Note: 1: Price excluding taxes.

Electricity supply contracts will also be affected by the maximum electricity level required at any one time. That is, a port with large fluctuations in electricity requirements may pay a higher electricity price than a more level electricity demand. In addition, a high maximum electricity level will increase the size and cost of electricity equipment such as transformers and cables.

[12] Industrial electricity price taxes in 2004 derived from the International Energy Agency publication, Energy Prices and Taxes Q1 2005 as cited in http://www.dti.gov.uk/energy/inform/energy_prices/ tables/table_531.xls: Germany 0%, Greece 0%, UK 7%, Finland 9%, Denmark 10%, France 13%, Austria 35%, Portugal 50%

[13] Average calculated based on the country's tax rates listed in footnote 12

The electricity supply price may be reduced by using an interruptible supply contract. Electricity suppliers offer lower prices for interruptible electricity supply as it enables them to meet peak electricity demands by shifting electricity supply from interruptible demands to non-interruptible demands. Shore-side electricity ships will still need to retain their auxiliary engines (AEs) anyway, in case of electricity failure or berthing at a port without shore-side electricity facilities. Since the ships are always able to use their AEs, the port will be able to allow the additional electricity for shore-side electricity to be interruptible. However the likely discount for an interruptible electricity supply is difficult to estimate, and therefore is not included in the cost calculations.

Electricity costs per year are shown in Table 4.16.

Table 4.16 Electricity costs (€/year/ship)

	Small	Medium	Large
	(€/year/ship)	(€/year/ship)	(€/year/ship)
Excluding electricity tax (i.e. tax = 0%)	10,600	29,400	75,700
Including electricity tax of 15%[13,14]	12,000	33,400	85,900

4.5.4 Total Operating Costs

Total additional operating costs for shore-side electricity while at berth compared to using 0.1% S MD are shown in Table 4.17. For all ship sizes the operating costs for shore-side electricity are higher than the operating costs with 0.1% S MD that is priced at €249/tonne. For fuel prices 20-30% higher than this assumed price the operating costs would be about the same for shore-side electricity or using 0.1% S MD. For prices above €320/tonne substituted fuel the operating costs for shore-side electricity are lower than the self generating option assuming the electricity price stays unaffected.

Table 4.17 Additional operating costs for shore-side electricity compared to the use of 0.1% S MD fuel (€/year/ship)

	Small	Medium	Large
	(€/year/ship)	**(€/year/ship)**	**(€/year/ship)**
Electricity costs (excluding tax)	10,600	29,400	75,700
Electricity costs (including tax of 15%)	12,000	33,400	85,900
Saved fuel (0.1% S MD) costs, low-high fuel price	-8,000 / -16,000	-22,300 / -44,500	-57,400 / -115,000
Saved maintenance costs	-1,100	-1,100	-1,100
Total operating cost (excluding tax i.e. 0%)	**1,500 / -6,500**	**6,000 / -16,200**	**17,200 / -40,400**
Total operating cost (including tax of 15%[13])[14]	**2,900 / -5,100**	**10,000 / -12,200**	**27,400 / -30,200**

[14] Indicative costs taking into account average tax on industrial electricity prices in European countries. Note that 15% is not applied on the operating cost part of the electricity costs in Table 4.15.

4.6 Costs to Ships – Total Costs

Table 4.18 outlines the total costs (capital and operating costs) to ships for using shore-side electricity instead of generating electricity on board using 0.1% S MD fuel. The costs for a switch to shore-side electricity are based on substituted MD fuel as ships are required to run their engines at berth on 0.1% sulphur fuel from 2010 according to the marine fuel sulphur directive 2005/33 (baseline).

Table 4.18 Total costs to ships for using shore-side electricity instead of 0.1% S MD to generate electricity on board (€/year/ship), (low / high fuel price)

	Vessel		
New build capex	**Small**	**Medium**	**Large**
Transformer capex (€)	78,050	114,478	203,889
Equipment lifespan (year)	10	10	10
Annualised costs (€/year)	9,623	14,114	25,138
Cable installation capex (€)	2,740	2,740	2,740
Equipment lifespan (year)	25	25	25
Annualised costs (€/year)	175	175	175
Total Capex (€)	80,790	117,218	206,629
Annualised capex costs (€/year)	**9,798**	**14,289**	**25,313**
Capex per kW AE installed (€/kW)	153	80	55
Retrofit capex			
Transformer capex (€)	111,500	163,540	291,270
Equipment lifespan (year)	10	10	10
Annualised costs (€/year)	13,747	20,163	35,911
Cable installation capex (€)	3,906	3,906	3,906
Equipment lifespan (year)	12.5	12.5	12.5
Annualised costs (€/year)	403	403	403
Total Capex (€)	115,406	167,446	295,176
Annualised capex costs (€/year)	**14,150**	**20,566**	**36,314**
Capex per kW AE installed (€)	218	114	78
O&M costs			
O&M costs excluding tax (€/year)[15] , low/high fuel price	**1,445 / -6,500**	**5,997 / -16,200**	**17,216 / -40,400**
Opex per MWh (€/MWh)	9.8	14.6	16.3
O&M costs including tax (€/year), low/high fuel price	**2,900 / -5,100**	**10,000 / -12,200**	**27,400 / -30,200**
Total annual costs - new build (€/year) (excluding tax)	**11,243 / 3,298**	**20,286 / -1,911**	**42,529 / -15,087**
Total annual costs - retrofit (€/year) (excluding tax)	**15,595 / 7,650**	**26,563 / 4,366**	**53,530 / -4,086**
Total annual costs - new build (€/year) (including tax)	**12,698 / 4,698**	**24,289 / 2,089**	**52,713 / -4,887**
Total annual costs - retrofit (€/year)(including tax)	**17,050 / 9,050**	**30,566 / 8,366**	**63,714 / 6,114**

