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Title: Evaluation of Potential for Refrigerant Recovery from Decommissioned Shipping Containers at California Ports

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EXECUTIVE SUMMARY

BACKGROUND

During the next thirty years it is expected that the total export and import business in the United States will increase by more than two and one-half times. The fastest growing proportion of the industry is refrigerated shipping containers, RSCs, which represent at present 30% of the shipping container traffic, and it very important that the shipping ports in California operate in an economically and environmentally friendly manner. The primary purpose of the present study was to investigate the emissions that are associated with this important and dynamic industry. It is well known that the United States imports more goods than it exports, but California Ports export more food products than are imported as shown in Figure 1es.

Shown in metric revenue tons

Figure 1es. Export and import statistics by commodity for the Port of Long Beach for the year 2009 (Note: Either the weight in kilograms or the volume in cubic meters, depending on what is larger, is used to determine the metric revenue tons)

In the current international operating environment there are four sources of emissions from the refrigerated shipping containers, and these sources are the following:

- Direct leakage of the RSC refrigerant. The most used refrigerant at the present time is HFC-134a, Figure 2e, which has a high global warming potential, GWP. However, most of the other refrigerants employed, such as R-404A are even higher than HFC-134a in GWP.
- Emissions from the diesel auxiliary power units, APU, engines used during road and rail transport or when shore power is not available.
- Emission of refrigerant from decommissioned shipping containers when placed out of service.
- Emissions from controlled atmospheres in the shipping containers, such as ethylene for fruit storage, not covered in this study. However, the need to precisely control the levels of O_2, CO_2, and N_2 in the container will be discussed, in order to show the level of sophistication that exists in the industry.

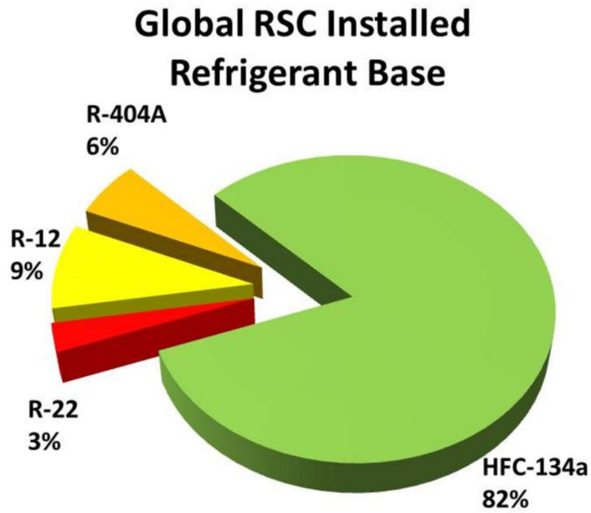


Figure 2es Global installed base of refrigerants used in Refrigerated Shipping Containers, 2010.

Before the recent developments in the use of refrigerated intermodal containers the typical refrigeration system on a reefer ship lasted 20 years, and it suffered from an average refrigerant leakage rate of 25% annually. This leakage rate was a large source of greenhouse emissions, and before the present study it was not known if the new container RSCs had similar leakage rates.

Another unknown concerning the use of RSCs was their rate of decommissioning due to their harsh environment, and there was confusion in the environmental community concerning the large and massive stacks of RSCs that sometimes accumulate in the ports. As a result of the present study it was determined that ***massive stacks of RSCs in California ports regions are not decommissioned RSCs***. The massive stacks of RSCs are stored in California port regions for seasonal industries such as agriculture, and it should be remembered that more food is exported from California ports than is imported. In fact, almost all seasonal industries typically have a capacity problem, especially in good years, and large quantities of containers and transportation equipment are acquired in advance to distribute a seasonal product.

METHODS

In order to develop the knowledge and information necessary to understand the international refrigerated shipping container industry it was necessary to visit and study the industry. The following important information, visits, and analysis were accomplished during the investigation: (1) Technical information and specifications for RSCs was obtained from the manufacturers; (2) A visit to a manufacturer of RSCs was made to obtain current practices and new developments; (3) Visits to the ports of California were made to observe and document the handling of RSCs; (4) A visit to a maintenance, repair, and refurbishing company was made and this company works closely in and around Southern California ports; and (5) An engineering analysis was carried out on the RSCs technical data, and as a result of this engineering analysis estimates of the emissions were made.

Due to the high level of security at California Ports ***special permissions*** are required for visits by individuals at California Ports. Knowledgeable workers inside the port themselves also had to be identified, and these workers had to be willing to answer technical questions concerning the operation and maintenance associated with the container refrigeration industry. Fortunately for the present project, the CARB Enforcement Division carries out regular inspection of the diesel generator sets used for RSCs during their intermodal use on trucks and trains. These staff members from the enforcement division of CARB were able to escort Professor Dwyer into the ports of Long Beach, Los Angeles, and Oakland, and they also identified those workers who were knowledgeable about the use and maintenance of RSCs.

In order to understand the data that was obtained in the investigation, it is necessary to explain how the ports are organized and how RSCs are used and distributed for international trade. More than 50% of the RSCs used for international trade are owned by leasing companies and the rest by shipping companies. The vast majority of RSCs are manufactured and assembled in Asia, and RSCs spend most of their time outside the USA due to ocean travel and time in foreign ports. There is no guarantee that an individual RSC will remain limited to trade with a single country, and they are typically traded between countries and trade routes due to seasonal influences.

In the California ports there are many different types of facilities that are organized into terminals. The individual terminals specialize in different types of cargoes, such as bulk goods, containers, autos, and etc. The terminals are independently owned, and they have responsibility for security, working with customs, and transporting the cargo from the ships to shippers inside the USA. Within a container terminal there is further specialization since refrigerated cargo must be connected to an electrical supply.

The employees of an individual terminal are independent of the shipping companies and the RSC manufacturers, and they are responsible for the pre-trip checkout of the RSCs and minor repairs. The terminals also contract with independent maintenance companies located outside the ports, in order to obtain parts and to carry out complicated repairs. As part of this contract Professor Dwyer interviewed three different terminals supervisors and one maintenance company supervisor who specialized in RSCs. The supervisors answered all of Professor Dwyer's questions, and they escorted Professor Dwyer on tours of the facilities. During the tours Professor Dwyer observed workers repairing RSCs and replacing refrigerant using proper protocols. Almost all of the in use data obtained in this report was obtained from the interviews with the supervisors.

RESULTS

Recent Improvements in the Refrigerated Shipping Container Industry

During the last 15 years there have been very important and significant engineering advances in all parts of the RSC industry, and these advances have been in the structural integrity of the container and in the refrigeration system itself. A summary of these advances is now given.

Structural Integrity – Compared to a typical trailer refrigeration unit, TRU, used on the roads in the United States, a RSC has to be much stronger and more air or gas tight. For example, a container ship fully loaded with refrigerated containers is typically stacked with RSCs more than five high with full heavy loads. This type of stacking requires that a RSC has to be more than an order of magnitude stronger than containers that are not stacked. Furthermore, the RSCs are continually loaded and unloaded from ships to stacked storage, to trucks, or to rail systems, and these intermodal transfers add wear and tear to the individual containers. If we add the ocean environment, ocean storms, and rail travel, we have an extremely difficult physical environment for an RSC. In fact the port supervisors and maintenance staff stated they have never loaded or unloaded a RSC more than ten years old, and this lifetime is due to the harsh environment of the RSC. RSCs are not inspected by any port authorities, and the decommissioning is determined by pre-trip inspections or in-service failures.

Refrigeration System Improvements – Over the last twenty years there has been very significant improvements in the refrigeration systems used in RSCs, and the improvements include both the refrigerants used and the equipment used to cool the refrigerated load. The original refrigerant used in RSCs was R12, which has an Ozone Depleting Potential, ODP, of 1, and its use was discontinued due to serious environmental problems associated with earth's ozone layer. At the present time the most popular refrigerants for new RSCs in California Ports are HFC-134a and R-404A, which both have an ODP of 0. However, both refrigerants have a significant Global Warming Potential, GWP, and their one hundred year GWP values are the following: GWP(HFC134a)=1300 and GWP(R-404A)=3260 (Note: Refrigerant R-404A is a mixture of three refrigerants). Also, the refrigerant R-404A has a working pressure in the refrigeration system that is 1.9 times higher than HFC=134a, and this fact can lead to a higher potential for leakage. For example, for equivalently designed refrigeration systems the leakage rate is proportional to the working pressure squared, or a leakage rate 3.6 times larger for refrigerant R-404A. Therefore, since refrigerant HFC-134a has a lower GWP and a lower working pressure, there are potential advantages of HFC-134a over refrigerant R-404A.

The efficiency of a refrigeration system is measured in terms of the Coefficient of Performance, COP, which is the ratio of the cooling energy achieved to the energy input required for the cooling to occur, or

$$COP = \frac{Cooling\,Energy\,Achieved}{Energy\,Input\,Required}$$

The COP has improved from 0.73 to 1.1, Ref. [4], over an almost 20 year period, and this represents an improvement of more than 50%. It should also be mentioned that there is a significant decrease in CO_2 emissions.

Estimates of Refrigerant Emissions from Refrigerated Shipping Containers in California Port Regions

Emissions from Decommissioning of RSCs

A very important fact that was obtained from this study was that ***massive stacks of RSCs in California ports regions are not decommissioned RSCs***. The massive stacks of RSCs are stored in California port regions for seasonal industries such as agriculture, and it should also be remembered that more food is exported from California ports than is imported. In fact almost all seasonal industries typically have a capacity problem, especially in good years, and large quantities of containers and transportation equipment are acquired in advance to distribute a seasonal product.

Since RSCs typically have a valuable load and are stacked on the outside of a ship, they are a given a pre-trip inspection before each trip. The purpose of the pre-trip inspection is to insure that the refrigerated cargo will reach its destination without damage, and both current and future RSC problems are identified and recorded for an individual RSC. If a repair is necessary and less than $500, it is usually carried out in the field. For repairs between $500 and $2000 the permission of the owner of the RSC is contacted for approval of the maintenance, and for repairs greater than $2000 consideration is given to the decommissioning of the RSC. If the RSC is less than 3 years old, it is usually covered under warranty, as long as the repair problem is not due to an accident or due to negligence. The sale price for a new RSC and generator set varies from $30,000 to $50,000 depending on RSC size and the level of sophistication of the refrigerant system.

If a decision is made to decommission a RSC, the following process is usually carried out: (1) The refrigerant is removed using the EPA procedure 40 CFR 82 F; (2) The salvageable parts of the refrigeration system are recovered, such as generators, compressors, etc.; and (3) The container is placed back into service for non-refrigerated loads. In our visits to California ports with the enforcement division of CARB we have observed refrigerant being removed with the prescribed equipment for EPA 40 CFR 82 F, and all of the workers in the port regions were completely aware and familiar with the ***need for and the use of this method*** of removing refrigerant from damaged or decommissioned RSCs. Therefore, the primary way that refrigerant is emitted from a RSC, other than leakage, is by accidents.

The following information, data, and calculations will be used to estimate refrigerant emissions from decommissioning of RSCs in California Ports

a. Based on discussions at the terminals in California Ports the Average Lifetime for an RSC is 10 years.

b. California ports fully comply with EPA regulation CFR 82F, and refrigerant is properly recovered from all RSCs that are decommissioned at or near California ports. However, the equipment used for regulation CFR 82F is currently able to recover between 80 and 90 percent of the refrigerant in a RSC. If the presently used refrigerants are replaced by CO_2 refrigeration systems then the lack of full recovery of the refrigerant could be eliminated.

Since 13,000 RSCs are decommissioned in California, it will be assumed that 15% of the refrigerant is not recovery using the CFR 82F protocol, and the refrigerant load is assumed to be 15 kg. The amount of refrigerant lost can be calculated as

$$Non-Recovered Refrigerant = (13{,}000)x(15)x(.15) = 29{,}250\ kg$$

c. Since the intermodal transport environment is harsh, it will be assumed that 1/2% of the RSCs are decommissioned due to accidents in the port regions, and the accidents occur equally in foreign and California ports. It will also be assumed that an engineering recover system for refrigerant could be developed in the future, and it could prevent the refrigerant from being vented in the future.

With the assumptions listed above the, we obtain the number of accidents per year as the following:

$$Number\ of\ Decommissioning\ Accidents = .005x\frac{260{,}000}{2} = 650$$

d. It will be assumed that 15 kg of refrigerant charge is released during the accident, and the total of refrigerant vented is

$$Refrigerant\ Released\ in\ Accidents = (Number\ of\ \ Accidents)\ x\ (RefrigerantCharge)$$

$$Refrigerant\ Released\ in\ Accidents = 650x15 = 9750\ kg$$

e. The RSCs in California ports only use refrigerants HFC-134a and R-404A, and we will assume an average Green House Warming Potential, GWP, of 2500.

With the information listed we can estimate the total equivalent amount of CO2 released by the refrigerant as

$$\boldsymbol{CO_2\ Equivalent = CO_2E = Refrigerant\ Released\ x\ GWP = (9{,}750 + 29{,}250)x2500}$$
$$\boldsymbol{= 97{,}500\ MTCO_2E = 0.0975\ MMTCO_2E}$$

Refrigerant Emissions due to Leakage from RSC systems

Another potential loss of refrigerant related to RSCs is leakage of refrigerant, and refrigerant leakage is common to almost all refrigeration systems due to their high pressure operation and the large amount of surface area needed to cool and remove ice from a RSC system. Previous estimates of leakage rates, References [2], [3], and [5], were based on outdated information, and new updated data has been obtained by visits to manufacturers, ports, and maintenance facilities. The new information and data from the terminals have yielded the following estimates:

a. Based on discussions with terminal supervisors it was estimated that the RSCs leakage rate was less than 1% for the first 3 years of being used, and at the end of life the leakage was approximately 10%. Therefore, at leakage of 5% was assumed during the lifetime of the RSC.

b. From the estimate on the number of trips per year it is consistent to assume that 1,666,000 RSCs spend 10 days in port per export/import cycle. This data is equivalent to having 45,640 RSCs working in the ports per year, or

$$Yearly\ Equivalent\ RSCs = 1{,}666{,}000\ x\ \frac{10}{365} = 45{,}640$$

Using a 5% leakage rate, a 15 kg charge, and a 2500 GWP, we calculate the refrigerant leakage rate as

$$Refrigerant\ Leakage\ Rate = (Leakage\ Rate\ )\ x\ (Refrigerant\ Charge)\ x\ (Yearly\ Equivalent\ RSCs)$$

$$Refrigerant\ Leakage\ Rate = (.05\ )\ x\ (15)\ x\ (45{,}640) = 34{,}200\ kg$$

Assuming a GWP of 2500 for the refrigerant we obtain the equivalent CO_2 emissions as

$$\boldsymbol{CO_2\ Emissions\ \ from\ Refrigerant\ Leakage = 34{,}200\ x\ 2500 = .0855\ MMTCO_2E}$$

Estimates of Emissions Associated with Diesel Generator Sets Attached to RSCs

With the large increases that have occurred with the use of intermodal shipping containers there have been significant increases in diesel engine generator sets used to power the RSCs during intermodal transport. While the RSCs are on the ship and stored in the port they are fully powered by ship or shore electrical power, but as soon as they are transferred to a truck trailer or rail car, they are powered by a diesel generator set. RSCs are usually transferred to a truck trailer immediately before they exit the port itself, and the largest portion of the RSCs are transported by truck to California locations and most of the California locations are in southern California. From the economic viewpoint truck intermodal transport is competitive with other transportation methods up to a distance of 500 miles, but for larger distances rail intermodal transport is usually more economical unless there is a time constraint associated with the load.

