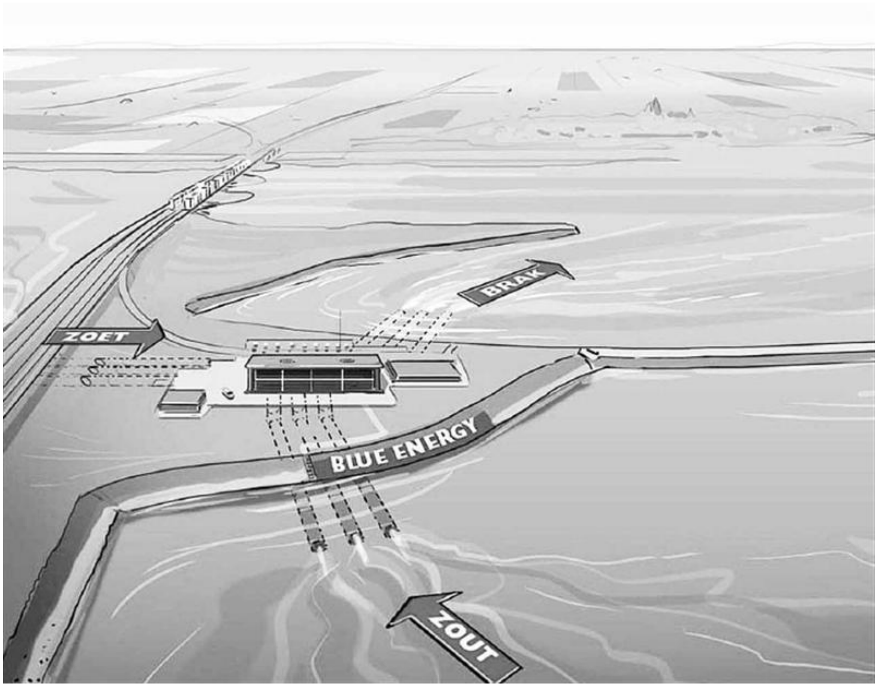
Rotterdam Mainport University of Applied Sciences - RMU

BLUE ENERGY

and

Emission Reduction



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Foreword

This project about "reduction of emissions of SOx, NOx and CO2" started with emphasis on electrical systems. The following main question have been selected: *Is Blue energy usable in the shipping industry?*

Blue Energy has been developed by REDstack BV (Reversed Electro Dialysis and stack). KEMA has designed a membrane which has made blue energy more profitable and reliable.

There are several ways of using blue energy, but we will concentrate on Kema: Reverse electro dialysis.

While the properties and concepts of Blue Energy are still being studied, this power source has been implemented in several different locations allready. Most of these are experimental, but so far they have been successful.

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1 Background

1.1 Introduction

The topic of this project “Blue Energy”, means energy that is obtained from sea water by means of the difference in salinity. While the mechanics and concepts of salinity gradient power are still being studied, this power source has been implemented in several different locations. Most of these are experimental.

The various companies that have utilized this power have done so in many different ways as there are several concepts and processes that lead to the power from salinity gradient.
So there are several methods to do this, but for this project we have chosen for the osmotic method. The reason of this subject is because it is being analyzed in the Netherlands by the Dutch company named KEMA. Their knowledge on this topic can be used as a guideline in our project.

KEMA was established in 1927 in Arnhem as a testing institute for the Dutch electricity sector. KEMA has become a global company that provides a large number of independent research and consultancy in the field of electrical energy with an international network of subsidiaries and representative offices.

KEMA is working on the electrical modification of polymers to make the production of special membranes cheap, this makes Blue Energy more economically interesting.
One of those applications is a polymer membrane that can be used for osmosis. The membrane lets fresh water trough but not salt water.
There is a height and potential energy due to the salinity of this water, so hydro electricity can be produced.
It is possible to produce membranes that pass only positive or negative ions. The difference between positive and negative ions can be directly converted into electricity.

In a country like the Netherlands, which has seawater in abundant it is very easy to analyze this system. This also provides opportunities for other countries with a river delta. Blue Energy produces electricity:

- Without emissions of greenhouse gases
- Without landscape and visual restrictions
- Without dependence on the environment.

The key waste product is brackish water. This byproduct is the result of natural forces that are being converted: the flow of fresh water into seas that are made up of salt water.

As members of this project group we have decided to focus on this company, and to analyze if this method of gaining energy may also be suitable for use on seagoing vessels.

It seems to be very interesting for us to analyze the possibilities for using this system, as this way of producing energy is still being analyzed.

2 Project assignment

2.1 Problem definition

The main question in our research is: “Is blue energy usable in the shipping industry?”
We have chosen to investigate one blue energy method: The osmotic method. The goal is knowledge and an application of the membrane system in the shipping industry.

The main question leads to the following sub questions.

- What is blue energy?
- What is the ratio between volume and the produced power?
- Is this system usable in all kinds of areas?
- Is this system usable on all kinds of vessels?
- What are the environmental problems while using blue energy and what are the regulations while using blue energy at sea?
- Is it possible to simulate salt/fresh water to keep the system running in all areas?
- What are the costs of this system, compared with other energy generators and is it in connection with the daily and long term maintenance, profitable to install this system?

Conclusion:

- Is this system profitable in relation to other generators?

2.2 Project Borders

The research of the problem definition will be answered by the investigation of Reverse Electro Dialysis.

There will be no further investigation of the following items in this project:

- There is no investigation of the recycling of this system.
- We will not simulate the system by means of a model.

2.3 Investigation

In this project we will give a wide scope of the main topic by answering the question: “what is blue energy?” (Chapter 3). The basic principles and the way of producing this form of energy will be explained. The information that is used during the project is based on a test installation at the Afsluitdijk and also information from the companies KEMA and REDSTACK of the goals they assume to get.

Producing blue energy must not be underestimated. On board vessels we are also limited on space, so we will have a look at the ratio between produced power and the needed volume.

We will investigate the areas in which this system may be run and on what kind of vessels it is applicable in relation to the needed volume. We are also interested if this system causes environmental problems in the sea areas, so “what regulations must be followed to keep this system running at sea?”(Chapter 6).

