# Shore Connected Power for the ferry / Ro Ro vessels in the port of Rotterdam



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| Feasibility study: | Shore Connected Power for the ferry / RoRo vessel in the Port of Rotterdam |
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## Executive Summary

"Is shore connected power for seagoing vessels an attractive solution to reduce air pollution from ships while berthing in port?" This question is asked by several policy makers and industry representatives. This report will give an answer to the above question for a specific type of ship in the Port of Rotterdam: the ferries and RoRo ships.

This research was focused on the ships of P&O Ferries and Stena Line at the berths in Hook of Holland and in the Beneluxhaven. The research has shown that there are no technical limitations to implement shore connecting power on the Ferries and Ro/Ro vessels. However, the ships will have to be modified. New technologies will have to be used and implemented on the shore side in the port of Rotterdam e.q. frequency converters and heavy duty transformers. This differs from previous studies and already implemented shore connected power at other places in the world. There are several safety issues that need to be taken into account, but with the right procedures and instructions a safe operation can be guarantied.

The cost of generating electricity onboard is based on the current soaring fuel price and maintenance costs. The onboard generated power costs approximately *€ 0.162* per kWh for a ship with a generator set up to 3.000kW and *€ 0,199* per kWh for a ship up to 750kW. The fuel that will need to be used for the diesel generators onboard of all ships in port (staying longer than 2 hours) is MGO (DMX) Marine Gasoil and contains a sulphur content with a maximum of 0,1%. This fuel is more expensive than the other marine fuels, the costs have gone up to a US$1290,- per Mt lately. The average required power onboard differs with the kind of ship.

Shore connected power can only be economically attractive if it meets the price of the onboard generated power. Each day the ferries berth in hook of Holland and in the Beneluxhaven and remain at their location during the day time. The ships operate on different timings. The effective use of shore power in Hook of Holland and in the Beneluxhaven is 11 hours, which means that the total amount of power for electricity needed on a yearly basis is 15GWh in Hook of Holland and 15GWh in the Beneluxhaven.

The overall investment of shore connected power for the berths in Hook of Holland and in the Beneluxhaven has been estimated of a total €9,6 million for modifications of the onshore infrastructure, and between €500.000 and €750.000 for the modifications per ship (retrofit). The price difference is related to the choice on which side the high voltage cable will be located and on shore what kind of converter is used; a static frequency or a dynamic frequency converter. A conversion of the shore frequency of 50Hz to the ships' frequency of 60Hz is needed. However, with a depreciation period of 15 years and the required power, the depreciation of the investment is less than one third of the total operational cost per year. The electricity price (<u>without all</u> the investments) for shore connected power is € *0,13 (0,128) per kWh*. This includes the energy price, the tax and the yearly fees for having the electricity from the shore. Including the investments on the exploitation, the cost for shore connected power is around €0,19 kWh.

When taking out the costs for the shore infrastructure from the exploitation, shore connecting power is even economically attractive. Getting the costs for the shore infrastructure reduced can be done by getting the necessary subsidies from government bodies. In the calculations model the infrastructure should be reduced with 60% to get a break-even point. This would mean on a total investment (ship and shore) of € 15,6 million by Stena Line and P&O Ferries, € 6,25 million is needed from the local / state governments to make it happen.

Furthermore, using shore connected power by the ferry ships will have a positive contribution to the environment. As it shows, the emissions of CO2, NOx, and fine dust are high. Reducing these levels to zero it will contribute to a better and cleaner environment on a large scale.

| | Hook of Holland Emission generator [ton/yr] | Benelux-haven Emission generator [ton/yr] | Total emission [ton/yr] | Emission from coal burned power plant [ton/yr] | Emission from gas burned power plant [ton/yr] | Maximum avoided emission with the use of shore connected power [ton/yr] |
|---|---|---|---|---|---|---|
| NOx | 159,5 | 158 | 323,5 | 39 | 25 | 298,5 - 92% |
| $PM_{10}$ | 5,8 | 5,8 | 11,6 | 0,5 | 0 | 11,6– 100% |
| $SO_2$ | 3 | 3 | 6,0 | 18 | 0 | 6,0– 100% |
| $CO_2$ | 9.455 | 9.134 | 18.589 | 18.348 | 16.923 | 1.666– 9%* |

** CO2, NOx, PM10, SOx emissions can be reduced to zero, if Green energy is used.*

In conclusion, shore connected power for Ferries and Ro/Ro will become feasible when the cost of the shore infrastructure is reduced via a financial construction. When financial instruments from national or local administrations can be used, the process of implementing shore connected power can be accelerated. Furthermore, the price of the onboard generated power fluctuates and depends highly on the value of the US Dollar and the EURO in relation to the bunker price. Therefore, with the staggering oil price shore connected power is economically attractive.

# Acknowledgments

*This report would not been possible without the input and dedication of the participating companies and especially the ferry companies who have shown their interest in shore connected power. Therefore, I would like to specially thank the people of P&O Ferries and Stena Line BV.*

*Participation companies who gave their input on the technical and economical impact are Croon, DCMR, GTI-West Industries BV, Havenbedrijf Rotterdam NV, SGS Environmental Services and Holland Marine Equipment BV.*

## Index

## 1. Introduction

The local air quality in the City of Rotterdam is an important issue. Reducing air pollution is necessary, to allow new developments within the port area, such as the Maasvlakte II. Therefore, the Rotterdam Municipal Council looks at several possible solutions to reduce harmful air emissions in and around the city of Rotterdam. These solutions include options for reduction from the ships within the port area at the location of the ferry terminals.

This report is the summary of the feasibility studies that looked into the possibilities of using shore connected power at the RoRO & Ferries ships at the berths of Stena Line and P&O Ferries in the port of Rotterdam. Ferries berth daily for a fixed amount of hours at the same terminal everyday. Economic and technical data have been taken from the various stakeholders. In this report a total analyses from these data and comparisons between shore connected power and onboard generated power is made.

*The feasibility study was centralised around the problem proposition:*
What are the economical and ecological benefits to have RoRo / ferry ships powered by shore connected power in the port of Rotterdam?

*The goal for this study:*
To get the necessary data from the power requirements from the Ro/Ro ships, which berth in the port of Rotterdam for a particular period on a frequent basis, in order to make the right analyses on whether to investment in the ships and in the shore infrastructure for shore connected power.

*The main questions:*

- Is it economically feasible to invest in the ship and in the shore infrastructure to get shore connected power compared with diesel generated power by the ship self?
- What is the environmental benefit for the port of Rotterdam and surrounding areas when the ship changes it energy supply from the diesel generator power onboard to sustainable energy supply from the shore?

The ships that have been used in this research are six ships from Stena Line and two ships from P&O Ferries located at four berths in the port of Rotterdam. Due to the fact that Stena Line will have some new vessels added to her fleet, these new vessels have already been taken into consideration in this study:

| Name of the Ferry | Owner | Location |
|---|---|---|
| MV Stena Trader & Traveller | Stena Line | Beneluxhaven-West |
| MV new building (in future but similar as above) | Stena Line | Hook of Holland |
| MV Stena Brittanica & Hollandica (in the future the Super ferries) | Stena Line | Hook of Holland |
| MV Pride of Rotterdam & Hull | P&O Ferries | Beneluxhaven-East |

This feasibility study is a cooperation between the following stakeholders:

- P&O Ferries
- Stena Line
- Port of Rotterdam
- ABB
- Croon
- Eneco infra
- GTI Energy & Infra

- GTI West Industries
- SGS Environmental Services
- Siemens Nederland
- Lloyds Register
- DCMR
- EON and Essent
- Wärtsilä
- Holland Marine Equipment

In the first phase of the research, a literature study of the concept of shore connected power was conducted. Then a technical research took place at the ships of P&O Ferries and Stena Line in the port of Rotterdam. The third phase was an investigation on the technical possibilities to provide shore connected power according to the specifications from the ships and the costs involved. The fourth phase was a environmental study and analyses of the ship and shore air emission. The final phase of this research was to combine the results into a final conclusion with recommendations.  All data have been analysed and results can be found in this report.

## 2. Regulations

The regulatory framework has recently introduced a number of new requirements with regards to the prevention of air pollution from ships. International Conventions and European Directives have been implemented at national level. With these new regulations, and the ambitions at local level by the Municipal Council, the shipping industry is forced to look at new ways of preventing air emissions, not only at sea but also within the port of Rotterdam.

The North Sea is now officially called an SECA area. Sulphur Emission Control Area, however from the latest IMO/MEPC57 emission workgroup meeting (April 2008) it was decided that this area will be changed from SECA into a micro ECA (emission control area). When ships are entering the (S)ECA, the amount of sulphur in the fuel, which is used in the engines, may not exceed 1,5%.