The type of intermodal transport of RSCs in port areas that is increasing the most is rail transport, and almost all rail transport of RSCs is powered by a diesel generator set. In the past, electrical power from central train generators was available for RSCs for rail intermodal transport, but the use of attached diesel generators has proved to be more cost effective and convenient than a central source of electrical power. One of the major reasons for increasing intermodal rail transport is to decrease the number of truck trips into the ports, but there are some important differences with the use of rail for RSCs compared to non-refrigerated cargoes, since the electrical power source is an attached diesel engine.

During the entire transport of a RSC it is continually powered by fossil fuels, but with the use of shore power the port criteria pollutants are dramatically lower than the criteria pollutants from an attached diesel gen set. For this reason we have calculated the diesel fuel use by the diesel gen sets in the port regions. It should also be mentioned that the criteria emissions from the RSC attached diesel gen sets are not presently accounted for in the port inventories.

Based on the current literature concerning the average power requirements for a RSC we have made the following estimates for emissions from diesel generator sets used to power RSCs in the port areas.

a. From the shipping companies reports the average power requirement for an RSC is 7 kW.

b. Assume that a RSC is powered for one day in the port regions. This assumption is a little long for a truck, and it is somewhat short for train.

c. The average fuel consumption rate for a RSC using 7 kW of power is ¾ of a gallon.

Therefore, the effective full time use of diesel gen sets is given by the following formula

$$\textit{Yearly Equivalent Diesel Gen Sets} = 1{,}666{,}000 \; x \; \frac{1}{365} = 4{,}564$$

The yearly amount of diesel fuel used by the diesel gen sets is given as

$$\begin{aligned}\textit{Total Diesel Gen Set Fuel Use} &= 3/4(\textit{gallons}) \; x \; 4564(\textit{GenSets}) \; x \; 24(\textit{hours}) \; x \; 365(\textit{days}) \\ &= 29{,}999{,}000 \; (\textit{gal diesel fuel}) / \textit{year}\end{aligned}$$

Using the density of light diesel fuel as approximately 800 kg/m3, and mass amount of diesel fuel can be calculated as

$$\textit{Mass of Diesel Fuel Used} = 90{,}837{,}000 \; (\textit{kg diesel fuel}) / \textit{year}$$

Of course, the use of diesel fuel generates CO_2 emissions as well as criteria pollutions, and the CO_2 emissions can be obtained from the carbon content of diesel. For an approximate diesel fuel molecular weight of 170, diesel fuel can be represented as $C_{12.3}$ $H_{22.1}$, which gives a carbon content of 86.8 %. Therefore, the CO2 emissions from

$$\boldsymbol{CO_2 \textit{ Emissions from Diesel Fuel} = (90{,}837{,}000) \; x \; (.868) \; x \; \frac{44}{12} = 289{,}100{,}000 \textit{ kg } CO_2 \,/\, \textit{year}}$$

$= \mathbf{0.289\ MMTCO_2E\ /\ year}$

It is interesting to compare diesel fuel from RSC Gen Sets to estimates from the idling of diesel trucks at California Ports 2007, Ref. [8], which is 2,920,000 gals/year. Comparing these two numbers we come to the conclusion that the diesel fuel used to power RSC generator sets in the port areas is more than 10 times larger than the diesel fuel used to power idling of diesel trucks in California ports. Also, the emission standards for diesel generator sets in the year 2007 are not as good as the diesel trucks at idle, and the corresponding emissions will be larger per gallon of diesel fuel used for diesel generator sets relative to diesel trucks idling.

Another important point to remember is that the generator sets that are used to power RSCs are California based, and they have to meet the standards of the "TRU Airborne Toxic Control Measure". This measure will insure that in-use engines meet the most stringent standard of Ultra-Low-Emission TRU (ULETRU), and the measure insures that all new engines will meet the most stringent standard by January 1, 2013. All TRUs and TRU gen sets should meet the TRU in-use standard by 2020. In general this measure will greatly improve the emissions characteristics of the diesel engines used for the generator sets of RSCs.

Summary of the Total Emissions from RSCs in California Port Regions

The total emissions from RSCs in California port regions are presented in Table I.es, and these results are considerably lower than previous estimates.

Table I. Summary of total RSC emissions at port regions

Emission Category	**($MMTCO_2E$)**
Decommissioning of Shipping Containers	0.0975
Leakage of Refrigerant	0.0855
Shipping Container Diesel Engines	0.289
Total Sum of Emissions	**0.472**

IMPORTANT NEW DEVELOPMENTS IN THE USE OF CO_2 REFRIGERANTS FOR REFRIGERATED SHIPPING CONTAINERS

During the last few years the RSC manufacturing companies have made substantial progress in the development of a RSC that uses the natural refrigerant CO_2, and they have had test demonstrations during the last two years. While CO_2 was long considered as an ideal working medium for refrigeration systems, there was always a penalty in energy performance. The use of CO_2 in stationary commercial refrigeration has grown rapidly in northern Europe, and compressor manufacturers and suppliers of refrigeration system components have developed designs that optimize performance of CO_2 systems. The use of CO_2 as a commercial refrigerant has been the most rapid for stationary commercial refrigeration systems, and the developments in this part of the refrigeration industry has shown that CO_2 systems can be as energy efficient as HFC systems, Ref. [4].

Demonstrations by the RSC industry have been carried out and they have resulted in enough progress that it is expected to have CO_2 refrigeration systems that will play an ever increasing role in the RSC industry. In the future the major complication of CO_2 systems will be the increased leakage of CO_2 due to the high operating pressures in the compressor. However, the RSC industry is high tech, and there is regular maintenance with pre-trip inspections that can easily treat this potential problem.

IMPORTANT NEW DEVELOPMENTS IN THE SHIPPING CONTAINER INDUSTRY

Although the emissions from container ships are not a topic that was proposed to be covered in this investigation, some brief comments will be made about the progress and problems in the industry. This progress has been most dramatic on the very large container ships that are expected to achieve a cargo capacity of 18,000 TEU. These very large ships are powered by low speed two-stroke diesel engines that have overall thermal efficiencies better than most power plants today and similar to fuel cells. Therefore, these engines are among the best in the world in reducing CO_2 per unit of power produced.

At the present time large diesel engines on container ships require heavy fuel oil which contains relatively large amounts of sulfur. Recently, it has been shown that exhaust gas scrubbing is a cost effective alternative to lowering the sulphur content of fuels for reducing SOx and particulate emissions. Exhaust gas scrubbing is a feasible solution both for new installations and as a retrofit to existing ships. The SO_X removal efficiency of scrubber systems is over 97%, and it is possible to operate with a 3.5% sulphur fuel level and still have emissions levels that are equivalent to the future 0.1% sulphur fuel limit.

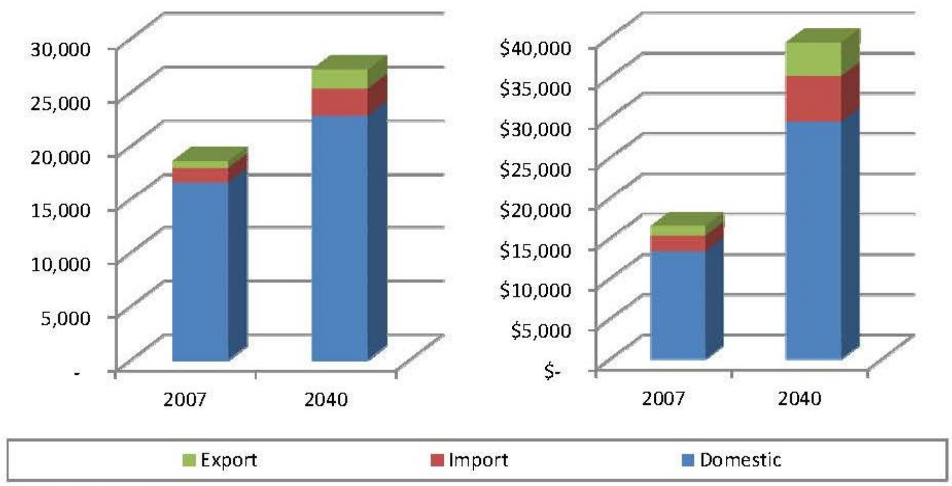
BACKGROUND AND INTRODUCTION

Some Background on Refrigerated Transport Related to California Ports

As global agriculture grows, there is a worldwide demand to expand the cold storage industry, since perishable items are the largest, most profitable, and fastest growing sector of international trade. Additionally, the export and import of frozen and refrigerated items for the retail, pharmaceutical, and food service industries are on the rise. Given these dynamic increases, the cold chain industry is quickly becoming central to all kinds of global trade in just about all commodities.

Globalization has made the relative distance between areas of the world much smaller, however the physical separation of these same regions is an important reality. The greater the physical separation, the more likely freight becomes damaged by the import and export processes. To ensure that shipments are not compromised during transport, many businesses are turning to, and relying on improved cold chain technology.

An example of the expected growth in international trade is shown in Figure 1 where the total freight tonnage and monetary value are given and predicted for the United States in the years 2007 and 2040, Ref [1].



Source: FAF 2010

Figure1. Total Freight Tonnage, left, (millions of USA tons) and Value, right, ($billions) for the United States in 2007 and the projected values in 2040

Also shown in Figure 1 are the exports and imports portions of this trade relative to the total freight values, and in terms of value both the exports and imports will grow dramatically during the period shown. For example, combined imports and exports will grow from 19% to 25% per year of the total freight value, and it should be pointed out that the total freight value itself will grow from $16.5 trillion to $39.3 trillion. Certainly this type of growth emphasizes the importance of the United States Ports, and it is imperative that the ports function in an environmentally and economically friendly fashion. [Note 1: The good news for the United States and especially California in this prediction is that there is an indication of future parity between imports and exports, 14% imports and 11% exports, which is a significant improvement over the present situation.] [Note 2: It is not expected that the long term growth of freight tonnage for the year 2040 will be influenced very much by the current recession in the USA.]

At the present time the United States does export more food products than it imports, and some results for the Port of Long Beach are shown in Figure 2, Ref. [2]. As can be seen from the figure, the present ratio of food exports to imports is more than two and one half times higher for exports. Of course, not all food products are shipped in RSCs, but food products represent a large percentage of RSC loads.

Shown in metric revenue tons

Figure 2. Export and import statistics by commodity for the Port of Long Beach for the year 2009 (Note: Either the weight in kilograms or the volume in cubic meters, depending on what is larger, is used to determine the metric revenue tons)

With the expansion of trade that is predicted, the cold chain industry must expand and move beyond a traditional cooler or freezer unit, and there has to be a close integration of all aspects of the cold chain. The current market consists of ships, refrigerated shipping containers, intermodal transportation, and quality warehouse facilities. However, the companies that offer individualized and added value services as part of a complete package succeed far beyond competitors. In the current market, customers are demanding services such as inventory tracking, recall efforts, and exporting and transportation services throughout the entire cold supply chain. Most suppliers are looking for an integrated company structure to perform all functions.

The primary components of a successful cold supply chain involves the following major players: (1) Ports; (2) Ships; (3) Refrigerated Shipping Containers; (4) Intermodal land transport; (5) Product Preparation Specialist; and (6) Refrigerated Warehousing Companies. The success of the individual companies depends on factors such as high service levels, lower cost, faster inventory turnovers, quicker reporting, and the ability to provide customers with faster and more efficient service. Instead of simply offering one service operating companies are consolidating services, making it more convenient and cost effective for their clients. For example, the cold supply chain must provide many services such as blast freezing, certificates of export, and USDA stamps of approval, consolidate the load for distribution, and make all arrangements until the shipment leaves port.

Some Background on Refrigerated Transport in the Vicinity of Ports

In this section of the report we will use the ports of Los Angeles and Long Beach as examples to describe the structure and workings of the cold chain industries and the shipping, storage, and distribution of refrigerated products. At the present time refrigerated shipping containers dominate the industry, and their electrical refrigeration systems can be powered by ship power, shore power, or diesel engine generator sets. These systems are very flexible, and in some situations it is possible for the refrigerated shipping container to go from producer to the consumer directly. However, that situation occurs rarely, and there is a need for many intermediate steps between the producer and consumer. Shown in Figures 3 and 4 is a sketch of typical processes that are encountered for export, Figure 3, and import, Figure 4, of refrigerated shipping containers. Of particular importance in Figures 3 and 4 are the many possibilities for the refrigerated shipping container to be repaired, refurbished, or recycled during the import or export paths. These types of actions are possible since refrigerated shipping containers are sophisticated and expensive devices. It should also be mentioned that the typical value of a refrigerated load is $300,000, and for this reason alone there are very strict pre-trip inspections and checkouts of RSCs.

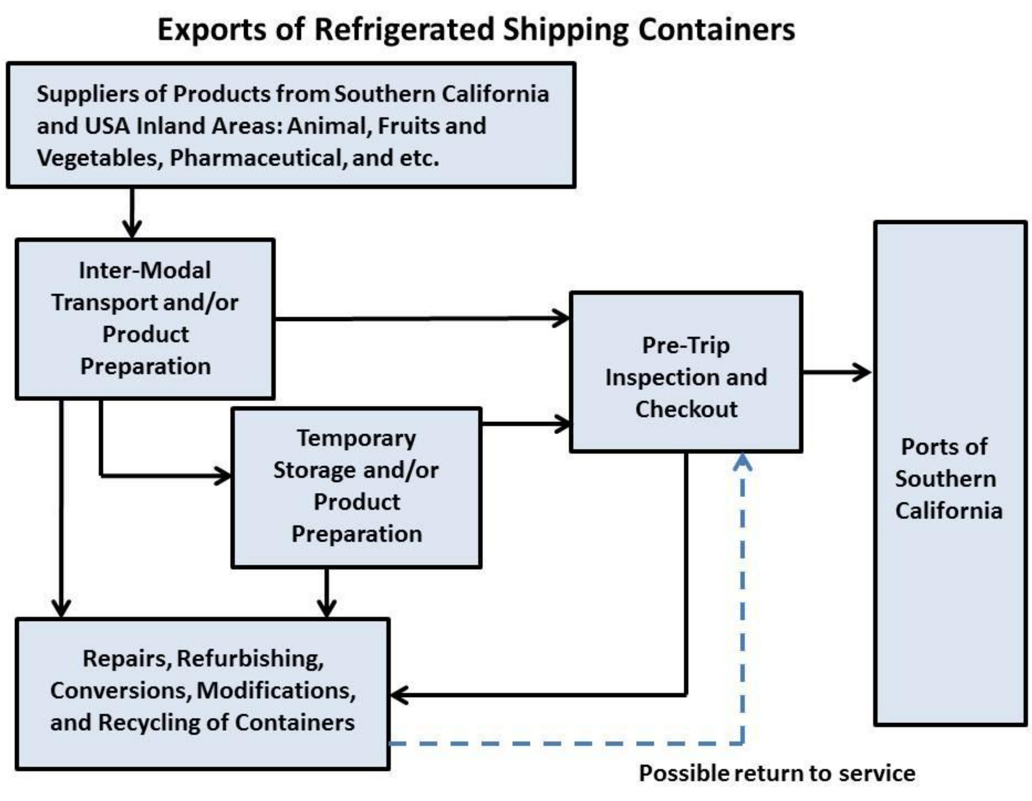


Figure 3 – Steps in the Export of Refrigerated Products from California Ports

We begin by considering the export of refrigerated products from Southern California locations which are dominated by the Ports of Los Angeles and Long Beach. At the present time, the major suppliers are local, inland states, and products from northern Mexico, and the products cover a wide range, such as animal, vegetable, fruit, and pharmaceutical. In general, the product can be transported directly by truck or rail, or prepared and packaged for intermodal transport at a temporary location. In some cases a controlled atmosphere is necessary to keep the product from damage during transportation to the final consumer.

Many large inland product suppliers, such as meat packers, have the ability to prepare their product for a refrigerated shipping container, and ship the product directly to the port. However, a large number of suppliers must use temporary storage warehouses to prepare, package, and store their product. Also, there is the possibility of an individual shipping container transporting different loads at different temperatures.