A difference of salinity is required to run this system. Therefore we will investigate the possibilities to simulate salt and fresh water to keep this system running (Chapter 7).

The system is not priceless and still in development. The maintenance and manufacturing costs of this system will be investigated and compared to other energy generators.

So finally we are interested if this system is more profitable in relation to other generators and if it is possible to reduce the emissions of Sox, NOx and CO2 on board vessels.

3 What is Blue Energy?

3.1 Introduction

The term 'Blue Energy' refers to all forms of energy using water. In this project we will only investigate a method which uses the difference in salinity of water to make energy.

This chapter consists of the following subjects:

- The basic principle of this form of energy (Red or Reversed Electro Dialysis).
- Potential difference - From salinity to Energy.
- Test unit
- Concept version test unit on board of seagoing vessels

3.2 Basic principle

Blue energy can be generated because of the difference in salinity. Reverse electrodialysis (RED) is a non-polluting, sustainable method to generate energy from the mixing of fresh and salt water. RED can be applied where two solutions which differ with respect to their salinity gradient, are mixed e.g. where river water flows into the sea.
In RED, a concentrated salt solution and a fresh water are brought into contact through an alternating series of anion exchange membranes (AEM) and cation exchange membranes (CEM) (Figure 3.1).

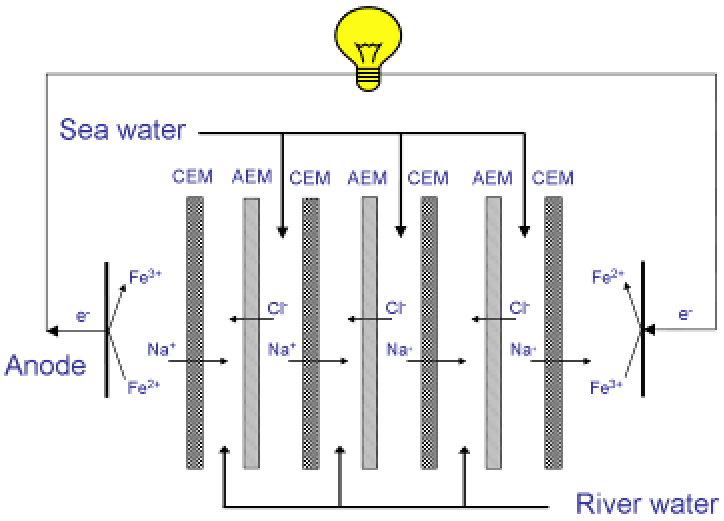


Fig. 3.1 Reverse Electro Dialysis, water system.

There are two different types of selective ionic membranes used in this system (fig. 3.1 electric system):

- Positive selective membrane (CEM).
- Negative selective membrane (AEM).

The difference in chemical potential between both solutions is the driving force for this process. The chemical potential difference generates a voltage over each membrane and the overall potential of the system is the sum of the potential differences over the sum of membranes.

3.3 Potential difference- From salinity to Energy

In this project fresh water has a salinity of 1.018kg/m^3 and salt water 1.050kg/m^3 (the brine). Chapter 7 will describe these values.

So when there is a difference in salinity between two liquids, it will be possible to create an osmotic pressure. Because the fresh water side tends to be equal to the salt water side, the ions from the solution with a higher concentration of Na^+Cl^- flow to the solution with a lower concentration.

After the ions have been caught by the membranes, the negative ions will flow into the cathode which will create a negative potential and the potential difference that is caused can be directly used for energy.

3.4 Test unit

Blue Energy is still being tested by KEMA on the Afsluitdijk. It consists of an accumulation of modules, as big as a 20" container, each with a capacity of 250 kW.

During this project we are going investigate if this installation of 250 kW may replace a small generator, which means a high reduction of emissions of SOx, NOx and CO2.

3.5 Concept version blue energy system on board of seagoing vessels

This picture gives a clear view of a blue energy system which can be applied on board of seagoing vessels. Sea water (1035 kg/m^3) will enter the system at the inlet. Here it will run through a filter and enters the evaporator, an amount of liquid will bypass the evaporator and enters the fresh water stage (combined 1018 kg/m^3). The brine (1037 kg/m^3) of the evaporator will enter the system at the salt water stage. A big part of the flow of brine will bypass the system because the flow of brine is too much for the system. All the water will flow back into the sea (1035 kg/m^3).

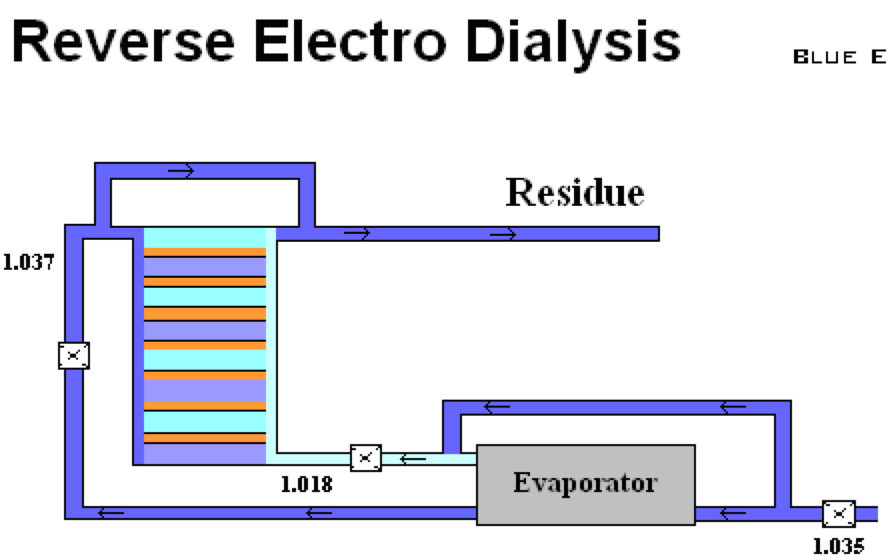


Fig. 3.3 Reverse Electro Dialysi, Blue Energy System.