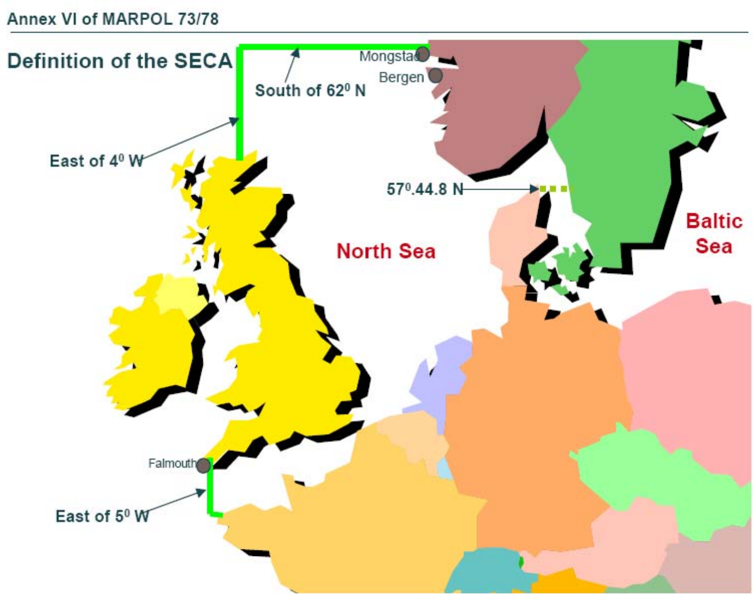



*Fig 1. Location of the ECA (formally known as SECA).*

Below are the dates that the SECA area's are enforced:

01 January 2008 MGO with 0.1% available in the EU-ports
**01 January 2010 0.1% limit for vessels at berth in EU ports into force**

From the IMO/MEPC57 emission workgroup meeting new emission limits have been proposed. ECA area and global Sulphur content in fuel:

| Emission Control Area – Sulphur content | |
|---|---|
| Period | Maximum amount of Sulphur content in fuel (% m/m) |
| Until till 1st of March 2010 | 1,50% |
| 1st of March 2010 till 1st of January 2015 | 1,00% |
| From 1st of January 2015 | 0,10% |
| Global Sulphur content | |
| Period | Maximum amount of Sulphur content in fuel (% m/m) |
| Until till 1st of January 2012 | 4,50% |
| 1st January 2012 till 1st of January 2020 | 3,50% |
| From 1st of January 2020 | 0,50% |

With the above in mind, reducing emission from the ships in the port of Rotterdam is necessary. Reducing emission can be done by changing the fuel, implementing scrubbers or Selective Catalytic Reduction (SCR’s) installations in the ship. One alternative option is power generated from the shore and via a high voltage cable connected to the ship: shore connected power.

## 3. Shore connected power

Shore connected power has been given different names over the last few years. In the USA shore connected power is called 'cold ironing' and in LA Long Beach it is referred as 'Alternative Marine Power' (AMP). For this report the name of shore connected power is used.

There is currently no existing standard for shore-to-ship electricity supply systems. However, different workgroups of the International Shipping Organisations (ISO) are currently looking into standards for different ship types. For the ferry ships, a specific standard doesn't really matter because the ships lay on fixed berths everyday and they are usually operating at their own terminals. Some form of connection point at the quay site is needed where a flexible cable can be connected between the ship and the shore-side electrical system.

Basically, the design for shore connected power can be divided into two parts; the onshore and the offshore installation.

*Onshore:*
The idea is to link a flexible cable between the quay and the ship. The electrical power must be distributed to the connecting point near the ship, from a local high-voltage substation. The high voltage plan in the Netherlands can be seen in figure 2.

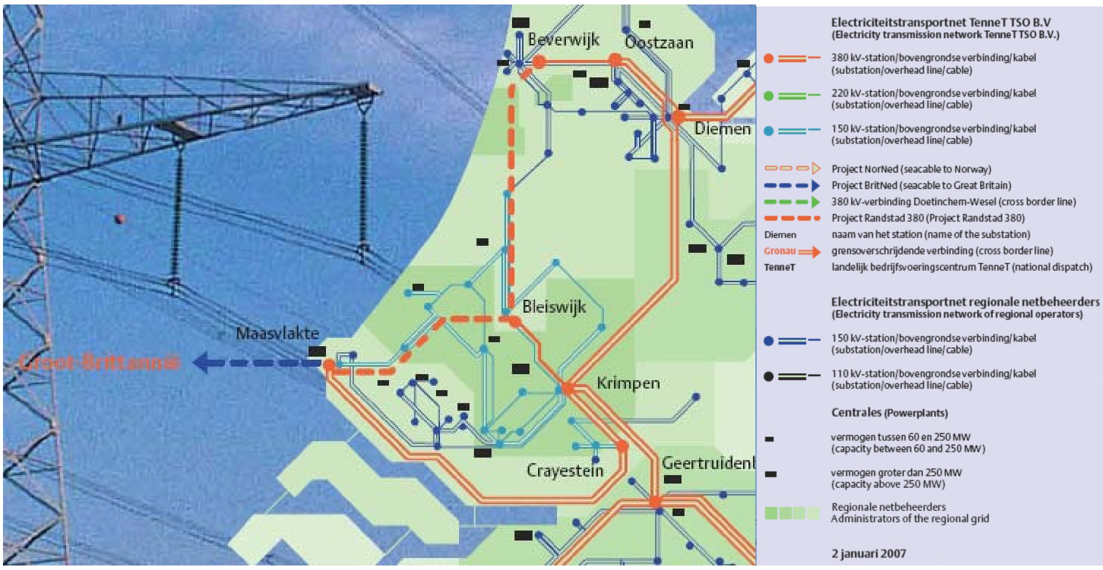
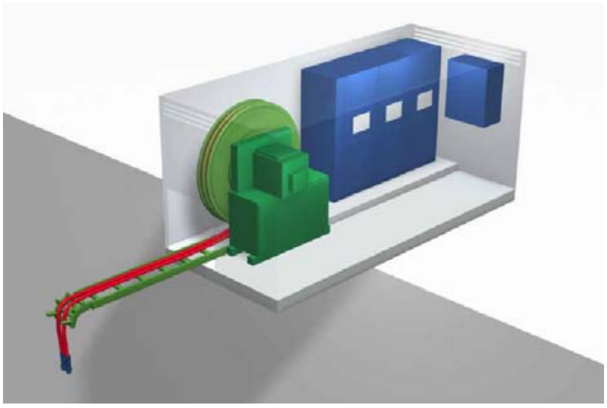


*Fig 2. High voltage Energy grid in The Netherlands; source*

*Offshore:*
Onboard the vessels, an entrance for the connecting cable is needed. The ships are operating either with a low voltage switchboard of 440V or with a high voltage switchboard of 6,6kV. The shore voltage from the grid is 23kV, it is therefore necessary to reduce the voltage. Several transformers in the shore line have to be placed. In most shore power studies the voltage used on the main switch board is low voltage (below <1000V) and the high voltage (>1000V) will need to be transformed onboard.

*Note: A high-voltage cable makes it possible to transfer 25 times more power than with a normal 400V cable of the same dimension.*

The researched ships run on a frequency of 60 Hz and the European shore frequency is 50Hz. Therefore, the power supply needs to be converted from 50 to 60Hz. Preferably, this is done on the shore. The conversion of shore power will be done from 23kV/10kV-50Hz to 10kV-60Hz and onboard reduced to either 6,6kV or 440V. The costs of converting the frequency by a static frequency converter is one of the main costs of the whole ship-shore power configuration.



The costs for frequency converters depend on the converter type and the voltage and power capacity. From previous studies 300 random vessels were checked according to their onboard frequency. Just over 50 % of the vessels seem to use 60Hz onboard frequency.

*Fig. 3. Cable reel onboard; source Sam Electronics*

In general, the following parameters are usually of importance when the cost and system requirements are investigated for shore-ship supply:

- Shore-side frequency (usually 50 Hz in Europe including UK),
- Onboard frequency (60 Hz or 50 Hz),
- Shore side supply of high voltage electricity (voltage, distance to nearest supply point and installation practicalities),
- Required power level,
- Available spaces for onboard transformer, and weight restrictions of the vessel. The extra weight of equipment (transformer) or loss of cargo space may for some vessels result in reduced profitability or increased fuel consumption,
- The location onboard for the transformer(s),
- Onboard cable installation practicalities and distances.