In order to support the cold supply chain there are many facilities surrounding the ports, and these facilities take up a space that is much larger than the port itself. For example, a partial list of the support facilities in the Los Angeles/Long Beach regions is the following:

- Near-Port cold storage facilities – 8 facilities for all California ports
- Inland Empire – Home of 350 million square feet of warehousing
- Alameda Corridor – 20 miles of port facilities outside the ports
- Support facilities for trucking and refrigeration

In order to understand the issues and emissions from refrigerated shipping containers it is necessary to include the entire infrastructure of the cold chain shipping industry, not just the port areas.

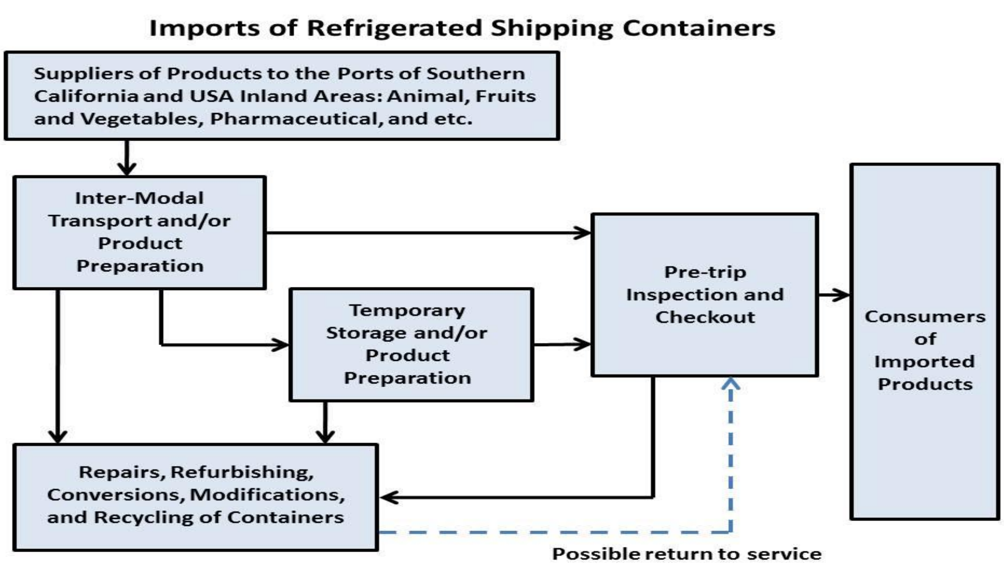


Figure 4 – Steps in the Import of Refrigerated Products to California Ports Shipping Containers and Their Emissions

Background on Emissions from Refrigerated Shipping Containers

The primary purpose of this research is to determine the sources of emissions from refrigerated shipping containers, and it has been necessary to consider the entire port area rather than just the port itself. Both refrigerant and regulated emissions from shipping containers are recognized as a possible significant source of greenhouse gases (GHGs), and at the present time we lack basic information about the total refrigeration operation. As can be seen from the discussion given previously, the refrigeration process involves a complex interaction from the product supplier, to intermodal transport, to temporary storage, to ocean shipper, to port, to temporary storage again, to intermodal transport again, to wholesaler, and to seller.

Refrigerated shipping containers that are involved in ocean transport face a harsh environment on the ship due to waves and storms, as well as intermodal transport on trucks and trains. For these reasons the average leakage rate was 25% of their refrigerant per year in the 1990's, which is quite large. However, an important result of the present study is that there has been a significant reduction in the RSC leakage rate due to engineering improvements. These improvements have been driven by the growth and value of the international trade in refrigerated commodities. Some RSCs are very sophisticated, since an individual container can have multiple compartments at multiple temperatures. For these reasons, they are frequently supplied with refrigerant and spare parts, and they must continually be connected to a power source. While on a ship or at a storage location electrical power can be supplied directly, but during ground transport they usually need a diesel generated set.

With this operating environment there are four sources of emissions from the refrigerated shipping containers:

- Direct leakage of the RSC refrigerant. The most used refrigerant at the present time is HFC-134a, Figure 5, which has a high global warming potential, GWP. However, most of the other commonly used refrigerants, such as R-404A are even higher than HFC-134a in GWP.
- Criteria emissions from the diesel auxiliary power units, APU, engines used during road and rail transport or when shore power is not available.
- Emission of refrigerant from decommissioned shipping containers when placed out of service.
- Emissions from controlled atmospheres in the shipping containers, such as ethylene for fruit storage, not covered in this study. However, the need to precisely control the levels of O_2, CO_2, and N_2 in the container will be discussed, in order to show the level of sophistication that exists in the industry.

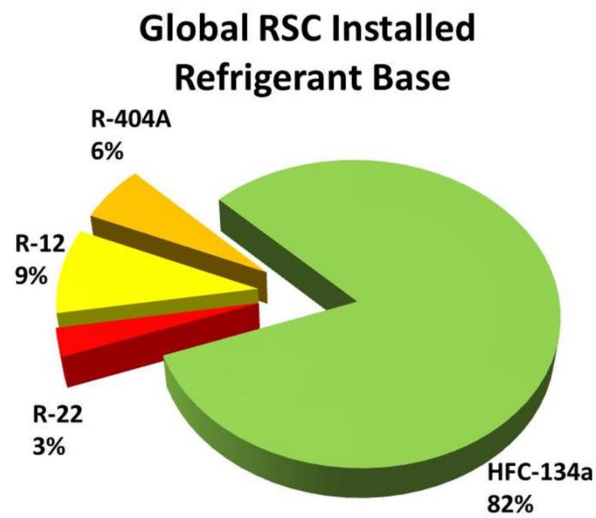


Figure 5 Global installed base of refrigerants used in Refrigerated Shipping Containers, 2010 (Data was provided by Carrier-Transicold).

As a result of the present study we are beginning to know the details of the cold chain process in the port areas, and in order to estimate the emissions we have to know the amount of time that RSCs spend in the various parts of Figures 3 and 4. Given below is a list of the questions that have been partially answered, and as a result we will be able to estimate the emissions from refrigerated shipping containers.

- How is the handling of RSCs different from non-refrigerated containers?
- What is the typical time for transport of a refrigerated shipping container on the ship, in the port area, at the port, at cold storage, and external storage waiting for transport to the consumer?
- What is the average time for empty RSC containers to be stored before shipping to a new destination? This can be a serious problem in Southern California due to the imbalance of exports over imports.
- What are the criteria for decommissioning a refrigerated shipping container?
- When a shipping container fails during intermodal transport, how is it handled?
- Where are shipping containers decommissioned? Does it go to a recycling or refurbishing company?
- What are the characteristics of a typical diesel generator used on refrigerated shipping containers?

METHODS

In order to develop the knowledge and information necessary to understand the international refrigerated shipping container industry it was necessary to obtain information about the refrigerated shipping industry by visiting and analyzing the industry. The following important information, visits, and analysis were accomplished during the investigation: (1) Technical information and specifications of RSCs were obtained from the manufacturers; (2) A visit to a manufacturer of RSCs was made to obtain current practices and new developments; (3) Visits to the container terminals of California were made to observe and document the handling of RSCs; (4) A visit was made to a maintenance, repair, and refurbishing company were made and this company works closely in and around Southern California ports; and (5) An engineering analysis was carried out on the RSCs technical data, and as a result of this engineering analysis estimates of the emissions were made.

Due to the high level of security at California Ports ***special permissions*** are required for visits by individuals at California Ports. Also, knowledgeable workers inside the terminals themselves had to be identified, and these workers had to be willing to answer technical questions concerning the operation and maintenance associated with the container refrigeration industry. Fortunately for the present project the CARB Enforcement Division carries out regular inspections of the diesel generator sets used for RSCs during their intermodal use on trucks and trains. These staff members from the enforcement division of CARB were able to escort Professor Dwyer into the ports of Long Beach, Los Angeles, and Oakland, and they also identified those workers who were knowledgeable with the use and maintenance of RSCs. However, the CARB Enforcement Division does not monitor activities of RSCs in the railroad facilities associated with California Ports due to extraordinary security and safety regulations in the rail yards. It should be mentioned that the use of RSCs for intermodal rail transport is growing and rail transport is a large percentage of the RSC industry. Also, the use of diesel generator sets is the primary way of powering the RSCs during intermodal rail transport.

In order to understand the data that was obtained in the investigation, it is necessary to explain how the container terminals are organized and how RSCs are used and distributed for international trade. More than 50% of the RSCs used for international trade are owned by leasing companies and the rest by shipping companies. The vast majority of RSCs are manufactured and assembled in Asia, and RSCs spend most of their time outside the USA due to ocean travel and time in foreign ports. There is no guarantee that an individual RSC will be limited to trade with a single country, and they are typically traded between countries and trade routes due to seasonal influences.

In the California ports there are many different types of facilities that are organized into terminals. The individual terminals specialize in different types of cargoes, such as bulk goods, containers, autos, and etc. The terminals are independently managed and owned, and they have responsibility for security, working with customs, and transporting the cargo from the ships to shippers inside the USA. Within a container terminal there is further specialization since refrigerated cargo must be connected to an electrical supply.

The employees of an individual terminal are independent of the shipping companies and the RSC manufacturers, and they are responsible for the pre-trip checkout of the RSCs and minor repairs. The terminals also contract with independent maintenance companies located outside the ports, in order to obtain parts and to carry out complicated repairs. The pre-trip checkout is required, and it is very detailed, Appendix I. For example, the refrigerant level is checked and compared with the values in the RSCs data logger, and the unit is run thru various tests. This pre-trip is essential considering the load volume, the amount of time that the product is in the container, and the load dollar value that each RSC carries on a single voyage.

As part of this contract Professor Dwyer interviewed three different terminals supervisors and one maintenance company supervisor who specialized in RSCs. The supervisors answered all of Professor Dwyer's questions, and they escorted Professor Dwyer on tours of the facilities. During the tours Professor Dwyer observed workers repairing RSCs and replacing refrigerant using proper protocols. Almost all of the in use data obtained in this report was obtained from the interviews with the supervisors. The supervisors are independent of the shippers and the RSC manufacturers, and Professor Dwyer did not have a reason to doubt the information supplied. To obtain actual data on the RSC histories, the owner of the international RSCs would have to be contacted. This could be complicated since the owners of the RSC are international companies, and special permissions would be required.

The terminals visited at California ports were the following: (1) **Long Beach-International Transportation Services Terminal** (Winner of the Port Green Flag Award); **Los Angeles-Yusen Terminal Inc.** (Winner of 3 consecutive Clean Air Action Plans); and **Oakland-Total Terminals International and SSA-Marine**. All of the owners of these terminals have both a widespread global and USA presence, and the parent organizations have their headquarters in Asia.

This project and study would like to thank ConGlobal Industries, one of the United States largest RSC equipment maintenance and repair companies, and Carrier-Transicold, the world's largest manufacturer of RSCs, for the time and effort that they devoted to help us understand their role in the refrigerated shipping container industry. ConGlobal Industries has a major presence in the Long Beach/Los Angeles port region, and a rewarding day was spent at this facility.

RESULTS

A Description of the Modern Refrigerated Shipping Container, their Construction, and their Use/Maintenance in California Port Regions

During the last 15 years there have been very important and significant engineering advances in all parts of the RSC industry, and these advances will be now described and documented. A recent paper describing some of the engineering developments is given in Appendix II, and they will now be summarized in this section.

Part 1. Structural Integrity – Compared to a typical trailer refrigeration unit, TRU, used on the roads in the United States, a RSC has to be much stronger and more air or gas tight. For example, a container ship fully loaded with refrigerated containers is shown in Figure 6, and it is seen that the RSCs are stacked more than five high with full heavy loads. This type of stacking requires that a RSC has to be more than an order of magnitude stronger than containers that are not stacked. Furthermore, the RSCs are continually loaded and unloaded from ships to stacked storage, to trucks, or to rail systems, and these intermodal transfers add wear and tear to the individual containers. If we add the ocean environment, ocean storms, and rail travel, we have an extremely difficult physical environment for an RSC. In fact the lifetime of the current high quality RSCs is no more than ten years.

Figure 6. A container ship loaded with Refrigerated Shipping Containers

Another important difference between a RSC and a TRU is the amount of time that the refrigerated load is in the container. For international transport of refrigerated loads in the Pacific Ocean region the ship time can be three weeks and the land transport time on both the export and import ends can add another three weeks. For a TRU the travel distances are typically less than 500 miles, and this equates to less than a day of travel. Therefore, both the quality of the internal cooling distribution as well as the air leakage rate from the container must be carefully controlled for international transport of refrigerated loads. The bottom line is that RSCs are very high quality refrigeration systems relative to TRU systems.

An example of the need for a high quality refrigeration system is shown in Figure 7, Reference [9]. where the atmospheric concentration conditions for optimal product delivery are presented for some fruits and vegetables as a function of the partial concentrations of CO_2 and O_2 in the shipping container. By controlling the nitrogen concentration in the container's atmosphere, the conditions in the entire graph can be obtained, while with the use of only fresh air control, the very narrow gray line can be obtained. The N_2 used to control the container concentrations is typically extracted from the outside air with the use of a special membrane separator, and the use of this system results in delivery of the product in optimal condition during ship times of many weeks. It should also be mentioned that some products, such as pharmaceuticals, require very narrow temperature control as low as one degree centigrade for the entire shipping duration.

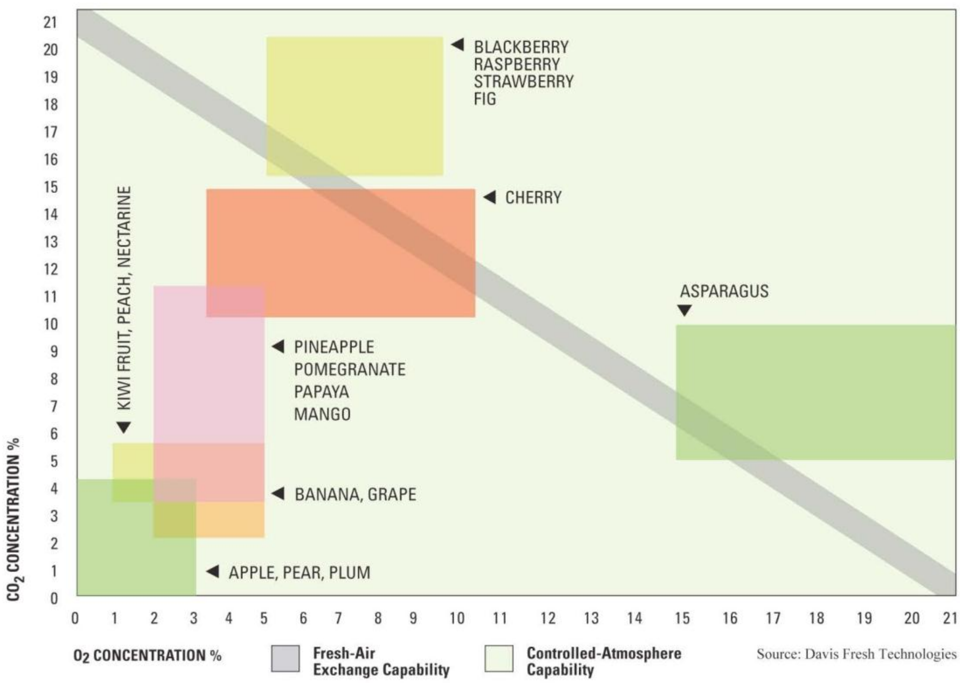
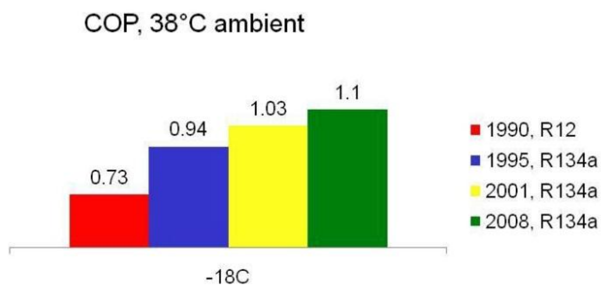


Figure 7 Shipping Container atmospheric concentrations needed for fruits and vegetables to arrive at destination port with optimal condition.