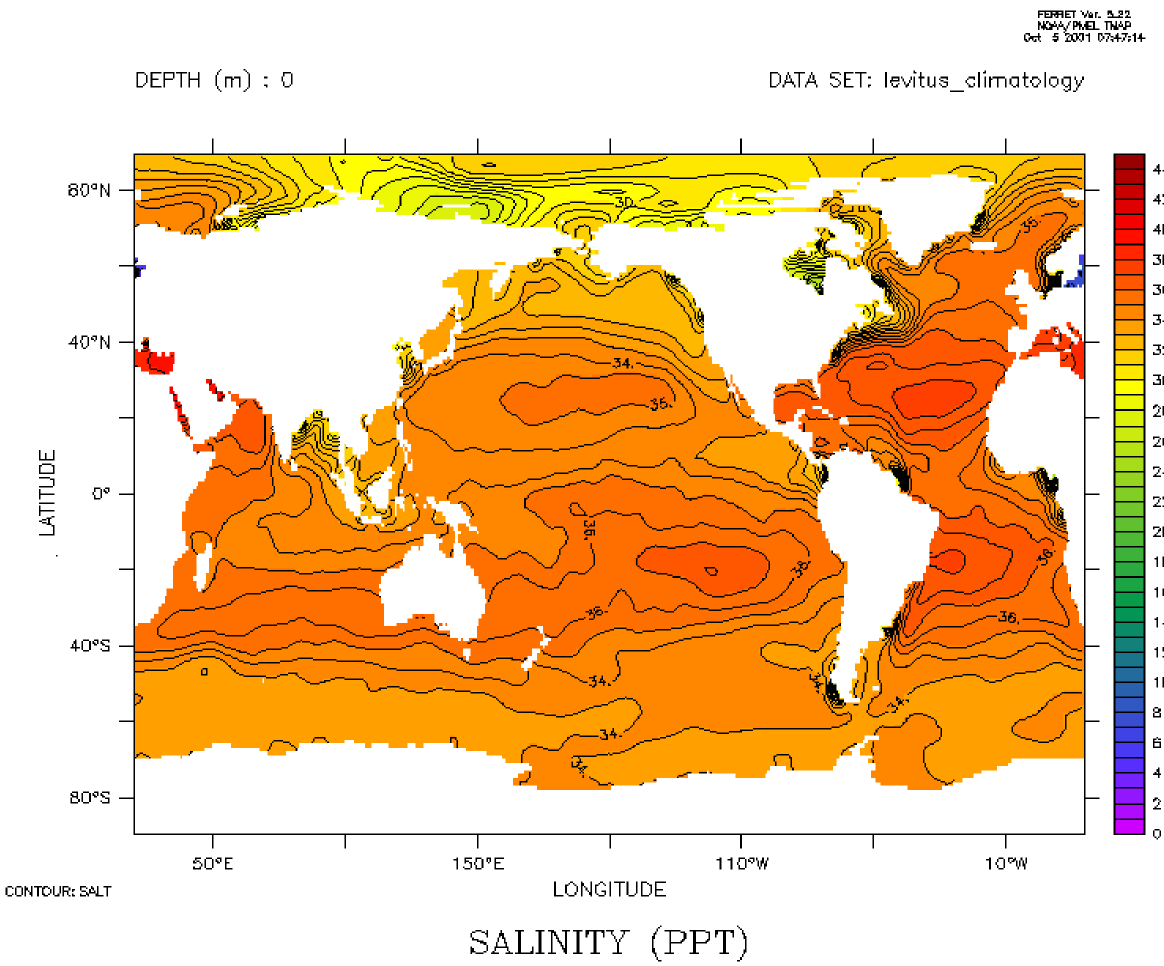
4 Is this system usable in all kinds of areas?

4.1 Introduction

In this sub question it will be analyzed if this system can be used in all kinds of areas. To get energy from the membrane system salt and fresh water is required. The greater the difference in salinity between fresh and salt water, the higher the output(kW). Because of the difference in output, it is very important to investigate the salinity of the sea water around the world. There are organizations that investigate this salinity.

4.2 Basic principle

Before starting with the investigation of the salinity of sea water, it is important to know how this difference in salinity is established. The amount of salt is mainly depended of the rain and the evaporation of the sea water. More rain means a lower salinity. More evaporation means a higher salinity.
There is also a salinity difference between surface water and deeper water. Salt water weighs more than fresh water. That means that the salinity increases by the dept. In our case that doesn't make so much sense because we cannot suck deeper than the draft of the vessel. For that reason we decided to investigate only the salinity of the surface sea water.



4.3 Conclusion

The image in the previous paragraph shows the salinity of the surface sea water on the world. As you can see the salinity on the main trading routes varies between 34 and 36 ppt. (A unit of measurement of salinity similar to part per thousand). That means that the density of seawater is between 1034 and 1036 kg/m^3. For the calculation, an average of 1035 kg/m^3will be used. That means in relation to fresh water, a difference of salinity of 35 Kg/m^3.

5 Is this system usable on all kind of vessels?

5.1 Introduction

By means of this sub question it will be analyzed if this system is applicable on all kinds of vessels. Each type of vessel is different. A tanker for example which is equipped with her own load/discharge systems requires much more power than a bulk carrier or container vessel that are loaded/discharged by means of facilities from shore.

To answer this question two different vessels have been taken as example. It regards two middle sized vessels:

- a 36,000 ton tanker
- a 35,000 ton container feeder

Vessel type	Size (deadweight)	Generator capacity (kW)	Amount of generators
Tanker	36.000	1250	3
Feeder	35.000	950	2

The data mentioned above indicates that a tanker requires much more power than other type of vessels. Most tankers are equipped with their own cargo handling facilities. These facilities are mostly powered by means of electricity.

To give an answer to the above mentioned question it will be concluded that this system can be used on all kinds of vessels. The only difference is that a system like this should be larger on a tanker than on a container feeder. In fact a tanker should be equipped with a more powerful system than e.g. a feeder.