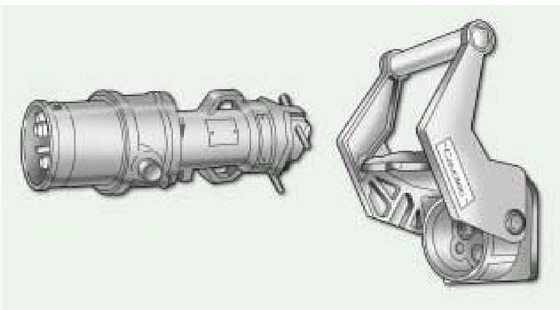


*Fig. 4. Cable connector: source Cavotec*

## 4. Specifications

### *4.1 US Dollar and fuel price*

In order to make the right analyses, it is necessary to know the present operational costs when the ship is in port. In other words "how much does it cost to run a diesel generator in port". All costs must be calculated: maintenance costs (spare parts and labour), the consumption of fuel during the port stay and the consumption of lubrication oil. The fuel costs have tremendously increased since the beginning of 2007. The price per metric Ton (MT) for Marine Gasoil has been doubled to a US$ 1.290 on 22nd of May, see appendix 3. And the end is by far not near.

Furthermore, the fuel prices are traded in US Dollars. Therefore, the US Dollar had to be converted into Euro. The US Dollar rate compared with the Euro has been increased, but is relatively stable at the moment against the Euro. The Euro is about US$ 1,57 (according to FX-converter on 22nd of May 2008). All cost are given in Euro due to the fact that the currency used in the port of Rotterdam is the Euro and the energy companies are using this as well for the energy trading.

| | MGO | S-IFO 380 | Lub. Oil | Date | |
|---|---|---|---|---|---|
| Oil price $ per MT | $1,290.00 | $636.00 | $1,850.00 | 22-may-08 | Acc. to bunkerworld |
| US$ / € | $ 1.57 | | | 22-may-08 | Acc. to FX conversion |
| Oil price € per MT | € 821.66 | € 405.10 | € 1,178.34 | | |

### *4.2 Required power and durations in port*

In order to make the right comparison between the ship running on a diesel generator versus shore connected power, it is necessary to know how much power (in kW) is used by the ship while in port.

The fuel used on the generators in port is Marine gasoil MGO (DMA DMX). The density will typically be close to 860 kg/m3 (at 15°C) at a price of US$ 1290 per MT
*Note: Within the European Union (EU) the max. S level of marine gasoil for use in territorial waters is 0.10 m/m % max in 2008.*

In general the ferries have night crossings to and from a port in the UK and the port of Rotterdam. The duration of the occupation of the berths in Hook of Holland and in the Beneluxhaven is around 12 hours each day. With the right procedures it should be possible to minimize the switch-over time from ship to shore connected power. Connecting and disconnecting to shore power should take about half an hour with an automated system. This would mean 11 effective hours of shore connected power. As a result, the total time that shore connected power can be used will be 365 days x 11h = 4.015 hours.

In order to make a good comparison, the maintenance of the engines has been taken in the calculations as well. With a maintenance programme of 10 years and 70.000 running hours, this results in € 15,71 per hour for the (big) passenger ferries and € 12,50 per hour for the (smaller) RoRo ships, according to the specifications and estimated cost of parts by the engine manufacturers. The amount and number of spare parts and labour hours have been taken into consideration and calculated which results in the hour rate. The lubrication oil consumption of the generators is also important to consider within the calculation. The price of lubrication oil is about US$1,85 per litre.

In figure 5 the complete power requirement and number of hours in port have been summed up for each location. The total amount of 15,0 GWh in the Beneluxhaven and 15,0 GWh in Hook of Holland is required per year. According to the energy companies, it is not a problem at all. Especially in the Botlek area, there is an overcapacity of energy.

The result can be taken into two segments: the standard RoRo ships which have an average power requirement of 750kW and the passenger ferries which have an average power requirement of 3.000 kW (3,0 MW). The result shows that the bunker price has the most impact on the price per kWh. The number of hours and days along side have no influence on the price per kWh only the required power! Therefore, the bigger passenger ferries, which require more power, are relatively cheaper in operation than the smaller RoRo vessels: € 0,162 per kWh respectively € 0,199 per kWh. See also the below table with the price per kWh.

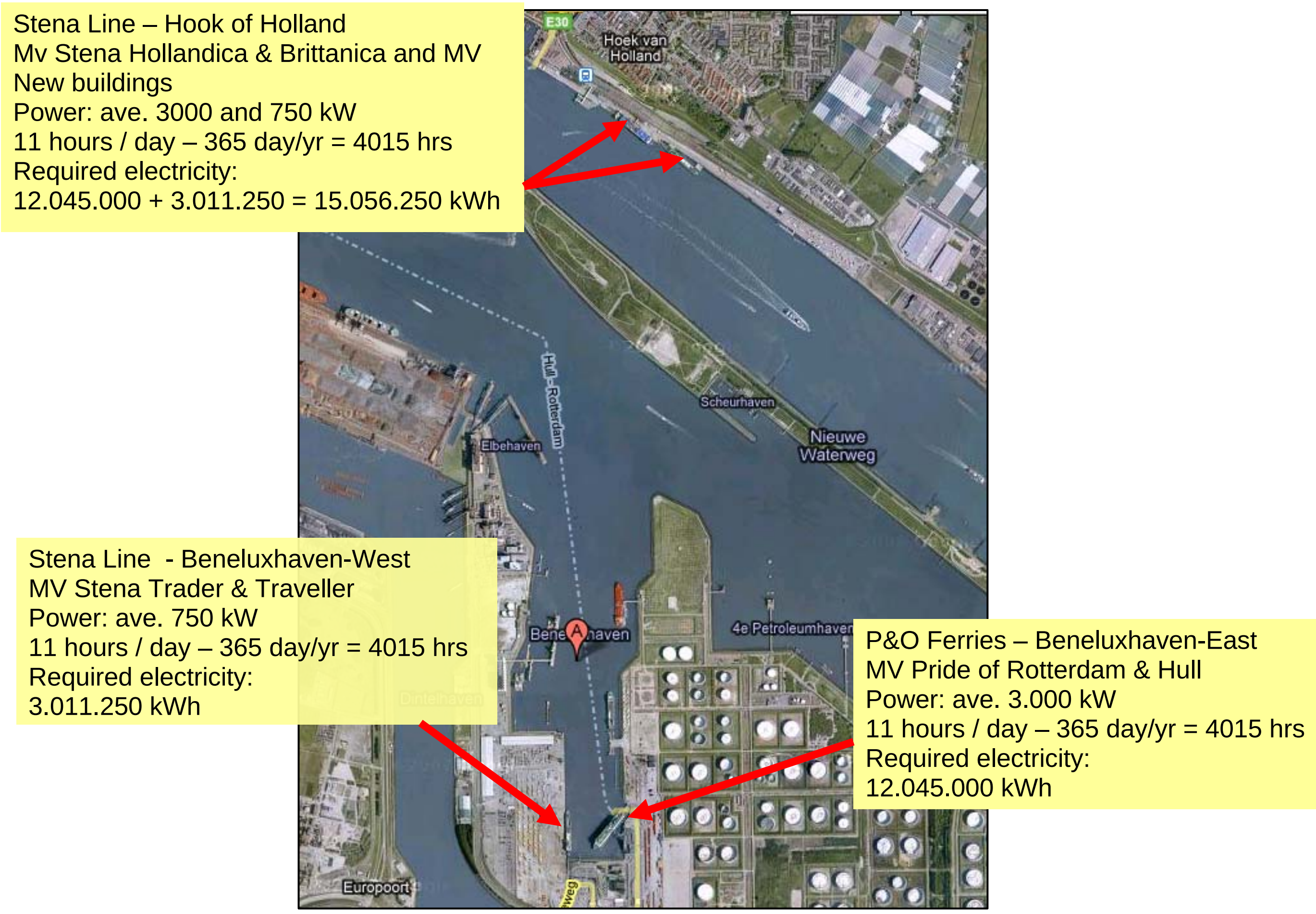



*Fig. 5 Overview of the location of the ferries in Beluxhaven and in Hook of Holland; soucre Google maps*