Note: Negative values in the total annual costs mean savings compared to the baseline scenario and these are potentially financially attractive scenarios for the ship operators, assuming there is no additional charge for the shore side electricity infrastructure on land.

[15] The differences to results presented in Table 4.17 are due to rounding from the underlying spreadsheet calculations

4.7 Total Costs of Shore-side Electricity Systems

To assess the cost effectiveness of shore-side electricity, a converted berth and converted ships have to be assessed together as neither a converted ship nor a converted berth on their own will reduce any emissions. Total system cost estimations can be seen in Table 4.19-Table 4.22 for the four different tax/fuel price combinations. The only overall potentially financially attractive option for the presented combinations is the 'new large ships'- 'no tax on electricity'-'high fuel price' combination in Table 4.21.

Table 4.19 Total shore-side electricity system costs (excluding electricity tax, low fuel price)

AE Size	Annualised port costs per berth[16]	Annualised ship costs (excluding tax)	Number of ships needed per berth	Annualised costs for all ships (excluding tax)	Annualised total system costs (excluding tax)
	a	b	c	d = b*c	e = a+d
NEW SHIPS	(€/berth/year)	(€/ship/year)	(-)	(€/berth/year)	**(€/berth/year)**
Small	53,425	11,243	8.76	98,488	**151,914**
Medium	56,644	20,287	8.76	177,711	**234,356**
Large	59,864	42,529	8.76	372,555	**432,418**
RETROFIT SHIPS					
Small	53,425	15,595	8.76	136,611	**190,036**
Medium	56,644	26,563	8.76	232,695	**289,340**
Large	59,864	53,530	8.76	468,924	**528,788**

Table 4.20 Total shore-side electricity system costs (including tax, low fuel price)

AE Size	Annualised port costs per berth[16]	Annualised ship costs (including tax)	Number of ships needed per berth	Annualised costs for all ships (including tax)	Annualised total system costs (including tax)
	a	b	c	d = b*c	e = a+d
NEW SHIPS	(€/berth/year)	(€/ship/year)	(-)	(€/berth/year)	**(€/berth/year)**
Small	53,425	12,698	8.76	111,234	**164,659**
Medium	56,644	24,289	8.76	212,772	**269,416**
Large	59,864	52,713	8.76	461,766	**521,630**
RETROFIT SHIPS					
Small	53,425	17,050	8.76	149,358	**202,783**
Medium	56,644	30,566	8.76	267,758	**324,402**
Large	59,864	63,714	8.76	558,135	**617,999**

[16] This calculation is based on costs per berth as the average of low and high costs for a berth (see Table 4.6 and Table 4.6).

Table 4.21 Total shore-side electricity system costs (excluding tax, high fuel price)

AE Size	Annualised port costs per berth[16]	Annualised ship costs (excluding tax)	Number of ships needed per berth	Annualised costs for all ships (excluding tax)	Annualised total system costs (excluding tax)
	a	b	c	d = b*c	e = a+d
NEW SHIPS	(€/berth/year)	(€/ship/year)	(-)	(€/berth/year)	**(€/berth/year)**
Small	53,425	3,298	8.76	28,890	**82,315**
Medium	56,644	-1,911	8.76	-16,740	**39,904**
Large	59,864	-15,087	8.76	-132,162	**-72,298**
RETROFIT SHIPS					
Small	53,425	7,650	8.76	67,014	**120,439**
Medium	56,644	4,366	8.76	38,246	**94,890**
Large	59,864	-4,086	8.76	-35,793	**24,071**

Table 4.22 Total shore-side electricity system costs (including tax, high fuel price)

AE Size	Annualised port costs per berth[16]	Annualised ship costs (including tax)	Number of ships needed per berth	Annualised costs for all ships (including tax)	Annualised total system costs (including tax)
	a	b	c	d = b*c	e = a+d
NEW SHIPS	(€/berth/year)	(€/ship/year)	(-)	(€/berth/year)	**(€/berth/year)**
Small	53,425	4,698	8.76	41,154	**94,579**
Medium	56,644	2,089	8.76	18,300	**74,944**
Large	59,864	-4,887	8.76	- 42,810	**17,054**
RETROFIT SHIPS					
Small	53,425	9,050	8.76	79,278	**132,703**
Medium	56,644	8,366	8.76	73,286	**129,930**
Large	59,864	6,114	8.76	53,559	**113,423**