Above mentioned data depends on a type of vessel. If it regards a container feeder that carries e.g. freezing containers that are being fed by the power of the ship, a much larger power system must be installed.
Hereby can be concluded that the higher the required power on the ship, the larger the installation should be.
By answering this question it doesn't mean that there are no other limitations for using this system on board of vessels. By answering the other sub questions it will be clear if there are other possible restrictions of this system when it regards the costs, needed space etc.

6 What are the environmental problems while using blue energy and what are the regulations while using blue energy at sea?

6.1 Introduction

Every process consists of both advantages and disadvantages. After comparing the dis- and advantages with each other one can conclude whether a system is efficient or not. This will be the same for the system we will investigate for this project. One disadvantage that we will encounter at the end of the process is the by-product. Brackish water will be the end by-product which will come out of the system as the last part of the process.

6.2 Marpol regulations

But what to do with this by-product? Is it clean enough to dump into seas, or should it be given ashore as bilge? To get the answer to this question the properties of this water should be investigated in relation with the MARPOL requirements.

The brackish water that comes from this system can be seen as sewage. Light chemicals are added to the water to prevent corrosion of the pipe system and fouling on the membranes. Chemicals used for this purpose are for example:

- Hydrogen peroxide (HCl)
- Nitric acid (HNO_3)
- Dilute hydrochloric acid (H_2O_2)

Above mentioned chemicals are very harmful. But it is very important to know that it regards solutions of very small amounts (less than 1%) of these chemicals. This is the reason why “light chemicals” are mentioned above.

As it regards diluted light chemicals the MARPOL Regulations for sewage can be applied on this water.

Annex IV, contains a set of regulations regarding the discharge of sewage into the sea, ships equipment and systems for the control of sewage discharge, the provision of facilities at ports and terminals for the reception of sewage and requirements for survey and certification.

According to the MARPOL definitions sewage is:

1. Drainage and other wastes from any form of toilets and urinals
2. Drainage from medical premises through wash basins, wash tubs and scruppers located in such premises
3. Drainage from spaces containing living animals
4. Other waste waters when mixed with the drainages defined above

The brackish water that comes from this system is a part of the 4th category of the above mentioned definitions. This means that we have to apply the regulations of annex IV of MARPOL on this water.

This system hasn’t been installed on any kind of ships yet. This means that we can apply regulation 2 on the following vessels that will be equipped with this system in the future:

(a) (i) new ships of 400 tons gross tonnage and above;

(ii) new ships of less than 400 tons gross tonnage which are certified to carry more than 15 persons;

(iii) new ships which do not have a measured gross tonnage and are certified to carry more than 15 persons; and

(b) (i) existing ships of 400 tons gross tonnage and above, 5 years after the date of entry into force of this Annex;

(ii) existing ships of less than 400 tons gross tonnage which are certified to carry more than 15 persons, 5 years after the date of entry into force of this Annex;

(iii) existing ships which do not have a measured gross tonnage and are certified to carry more than 15 persons, 5 years after the date of entry into force of this Annex.

So regulation 2 of annex IV can be fully applied on this system if we consider the by-product as sewage.

Generally sewage may not be dumped in to seas. But there are some conditions defined in regulation 8 that make this possible if this will be done according to these conditions. Those are as follows:
(1) Subject to the provisions of Regulation 9 of this Annex, the discharge of sewage into the sea is prohibited, except when:

(a) the ship is discharging comminuted and disinfected sewage using a system approved by the Administration in accordance with Regulation 3(1)(a) at a distance of more than four nautical miles from the nearest land, or sewage which is not comminuted or disinfected at a distance of more than 12 nautical miles from the nearest land, provided that in any case, the sewage that has been stored in holding tanks shall not be discharged instantaneously but at a moderate rate when the ship is en route and proceeding at not less than 4 knots; the rate of discharge shall be approved by the Administration based upon standards developed by the Organization; or

(b) the ship has in operation an approved sewage treatment plant which has been certified by the Administration to meet the operational requirements referred to in Regulation 3(1)(a)(i) of this Annex, and

(i) the test results of the plant are laid down in the ship's International Sewage Pollution Prevention Certificate (1973);

(ii) additionally, the effluent shall not produce visible floating solids in, nor cause discoloration of, the surrounding water; or

(c) the ship is situated in the waters under the jurisdiction of a State and is discharging sewage in accordance with such less stringent requirements as may be imposed by such State.

(2) When the sewage is mixed with wastes or waste water having different discharge requirements, the more stringent requirements shall apply.

Although the clearance of the conditions explained in regulation 8, there are some exceptions that should be taken into account. These are explained in regulation 9 of MARPOL as follows:

Exceptions:
Regulation 8 of this Annex shall not apply to:

(a) the discharge of sewage from a ship necessary for the purpose of securing the safety of a ship and those on board or saving life at sea; or

(b) the discharge of sewage resulting from damage to a ship or its equipment if all reasonable precautions have been taken before and after the occurrence of the damage, for the purpose of preventing or minimizing the discharge.