***RoRo Ship with power requirement of 750 kW***

| | | | | | |
|---|---|---|---|---|---|
| Number of hours per day alongside | | 11 | hrs | | |
| Number of day per year | | 365 | Days | | |
| The mean power consumption at winter time | | 650 | kW | | |
| The mean power consumption at summer time | | 850 | kW | | |
| The mean in kW for one year | | 750 | kW | | |
| Total power consumption | | 3.011.250 | kWh | | |
| ***Ship Generated power*** | | | | | |
| Fuel Consumption of Aux engines | | 61,0 | gr/MW | 219,6 | gr/kWh |
| Lub. Oil consumption aux engine | | 1,3 | ltr/hr | 5219,5 | ltr/yr |
| Maintenance acc. to Mitsubitsu generator set | € | 875.000 | 10 yrs | 70.000 | hrs in 10 yrs |
| Maintenance on Aux. Engine | € | 50.188 | yr | € 12,50 | hr |
| Theoretical consumption of Fuel | € | 543.337 | yr | | |
| Lube oil cost per year | € | 6.150 | yr | | |
| Maintenance cost per year | € | 50.188 | yr | | |
| Total costs per year | € | 599.675 | yr | | |
| **Per kWh onboard** | **€** | **0,1991** | kWh | | |

***Passenger Ferries with power requirement of 3000 kW***

| | | | | | |
|---|---|---|---|---|---|
| Number of hours per day alongside | | 11 | hrs | | |
| Number of day per year | | 365 | Days | | |
| The mean power consumption at winter time | | 2500 | kW | | |
| The mean power consumption at summer time | | 3500 | kW | | |
| The mean in kW for one year | | 3000 | kW | | |
| Total power consumption | | 12.045.000 | kWh | | |
| ***Ship Generated power*** | | | | | |
| Fuel Consumption of Aux engines | | 52,8 | g/MW | 190,1 | g/kWh |
| Lub. oil consumption aux engine | | 2,0 | ltr/hr | 8030 | ltr/yr |
| Maintenance acc. to Mitsubitsu generator set | € | 1.100.000 | 10 yrs | 70.000 | hrs in 10 yrs |
| Maintenance on Aux. Engine | € | 63.093 | yr | € 15,71 | hr |
| Theoretical consumption of Fuel | € | 1.881.193 | yr | | |
| Lube oil cost per year | € | 9.462 | yr | | |
| Maintenance cost per year | € | 63.093 | yr | | |
| Total costs per year | **€** | **1.953.748** | yr | | |
| **Per kWh onboard** | **€** | **0,1622** | kWh | | |

Shore connected power should therefore meet the price per kWh which is generated onboard the ship in order to have an economically proof concept.

## 5. Total Investment; ship and shore

### *5.1 Ship investment*

The power supply from the shore to the ship is not an easy one. The configurations of ships in general are all very different. Several main questions need to be answered before any estimation can be made.

Due to the fact that every ship is a different one and the electrical outline is always different e.q. the voltage on the switchboard, frequency of the ship, amount of power necessary to operate the ship, it is difficult to come up with a general standard for the shipping industry.

The ships have been examined by several engineers of different system integrator companies. They have done the necessary research and engineering to configure which kind of technical solution would be available and the costs of implementing additional equipment onboard the ships.
The following items have been reviewed.

- Low Voltage switchboard
- Switch board control system
- Cable routing
- High voltage cable
- Isolator cabinet
- Shore side connection

In search of all cost involved implementing shore power, for instance how the cable should run, there are several options available. In the calculation below, the cable will come from the shore to the ships. In figure 6, one example is shown of the shore connected power system, drawn with the different power and frequencies.. Here the flexible cable is placed on shore. The cable will need to be taken into the ship from the hatch on the side of the ship. The cable will need to be connected to the connection panel inside the ship.

Ship conversion :

- Electrical works/deliveries, itemized per vessel
- Cable reel with flexible cable and control panel
- Voltage transformer
- Shore junction box with sockets
- 440V Auxiliary power supply for cable reel
- High voltage cabling and control cable
- Cable ladders and multi cable transits
- Cold wire testing, megger test, and high voltage testing
- Engineering and software development
- Construction, paint Works and project management
- Installation and commissioning

Total per ship € 500.000 – 700.000

Is not possible to give an exact price because every ship is different as said before. However, for the mentioned ships the cost involved per ship are between these figures.

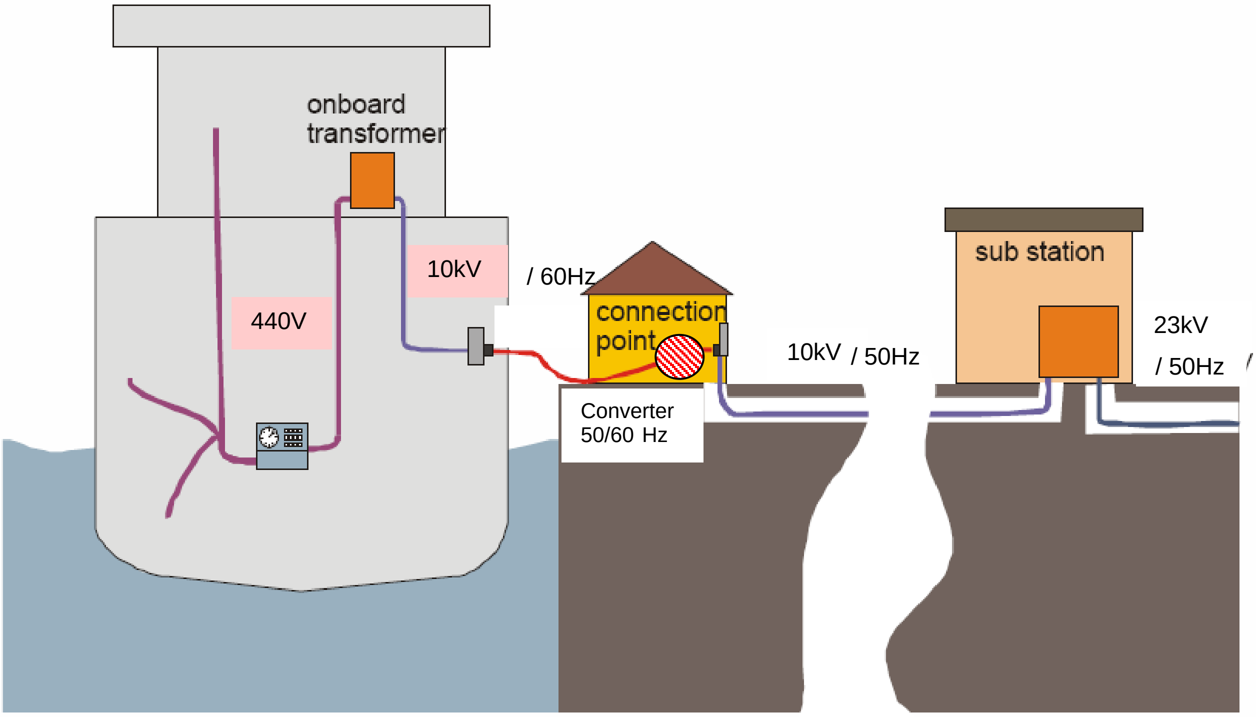



*Fig. 6. A general outline of shore connected power*

### *5.2 Shore investment*

For shore connected power a net connection is required. The net connection will be installed in a substation located next to an existing net connection. Because the vessels operate at 60 Hz – 10kV/6,6 kV and the net connection operates at 50 Hz – 23 kV, a frequency converter and a voltage transformer are required. The converter is an essential part of the installation.

For the feasibility study a static frequency converter is proposed. A static frequency converter uses electronic technology to adapt the frequencies. Because the converter operates at an different in- and output voltage level then the rated 23 kV of the net connection and the rated 10kV / 6,6 kV of the vessel's installation, distribution transformers and switchgear is required to adapt the in- and output voltage of the converter.

The shore power installation consists of the basic elements, in the below diagram (figure 7) a possible design of the infrastructure has been drawn with the basic elements:

- Net (main) connection
- Cable connections
- Distribution transformers
- Local main distribution board (high voltage installation)
- Substation parking area
- Transformer (to adjust the grid voltage and vessel voltage at the input/output voltage of the converter)
- Frequency converter (to adjust the grid frequency at the vessel frequency)
- Depending which type converter is chosen a 10 kV sub distribution board is needed
- 10kV / 6,6 kV sub distribution board
- Substations Vessel area
- Shore power connection box