5. Cost Effectiveness

Table 5.1 presents the cost effectiveness of the shore-side electricity technology for different pollutants compared to ships using 0.1% sulphur MD for the ‘no tax on electricity’ and ‘low fuel price’ combination. Table 5.2 presents the cost effectiveness for substituting 2.7% sulphur fuel assuming, for illustrative purposes, that the costs stay the same as for the switch from 0.1% sulphur MD. The highest cost effectiveness would be shown for the ‘no tax on electricity’ and ‘high fuel price’ combination.

Table 5.1 Shore-side Electricity, Costs per tonne of emissions reduced, compared to engines using 0.1% S MD (2010 EU fuel requirement for ships at berth)

Ship type	Emission	Small (€/tonne pollutant)	Medium (€/tonne pollutant)	Large (€/tonne pollutant)
New	NOx	10,259	5,703	4,085
Retrofit	NOx	12,834	7,041	4,995
New	SO_2	-	-	-
Retrofit	SO_2	-	-	-
New	VOC	310,945	172,859	123,801
Retrofit	VOC	388,976	213,415	151,392
New	PM	438,376	243,700	174,537
Retrofit	PM	548,386	300,876	213,435

Table 5.2 Shore-side Electricity, Costs per tonne of emissions reduced, compared to engines using 2.7% RO (current average)

Ship type	Emission	Small (€/tonne pollutant)	Medium (€/tonne pollutant)	Large (€/tonne pollutant)
New	NOx	9,662	5,371	3,847
Retrofit	NOx	12,086	6,631	4,704
New	SO_2	9,889	5,498	3,937
Retrofit	SO_2	12,370	6,788	4,815
New	VOC	310,945	172,859	123,801
Retrofit	VOC	388,976	213,415	151,392
New	PM	152,631	84,850	60,769
Retrofit	PM	190,933	104,757	74,312

Table 5.3 presents the additional costs of shore-side electricity per tonne of 0.1% S MD fuel which would otherwise have been used. This means that the total costs of shore-side electricity are currently estimated to be €215-675/tonne higher than electricity production on board with €249/tonne 0.1% S MD. The shore-side electricity option becomes therefore potentially financially attractive if the price for substituted fuel is higher than €450-900/tonne. That was at the time of finishing the report in September 2005 the case[17]

Table 5.3 Costs per tonne of fuel substituted by using shore-side electricity

Cost of shore-side electricity system per tonne of fuel	**Small**	**Medium**	**Large**
Ship type	**(€/tonne of fuel)**	**(€/tonne of fuel)**	**(€/tonne of fuel)**
New	540	300	215
Retrofit	675	370	263

[17] 1st September 2005: www.bunkerworld.com quote €540/tonne for MGO, making shore-side electricity under certain conditions a potentially financially competitive option.

6. Scale up for all EU Berths with EU-Flagged Ships on Regular Service

As mentioned in the General Report only commercial ships > 500 GT are included in this study. Assumptions on the number of existing ships in the EU-flagged fleet are shown in Table 6.1.

It is estimated that a maximum of about 60% of EU-flagged vessels are on sufficiently regular service to EU ports to warrant the installation and use of shore-side electricity.

For the illustrative purpose of this study only, regular service means ships that visit the same EU port more than 6 times per year. This is a working assumption purely for the purposes of this study, as the underlying databases used in this study do not enable a direct identification of such vessels based on the definition in the Sulphur Content of Marine Fuels Directive, which is presented in a different way to our working assumption.

Table 6.1 Number of existing ships in the EU-flagged fleet

Description	
Number of EU-flagged vessels >500GT	7,150
Estimated % of EU fleet that potentially qualifies for use of shore-side electricity	58%
Number of EU-flagged vessels that might be converted	4,150
Required ships per berth assuming a 70% berth utilisation	8.76
Berths to be converted	474

The costs for applying shore-side electricity to all EU ports with existing EU-flagged ships on regular service are shown in Table 6.2. This table illustrates costs for retrofitting each measure to all existing ships. The additional costs for each individual new ship are presented in Table 4.18.

Table 6.2 Costs for applying measures to the existing regular service EU-flagged fleet

	Small	Medium	Large	Total
Fraction of total EU-flagged ships[18]	33%	33%	33%	100%
Costs for retrofitting SSE to 58% of EU-flagged ships and EU ports, annualised costs (€millions/year)	30	46	84	159

[18] The AE engine size categories were determined by splitting all the engine sizes in the EU fleet into 3 equally sized groups. The average engine size in each of these groups were used as the representative engines size. See also General Report.