Refrigeration System Improvements – Over the last twenty years there has been very significant improvements in the refrigeration systems used in RSCs, and the improvements include both the refrigerants used and the equipment used to cool the refrigerated load. The original refrigerant used in RSCs was R12, which has an Ozone Depleting Potential, ODP, of 1, and its use was discontinued due to serious environmental problems associated with earth's ozone layer. At the present time the most popular refrigerants for new RSCs in California Ports are HFC-134a and R-404A, which both have an ODP of 0. However, both refrigerants have a significant Global Warming Potential, GWP, and their one hundred year GWP values are the following: GWP(HFC134a)=1300 and GWP(R-404A)=3260 (Note: Refrigerant R-404A is a mixture of three refrigerants). Also, the refrigerant R-404A has a working pressure in the refrigeration system that is 1.9 times higher than HFC=134a, and this fact can lead to a higher potential for leakage. For example, for equivalently designed refrigeration systems the leakage rate is proportional to the working pressure squared, or a leakage rate 3.6 times larger for refrigerant R-404A. Therefore, since refrigerant HFC-134a has a lower GWP and a lower working pressure, there are potential advantages of HFC-134a over refrigerant R-404A.

The refrigeration systems of RSCs have significant engineering advantages over the TRU systems used for road transport in United States, since they are all electrically driven refrigeration systems. A typical TRU is driven by a diesel engine and the refrigeration compressor's piston is not sealed from the atmosphere. The electrical generator used to drive the compressor and refrigeration subsystems in modern RSCs allows for many improvements in the overall energy efficiency of the RSC, and electric drive is convenient for semi-hermetically sealing the overall refrigeration system. Therefore, electric drive has made major improvements in energy efficiency and has reduced leakage.

Some of these improvements will now be shown with the use of Figure 8, Ref. [4], which illustrates some of the components of a refrigeration system and the overall improvements in RSC energy efficiency during the last 20 years.



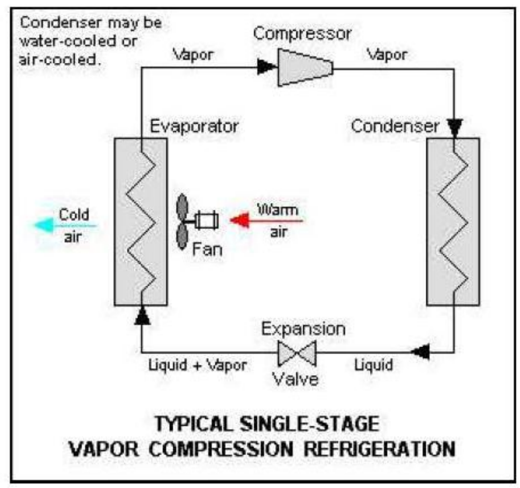


Figure 8 – Basic refrigeration cycle and energy performance improvements in recent years

The efficiency of a refrigeration system is measured in terms of the Coefficient of Performance, COP, which is the ratio of the cooling energy achieved to the energy input required for the cooling to occur, or

$$COP = \frac{Cooling\,Energy\,Achieved}{Energy\,Input\,Required}$$

From Figure 8 it seen that the COP has improved from 0.73 to 1.1 over an almost 20 year period, and this represent an improvement of more than 50%. It should also be mentioned that this represents a significant decrease in CO_2 emissions.

The energy efficiency of a RSC is a function of the temperature range of the cooling required, or the difference between the internal load temperature and the outside ambient air temperature. For the results in Fig. 8 the load temperature or set point was -18°C and the outside ambient temperature was 38°C. The temperature range can influence the type of compressor used in the RSC, and at the present time the compressors are sealed reciprocating and sealed scroll devices. The compressor typically makes up 75% of the energy required with the remaining energy used for fan power, lubrication oil pumping, and removing frost from the evaporator related components. The increase in the COP has been the result of engineering improvements in the entire refrigeration system, as well as improvements in electronic control strategies.

Another area of improvement has been the distribution of cooling gas in the container. It is very detrimental to the RSC load if there are hot and cold regions inside of a container, especially since international loads require many weeks for delivery. During the last ten years the ability to have a uniform temperature inside the container has improved dramatically due to fan design and internal distribution of the cooling gases.

Estimates of Refrigerant Emissions from Refrigerated Shipping Containers in California Port Regions

We will now present our estimates of refrigerant leakage and loss from RSCs in the port regions of California, and the two major sources are refrigerant emissions from decommissioning of RSCs and leakage of refrigerant from RSCs. We will begin with the topic of refrigerant emissions due to decommissioning, and a very important point to be made is the following, ***massive stacks of RSCs in California ports regions are not decommissioned RSCs***. The massive stacks of RSCs are stored in California port regions for seasonal industries such as agriculture, and it should also be remember that more food is exported from California ports than is imported. In fact almost all seasonal industries typically have a capacity problem, especially in good years, and large quantities of containers and transportation equipment are acquired in advance to distribute a seasonal product.

Since RSCs typically have a valuable load and are stacked on the outside of a ship, they are given a pre-trip inspection before each trip. The purpose of the pre-trip inspection is to ensure that the refrigerated cargo will reach its destination without damage, and both current and future RSC problems are identified and recorded for an individual RSC. If a repair is necessary and less than $500, it is usually carried out in the field. For repairs between $500 and $2000 the permission of the owner of the RSC is contacted for approval of the maintenance, and for repairs greater than $2000 consideration is given to the decommissioning of the RSC. If the RSC is less than 3 years old, it is usually covered under warranty, as long as the repair problem is not due to an accident or due to negligence. The sale price for a new RSC and generator set varies from $30,000 to $50,000 depending on RSC size and the level of sophistication of the refrigerant system.

If a decision is made to decommission a RSC, the following process is usually carried out: (1) The refrigerant is removed using the EPA procedure 40 CFR 82 F; (2) The salvageable parts of the refrigeration system are recovered, such as generators, compressors, etc.; and (3) The container is placed back into service for non-refrigerated loads. Note: RSCs have the best structural qualities of all containers since they are designed to have reduced leakage for periods of weeks. It should also be pointed out that the Asian Pacific trade, which is the major part of California exports and imports, is of the highest quality in the world in terms of equipment and environmental standards. In our visits to California ports with the Enforcement Division of CARB we have observed refrigerant being removed with the prescribed equipment for EPA 40 CFR 82 F, and all of the workers in the port regions were completely aware and familiar with the ***need for and the use of this method*** of removing refrigerant from damaged or decommissioned RSCs. Therefore, the primary way that refrigerant is emitted from a RSC, other than leakage, is by accidents.

Estimates will now be made of the rate at which RSCs are decommissioned. In previous reports, Refs. [2], [3], and [5], the typical lifetime of a RSC was given as 20 years, and this estimate appears to be long, based on new information. With the growth of intermodal transport of RSCs and the increased size of the ships transporting them, there has been considerable more wear and tear as well as damage, and the lifetime of an RSC is now 10 years. This decrease in lifetime is due to being directly exposed to the ocean environment and the repeated intermodal loading and unloading of the RSC on ships, trucks, and trains. In fact, the terminal supervisors and maintenance staff stated they have never loaded or unloaded a RSC more than ten years old, and this lifetime is due to the harsh environment of the RSC. RSCs are not inspected by any port authorities, and the decommissioning is determined by pre-trip inspections or in-service failures.

The first step in determining the decommissioning rate of RSCs is to estimate the number of RSCs that are required to move the yearly volume of containers exported and imported in California ports. The estimate will now be presented

a. Total Yearly Container **Volume** for both export and import in California Ports – 20 million TEU (Twenty Foot Equivalent Units)

b. Approximately 30% of the container volume is RSCs or 6 million TEU

c. How many RSCs are needed? – Since the majority of the RSCs are 40 foot long we have to estimate the average size of a RSC, and based on discussions at the ports 80% of the containers are the 40 foot type and 20% are the 20 foot type. Therefore, the average size and volume of a RSC container can be calculated from the following formula:

$$\text{Average RSC Container Size} = [.8x40 + .2x20] = 36 \text{ feet}$$

$$\text{Average RSC Container Volume} = 36/20 = 1.8 \, TEU$$

Since the same RSC can be used for import and export the total number of RSCs to handle the RSC container volume can be calculated as

$$\text{RSCs Required} = \frac{\text{RSC Volume}}{2x1.8} = \frac{6,000,000}{2x1.8} = 1,666,000 \text{ RSC Containers}$$

d. How many RSCs are needed per year? Since an RSC can be used more than once per year, we have to determine the number of times a RSC can be used during a given year. The following estimates will be used to determine this value:

i. An RSC is assumed to be placed in storage 7 weeks during the year in order to meet the very large volume needed during peak season of trade in a given product. Thus, there are 45 weeks for use in product transport.

ii. The time needed for a new export/import cycle at a California port is 7 weeks. (4 weeks of ocean travel; 1 week of loading and unloading at ports; and 2 weeks to obtain and deliver or pick up the product inland)

iii. The number of import/export cycles that a given RSC can make per year is thus given as:

$$\text{RSC Trips / Year} = \text{Useful Weeks / Time Between Cycles} = \frac{45 \text{ Weeks}}{7 \text{ Weeks}} = 6.43 \frac{\text{Trips}}{\text{Year}}$$

Therefore, the number of RSCs needed to handle the volume of refrigerated products exported and imported at California ports is

$$\textbf{Individual RSCs Required} = \frac{\textbf{RSCs Required}}{\textbf{RSC Trips / Year}} = \frac{\textbf{1,666,000}}{\textbf{6.43}} = \textbf{260,000}$$

Estimates of Emissions Due to Decommissioning of RSCs in California Ports

The following information, data, and calculations will be used to estimate refrigerant emissions from decommissioning of RSCs in California Ports

a. Based on discussions at the terminals in California Ports the Average Lifetime for an RSC is 10 years.

b. California ports fully comply with EPA regulation CFR 82F, and refrigerant is properly recovered from all RSCs that are decommissioned at or near California ports. However, the equipment used for regulation CFR 82F is currently able to recover between 80 and 90 percent of the refrigerant in a RSC. If the presently used refrigerants are replaced by CO_2 refrigeration systems then the lack of full recovery of the refrigerant could be eliminated.

Since 13,000 RSCs are decommissioned in California, it will be assumed that 15% of the refrigerant is not recovery using the CFR 82F protocol, and the refrigerant load is assumed to be 15 kg. The amount of refrigerant lost can be calculated as

$$Non-Recovered\,Refrigerant = (13{,}000)x(15)x(.15) = 29{,}250\ kg$$

c. Since the intermodal transport environment is harsh, it will be assumed that 1/2% of the RSCs are decommissioned due to accidents in the port regions, and the accidents occur equally in foreign and California ports. It will also be assumed that an engineering recover system for refrigerant could be developed in the future, and it could prevent the refrigerant from being vented in the future.

With the assumptions listed above the, we obtain the number of accidents per year as the following:

$$Number\ of\ \ Decommissioning\ \ Accidents = .005x\frac{260{,}000}{2} = 650$$

d. It will be assumed that 15 kg of refrigerant charge is released during the accident, and the total of refrigerant vented is

$$Refrigerant\ Released\ in\ Accidents = (Number\ of\ \ Accidents)\ x\ (Refrigerant Charge)$$

$$Refrigerant\ Released\ in\ Accidents = 650x15 = 9750\ kg$$

e. The RSCs in California ports only use refrigerants HFC-134a and R-404A, and we will assume an average Green House Warming Potential, GWP, of 2500.

With the information listed we can estimate the total equivalent amount of CO2 released by the refrigerant as

$$\boldsymbol{CO_2\ Equivalent = CO_2E = Refrigerant\ Released\ x\,GWP = (9{,}750 + 29{,}250)x2500}$$
$$\boldsymbol{= 97{,}500\ MTCO_2E = 0.0975\ MMTCO_2E}$$

Estimates of Emissions Due to Leakage of RSCs in California Ports

Another potential loss of refrigerant related to RSCs is leakage of refrigerant, and refrigerant leakage is common to almost all refrigeration systems due to their high pressure operation and the large amount of surface area needed to cool and remove ice from a RSC system. Previous estimates of leakage rates, References [2], [3], and [5], were based on outdated information, and new updated data has been obtained by visits to manufacturers, ports, and maintenance facilities.

The new information and data from the terminals have yielded the following estimates:

a. Based on discussions with terminal supervisors it was estimated that the RSCs leakage rate was less than 1% for the first 3 years of being used, and at the end of life the leakage was approximately 10%. Therefore, at leakage of 5% was assumed during the lifetime of the RSC.

b. From the estimate on the number of trips per year it is consistent to assume that 1,666,000 RSCs spend 10 days in port per export/import cycle. This data is equivalent to having 45,640 RSCs working in the ports per year, or

$$\textit{Yearly Equivalent RSCs} = 1{,}666{,}000 \; x \; \frac{10}{365} = 45{,}640$$

Using a 5% leakage rate, a 15 kg charge, and a 2500 GWP, we calculate the refrigerant leakage rate as

$$\textit{Refrigerant Leakage Rate} = (\textit{Leakage Rate}) \; x \; (\textit{Refrigerant Charge}) \; x \; (\textit{Yearly Equivalent RSCs})$$

$$\textit{Refrigerant Leakage Rate} = (.05) \; x \; (15) \; x \; (45{,}640) = 34{,}200 \; kg$$

Assuming a GWP of 2500 for the refrigerant we obtain the equivalent CO_2 emissions as

$$\boldsymbol{CO_2 \; Emissions \; from \; Refrigerant \; Leakage = 34{,}200 \; x \; 2500 = .0855 \; MMTCO_2E}$$

During the discussions of refrigerant loss at California ports with terminal workers, the question was asked if there were any significant differences between RSCs with refrigerant R-404A and HFC-134a, and the general answer was “nothing significant”. A potential difference between these different refrigerants is that R-404A systems work at higher pressures than HFC-134a systems, and for an equivalent system the leakage rate is proportional to the pressure squared. Since the pressure of a typical R-404A system operates at 1.9 times the value of a HFC-134a system, the leak rate could be 3.6 times larger for the R-404A system. The present study did not specifically compare R404-A and HFC-134a systems, but it is a subject that might be investigated in the future.

Another interesting point is that CO_2 refrigeration systems operate at pressures that are 10 times the pressure of R134a systems, and the leakage rate for an equivalent system would be 100 times that of an R-134a system. Therefore, it is not unreasonable for CO_2 system to be expected to lose 100% of their refrigerant per year, but the GWP of CO_2 is 1. The refrigerant loss is certainly a potential maintenance issue, but in the high tech RSC environment, this issue can be handled with the pre-trip maintenance inspections. However, for smaller systems such as home refrigerators and air conditioners the replacement of refrigerant could be an issue, and additional studies have to be carried out.

Estimates of Other Emissions Associated with Refrigerated Shipping Containers

With the large increases that have occurred with the use of intermodal shipping containers there has been a significant increase in diesel engine generator sets used to power the RSCs during intermodal transport, Fig. 9. While the RSCs are on the ship and stored in the port they are fully powered by ship or shore electrical power, but as soon as they are transferred to a truck trailer or rail car, they are powered by a diesel generator set. RSCs are usually transferred to a truck trailer immediately before they exit the port itself, and the largest portion of the RSCs are transported by truck to California locations and most of the California locations are in southern California. From the economic viewpoint truck intermodal transport is competitive with other transportation methods up to a distance of 500 miles, but for larger distances rail intermodal transport is usually more economical unless there is a time constraint associated with the load.