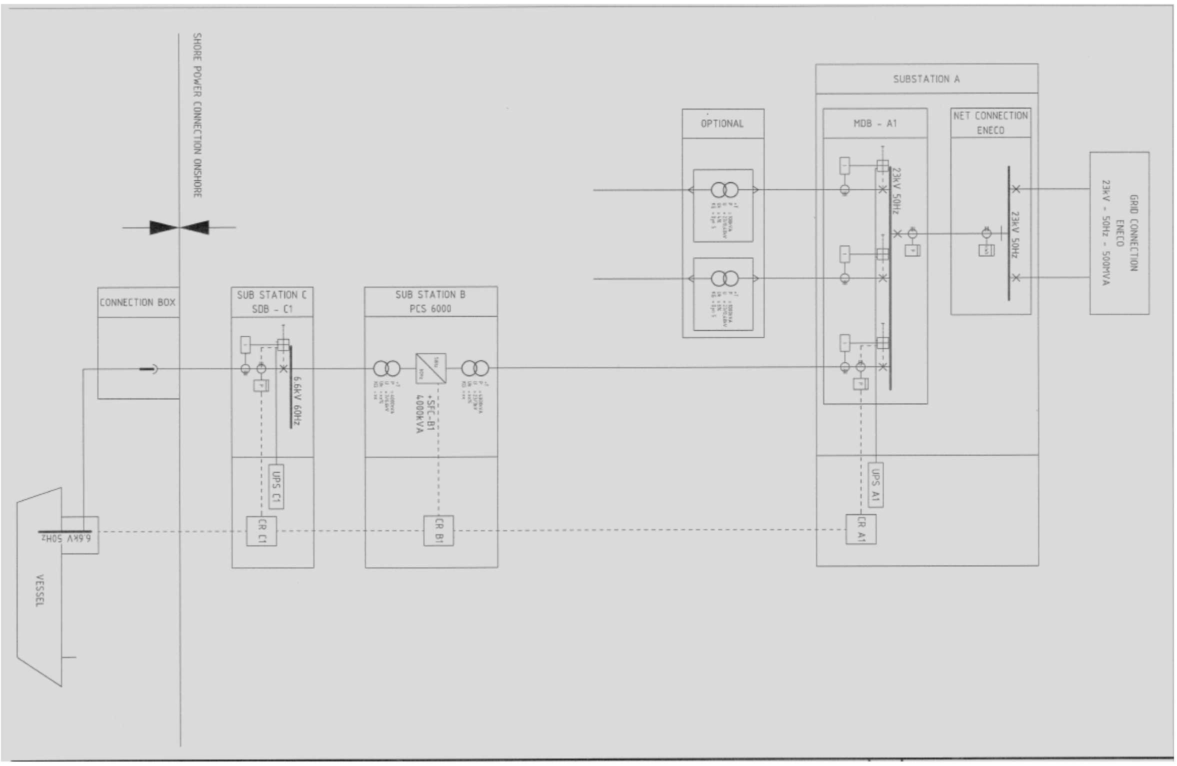


Fig. 7. A possible design of the outline for the shore configuration; source GTI Marine & Offshore

Note:
*Besides costs for the net connection and consumed electrical power also periodical costs are charged for the net connection and the net cables by Eneco. These rates have been stipulated in the DTE. In the cost analysis this has been taken in the calculations.*


Fig 8. Example of a static converter; source ABB

In the below table the price for a 4MVA connection on the national grid has been calculated. Also, an estimated 2500 meter length for the cable in the Beneluxhaven and 1300 meter in Hook of Holland has been used in the calculation. The overall investment on shore for one connection is about € 4,3 million.

Cost of the shore infrastructure:

| | |
|---|---|
| 4 MVA net connection Eneco with STATIC converter | |
| Net connection 23 kV based on DTE Eneco | |
| Cable connection based on DTE Eneco | |
| Drilling tracks, way other obstacles (estimation) Eneco | |
| Removing current net connection (estimation) Eneco | |
| Research cable run Eneco | |
| kWh-meter Eneco | |
| **Total ENECO-Netbeheer** | **€ 853.875** |
| | |
| Sub 23kV-MDB-A1 HV distribution board | |
| Substation Distribution transformers | |
| Combined substation A | |
| Substation(s) | |
| Engineering and commissioning | |
| PLC for security and automation | |
| Subtotal INFRA | € 624.870 |
| Static Frequency converter with heat exchanger | € 2.828.000 |
| **Total** | **€ 4.306.745** |

However, this doesn't mean that for each connection the same investment is required. Especially because at the location in Hook of Holland there are two berths at one quay and in the Beneluxhaven there are also two berths as can been seen in figure 9. A smart way of laying the cables and the connection would save a large amount on the investment.

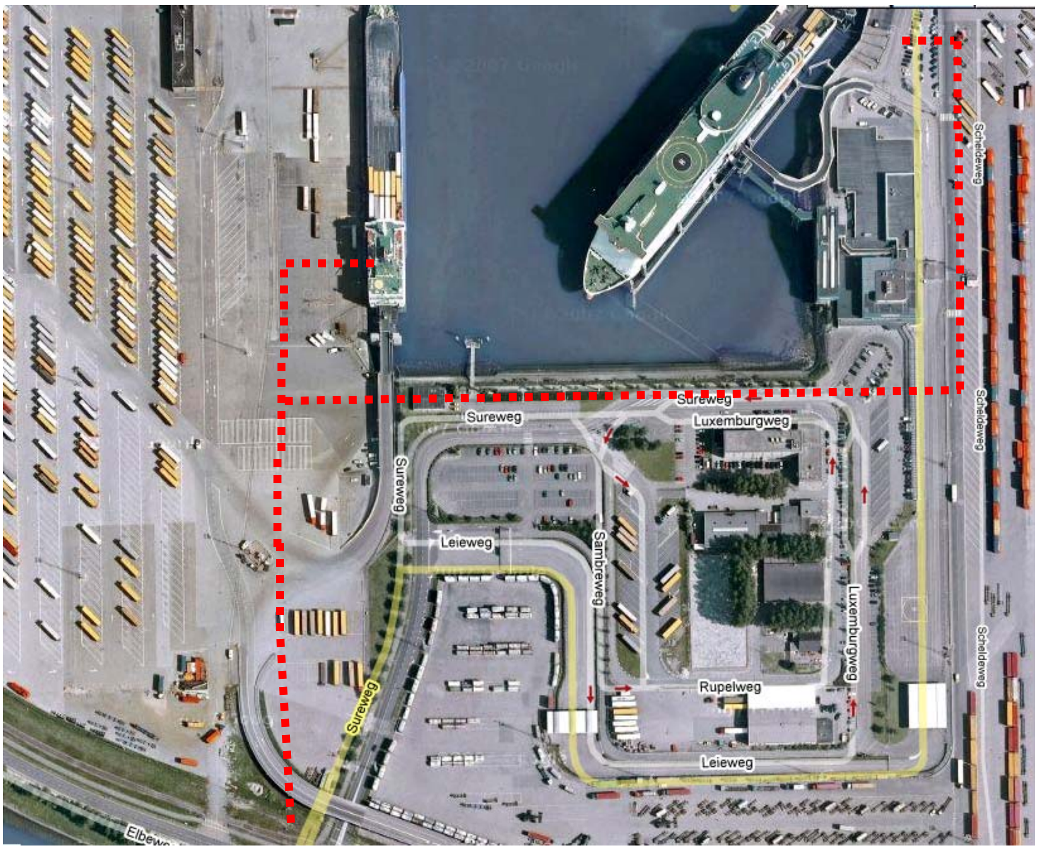
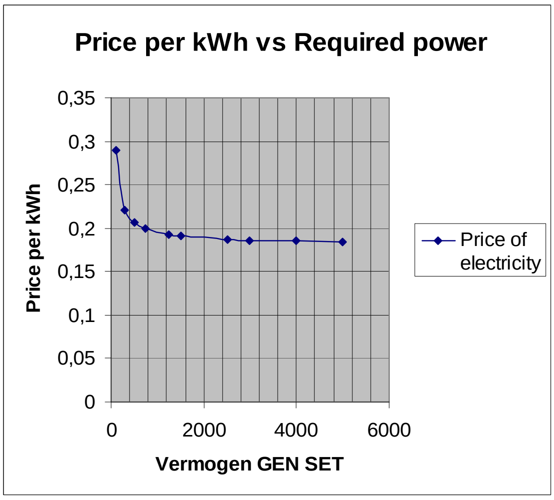



*Fig. 9 Photo of the STENA Line and P&O Ferries terminal in the Beneluxhaven. The red dotted line shows the proposed way of the cable to be laid on the premises of the terminal of P&O Ferries and Stena Line..*

5.3. Electricity cost from the energy supplier

In the Netherlands, the energy market is almost completely privatised. This means that the choice of energy supply is free. However, the transport of energy is still not privatised. In the Port of Rotterdam there is only one company, “Eneco Netbeheer BV”, who can do the transportation of the power supply. The power supply itself can be chosen. “Ecostroom” for instance, is a power supply which consists of a large amount of green energy such as wind turbines and sun generated energy, hydropower and biomass.

For this research, the figures from the energy supplier are based on sustainable generated energy with a neutral $CO_2$ emission. In the next chapter the comparison is made between energy production on the ship by the diesel generators versus energy production on shore by a power plant.