6.3 Conclusion

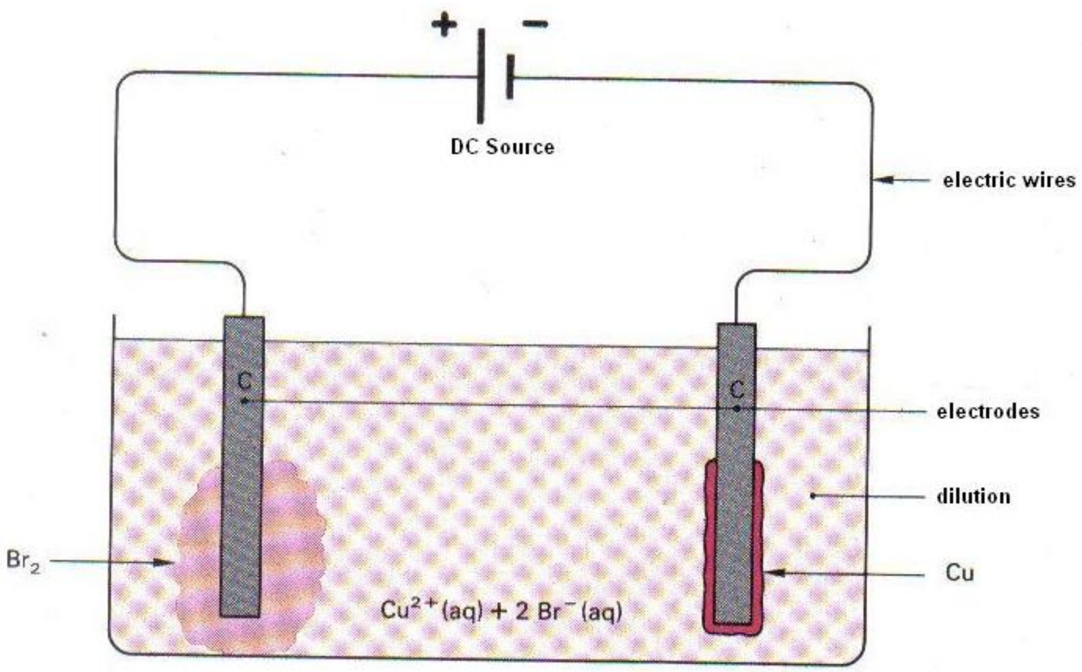
The brackish water that comes from this system contains light chemicals. The reason for this is already explained in the section above. Due to this it is not allowed to dump this water into seas. New ships of 400 tons gross tonnage and above that are equipped with this system should purify this water before dumping it into seas. Another alternative is to store this water in a tank (similar to bilgewater tank), and give it ashore as bilge. But this will take in more space, which can be used for cargo. The best way to get rit of this water is to purify it, and dump it back into seas. The best way to do this is by installing a treatment plant on board. This will be similar to the already known Oil Discharge Monitor's (ODM's) on board vessels, but with the ability to subtract the chemicals from the water before dumping it into seas.
The exceptions (regulation 8) will not be applied to this system.

Fig. 6.1 ODM

Another purifying method of above mentioned dilutions is by means of electrolysis. Electrolysis is a method of using an electric current to drive an otherwise non-spontaneous chemical reaction. Nowadays electrolysis is a very common method in the commercial sector. The basic elements of electrolysis are:

- A DC supply source
- 2 electrodes
- 2 electric wires to connect the electrodes to the powers source
- A tank with the dilution

The picture shown below gives an indication of the electrolysis process. A dilution of copper bromide has been used for this example.



Due to the DC the electrodes are changed into a cathode and an anode. The dilution consists of copper (Cu^{2+})- and Bromide (Br^-) ions.
The following chemical reactions prove the accumulation of copper (Cu) on the anode and bromine (Br_2) on the cathode:

- $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$
- $2Br^-(aq) + \rightarrow Br_2\,(aq) + 2e^-$

This is the way electrolysis works. We can also use this same method to subtract the chemicals from the brackish water in the Blue Energy system. But we still have one problem. It is remarkable that there is an accumulation of solid copper on the anode and a bromide solvent in the area of the cathode on the picture shown above. Some substances solve in water, but some doesn't. Except of solid or liquid form of accumulation we also know the accumulation of gas by some substances. This is e.g. the case by a hydrochloric acid (HCl) dilution. Both Hydrogen as Chlorine will change into gas during electrolysis. These are very explosive and harmful gasses, en may not be escaped. This is the reason for not using an electrolysis installation as a brackish water purifier as alternative.

7 Is it possible to make salt/fresh water to keep the system running in all areas?

In fresh water area's there is no salt water and in salt water there is no fresh water. To run a membrane system both salt and fresh water is needed.

7.1 Making fresh water

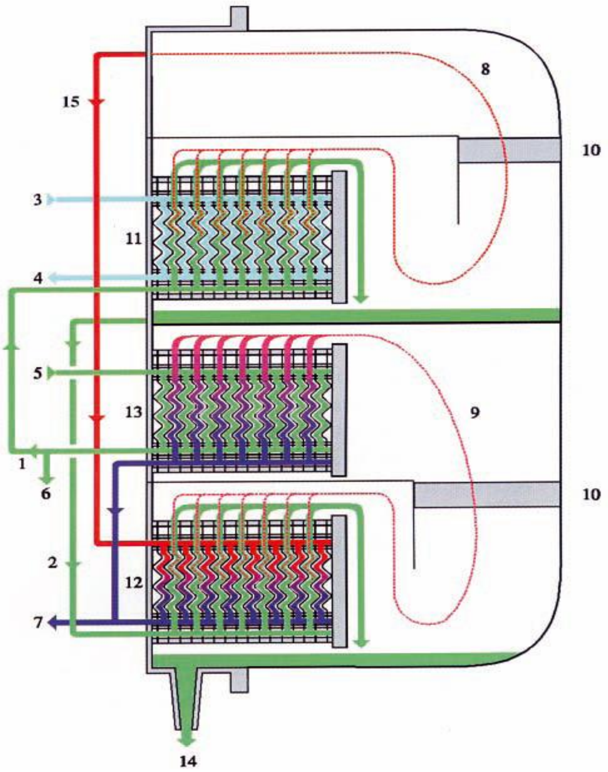
Is it possible to make enough fresh water to run the membrane system?
There are two ways of making fresh water.

1. By means of reversed osmosis.
2. By means of an evaporator.

1. Making fresh water by means of a reversed osmosis system costs a lot of electrical energy. Because we want to make electrical energy this is not a good option.

2. An evaporator uses the waste cooling water or the exhaust gases as a energy source. This energy is a free energy source on board because the main engine uses only 46% to 50% of the energy that is stored in its fuel. 20% is wasted with the cooling water and 30% is wasted with the exhaust gasses. If we can use this energy to make fresh water we have a free energy source.

7.2 How an evaporator works



1. Seawater feed, stage one
2. Seawater feed, stage two
3. Heating medium in
4. Heating medium out
5. Seawater cooling in
6. Seawater cooling out
7. Freshwater out
8. Vapour, stage one
9. Vapour, stage two
10. Demister
11. Evaporator, stage one
12. Evaporator, stage two
13. Condenser
14. Brine out
15. Connecting pipe

The feedwater to be distilled is taken from the cooling water outlet of the condenser (13). It enters the evaporator of stage one (11) where some of it evaporates as it passes between the plates heated by the external heating medium.