Figure 9. Diesel generator set mounted on an intermodal RSC

The type of intermodal transport of RSCs in port areas that is increasing the most is rail transport, Ref. [7], and almost all rail transport of RSCs is powered by diesel engines. In the past electrical power from central train generators was available for RSCs for rail intermodal transport, but the use of attached diesel generators has proved to be more cost effective and convenient than a central source of electrical power. One of the major reasons for increasing intermodal rail transport is to decrease the number of truck trips into the ports, but there are some important differences with the use of rail for RSCs compared to non-refrigerated cargoes, since the electrical power source is an attached diesel engine.

Shown in Fig. 10 is the distribution of the total container traffic in the San Pedro ports, and this traffic has been listed in the following categories:

- Direct Intermodal: Transport of the containers by train using “on dock”, “near dock” (within five miles), and “off dock” rail yards.
- Transload Intermodal: The container load is first transported by truck to an off-dock warehouse, and the load or part of the load is eventually loaded on an intermodal rail train.
- Regional Trucks: Transport of the RSCs by trucks to their destination.

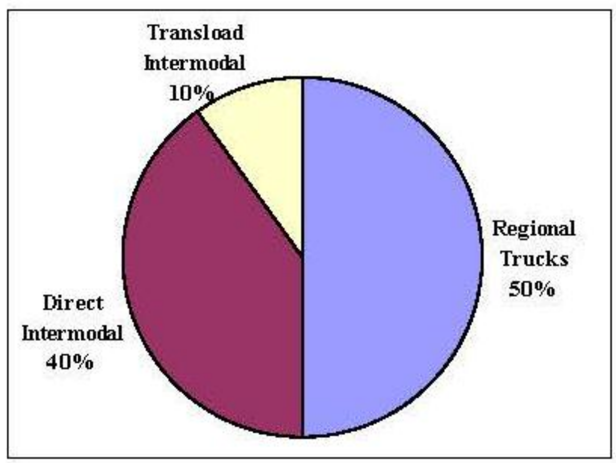


Figure 10. The distribution of total container traffic in San Pedro ports, as of 2006

The only part of container traffic that does not use direct truck transport in Figure 10 is the “on dock” portion of the Direct Intermodal category, and it should be mentioned that train loading and unload takes a longer time than the other modes of loading and unloading, since the trains are long and stacking is at most two high.

For all intermodal rail transport a RSC must also be moved to the rail yard of the train shipper before it is transported to its final inland destination, and this process is considerably slower than truck transport. Because of the necessity of the loading, unloading, and transferring to different rail yards of RSCs, the amount of time used and emissions from the diesel generator sets will be estimated, since it is not currently included in the port region emissions.

During the entire transport of a RSC it is continually powered by fossil fuels, but with the use of shore power the port criteria pollutants are dramatically lower than the criteria pollutants from an attached diesel gen set. For this reason we have calculated the diesel fuel use by the diesel gen sets in the port regions.

The total fuel use for generator sets attached to RSCs in the port areas can be calculated as the following:

Based on the current literature concerning the average power requirements for a RSC we have made the following estimates for emissions from diesel generator sets used to power RSCs in the port areas.

a. From the shipping companies reports the average power requirement for an RSC is 7 kW.

b. Assume that a RSC is powered for one day in the port regions. This assumption is a little long for a truck, and it is somewhat short for train.

c. The average fuel consumption rate for a RSC using 7 kW of power is ¾ of a gallon per hour.

Therefore, the effective full time use of diesel gen sets is given by the following formula

$$Yearly\ Equivalent\ Diesel\ Gen\ Sets = 1,666,000\ x\ \frac{1}{365} = 4,564$$

The yearly amount of diesel fuel used by the diesel gen sets is given as

$$Total\ Diesel\ Gen\ Set\ Fuel\ Use = 3/4(gallons)\ x\ 4564(GenSets)\ x\ 24(hours)\ x\ 365(days)$$
$$= 29,999,000\ (gal\ diesel\ \ fuel)/year$$

Using the density of light diesel fuel as approximately 800 kg/m3, and mass amount of diesel fuel can be calculated as

$$Mass\ of\ \ Diesel\ Fuel\ Used = 90,837,000\ (kg\ diesel\ \ fuel)/year$$

Of course, the use of diesel fuel generates CO_2 emissions as well as criteria pollutions, and the CO_2 emissions can be obtained from the carbon content of diesel. For an approximate diesel fuel molecular weight of 170, diesel fuel can be represented as $C_{12.3}$ $H_{22.1}$, which gives a carbon content of 86.8 %. Therefore, the CO2 emissions from

$$\boldsymbol{CO_2\ Emissions\ \ from\ Diesel\ Fuel = (90,837,000)\ x\ (.868)\ x\ \frac{44}{12} = 289,100,000\ kg\ CO_2\ /\ year}$$

$$= \boldsymbol{0.289\ MMTCO_2E}$$

It is interesting to compare diesel fuel from RSC Gen Sets to estimates from the idling of diesel trucks at California Ports 2007, Ref. [8], which is 2,920,000 gals/year. Comparing these two numbers we come to the conclusion that the diesel fuel used to power RSC generator sets in the port areas is more than 10 times larger than the diesel fuel used to power idling of diesel trucks in California ports. Also, the emission standards for diesel generator sets in the year 2007 are not as good as the diesel trucks at idle, and the corresponding emissions will be larger per gallon of diesel fuel used for diesel generator sets relative to diesel trucks idling.

Another important point to remember is that the generator sets that are used to power RSCs are California based, and they have to meet the standards of the "TRU Airborne Toxic Control Measure". This measure will insure that in-use engines meet the most stringent standard of Ultra-Low-Emission TRU (ULETRU), and the measure insures that all new engines will meet the most stringent standard by January 1, 2013. All TRUs and TRU gen sets should meet the TRU in-use standard by 2020. In general this measure will greatly improve the emissions characteristics of the diesel engines used for the generator sets of RSCs.

In summary the total emissions from RSCs in California port regions is presented in Table I, and these results are considerably lower than previous estimates, Ref. [5] and [6].

Table I. Summary of total RSC emissions at port regions

Emission Category	**(MMTCO$_2$E)**
Decommissioning of Shipping Containers	0.0975
Leakage of Refrigerant	0.0855
Shipping Container Diesel Engines	0.289
Total Sum of Emissions	**0.472**

IMPORTANT NEW DEVELOPMENTS IN THE USE OF CO2 REFRIGERANTS FOR REFRIGERATED SHIPPING CONTAINERS

During the last few years the RSC manufacturing companies have made substantial progress in the development of an RSC that uses the natural refrigerant CO_2, and they have had demonstration trials during the last two years, Ref. [4]. CO_2 was first proposed as a refrigerant 160 years ago, and its peak occurred in the mid-1920s, but CO_2 quickly fell out of favor with the development of CFCs in the late-1920s. While CO_2 was long considered as an ideal working medium for refrigeration systems, there was always a penalty in energy performance.

Recently, the use of CO_2 in stationary commercial refrigeration has grown rapidly in northern Europe, and compressor manufacturers and suppliers of refrigeration system components have developed designs that optimize performance of CO_2 systems. The use of CO_2 as a commercial refrigerant has grown most rapidly for stationary commercial refrigeration systems, and the developments in this part of the refrigeration industry have shown that CO_2 systems can be as energy efficient as HFC systems.

The use of CO_2 as a refrigerant for RSCs has the following advantages: CO_2 has a GWP of one; it has zero ozone-depletion potential; and it is classified as non-toxic. Further, CO_2 requires no disposal, is cost effective, is available worldwide, and it has excellent heat transfer and heat reclaim properties. It should also be noted that CO_2 has important regulatory advantages since the refrigerant is protected against phase-outs, taxes, and European F-gas regulations. However, to be a successful refrigerant for RSC equipment manufacturers, CO_2 must meet the severe challenges and demands of the international RSC industry. For example, it must achieve the energy performance levels of HFC machines, which includes cooling capacity, power consumption, good pull down times, and excellent temperature control in a very difficult physical environment.

The demonstrations carried out and described in Ref. [4] have resulted in enough progress that it is expected that CO_2 refrigeration systems will play an ever increasing role in the RSC industry. The major developments have been the following:

- Multi-stage CO_2 compressors now have efficiencies similar to HFC systems.
- Auxiliary heat exchanges have improved sub-cooling and unloading that allow CO_2 systems to perform just as well as HFC systems.
- Operation of CO_2 systems in the supercritical range has allowed RSCs with CO_2 as a refrigerant to operate well in the broad range of ambient temperature conditions seen in RSC applications.
- Improved heat transfer surfaces in the new RSCs have improved the performance of new evaporators and condensers, and they have provided optimum cooling capacity and system efficiency.

In the future, the major complication of CO_2 systems will be the increased leakage of CO_2 due to the high operating pressures in the compressor. However, the RSC industry is high tech, and there is regular pre-trip maintenance that can easily treat this potential problem. In other refrigeration industry areas such as home refrigeration and automobile air conditioning the relative high cost and time needed for replacement of CO_2 refrigerant could be a much more challenging problem, and other type of systems may have to be considered.

IMPORTANT NEW DEVELOPMENTS IN THE SHIPPING CONTAINER INDUSTRY

Although the emissions from container ships is not a topic that is covered in this investigation, some brief comments will be made about the progress and problems that have been made and exists in the industry. This progress has been most dramatic on the very large container ships that are expected to achieve a cargo capacity of 18,000 TEU. These very large ships are powered by low speed two-stroke diesel engines that have overall thermal efficiencies better than most power plants today and similar to fuel cells. Therefore, these engines are among the best in the world in reducing CO_2 per unit of power produced (Note: See Appendix III).

In terms of other emissions the new diesel engines have dramatically reduced NOx emissions with use of direct fuel injection, direct water injection into the cylinder, the use of exhaust gas recirculation, EGR, and selective catalytic reduction, SCR, technologies. In the year 2016 these large ships will achieve Tier III levels of 2 g/kWh for NOx in control areas. In order to achieve better performance in the port regions themselves, the large ships can be powered by auxiliary engines with the use of liquefied natural gas, LNG, or compressed natural gas as the fuel (Note: See Appendix IV). With the use of natural gas engines the emissions levels can be the same as emissions from shore power and more cost effective. There is a strong case to be made that these large container ships with auxiliary natural gas engines are a better solution to port emissions than electrical shore power provided by the ports.

At the present time large diesel engines on container ships require heavy fuel oil which contains relatively large amounts of sulfur. Recently, it has been shown that exhaust gas scrubbing is a cost effective alternative to lowering the sulphur content fuels for reducing SOx and particulate emissions. Exhaust gas scrubbing is a feasible solution both for new installations and as a retrofit to existing ships. The scrubber concept is based on closed loop system, using fresh water with caustic soda (NaOH) added to the scrubbing water. Clean effluent from the treatment plant meets quality requirements and can be discharged overboard. The SO_X removal efficiency of scrubber systems is over 97%, and it is possible to operate with a 3.5% sulphur fuel level and still have emissions levels that comply with the future 0.1% sulphur fuel limit.

In general it can be said the international container shipping industry is such a large and profitable enterprise that the industry is aggressively pursuing all possible energy and environmental improvements. As new California and international regulations are introduced for coastal and port regions it is expected that the industry can achieve the new standards.

IMPORTANT PROJECT AMENDMENTS AND HISTORY

The present study and project got off to slow start due to the fact that the original principal investigator resigned from the Foundation of California Community Colleges, FCCC, and the project had to be amended so that Professor Harry A Dwyer from the University of California at Davis could be subcontracted to carry out the proposed study. Fortunately, it was discovered that the original goal of measuring leakage rates from RSCs was not a good one, and that the goals of the project were amended to study the modern RSC industry in California Ports.

Due to the information and help that Professor Dwyer received from the RSC manufacturers, maintenance companies, CARB enforcement workers, and Port workers, it was not necessary to use field experts, engineering students, or leak detection equipment on the project. Therefore, the funding that was allocated for those services was not spent.

CONCLUSIONS AND SUMMARY

The present study has been very successful in developing an understanding of the changes that have occurred over the last fifteen years in the international trade of refrigerated cargoes. Specifically, the study has obtained data and information on the most dynamic and fastest growing part of the industry, which is the use of intermodal refrigerated shipping containers, RSCs. In order to obtain this data, it was necessary to visit and interact with the manufacturers of RSCs, the maintenance organizations, and the Ports of California. Only by having these type of interactions was it possible to estimate the emissions related to the use of RSCs in the port regions of California. The following are the major conclusions of the study.

- During the last fifteen years the transport of refrigerated cargo has largely converted to external intermodal RSCs from dedicated internal refrigeration inside ships, known as reefers. This change has decreased the lifetime of the refrigeration systems due to intermodal transfers and exposure to the environment, but the leakage rate of refrigerant has decreased from 25% to 5% per year during the lifetime of the RSC.
- The monetary value of typical load in a RSC has increased to an average of $300,000, and comprehensive maintenance and pre-trip inspections of RSCs insure that these valuable loads arrive to the consumer as a high quality product. The pre-trip inspections identify RSC units that should be repaired or decommissioned, and all the decommissioning of RSCs meets US EPA standards for disposal of refrigerant.
- Since the RSCs used in international trade transport their loads for periods of weeks, they are designed as very high quality containers with very low air leakage rates. For this reason RSCs are salvaged for valuable parts, and they are then typically placed back into service with dry unrefrigerated loads.
- A RSC has a higher quality refrigeration system than the Trailer Refrigeration Units, TRU, that are used to transport refrigerated containers on US highways. At the present time a RSC refrigeration system uses a very efficient semi-hermetic compressor with electrical drive, and electric drive is not typical for TRUs. Also, the cooling system maintains a more uniform temperature, since RSC loads have trip times of many weeks compared to a TRU load of a day.
- The large increase in the use of intermodal RSCs for international export and import has resulted in a significant increase in the use of diesel electric generator sets to power the RSCs during their transport to rail yards and to off dock warehouses near the ports. At the present time rail transport is increasing for both local and out of state transport of RSCs,

and the predominant method of powering RSCs is with use of diesel electric generator sets. It should also be mentioned that the vast majority of dedicated rail refrigerant cars are powered by diesel engines.

- The average power required to keep a refrigerated load cool in a RSC is 7kW, and at the present time this power requirement uses a very significant amount of diesel fuel. In fact, the amount of diesel fuel used to power RSCs in the port areas is much larger than that used to power idling trucks in the port itself.

Based on the data and information we have obtained in this study, we are able to obtain the following estimate for the emissions due to RSCs in the port areas.

Table I. Summary of total RSC emissions at port regions

Emission Category	($MMTCO_2E$)
Decommissioning of Shipping Containers	0.0975
Leakage of Refrigerant	0.0855
Shipping Container Diesel Engines	0.289
Total Sum of Emissions	**0.472**

These estimated results are considerably lower than previous estimates. Due to future growth and increased value of their product the refrigerated shipping industry has been able to develop and pioneer very important improvements for future RSCs. The most important of the improvements is the development of a RSC which uses CO_2 as the refrigerant. In fact all the engineering design and optimization has been completed, and plans are in place to introduce CO_2 RSCs into a large portion of the RSC fleet in the coming years.

A final point to be made in this conclusion is that the large container ships currently being built are among the most environmentally friendly vessels in the world. Their thermal efficiencies and emissions are continually being reduced.

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APPENDIX I – A LIST OF THE PROCEDURES CARRIED OUT DURING A PRE-TRIP CHECKOUT

Feliba PTY LTD
Keeping Things Cool

Services | Locations | Industry | Contact | About

Pre Tripping

Pretrip | Breakdown | Presail | Monitor | Survey | Star Cool

The PTI

Pre Trip Inspections (PTI's) are a form of maintenance service which are required between each voyage to ensure a high standard of operation is maintained for each cargo being transported. This is essential considering the volume and expense each reefer carries on a single voyage.