In order to get a (new) connection from the Eneco Netbeheer the following will have to be taken into account:

- Yearly connection fee
- Yearly maintenance fee for the cable
- Yearly transport fee

Bearing these specifications in mind, the following table shows the costs of all the relevant items obtained from various parties. The end give an indication of the price per kWh for shore connected power of € 0,128. The costs only for the energy and are without the whole investment offshore and onshore. The prices of Eneco Netbeheer are standardized and regulated by the Dutch government (DTE).

***Shore Connected Power***

*Eneco Netbeheer DTE prices*

| | | | | | | |
|---|---|---|---|---|---|---|
| Usage of energy | € | 0,00990 | kWh | | | |
| System services | € | 0,00117 | kWh | | | |
| | *High peek hours* | | *3289* | *Low peek hours* | | *1456* |
| Electric energy price ashore* | € | 0,11000 | kWh | € | 0,08500 | kWh |
| Energy tax | € | 0,01000 | kWh | € | 0,01000 | kWh |
| Electric energy price ashore | € | 0,13107 | kWh | € | 0,10607 | kWh |
| Net electricity cost per year | € | 1.367.879 | | € | 490.043 | |
| Total shore electricity price High and low | € | 1.857.923 | | | | |
| Including fixed cost | € | 72.875 | | | | |
| Total | € | 1.930.797 | | | | |
| Price per kWh excl. Investment | **€** | **0,128** | | | | |

** Energy price based on www.endex.nl on 22 may 2008*

## 6. Environmental Impact

Ships have to reduce their level of emission in ports due to the living areas. Therefore, it is important to calculate the emission effect(s) of shore connected power compared with the diesel generators onboard the ships. In order to have the right emission data collected, it is important to know the amount and kind of emissions produced by ship's diesel generators. The comparison is made between the diesel generators onboard the ferries, the power plants on shore and sustainable energy.

In this report the power from the shore is energy which is generated from a power plant using sustainable fuel and energy generated by wind or hydropower. Therefore, the emission from the generated energy is emission free or with other words: neutral emission. The energy generated on shore will be compared with the specifications from the diesel generators onboard the six ships.

Furthermore, in this report we have not calculated the process of manufacturing of for example the windmills. The calculation would be too complex for this feasibility study, due to the fact that we also do not calculate the manufacturing of a diesel generator for the ships, see appendix 1 for further details of the emissions.

| | Hook of Holland Emission generator [ton/yr] | Benelux-haven Emission generator [ton/yr] | Total emission [ton/yr] | Emission from coal burned power plant [ton/yr] | Emission from gas burned power plant [ton/yr] | Maximum avoided emission with the use of shore connected power [ton/yr] |
|---|---|---|---|---|---|---|
| NOx | 159,6 | 158 | 323,5 | 39 | 25 | 298,5 - 92% |
| $PM_{10}$ | 5,8 | 5,8 | 11,6 | 0,5 | 0 | 11,6– 100% |
| $SO_2$ | 3 | 3 | 6,0 | 18 | 0 | 6,0– 100% |
| $CO_2$ | 9.455 | 9.134 | 18.589 | 18.348 | 16.923 | 1.666– 9%* |

** CO2, NOx, PM10, SOx emissions can be reduced to zero, if Green energy is used.*

From the above table it appears that there is a benefit for each component by switching over to shore connected power. Getting the energy from the gas burning power plant, the profit comes from the fact that gas contains no sulfur. And by burning gas there is no release of PM10 as well. The differences in the discharge at CO2 per produced quantity energy is caused namely through the higher hydrogen content of gas with respect to diesel and of diesel with respect to coals. Energy produced by a coal burned power plant will not benefit the CO2 emission compared with the ships emission. However, NOx and PM will be reduced.

Shore connected power would make a considerable reduction of the local influence of the emission of NOx and PM10. The contribution of the discharge caused by the production of electricity in the power plant, which is required for the shore connected power, at the concentration on living condition can be neglected. This is very small due to the height of the exhaust pipe of the power plant.
Therefore, when shore connected power will be implemented the emission of NOx and PM10 will be diluted.

The other important factor is $CO_2$. The city of Rotterdam is linked with the Clinton Global Climate Initiative foundation and therefore has its self obliged in reducing the $CO_2$ levels within its area. From the calculation of the engine manufacturer the $CO_2$ emission is 18.348 ton $CO_2$ per year. This can be saved when using green energy and instead of the diesel engines onboard the ferries. When the ship is using the power generated from a gas power plant, the local emission would go down for the $NO_x$, $CO_2$, $SO_x$ and PM10 with respectively 298 ton of $NO_x$, 1666 ton of $CO_2$, 6 ton of $SO_x$ and 11,6 ton of PM.

This is the environmental impact if shore connected power is used on the ships of Stena Line and P&O Ferries. The City of Rotterdam has committed itself in the Rotterdam Climate Initiative with the goal to reduce $CO_2$ with 50% from the figures in 1990 to 2025. With implementing shore connected power it contributes in achieving this goal by using sustainable fuel as the supplying energy, the so called zero emission production.

## 7. Comparisons

7.1. Total cost overview

A total analyses can be made with acquired cost of the electricity and the investment on the ships and shore. Within this analysis the investment is calculated with a depreciation cost. The depreciation is based on the straight line method. For the calculation of depreciation it is common to use straight line depreciation due to a fixed amount of depreciation. A fix amount for depreciation of the installation is used but due to the interest rate, the total amount will reduce every year. Obviously it is up to the financial department how they want to depreciate the investment and which method they want to use. In this report we just show a commonly used one.

| **Beneluxhaven (East & West)** | | **Hook of Holland** | |
|---|---|---|---|
| Shore Infra installation | € 4.306.745 | Shore Infra installation | € 5.323.875 |
| Shipinvestment 4 ships | € 2.980.000 | Shipinvestment 4 ships | € 2.980.000 |
| ***Investing model*** | | ***Investing model*** | |
| Investment interest rate % | 7,5% | Investment interest rate % | 7,5% |
| Depreciation period | 15 | Depreciation period | 15 |
| Total depreciation per year | € 777.253 | Total depreciation per year | € 885.747 |
| Total costs per year | € 1.988.375 | Total costs per year | € 1.930.797 |
| Total cost shore power per Year | € 2.765.628 | Total cost shore power per Year | € 2.816.544 |
| **Per kWh** | **€ 0,184** | **Per kWh** | **€ 0,187** |

Comparing both ways of energy supply for the ship power, the total figures will have to be compared. The depreciation with an investing interest rate of 7,5% in 15 years is used for this calculation. When the interest rate is change to a lower percentage the price per kWh will go down.

7.2 Total comparison of ship and berth location

In the overall calculations are compared with the individual ships. This means that the four ships which will berth in Hook of Holland are compared with the price per kWh when they are along side in Hook of Holland. The same method is done for the two ships along side in the Beneluxhaven.

In the below table the end figures are projected. A separate calculation has been made between the shore connected power (including ship and shore investment) and the cost of onboard generated power.

In the second calculation there is no shore investment, but only the investment of the ships and therefore there are separate kWh prices. This is used to see if a subsidy by reducing the shore investment, would make shore connected power more interesting for the individual companies.

***SUMMARY***

| | | | | |
|---|---|---|---|---|
| SHIP FUEL GENERATED | Ship with 3.000 kW | | Ship with 750 kW | |
| Price per kWh onboard | € 0,162 | | € 0,199 | |
| SHORE CONNECTED POWER | **Hook of Holland** | | **Benelux haven** | |
| Total cost shore power **<u>per Year</u>** (including shore investment, shipinvestment, price of electricity | € 2.816.544 | | € 2.765.628 | |
| Per kWh | € 0,1871 | | € 0,1837 | |
| Return of investment (all included) | Ship with 3.000 kW | Ship with 750 kW | Ship with 3.000 kW | Ship with 750 kW |
| Exploitation profit / lose per year | € 302.799- | € 36.366 | € 39.380 | € 229.105- |
| SHORE CONNECTED POWER <u>without</u> shore investment on the exploitation | | | | |
| Total costs without shore investment per year | € 2.248.664 | | € 2.290.348 | |
| Per kWh onboard | € 0,149 | | € 0,152 | |
| Return of investment (all included) | Ship with 3.000 kW | Ship with 750 kW | Ship with 3.000 kW | Ship with 750 kW |
| Exploitation profit / lose per year | € 151.505 | € 149.942 | € 134.436 | € 151.118 |

The fuel price is very volatile. The fuel oil prices have increased significantly during 2007 and calculations have been made at a high peek. With the current fuel prices, calculations show that shore connected power will be economically more and more feasible.