The vapours generated pass through a demister (10) where any drops of seawater retrained are removed and fall due to gravity to the brine sump of stage one and further as feed-water for stage two.

The vapours flow through a connecting pipe (15) to the evaporator (12) of stage two where it is utilized as heating medium by transferring its heat to evaporation to the feed-water (brine) coming from the surplus feed of stage one.

The vapours generated in stage two evaporate as in stage one, after the demister (10) the vapours continue to the condenser (13) where they condense into freshwater as they pass between the cold plates cooled by the cooling water.

The evaporation processes are performed under vacuum at evaporating temperatures of about 70 and 45°C in the first and second stage respectively. The vacuum is maintained by only one ejector containing three independent stages.

This evaporator has a maximum capacity of 50-75m^3, one evaporator is not enough to run the blue energy system.

Further calculations will be made with a capacity of 75m^3 per day per evaporator.

7.3 How much water is needed for the system?

A 250kw installation needs roughly 10,800m^3 of fresh water per day and the same amount of salt water. In the concept version on board of vessels only 1,050m^3 per day is required. This number is a compromise of the volume and produced water of the fresh water generators.

To make 10,800m^3 of fresh water 144 fresh water generators are needed (10,800/75=144). To make 1,050m^3 of fresh water 14 fresh water generators are needed (1,050/75=14). Fresh water will not conduct power very well without NaCl. The idea is to add salt water to the fresh water. This has two benefits:

1. The water will conduct power better.
2. Less fresh water generators are needed.

The ratio between fresh and salt water will be 1:1.
525m^3 fresh water + 525m^3 salt water = 1,050m^3 brackish water
To make 525m^3 of fresh water seven fresh water generators are needed.

As shown in the diagram only half of the fresh water generators are needed.

Installations	250 kW	Concept version 5,85 kW

* These values are taken from the actual situation on the afsluitdijk. For our calculations we will use the values of the concept version.

** See paragraph 8.2 for explanation.

7.4 How much fresh and salt water will we create and with what salinity.

Seven fresh water generators will be used. The fresh water will be mixed with salt water to have a better conduction of electricity. The brine of the fresh water generator will be used to make the NaCl concentration higher for the salt water.

	Fresh water	Mixed with salt water	Brine
Salinity	1000 gram/liter	1018 gram/liter	1037 gram/liter
NaCl per liter water	0 gram	18 gram	37 gram/liter
Amount in m^3	525 m^3 per day	1050 m^3 per day	1050 m^3 per day

7.5 Making salt water in fresh water areas.

In fresh water areas like the Baltic Sea it is not a problem to get fresh water. In the fresh water areas salt water is a problem. The NaCl difference must be the same as in salt water areas. The difference in salt water areas is 19 grams of NaCl.

The salinity in fresh water areas must increase with 19grams of NaCl per liter water to get the same amount of power.

Per day there is a flow of 1050000 liters (1050 m^3 per day). The needed amount of NaCl per day is:

1050000*19= 19950000 g =>19950 kg => 19.95 ton

7.6 Conclusion

The conduction of fresh water is another problem in fresh water areas. Fresh water alone isn't a good conductor, the additions makes the fresh water a conductor. The fresh water also needs a small amount of NaCl. This means that a lot more tons of salt is needed.

Because a vessel earns his money with selling space this is not an option.
This system is not suitable to use in fresh water areas.

8 What is the ratio between volume and produced power?

8.1 Introduction

In this section we are going to compare the ratio between volume and produced power of the following systems:

- A 1250kW MAN B&W diesel engine.
- Membrane system (including pumps, filters, evaporators and transformer).

8.2 Volume

The volume of the MAN B&W diesel engine is 6 x 2 x 1,5 = 18m^3.

The membrane system consists of 1000m^2 of membranes. To create a space between a pair of membranes spacers are added. Every m^2 of membrane with a spacer has a width of 1mm. So the membrane system itself takes 1m^3.

The dimensions of an evaporator are: L= 1.47m D= 2.47m H=2.685m Volume= 9.55m^3
Total volume of seven evaporators = 66.9m^3

The dimensions of one pump are: L= 0.834m D= 0.450m H= 0.225 Volume= 0.34m^3
Total volume of 2 pumps = 0.6m^3

The dimensions of a filter are: L= 0.23m D= 0.23m H=0.32m Volume= 0.017m^3
Total volume of 3 filters 0.05 m^3

The piping system will not be included in the calculations

Volume membrane systeem	Volume (m^3)
Membrane	**1**
Evaporator	**66.9**
Pumps	**0.34**
Filters	**0.02**
Total	**68.26**

8.3 Produced power

The theoretical power of the MAN B&W diesel engine is 1250 kW
The efficiency of this engine is 48%
Effective power: 600kW

The theoretical power of the membrane system is 5,85 kW
The efficiency of this system is 12%
Effective power : 708Watt

8.4 Efficiency

Explanation of the efficiency:
5.85 kW is the theoretic power. This calculation is in a perfect condition (without losses). In a perfect condition the fluids have an infinity time to exchange ions. Because in practice this will not happen, a loss of 80% will be calculated.

Pumps and filters will also give a loss of power. A loss of 8% will be calculated. Together with the 80% loss mentioned before the effective power of the membrane system will be
Pe = 5850 [W] * 0.12 = 708 Watt

8.5 Power

Explanation theoretical power.(all figures are explained in chapter 8)
The power of a membrane system is depending on a few things:

- Salinity difference (NaCl difference)
- Water flow
- m^2 of membrane

Salinity difference.

Brine of the evaporator	= 37 g/l
Sea water mixed with fresh water	= 18 g/l -
Salinity difference	= 19 g/l

These figures must be converted to another unit to make calculations.
Conversion of g/l to mol/l.
To calculated this, the molar mass of NaCl is needed. This is 58,4425 g/mol.