The PTI's Feliba carry out follow numerous controlled steps to ensure they are at or above this standard and that the machinery is at the best operational capacity. Below is a simplified representation of what Feliba's technicians follow whilst performing a Pre Trip Inspection.

Prior To Power Up, Check..

- Condition of cargo space and insulation
- Door condition, gaskets and fasteners
- Mounting of machinery frame on container
- Mounting of fan motors
- Mounting of compressor and level of compressor oil
- Length and condition of mains power cable and plug
- Insulation resistance of the compressor, motors, heaters & solenoids
- Electrical terminals for corrosion or loose connections
- State of the electrical box & relative components
- For missing or damaged components
- Drains for blockages or breakages
- Partlow clock status (uncommon these days)

Whilst On Power, Check..

- Function of relays, contactors and connectors
- Controller ID, date, time and software version

- Data logger status
- Current draw on compressor, motors, heaters and solenoids
- Unusual vibration or noises of moving components
- Compressor oil level
- Operating pressures, both suction and discharge at 0.0 ˚C
- Operating pressures, both suction and discharge at -18.0 ˚C
- Refrigerant level and state
- Return and supply temperature sensors
- Difference across the evaporator coil
- Superheat on expansion valve
- Pull down time to 0.0 ˚C and -18.0 ˚C
- Modulation (or hot-gas) at 0.0 ˚C
- Water switches
- Defrost operation, both manual and automatic
- Calibration of temperature sensors
- Status indictor lights

Appendix II - EFFICIENCY EVOLUTION AND SUSTAINABILITY IN CONTAINER REFRIGERATION APPLICATIONS

ID: 535

EFFICIENCY EVOLUTION AND SUSTAINABILITY IN CONTAINER REFRIGERATION APPLICATIONS

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ABSTRACT

This paper describes progressive energy efficiency improvements made to refrigeration systems and components used in the container refrigeration application. A systems approach and implementation of new component designs for compressors, heat exchangers, and air moving systems have allowed cooling and heating to be accomplished while reducing energy consumption. Compressor improvements include enhancements to reciprocating piston designs and more recently, adoption of scroll compressor technologies. Heat exchangers include heat transfer surfaces with highly efficient, enhanced profiles to maximize heat transfer. Air management systems include improved fan geometries and ducting designs. In addition, current components are now leveraging new technologies in materials and designs to improve sustainability. The use of natural refrigerant (CO_2) and low GWP foams as well as the elimination of hazardous materials are examples of recent steps being taken to further diminish container refrigeration's environmental impact.

1. INTRODUCTION

Since the introduction of containerized shipping in the mid-1950s (Mayo and Nohria, 2005), this method of shipping has become a favored means of transport for temperature sensitive cargos. The first container refrigeration machines were introduced in the late-1960s (Containerisation International April 2006). Since that time, the machinery and insulated containers have undergone a stream of design and technology changes that support more than 65% of all refrigerated cargo shipped globally.

During the last decade, compound annual growth (CAGR) for seaborne refrigerated trade has historically been around 7% (not including the recent economic crisis), and is currently around 100 million metric tons. Overall growth is driven mainly by world GDP and trade growth. Container ships account for 66% of refrigerated shipments, with reefer ships making up the balance. To support the containerized segment of the market, the global fleet of refrigerated containers has grown to more than 1 million units.

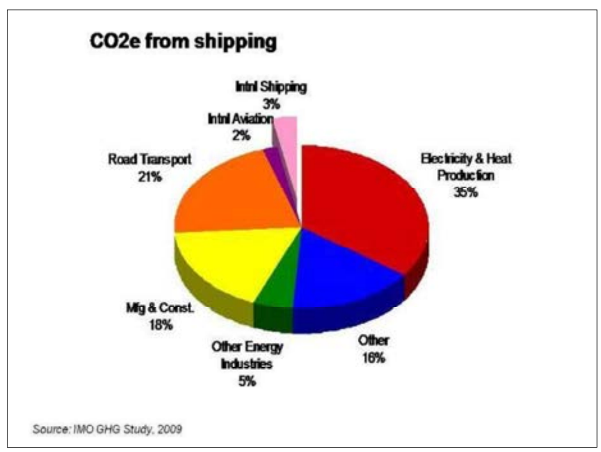

Figure 1: CO2 Emissions

Considering that the average energy consumption of a container refrigeration machine can reach more than 10,000 kWh per year. CO_2 emissions total more than 10 million metric tons for the installed base in excess of one million refrigerated containers. Though this is considered a relatively small number when compared to CO_2 emissions produced by the vessels themselves, and even smaller when compared to total emissions produced by global industry (Buhaug *et al*., 2009) , the result still requires attention and action to reduce it where possible. As the number of refrigerated containers continues to increase to support a growing trade and a continuing shift away from reefer ships to container ships, emissions is expected to grow approximately 6% annually.

[Type text]

Environmental and efficiency concerns have been central to container refrigeration unit use for much of the past four decades. The first integral refrigeration machines provided the capability of maintaining the cold chain far better than isothermal (or port-hole) containers that were cooled by a central plant. The 1980s saw advancements made to minimize equipment size and weight allowing maximum cargo space. In addition, controls advanced from solid state to microelectronics, bringing more precision to cargo temperature control. In the 1990s, along with the rest of the global HVAC/R industry, container refrigeration transitioned from equipment using ozone-depleting chlorofluorocarbon (CFC) refrigerants such as R-12 to non-ozone-depleting hydrofluorocarbon (HFC) alternatives such as R-134a.

Beginning in the late-1990s, energy efficiency was given renewed attention, leading to the development and deployment of container refrigeration units using scroll compressor technology. Figure 2 shows the advancement in system efficiency expressed in coefficient of performance (COP) at one typical rating point. This ratio compares the cooling produced with the energy required. The favorable trend is clearly seen.

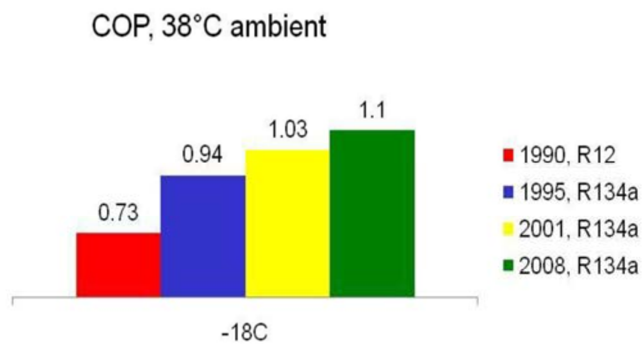

Figure 2: Efficiency Improvement

Today, the industry is becoming more focused on making further improvements to reduce the global warming potential (GWP) of refrigerated container shipping. In this regard, container machinery must be viewed from a full system perspective. Not only must we consider the refrigerant being used, but all components and their collective performance as they are integrated in the working machine. Global warming is influenced by both direct emissions of the refrigerant that is used and the energy consumption that is required to operate the machine. Both of these factors must be considered to achieve maximum emission reductions.

Equally as important, we should think broadly about the production processes and materials used in the construction of the container refrigeration machinery as these also contribute to the total carbon footprint of the equipment.

This paper has two objectives:

- First, to recognize the progress that has been made since container refrigeration machinery first came into use. Application of new technology and designs continue to provide improvements that make the equipment more effective.
- Secondly, to highlight opportunities for the continuing improvement of designs that will reduce the environmental impact of container refrigeration. By continuing to consider improvements from a systems viewpoint, engineers can incorporate more efficient components and more environmentally sound materials that make a favorable impact to both business and the environment.

2. CONTAINER REFRIGERATION TECHNOLOGY

Since their introduction, container refrigeration machines have become more advanced, capable and reliable. At a basic level though, each machine has the same fundamental parts. These include a compressor, an expansion device, an evaporator (coil with fan + motor), and a condenser (coil with fan + motor). Shown in figure 3, these key components are arranged together to form a vapor compression cycle that absorbs heat from the cargo and space within the container and then ejects that heat, plus heat generated in the compression process, outside the container.

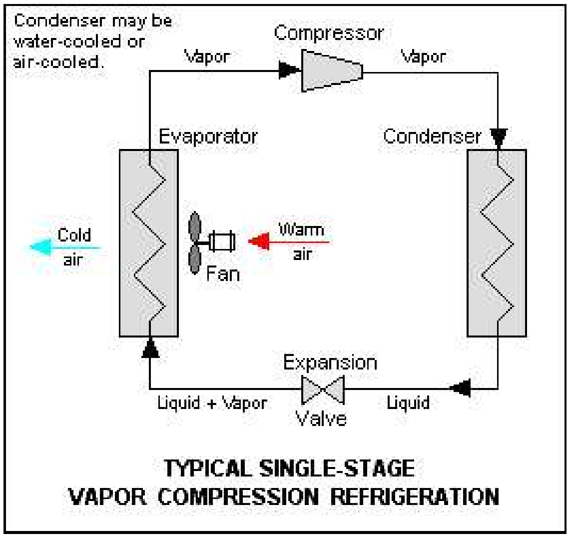

Figure 3: Vapor Compression Cycle

In this system the main energy consuming parts are the compressor and the air circulating fan motors for the evaporator and condenser heat exchangers. The compressor, for example, typically makes up more than 75% of the total system energy consumption. The air circulating fans motors typically represent another 12-15% of total energy consumption. But how these components are arranged, the care that is taken in their design, and the way they are controlled as a system play a significant role in the overall efficiency of the machine. Efficiency is calculated by comparing the cooling that is made available to the cargo inside the container to the energy required to produce it.

In the following pages, some examples are shown to illustrate how these components and their incorporation into the system have resulted in year-over-year reduction in system energy consumption.

2.1 Compressor design

Compressor designs for this application have continued to improve with unique changes made to pistons, valves, motors, and oil circulating systems. Container refrigeration is unique in its need for the temperature control system to be capable of providing cooling from frozen set points, to chilled non-frozen settings, to typical air conditioning settings. A typical reefer allows set points from -30°C to +30°C. To increase efficiency at low frozen set points, unique piston and valve designs were developed to improve the compression performance. An example of a contoured piston and canted valve plate is shown in figure 4. When combined with other valve improvements, compressor efficiency is improved by approximately 5% for container refrigeration applications.

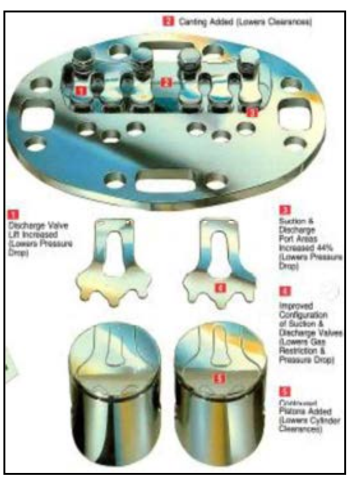

Figure 4: Carlyle canted valve plate and contoured pistons

Micro-electronic controllers along with new sensors have provided improved temperature control and unique control logic. New software is used to better manage component control (for compressors and fan motors) to only activate cooling and airflow when it is needed. Multi-speed fan motors were applied in containers from very early on. Lowering fan speed during frozen operation, when high air circulation is not necessary, results in a 75% reduction in fan power requirements. Equipment manufacturers such as Carrier, Thermo King and Daikin have also adopted further fan cycling control logic, typically called economy mode, that cycles fans speeds from high to low and on/off to further allow energy savings with cargos to do not require high or constant air circulation.

Motor suppliers have developed new material and manufacturing techniques to optimize these designs to closely match motor horsepower to fan requirements, increase efficiency, and reduce weight.

These changes became more important in 1993 as the industry transitioned away from CFC (R-12) refrigerant. R-134a refrigerant was adopted with efficiency and cooling performance that exceeded what had been formerly achieved with R-12. This was accomplished by combining former compressor improvements with new fan designs and adding a liquid-suction heat in the vapor compression circuit. The final result provided more cooling with less energy consumption.

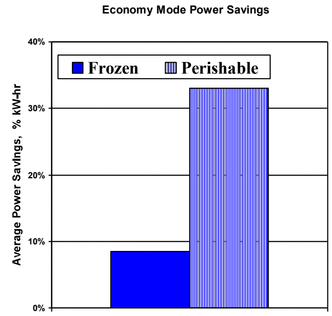

Figure 5: Fan cycling power savings

Scroll compressors were incorporated in OEM designs by Carrier, Thermo King and Daikin beginning in the late-1990s, further improving efficiency at high compression ratio conditions. Scroll compressors also allowed the effective use of economized refrigeration circuits to improve cooling. These systems became particularly effective for using less energy at lightly loaded conditions.

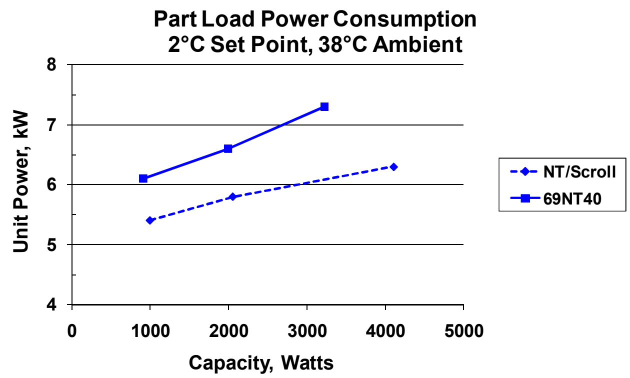

Figure 6: Power consumption comparison

2.2 Air Circulation

Depending on set point and the cargo being carried, air circulation within the container is vital to maintain uniform temperature control throughout the container. Fan designs have progressed from stamped metal propeller fans to high efficiency die cast and composite molded profiles. These new fan designs are coupled with velocity recovery vane stators to generate more airflow. These designs also have higher efficiency and lower power consumption than conventional fan designs.

Figure 7: Evaporator propeller fan (left) and vane axial fan (center) plus stator (right).

Conventional metal propeller fan designs are able to achieve static efficiency levels of approximately 35%. Leveraging state-of-the-art design tools and advanced molding technology, new fan designs can achieve more than 50% static efficiency providing more than 30% energy savings.

Figure 8: Condenser propeller fan (left). Molded condenser fan (right)

Ongoing optimization of fan designs has resulted in 3rd generation fans that reduce energy consumption by nearly 50% compared to early propeller fans (shown Fig. 9).

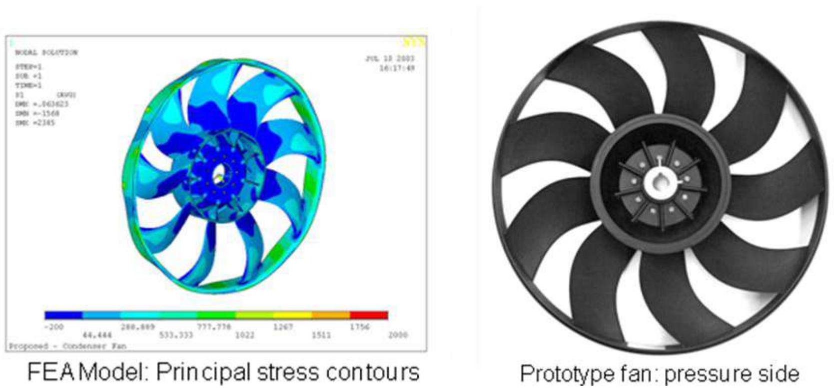

Figure 9: 3[rd] generation molded condenser fan

At the same time, growth of container refrigeration brought opportunity to carry new cargoes with broader temperature control requirements that translated to even lower temperature settings. To achieve this, engineers leveraged these compressor improvements and incorporated new designs to the heat transfer coils and air moving systems.