The summary makes it clear that the price per kWh for the ships, when switching over from diesel generated power to shore connected power, should be at least equal. Due to the size of the different ships it is very difficult to give an exact amount because the power requirements are different, which ends in a variations of the kWh price. However, a lot of reduction can be made through collaboration of buying energy on the energy market.

Also, it shows that the yearly costs should be lowered with € 500.000 than there is a break-even point. This can be done by having at least 60% reduction of the cost of the infra structure on shore.

## 8. Conclusion

### 8.1. Conclusion

*Economically & technology*

Economically and technology it is possible to have shore connected power. However, it is not a plug and play solution. There are technical issues about on which side the high voltage cable will be located; onboard or on shore. Therefore, there are several configurations possible.

The decision criteria for implementation depend almost solely on the price per kWh and the huge investment in the shore infrastructure. The decision which has to be made by the shipowner depends on the cost calculation whether the investment is worth making. As it can be seen from the calculation model though, the total investment is high.

The cost of the shore infrastructure and ship are a considerable investment. In order to have shore power implemented, a financial participation by the Dutch Government would be possible to realise and implement shore power in the Port of Rotterdam. However, the VAMIL rule (a return of investment subsidy tool) doesn't look suitable for ship-owners since they are in tonnage tax scheme.

When taking out the costs for the shore infrastructure from the exploitation, shore connected power is even economically attractive. Getting the costs for the shore infrastructure reduced can be done by getting the necessary subsidies from government bodies. In the calculations model the infrastructure should be reduced with 60% to get a break-even point. This would mean on a total investment (ship and shore) of € 15,6 million by Stena Line and P&O Ferries, € 6,25 million is needed from the local / state governments to make it happen.

Therefore, going ahead with shore connected power for P&O Ferries and Stena Line would be the outcome of this study.

*Ecologically*

Furthermore, shore connected power used by the RoRo / ferry ships will have a considerable contribution to the environment. As it shows, the emissions of $CO_2$, $NO_x$, and dust are high. Reducing these levels to zero it will contribute to a better and cleaner environment on a large scale.

Nevertheless, shore connected power is an attractive solution and beside the bottleneck of willing to do the investment, the company Eneco Netbeheer BV, the only company that delivers the transport of electricity, is a high cost factor for the initial connection. This would be something to really investigate if there is a more efficient way to get shore connected power up and running in the port of Rotterdam.

### 8.2. Recommendations

In this study the energy supply comes from the traditional energy companies. Ships have always been independent of the energy companies but depended on the oil companies. The energy suppliers have still a very strong position in the Dutch energy market. Therefore, also other alternatives should be investigated.

One of the alternatives is the idea to install a generator on shore which runs on natural gas. The emission of gas is mainly $CO_2$, but still much lower than the emission of a diesel generator. One of the advances is, that this gas engine can be directly fitted with a 60Hz generator which would reduce the converter costs on the shore. However, installing a separate gasgenerator for each berth is an even higher investment than by getting the energy from Eneco.

Nevertheless, within a few years the port of Rotterdam will have its own LNG terminal. It would be very interesting to make use of these facilities as well. After consulting with Pon Power, Wärtsilä and Cummins, there are manufactures of gas engines and therefore new ideas came across to do further research into the following ideas:

1. Set up gas (LNG) fuelled power plants (Wärtsilä trigeneration power plant) with 60Hz generators with a capacity of 30MW. Similar to the airport of Milan in Italy. See appendix 4 for more information.

2. Moving barges with gas generators with the possibility of a different power range: 1000 kW, 2500kW and 4000kW.

This report has looked into the shore infrastructure in the port of Rotterdam. Unfortunately, the ports in the UK have not been included. It would be very interesting to find out their intentions and possibilities on implementing shore connected power.

There are other ferry / RoRo companies operating in the port of Rotterdam. Norfolkline is one of them. A smaller desk research study has been done as well. Norfolkline operates in the municipal of Vlaardingen; in the Vulkaanhaven. They have 3 berths for their RoRo ships. For the ships of Norfolkline it would be interesting as well to invest in shore connected power with the same remark as mentioned above; 60% of shore investment should be subsidies or paid by other means before shore connected power will be economical feasible.

Therefore, it is beneficial to follow up on the feasibility study that has been conducted to find out more about these options and possibilities.

## Appendix 1. Emission from the ships vs the shore

Basic emission level of diesel generators (MGO fuel):

| | | | |
|---|---|---|---|
| Engine specific fuel consumption | | 190,000 | g/kWh |
| | NOx | 11,500 | g/kWh |
| | CO | 1,300 | g/kWh |
| | PM | 2,100 | g/kg fuel |
| | CO2 | 610,000 | g/kWh |
| Max. sulphur 0,1% | | 0,190 | g/kWh |

This results in the following total amount of emission:

| | | | | | |
|---|---|---|---|---|---|
| Total emission at 4 berths | | | | | |
| | NOx | 323.509 | kg | 323,5 | Ton/Yr |
| | CO | 27.985 | kg | 28,0 | Ton/Yr |
| | PM | 11.637 | kg | 11,6 | Ton/Yr |
| | CO2 | 18.589.450 | kg | 18.589,5 | Ton/Yr |
| max. sulphur 0,1% | | 5.902 | kg | 5,9 | Ton/Yr |
| Total fuel | | 3.405.450 | kg | 3.405 | Ton/Yr |

When taking energy from a coal burned power plant or a gas burned power plant the benefit for the environment is:

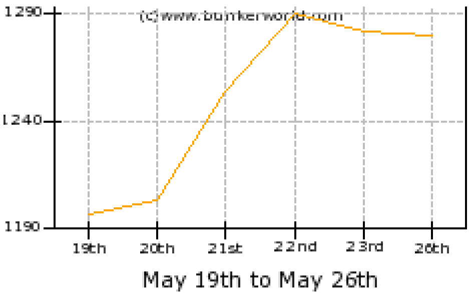
| ***Environmental effect from Coal Energy plant*** | | | **Gas plant** | | |
|---|---|---|---|---|---|
| NOx | 1,300 | g/kWh | NOx | 0,836 | g/kWh |
| CO | 0,000 | g/kWh | CO | 0,000 | g/kWh |
| PM10 | 0,016 | g/kWh | PM10 | 0,000 | g/kWh |
| CO2 | 987,000 | g/kWh | CO2 | 562,000 | g/kWh |
| SOx | 0,596 | g/kWh | SOx | 0,000 | g/kWh |
| Total environmental effect of the powerpant; extra power to be delivered for ship-shore power | | | Total environmental effect of the powerpant; extra power to be delivered for ship-shore power | | |
| NOx | 39.146 | kg | NOx | 25.174 | kg |
| PM10 | 482 | kg | PM10 | 0,00 | kg |
| CO2 | 18.347.787 | kg | CO2 | 16.923.225 | kg |
| SOx | 17.947 | kg | SOx | 0,00 | kg |
| CO2 reduction | 241,7 | Ton/year | CO2 reduction | 1.666,2 | Ton/year |
| SOx reduction | -12,0 | Ton/year | SOx reduction | 5,9 | Ton/year |
| PMreduction | 11,2 | Ton/year | PM reduction | 11,6 | Ton/year |
| NOx reduction | 284,4 | Ton/year | NOx reduction | 298,3 | Ton/year |

## Appendix 2. GLOSSARY /ABBREVIATIONS

| | |
|---|---|
| CO: | Carbon oxide |
| CO2: | Carbon Dioxide |
| Dwt: | Deadweight, a vessels total capacity of carrying cargo, bunker provisions etc |
| gr/kWh: | gram per kilowatt hour |
| GT: | Gross Tonnage, vessel size measure based on the vessels total volume |
| HFO: | Heavy fuel oil |
| Hz: | Hertz |
| Kg: | Kilogram |
| kV: | Kilovolt (1 kilovolt = 1 000 volts) |
| kWh: | Kilowatthour |
| MDO: | Marine diesel oil |
| MGO: | Marine gas oil |
| NOX: | Oxides of Nitrogen |
| NM: | Nautical mile (1 NM = 1.852 kilometres) |
| MW: | Megawatt |
| PAH: | Polycyclic Organic Hydrocarbons |
| PM: | Particulate Matter |
| SO2: | Sulphur dioxide |
| V: | Volt |
| W: | Watt |