Brine	= 37/58.4425	= 0.633
Mixed	= 18/58.4425	= 0.307-
Difference		= 0.326 mol/l

Water flow.
There are two flows of water a "fresh" and a salt water flow.
The fresh water will be made in an evaporator (525 m^3/day). Because the water needs to conduct current 525 m^3/day salt water will be added to the fresh water.
The brine of the evaporator will be used for the sea water. Because the brine has a higher salinity than normal sea water. There is more than enough brine.

Mixed water flow	= 1050 m^3/day
Brine water flow	= 1050 m^3/day

m^2 of membrane.
Now the water flow and the salinity is know, the m^2 of membrane can be calculated.
KEMA did a calculation with the outcome of 1000 m^2 of needed membrane.

Theoretical power.
This is also something KEMA did. KEMA had an outcome of 5.85 kW.

8.6 Conclusion

The table gives an indication of the volume, effective power and efficiency of a MAN B&W diesel generator and the membrane system. As shown in the diagram the volume in relation with the effective power is much better with a MAN B&W diesel generator than the membrane system. A membrane system cost a lot of space in relation with his capacity.

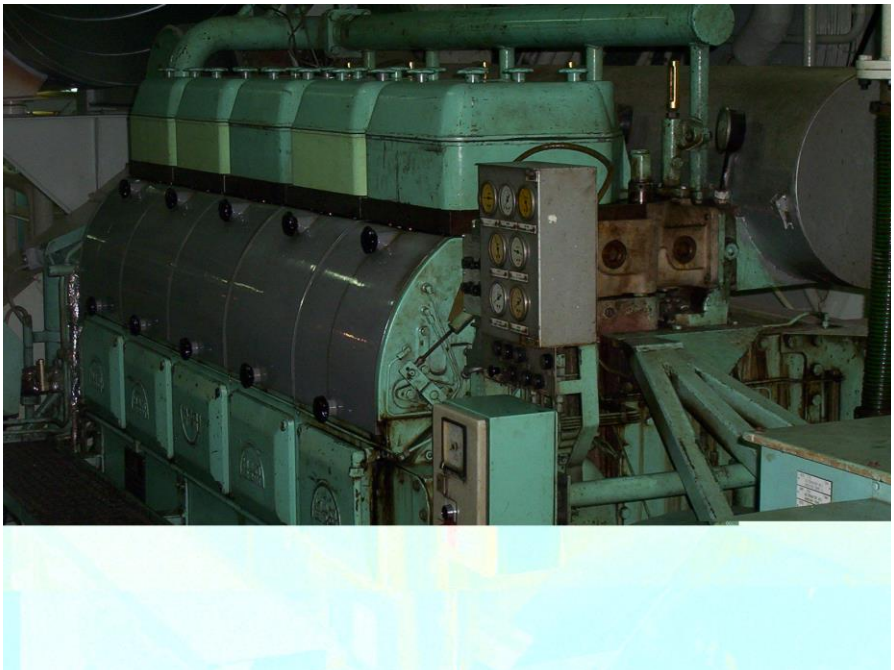
	Volume	Effective Power	Efficiency
MAN B&W	$18m^3$	600 kW	48 %
Membrane system	$68.26m^3$	0.7 kW	12%

9 What are the costs of this system, compared with other energy generators and is it in relation with the daily and long term maintenance, profitable to instal this system?

9.1 Introduction

Summarize the cost of the whole system, and compare this with other generators used on board of seagoing vessels.

In this section this system is going to be compared with an existing system to investigate its efficiency. We have chosen for a middle sized auxiliary engine which is very common on board of vessel. It regards a 1250kW MAN B&W diesel engine. A particular middle sized tanker is equipped with 3 engines with this capacity. Some items have been summarized to make it easier to compare these two systems with each other. These will be described in the following section.



9.1.1 The manufacturing costs of this system:

Engineers on board of vessels have a common rule to calculate the price of a particular new built diesel generator. According to this rule every kW corresponds to 1000USD $.
The manufacturing costs of the engine used for this comparison will be:

1250 * 1000USD $ = 1,250,000USD $
The installation costs of this system are also included in this price.

9.1.2 The costs of the auxiliary machinery

By the costs of the auxiliary machinery the daily costs are meant. These are the consumed fuel and lubrication oil of the engine mentioned above.
The fuel- and luboil consumption of this diesel engine is between 3,5- and 4,0 mt HFO in 24 hour and 24 ltrs. on an output between 500 and 600 kW. This is the required power during normal sea operation on board of a middle sized tanker.
Using the actual oil price for these calculations we will come to the following values:

Actual price IFO380: 377,00USD $/mt
3,75 * 377,00 = 1413,75 USD $ in 24 hours

Actual price Mobilgard M330:6,26USD $/ltr.
24 * 6,26 = 150,24USD $ in 24 hours.

Summarizing this will give a total value of 1563,99 on daily cost for this diesel engine.
The total yearly costs are 570.856,35 USD $ a year.

9.1.3 Maintenance

Maintenance is a very extensive topic when it regards the maintenance on an engine. Next to the daily maintenance (checking temperatures, oil level turbine washing etc.) the preventive maintenance is also a well known term on board of vessels. As example the same engine as used above will be taken. The total maintenance costs on board of a middle sized tanker equipped with 3 of these engines are approximately 65,000USD $ a year. This means that the total yearly maintenance costs for 1 engine is approximately 21,700USD $ a year.
These values are obtained from averages taken from the last 6 years.

9.2 Membrane system

Now the costs of this system are known we can compare them with the costs of the membrane system. As you can see in the previous sub questions we compare the average diesel engine with a membrane system. A membrane system with an input of 1000 m3 fresh and 1000 m3 salt water a day and a produced theoretical power of 5,85 KW.

9.2.1 The manufacturing costs of this system

The installation of a membrane system like this has never been done before. Therefore we first make a part list of the system. The prices of the parts are multiplied by the needed amount.

Element	Price per unit (USD)	Total price (USD)
Membranes	7,09	7.090
Pumps	9.923	19.846
Evaporator	125.720	880.040
Transformers	450	450
Filter	32.128	64.257
Other accessories	1000	1.000
		972.683

The total sum of the prices is 972.683 USD. The installation costs of this system are also included in this price.