Along with design improvements to fans, changes to the airflow passages have been made to allow more effective air delivery to the container cargo. These improvements have a twofold effect of increasing airflow and reducing fan power consumption. Increasing airflow creates an advantage of more uniform and stable cargo temperatures. Respiration heat is more readily removed, and heat leakage from outside the container is more quickly off set. A reduction in fan power directly results in reduction to the overall equipment energy consumption but it also allows design teams to reduce horsepower (hp) ratings of the electric motors that drive the fans. Smaller hp means less material in the motor, resulting in a more compact, lighter weight design.

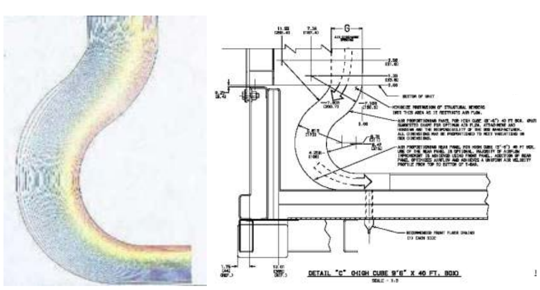

Figure 10: Curved container transition plenum

An example is creating a smooth transition from the refrigeration machine to the T-bar floor in the container. Rather than an abrupt 90° turn, many installations now take advantage of a curved transition to turn the airflow into the container floor. This approach reduces losses and pressure drop, improving airflow by as much as 10%.

Evaporator and condenser heat exchangers have incorporated improvements to both air side and refrigerant side heat transfer surfaces. Wavy fin patterns were used to increase fin heat transfer surface area and create enhanced airflow streams. The copper tubing used in the heat exchangers incorporated internal enhancements that more than doubled the heat transfer effectiveness.

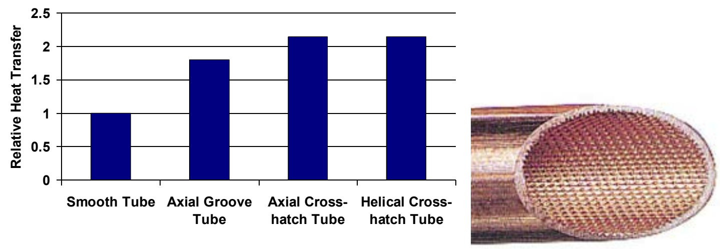

Figure 11: Heat exchanger tubing enhancements

As with all cooling equipment, moisture condensation on the cooling coils takes place and often builds in the form of frost and ice. Periodic defrosting is needed to keep the evaporator coil free of frost and allowing the most efficient cooling of the cargo. Early equipment used timers to initiate defrosting of the evaporator coil. Shippers could select defrost intervals of 3, 6, 12, or 24- hours depending on the type of cargo, set point, and the amount of fresh air allowed to circulate into the container. All these factors can influence the amount of frost and ice that will accumulate on the evaporator coil and how quickly it will build up. In many cases however, once an initial defrost has been completed, there is little remaining moisture in the container that will accumulate as frost on the coil. In new equipment, advanced control logic has been developed to anticipate when a defrost cycle is necessary based on how the system is performing. The temperature set point, air temperature changes within the container, and the duration of prior defrosts have been combined into smart controls that only initiates a defrost cycle when it is necessary. This avoids additional cooling to save energy costs over the duration of a shipment.

3. NEW TECHNOLOGIES

New technologies are challenging design teams to once again consider a change to the refrigeration system. Advancements in compressors, heat exchangers, and air circulation fans can now provide a path for consideration of natural refrigerants. For example, late last year, Carrier announced that it had successfully tested the world's first natural refrigerant container technology, using CO_2 (R-744). In the early 1990s, Norwegian thermodynamicist Prof. Gustav Lorentzen said, "…carbon dioxide comes very close to being the ideal working medium, provided that a process to give competitive energy performance can be designed." (Lorentzen, 1994).

Kauffeld (1998) proposed that R-744 has potential to replace R-134a in refrigerated container systems. He also noted the challenges associated with reducing energy consumption.

Jakobsen and Neska (1998) explored this further to identify operating conditions for refrigerated containers where CO_2 would have an advantage over HFC systems. And the authors listed technology developments that offered the possibility for reduced energy consumption.

Since that time, manufacturers of refrigeration system components have made significant progress to improve designs with CO_2 as a working fluid. Compressor offerings for both sub-critical and trans-critical applications are now available from several manufacturers. (Neska *et al*, 2010).

The challenge for transport refrigeration to create a system that meets the energy consumption levels of today's efficient HFC machines is significant. In order for CO_2 to work as a viable refrigerant in today's world, where things such as energy efficiency, cooling capacity, power consumption, and pull down are necessary starting points, we have to develop components and systems that can better control capacity and temperature using CO_2.

The first such component is the compressor, recognizing the critical importance for cooling capacity for a broad range of conditions experienced in container applications, the efficiency needed to ensure lowest possible power consumption, and the reliability to meet the demanding duty cycles in marine and transport environments. New compressor designs include multiple stages of compression that have optimum compression ratios and speed range capability that have not been available before. These features provide new opportunities for engineers to design CO_2 refrigeration cycles that rival the efficiency performance of the best HFC machines.

Multi-stage compressors also allow adjustments to the basic vapor compression cycle that improve overall efficiency. Already used in today's most efficient HFC equipment, auxiliary heat exchangers that provide sub-cooling and unloading features can be adapted in new ways to allow CO_2 systems that perform just as well.

Because of the broad range of ambient temperature conditions seen in the container application, CO_2 systems must also be able to operate in a supercritical state, given the properties of the refrigerant. This characteristic allows optimization of pressure in the system to increase efficiency.

Also, by taking a traditional flat coil and forming it into a new geometry, we can maximize the heat transfer surface area to improve capacity and efficiency. In evaporators using CO_2, greater volumetric refrigeration capacity at frozen set points can provide flexibility to optimize size and performance (Handschuh, April 2008). Using the best heat transfer surfaces on fins and in tubing, new evaporators and condensers can provide optimum cooling capacity and efficiency.

Manufacturers should also work to lower the GWP impact of foams and insulation materials. New materials and blowing agents are now available that allow high insulation properties without contributing to GWP.

4. CLOSING

The 1987 Montreal Protocol called for the steady phase out of all CFC and HCFC refrigerants across the globe because they contain chlorine, which has been shown to cause ozone depletion.
Nearly 20 years ago, air-conditioning and refrigeration manufacturers led the way in moving from CFC-12 to R-134a, which offers zero ozone-depletion with a Global Warming Potential of 1,320, an 84% improvement over CFC-12. Also, R-134a benefits from large global availability, as it is used throughout the automotive industry and in commercial building cooling systems.

While the air-conditioning and refrigeration industry overall has done its part to address the ozone depletion issue, the Kyoto Protocol – which went into effect in 2008 without the U.S. or developing countries – is not expected to meet its greenhouse gas emission goals by 2012.

While having a positive effect on ozone depletion, HFCs are a greenhouse gas as we know, so they will be covered by these targets, unless they are directly regulated through some other means like the Montreal Protocol, where an amendment has been introduced to reduce HFCs on a global basis.

Coming out of the Copenhagen discussion in 2009, there was some talk of including international transportation – like marine shipping – in the reduction targets, either at the international level or at the regional level, for example in the European Union (EU).

Regardless, shipping lines are coming under increasing pressure to reduce their carbon footprint. We have seen recently in the news that incentives are being offered in several EU ports for ships that produce low emissions and report energy efficiency.

As an industry we've made substantial progress on both ozone protection and global warming with substitutes to CFCs. HFC refrigerants are very minor contributors to global warming. While there may not be a "perfect refrigerant," natural refrigerants such as propane, ammonia and CO_2 offer no ozone depletion potential and very low GWP, though propane and ammonia have flammability and toxicity issues.

CO_2 was first proposed as a refrigerant 160 years ago, reaching its peak use in the mid-1920s, but falling out of favor with the development of CFCs in the late-1920s. While CO_2 has long been viewed as very close to being the ideal working medium for refrigeration systems, it has always come at the sacrifice of energy performance, as noted by Lorentzen in the mid-1990s.

. Over the last few years, the use of CO_2 in commercial refrigeration is growing rapidly in northern Europe. Compressor manufacturers and suppliers of refrigeration system components are actively working on designs aimed at optimizing performance with CO_2.

Progress made in stationary commercial refrigeration plants continues to reveal that CO_2 systems can be as energy efficient as HFC system. (Energy Consumption in Transcritical CO_2 Refrigeration, Danfoss)

For container shipping, CO_2 is the only refrigerant that offers a GWP of one, avoids harmful direct emissions, has zero ozone-depletion potential and is classified as non-toxic. Further, it requires no disposal, is cost effective and available worldwide, and has excellent heat transfer / heat reclaim properties. Finally, CO_2 refrigerant is protected against phase-outs, taxes, and European F-gas regulations.

To be successful, container refrigeration equipment manufacturers must work to combine the best of these components into a carefully designed system. The goal of these new systems should be to achieve a GWP equal to one, minimize environmental impact from materials used, and improve energy efficiency at the same time.

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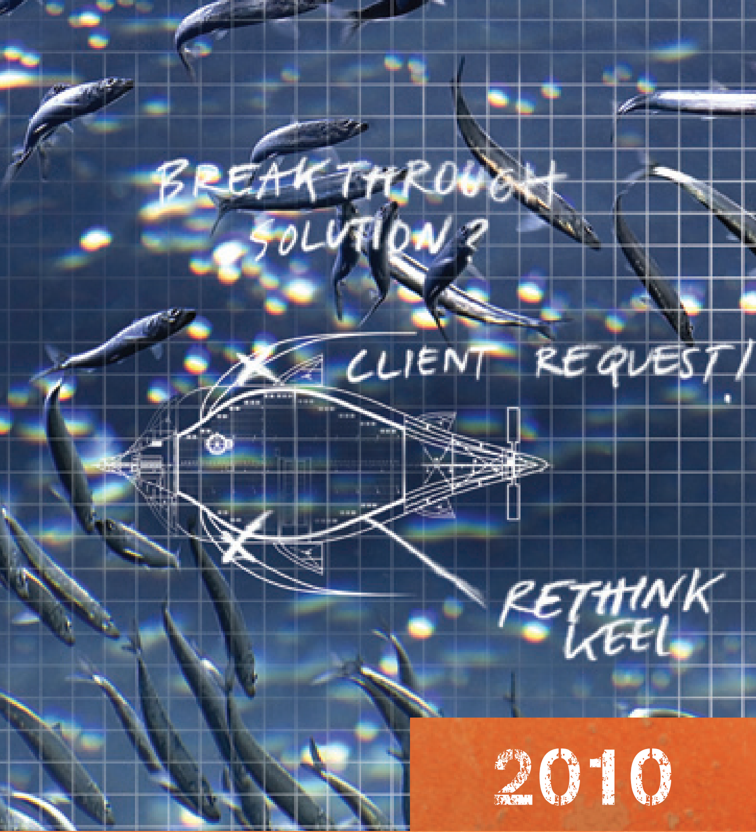
Appendix III



2010

SHIP POWER PRODUCT CATALOGUE

ENERGY
ENVIRONMENT
ECONOMY

WÄRTSILÄ

WÄRTSILÄ OFFERS THE MOST EFFECTIVE SOLUTIONS FOR ALL MARINE POWER AND PROPULSION NEEDS, AND IS THE MOST RESPONSIVE AND EFFICIENT PARTNER FROM FIRST CONCEPTS THROUGHOUT THE LIFETIME OF THE VESSEL.

TABLE OF CONTENTS

WÄRTSILÄ IN THE MARINE MARKET

Wärtsilä provides system solutions that support our goal of being the most responsive and efficient partner, from first concepts and throughout the lifetime of all types of marine vessels and offshore applications.

Wärtsilä is the leading provider of solutions for ship machinery, propulsion, automation, manoeuvring, ship design and services. We serve owners, operators and yards in the merchant, cruise & ferry, offshore, naval and special vessel markets.

Our customer support extends throughout all stages and levels, from design and construction to operation, in order to create feasible life-cycle

solutions. These are customized to meet specific design and operational requirements, thus ensuring optimal performance throughout the entire life-cycle of the vessel or offshore application.

● Automation and power distribution systems ● Ship design
● Low-speed engines ● Medium-speed engines ● Generating sets
● Auxiliary systems ● Controllable pitch propellers ● Fixed pitch propellers ● Steerable thrusters ● Transverse thrusters ● Nozzles
● Jets ● Gears ● Rudders ● Seals ● Bearings

ENVIRONMENTAL PERFORMANCE

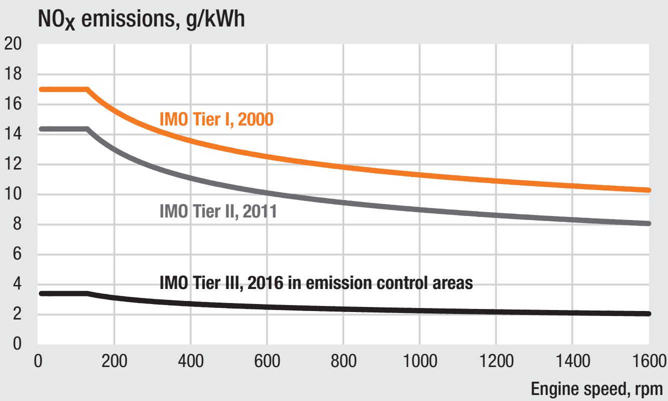
Wärtsilä's solutions are customized to specific ship design and operational requirements to ensure maximum efficiency, reliability and environmental performance over the entire lifecycle of the installation. Examples of Wärtsilä's achievements in environmental care are RT-flex engines, dual-fuel engines for LNG carriers and environmentally friendly stern tube sealing systems.

IMO NO_X EMISSIONS AND WÄRTSILÄ ENGINES

Annex VI of the MARPOL 73/78 convention entered into force on 19 May 2005. All Wärtsilä engines included in this booklet comply with the NOX limits specified in the Annex.

The exhaust emissions regulations in Annex VI of the MARPOL 73/78 convention are now referred to as IMO Tier I. In October 2008, the Marine Environment Protection Committee (MEPC) of IMO adopted amendments to the MARPOL Annex VI regulations. These specify further NO_X emission limits to be known as IMO Tier II and Tier III. Under IMO Tier II, the NO_X emission limits for engines installed in ships constructed on or after 1 January 2011 will be reduced, according to a speed-dependent function, about 20% from the presently valid IMO Tier I levels (see chart).

Under IMO Tier III, the NO_X emission limit for engines installed in ships constructed on or after 1 January 2016 will be reduced, according to a speed-dependent function, 80% from the presently valid IMO Tier I levels (see chart),



when the ship is operating in a designated Emission Control Area. Outside designated Emission Control Areas Tier II limits apply.

Wärtsilä will adapt its engines to comply with the new upcoming NO_X emission regulations.

CLEAN DESIGN CERTIFICATION FOR MEDIUM-SPEED ENGINES

Wärtsilä engines have achieved Clean Design certification as defined by the Det Norske Veritas (DNV) classification society. So far, the Wärtsilä 20, Wärtsilä 32 and Wärtsilä 34DF engine types have been delivered with the certificate, and in the future all other Wärtsilä engine types will follow.

Certification means that the NO_X emissions of the engines are approximately 20% lower than the current IMO Tier 1 level. This is another step in our continuing, proactive development of engines for lower exhaust emissions and reduced environmental impact.

The emission levels have been lowered largely by reducing the maximum combustion temperatures. This has involved a combination of measures: Early inlet valve closing (Miller timing), optimisation of the combustion chamber, and optimisation of the fuel injection equipment. This has reduced the emissions with only a marginal decrease in efficiency, or none at all. As per today, over 50 engines have been delivered complying with the DNV Clean Design NO_X requirement.