## Appendix 3. Bunkerprices from Rotterdam Bunkerworld 22nd of May 2008

MGO (DMA DMX)




| Date | $/MT | Hi | Low | ch/d | ch/% | ch/m | Qty |
|---|---|---|---|---|---|---|---|
| May 26 | 1,280.00 ▼ | 1,300.00 | 1,257.00 | -2.00 | -0.2 | +187.00 | 50 |
| May 23 | 1,282.00 ▼ | 1,305.00 | 1,258.00 | -8.00 | -0.6 | +207.00 | 50 |
| May 22 | 1,290.00 ▲ | 1,310.00 | 1,260.00 | +36.00 | +2.9 | +213.50 | 50 |
| May 21 | 1,254.00 ▲ | 1,265.00 | 1,235.00 | +50.50 | +4.2 | +186.50 | 50 |
| May 20 | 1,203.50 ▲ | 1,230.00 | 1,178.00 | +7.00 | +0.6 | +141.50 | 50 |
| May 19 | 1,196.50 ▲ | 1,210.00 | 1,178.00 | +8.50 | +0.7 | +128.50 | 50 |
| May 16 | 1,188.00 ▼ | 1,207.00 | 1,178.00 | -7.00 | -0.6 | +143.00 | 50 |

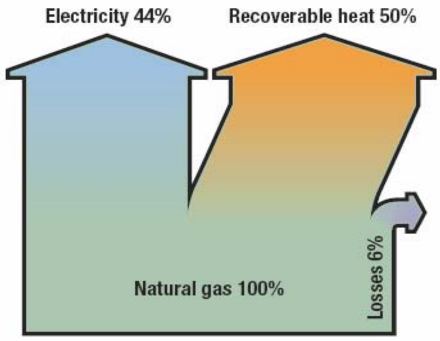
## Appendix 4. Airport terminal power plant

Example of the Trigeneration airport power plant of LINATE AIRPORT, ITALY
In June 2007, Wärtsilä and EuroPower SpA handed over a 24 MWe trigeneration power plant at Linate airport, Milan in Italy. The plant has been built for Malpensa Energia Srl, whose shareholders are the Milan airport management company SEA Aeroporti Milano and the Milan multi-utilities company AEM Milano.

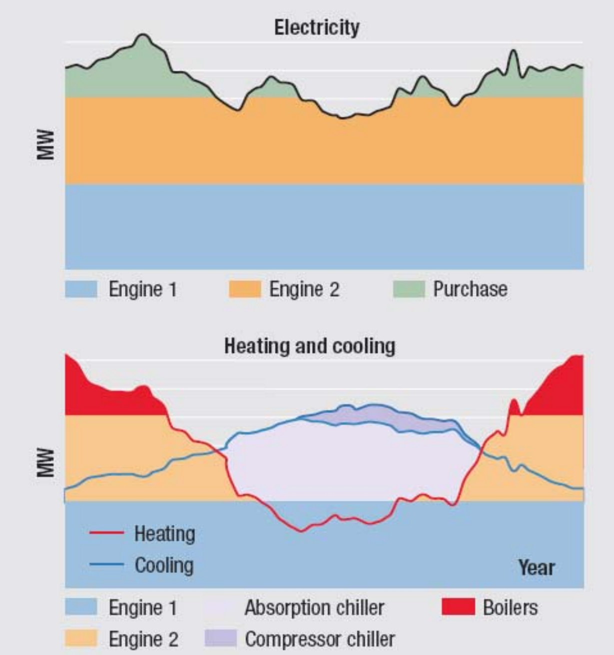
The trigeneration power plant is equipped with three Wärtsilä 20V34SG gas-fuelled generating sets, together with ancillary equipment, exhaust heat recovery economizers and two gas-fired boilers. The plant is located inside Linate airport. Operating on baseload, the plant is flexible in operation, economically meeting the variations in heat demand in summer and winter for both heating and air conditioning. The heat output of the plant is 81.7 MWth in winter and 74.8 MWth in summer, with a yearround electrical power output of 24 MWe. The heat recovery system for the three engines is designed for maximum heat recovery for heating services and the air conditioning of airport buildings. This full climate control system is typically referred to as a trigeneration installation. The heat is delivered as superheated water at 125°C and hot water at 70°C to the airport buildings and to a small village close to the airport. The plant also delivers electricity to the Italian national grid. Normally the generating sets run in parallel with the grid but they will also serve as emergency sets to maintain airport services in the event of a break in the grid supply.
Configuration:

- engines.....................3 x Wärtsilä 20V34SG
- total electrical output................. 24000 kWe
- total heat output....................... 17505 kWth
- total efficiency................................. 80.2 %

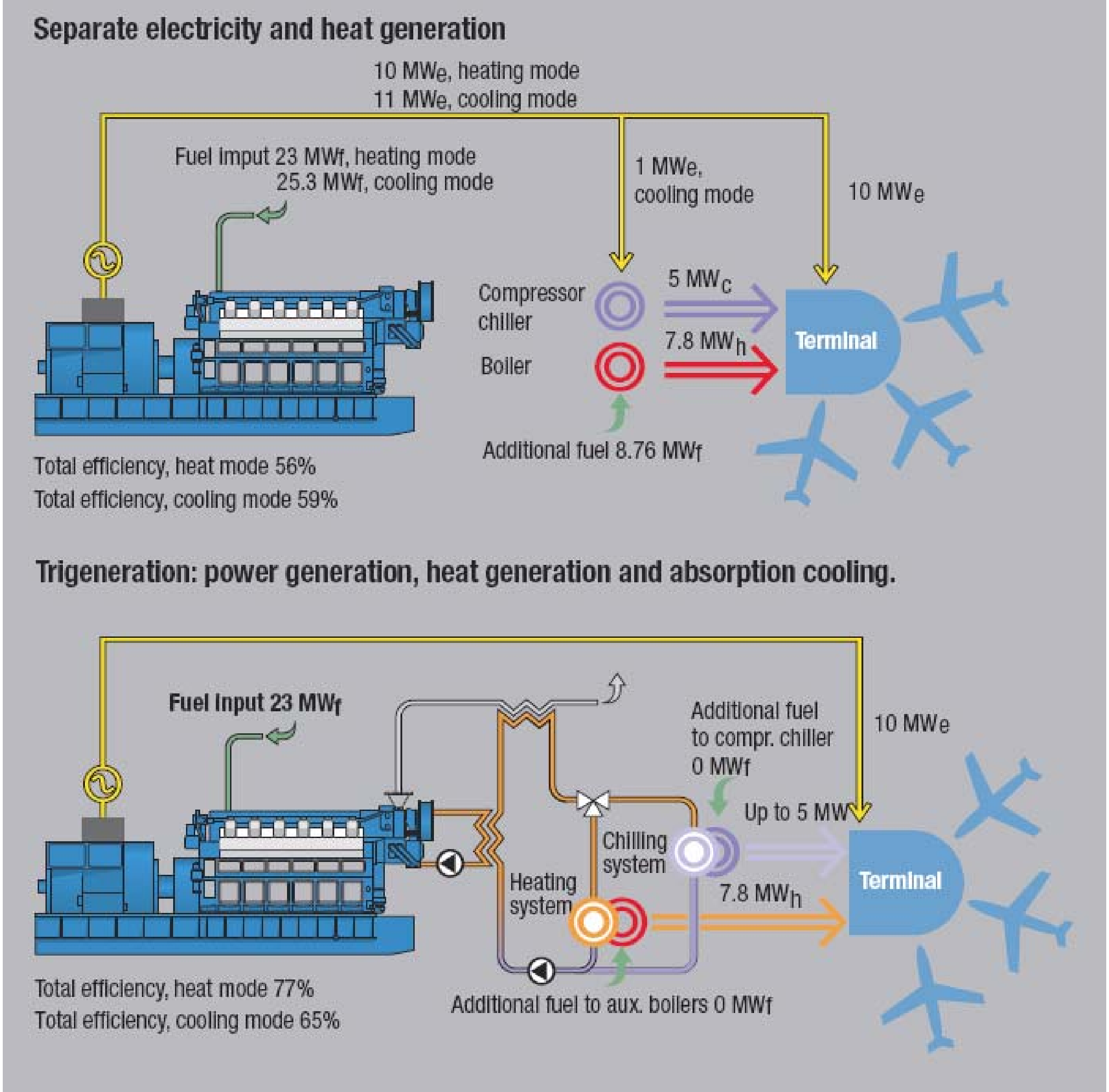
This leads to a more widespread use of air conditioning, and awareness of environmental issues calls for more efficient use of fuel.
Wärtsilä Power Plants has ready-made solutions for trigeneration which can be easily adapted to the specific needs of the aviation market and delivered within tight time schedules.




Principal heat balance of a Wärtsilä gas engine.




Trigeneration enables optimized plant operation around the year and guarantees both airport safety and comfort in all occurring situations.




The main advantage of trigeneration is shown in this diagram. With a Wärtsilä trigeneration power plant you will obtain the same output with considerably less fuel input than with separate power and heat generation.