9.2.2 The costs of the membrane system

By the costs of the membrane system the daily costs are meant.
Due to pollution of the membranes they need to be back flushed.
When the system is back flushing, there is no output. There is no knowledge how often, and how long the back flush process will take. Therefore we cannot tell what the costs of the back flushing will be. This will be shown from practice. So currently the costs are negligible.

9.2.3 The maintenance of the membrane system

The membrane system on a sea going vessel has never been done before.
The cost of the system is a reflex we assume to get, from all the individual parts together.
Therefore it is very difficult to determine the costs of the maintenance.

9.2.3.1 Membranes

The membranes need to be cleaned sometimes. The dirt between the membranes is coming from the salt. The salt provides fouling (biological film) between the membranes.
Fouling reduces the output of the membrane system. Dirt coming from the seawater like sand is filtered out before the water entered the membrane. The only maintenance cost of the membranes is the lost of produced power when the system is not running because it need to be cleaned.

9.2.3.2 Pumps

Type: Neptune

Seals and bearings of the pumps need to be replaced preventive.
The overhauling time is based on running hours. The centrifugal pumps need to be overhauled approximately once a year or when the pump is leaking around the shaft. The overhauling costs are 500 USD. For the membrane system we use two pumps. The maintenance costs are 1000 USD/year.

9.2.3.3 Evaporators

The maintenance cost of one evaporator is about 4100 USD a year. Multiplied by the amount of evaporators were the system consists of: 28.700 USD a year.

9.2.3.4 Transformer

Under normal load the transformer needs to be checked once a year. This is done by means of a temperature check. The temperature check can be done with an IR camera. High temperature means dirt/dust. This dirt decreases heat removal and winding lifetime. The transformer can be cleaned with a vacuum. The maintenance costs during operation are very low. The costs are negligible

9.2.3.5 Filters
Because of the small spaces between the membranes the sea water need to be very clean. Therefore we need a type alf90 from Alfa Laval. This is a self cleaning filter. The maintenance cost of one filter is about 1400 USD a year. We have too of these filters, so the total maintenance cost is about 2800 USD a year.

The total of maintenance costs are shown in the figure below.

Element	Price (USD)	Total price (USD)
Membranes	X	x
Pumps	500	1000
Evaporator	4.100	28.700
Transformers	X	x
Filter	1400	2800
Other accessories	X	x
Total maintenance costs		32.500

9.3 Conclusion

In this chapter all the costs of both systems are described. The above mentioned prices are from the following companies; Kema, Nijhuis pompen BV. and Alfa Laval. In the next chapter all the numbers from this chapter together with the numbers of the previous chapters are together in one table. In this way you will get a clear view of the numbers, so it is easier too give a good conclusion.

10 Is this system profitable in relation to other generators?

10.1 Conclusion

In this section we are going to make a conclusion of the system using the calculated values from a diesel generator and the membrane system.

	Membrane system	**Diesel Generator**
Volume(m^3)	68,2	18
Capacity(kW)	5,85	1250
Efficiency(η)	0,12	0,48
Installation costs (USD)	972.683	1.250.000
Maintenance costs (USD)	32.500	21.700
Yearly costs (USD)	0	570.856,35

To get a good compare the values are divided, by the capacity of each system. As shown in the table below per KW, it is clear that the membrane system is in all way less sufficient then the conventional generator.

	Membrane system	**Diesel Generator**
Volume(m3)	11,65	0,0144
Capacity(kW)	1	1
Efficiency(η)	0,12	0,48
Installation costs (USD)	166.270	10.000
Maintenance costs (USD)	5.555	12
Yearly costs (USD)	0	456

10.2 Advises for further investigation

From the above mentioned values we can conclude that this system is non effective.
But the membrane system can be more attractive in the future. This is because of the increasing of the costs of marine diesel oil. This increasing is caused by the stringent requirement of the diesel quality. This quality improvement has got one purpose "Reduction of emissions". In the table below we make a break-even calculation between the conventional diesel engine and membrane system in relation too the increasing of the costs of marine diesel oil. In this table we assume a life time of at least 20 years.

Costs (USD)	**Membrane**	**Diesel engine**
Installation	8.313	500
Maintenance	5.555	12
Running	0	4.561
Total Yearly costs (USD)/Kw	13.868	968

13.868-(500+12)= 13.356
13.356*1250= 16.695.000 USD/Year
16.695.000 /365= 45.739 USD/24h
45.739 /3,75= 12.197 USD/mt

The costs of 1 mt is now 377 USD.
This mean's that the oil price need to be 32 times higher than it is now.
In relation too the increasing of the diesel oil price we can conclude that the system is non effective.

Because of the clean producing of KW's it may be that the government will partly finance the costs of this system to work on a better environment. This is the same principle as with cars.

Furthermore the membrane system is still in the test phase, and can be improved. Companies are still improving the membranes. This means that the membranes pass the ions faster and more effective. If the membranes are being more developed in the future, the system can have a smaller volume and less of seawater input for the same output.

Another point that can be approved in the future, is the recycling of the residue.

The fresh side of the membrane.
When the residue from the membrane will be recycled, and go's back too the inlet of the membrane mixed with the new seawater, the water will be less \salt

The salt side of the system.
The advises for further investigation of the salt side of the system. If the salinity difference can be higher, the power will also increase. If the salt water side contains more NaCl, the salinity difference will be higher, so as the power output. If an effective way of making this high concentrated NaCl water can be found. The system will get a better performance.

11. Sources

With the help of the following sources this project has been a success:

Internetsites:
- http://www.lenntech.com/membrane-cleaning.htm
- www.alfalaval.nl
- www.kema.nl
- www.redstack.nl
- www.MANB&W.com
- www.bunkerworld.com
- www.osmarine.nl
- http://sedac.ciesin.columbia.edu/entri/texts/acrc/maniv.txt.html
- http://www.water.siemens.com

Books and literatures:
- “MARPOL Consolidated IMO”
- “Scheepsdieselmotoren”
- “Chemie Overal”
- Hulpwerktuigen 1

Companies:
- HRO
- KEMA
- Alfa Laval
- JO Tankers B.V.
- Scheepvaar & Transportcollege Rotterdam