WÄRTSILÄ ENVIRONMENTAL TECHNOLOGIES

WÄRTSILÄ DUAL FUEL ENGINES WITH SUPERIOR ENVIRONMENTAL PERFORMANCE

Gas operation gives a great environmental advantage compared to diesel mode seen from the exhaust gas emission point of view.

When operating the engine in gas mode the exhaust emissions are extremely low. In gas mode operation, the NO_X emissions are over 80% below the current IMO level and by this comply with the upcoming IMO Tier III standard. The SO_X emissions are almost negligible and the amount of emitted particles is less than 10% compared to a conventional marine diesel engine running on diesel. Further, gas operation generates in general 25-30% lower CO_2 emissions compared to diesel operation.

The gas engine is a clean, reliable and high efficiency engine. The engine is a perfect solution when the target is to achieve low exhaust emissions in a cost efficient way.

WÄRTSILÄ COMMON-RAIL

Wärtsilä common-rail engines, branded as RT-flex for low-speed engines and EnviroEngine for medium-speed engines, offer distinct benefits to ship owners. One of the major benefits is smokeless operation at all engine load levels, also at low load and low revolution speed. The lower running costs of Wärtsilä common-rail engines derive from reduced maintenance and lower part-load fuel consumption. Precise control of injection and high injection pressures at all speeds give steady running at very low running speeds without smoking, down to 10–12% of nominal speed for low-speed engines. Particular attention has been given to making the system reliable. The common-rail concept also has inherent redundancy, adding to reliability and safety.

The design of the common-rail system is optimized for new engines but it can also be retrofitted to existing engines.

WÄRTSILÄ LOW LOSS CONCEPT

The Wärtsilä Low Loss Concept (LLC) is a specially developed and patented diesel electric system. One of the LLC features is reduced electrical losses compared with conventional diesel electric systems. This saves fuel and reduces exhaust gas emissions. The LLC obviates the need for propulsion transformers with associated electric losses. Results from full scale measurements have shown total electric losses in the range of 6% for the LLC, which is significantly less than in conventional systems.

ENERGOPAC

Fuel savings and a reduction in emissions can be achieved with Wärtsilä Energopac. This is an integrated propulsion and steering system which increases the propulsion efficiency, but does not compromise on manoeuvring characteristics and comfort levels. Energopac includes a special propeller design, a sophisticated high-lift flap rudder equipped with an efficiency bulb and a special fairing cap connected to the propeller hub. The bulb and fairing cap work together to streamline the water flow behind the propeller while the twisted leading edge and rudderflap reduce rudder drag. Depending on the specific application, the power savings and emissions control with Wärtsilä Energopac may result in operational savings of up to 9%.

WÄRTSILÄ HIGH EFFICIENCY NOZZLE

The WÄRTSILÄ HR (high efficiency) nozzle differs from a conventional nozzle through a special rounded leading edge and S-shaped outer surface. Since their introduction with small propellers (less than 3.5 m diameter), several hundred have since been applied to a wide variety of vessels. Full-scale tests on several vessels indicate an improved bollard pull in the order of 7–10%. This means an improvement of up to 13% in free-running conditions compared to a conventional nozzle.

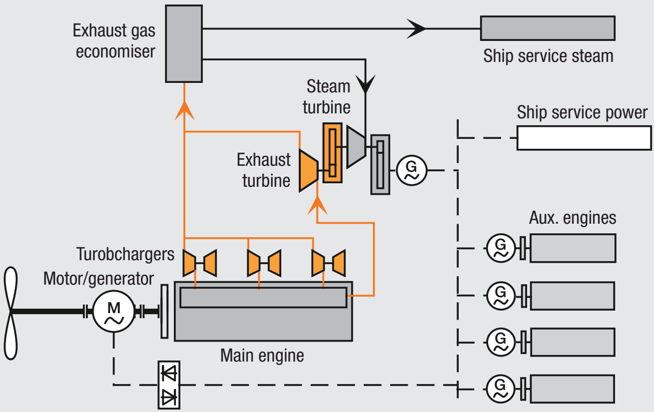
ENVIROSEALS: OCEANGUARD AND AIRGUARD

Any oil loss to the environment from a ship's stern shaft sealing system is unacceptable. Enviroseals offer pollution-free sealing systems with a proven track record on all types of vessels. Enviroseals are equally suited to retrofitting to existing standard seal installations or, as is now common, to be specified by owners for new-buildings.

Wärtsilä's Enviroseal systems prevent both the leakage of bearing oil into the sea and the ingress of water into the bearing system. They ensure continuous operation between planned maintenance periods, with no unplanned dry dockings for emergency repairs.

The Oceanguard system is unique in that it enables all potentially polluting oil to be contained within the vessel using a double barrier comprising a combination of face seal and lip seal technologies and a low-pressure void space. This sealing system is ideal for use on cruise ships and ferries.

The Airguard system, with its air-induced controlled pressure components, ensures the seal is a truly anti-pollution lip seal. This sealing system is ideal



Schematic of a High-Efficiency Waste Heat Recovery plant typical for large container ships with the turbogenerator supplying both assisted propulsion and ship´s service power. The shaft motor can also serve as a shaft generator for added flexibility in operation.

for use on LNG carriers, containers ships, bulk carriers and many other vessel types.

HIGH-EFFICIENCY WASTE HEAT RECOVERY (WHR)

Waste heat recovery is an effective technology for simultaneously cutting exhaust gas emissions and reducing fuel consumption. High-Efficiency Waste Heat Recovery plants can be installed with Wärtsilä engines.

Waste heat recovery on low-speed engines: this technology has been already successfully fitted in several installations to Wärtsilä RT flex common-rail low-speed marine engines. It enables up to 12% of the main engine shaft power to be recovered as electrical power for use as additional ship propulsion power and for shipboard services. These WHR plants thus cut exhaust gas emissions and deliver fuel savings of up to 12%.

In the WHR plant, a turbo-generator combines input from a steam turbine and an exhaust gas power turbine to generate electrical power while steam from the economizer is available for ship service heating.

Waste heat recovery on medium-speed engines: heat can be recovered with an Organic Rankine Cycle (ORC). While steam cycles use water as media, the ORC units can utilize various types of organic media. A non-flammable and non-toxic media can be used to utilize exhaust gas heat and also lower grade of heat sources like HT water from the engines. The heat is transferred to the ORC media via an evaporator. The evaporated media spins a turbine which is connected to a generator. The media is cooled down through a condenser and pumped back to the evaporator for another cycle. It is also possible to re-use the heat after the turbine and preheat the media through a regenerator before it enters the evaporator. Due to its flexibility, the system can be fully optimized to achieve the same efficiency as in the steam cycle.

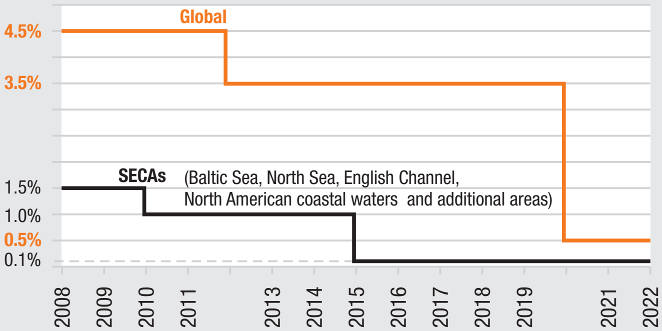
WÄRTSILÄ SCRUBBER

As part of the revised and adopted Marpol Annex VI, new limitations on SO_X emissions have been introduced by IMO; particulate matter emissions reduction is part of the same regulation. Particulate matters are considered simultaneously reduced with SO_X.

The following regulations (see chart) will be applied to all ships: new buildings and existing vessels. The regulation has different SO_X limitations and time of implementation: tighter limitations will be applied earlier in emission control areas, while the global sulphur cap will be significantly reduced by 2020 or 2025 (in case of postponement of the implementation year).

There are no restrictions in the use of high sulphur heavy fuel oil and abatement technologies are allowed for achieving compliance.

SO_X and particulate reduction



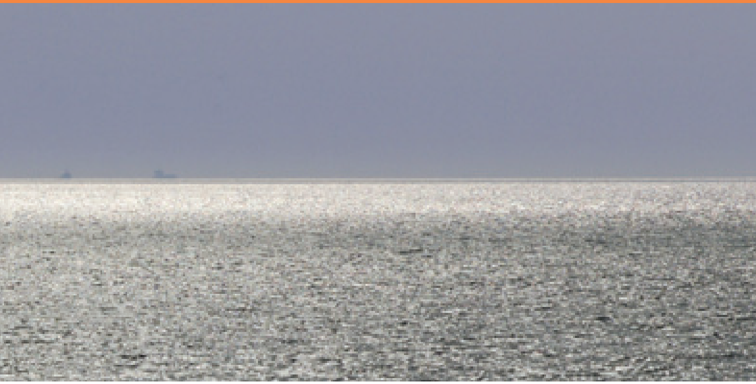
– Particulates are regulated by the reduced fuel sulphur content
– SO_X cleaning technologies are allowed as an alternative

Exhaust gas scrubbing is a cost effective alternative to low sulphur content fuels for reducing SO_X emissions. Wärtsilä has developed a feasible solution, both for new installations and as a retrofit to existing ships. Combustion units can be diesel engines of any type or application, 2-stroke or 4-stroke. In the case of Integrated Scrubber, also flue gases from oil-fired boilers can be cleaned.

Wärtsilä scrubber concept is based on closed loop system, using fresh water with caustic soda (NaOH) addition to the scrubbing water. A small bleed-off is extracted from the loop to remove the accumulated impurities from the scrubbing water and led to the emulsion breaking water treatment plant. Clean effluent from the treatment plant full-fills IMO quality requirements and can be discharged overboard. If operation in zero discharge mode is requested, the effluent can be led to a holding tank for scheduled and periodical discharge.

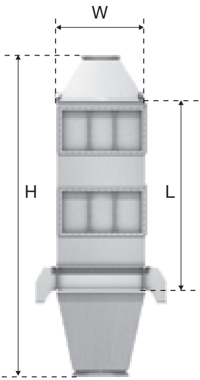
The SO_X removal efficiency of Wärtsilä scrubber system is over 97%, making it possible to operate with 3.5% sulphur fuel and still comply with 0.1% sulphur fuel limit.

There are different scrubber configurations available. Main Stream Scrubber is designed to be installed in the main exhaust gas stream of an individual diesel engine. Integrated Scrubber is based on design where one single unit can clean the exhaust gases of several main and auxiliary engines and oil-fired boilers onboard. The scrubber system is equipped with an automation system for operation, emissions monitoring and safety control. Wärtsilä scrubber system has been approved by several classification societies.



WÄRTSILÄ NOR REACTOR OVERALL DIMENSION TABLE

Size	Engine power kW	W mm	H mm	L mm	Flanges DN mm
1	<1260	945	4505	3440	500
2	1261–2240	1260	4690	3440	700
3	2241–3500	1575	5045	3440	800
4	3501–5040	1890	5215	3440	1000
5	5041–6860	2205	5410	3440	1200
6	6861–8960	2520	5915	3440	1300
7	8961–11 340	2835	6110	3440	1500
8	11 341–14 010	3150	6485	3440	1600
9	14 011–169 50	3465	6685	3440	1800
10	16 951–20 170	3780	6885	3440	2000



WÄRTSILÄ NITROGEN OXIDE REDUCER

Wärtsilä has developed a nitrogen oxide reducer (NOR) based on selective catalytic reduction technologies. The programme covers Wärtsilä's medium-speed engine portfolio. The reduction in NO_X emissions is by 85-95%.

The size of the NOR is optimized in terms of performance and costs.

The main components of the SCR installation are the reactor, which is the core of the installation, a reagent pumping unit, a dosing unit for controlling the reagent flow and injection unit for feeding the reagent into the duct. The dosing unit is provided with a dedicated control cabinet. An emission monitoring system is part of the delivery.

WÄRTSILÄ OILY WATER SEPARATOR

The Wärtsilä Senitec M-series oily water separator gives the operator effective control over all bilge and sludge media as well as over any discharges made into the sea. The technology behind the Wärtsilä Senitec M-series is a combination of optimized traditional methods and innovative new solutions. It consists of a four-stage, emulsion-breaking separator, where each stage handles one key component of the sludge and bilge mix. It can handle input flows with an oil content of between 0 and 100%, making it the most versatile separator on the market.

Wärtsilä Senitec M-series has successfully passed USCG / IMO type approval in accordance with 46 CFR §162.050 and MEPC.107(49). The guarantee amount of oil in water after treatment is less than 5 ppm.

WÄRTSILÄ SENITEC OILY WATER SEPARATOR M-SERIES

Technical data	M 1000	M 2500
Capacity, max	24 m^3/day	60 m^3/day
Length	2344 mm	3210 mm
Width	1100 mm	1400 mm
Height	1855 mm	1855 mm
Weight, dry	650 kg	950 kg
Weight, wet	1950 kg	2700 kg
Power	10 kW	10 kW

WÄRTSILÄ BILGEGUARD

Wärtsilä BilgeGuard is a fully automated bilge discharge monitoring system which constantly oversees and monitors the oil content in all discharges overboard. Should the oil content rise above the set limit, the flow will be re-reouted back to the bilge tank. The system logs the discharge quantity and oil content as well as time and location of the ship. All data is stored in memory for later retrieval.

The system is enclosed in a locked, tamper-proof cabinet and all accesses are logged in memory. For both crew members and ship management, the Wärtsilä BilgeGuard provides a priceless safety net and possibility to make evident the compliance with applicable regulations.

Wärtsilä Senitec M-series oily water treatment unit.

Wärtsilä BilgeGuard.

SHIP DESIGN AND MARINE CONSULTANCY

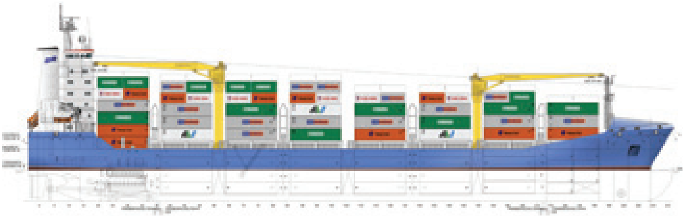
WÄRTSILÄ SHIP DESIGN

Wärtsilä primarily provides designs for merchant, offshore and special vessels. Offshore construction vessels, anchor handling vessels, platform supply vessels, cable layers, pipe layers, container vessels, chemical tankers, ice breakers, research vessels and offshore windpark installation vessels are amongst our most recent references. We provide initial design (general arrangement drawings and related documents), basic design (classification drawings and related documents) and detail design (production drawings and related documents).

Wärtsilä covers the full range of ship design disciplines, including naval architecture, structural engineering, accommodation and outfitting, mechanical engineering and electrical engineering.

MARINE CONSULTANCY

Wärtsilä provides a comprehensive range of marine consultancy services for ship owners who intend to engage, or have already engaged in a newbuilding contract with a shipyard. Consultancy services provided to ship owners prior to the signing of a newbuilding contract include the performance of technical and commercial feasibility studies, the creation of conceptual ship designs, the preparation of full tender documentation, and the technical and commercial evaluation of shipyard offers. Plan approval, design optimization and onsite newbuilding supervision are some of the consultancy services provided to ship owners after the signing of a newbuilding contract.



SCHIFFKO CV 1300 Container vessel

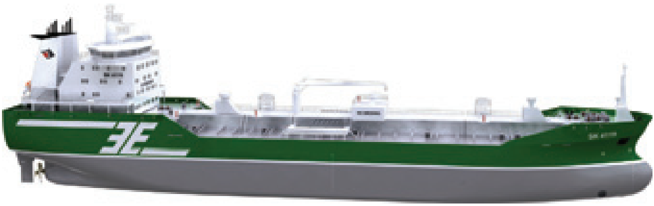
Length overall .... 155.00 m
Breadth .... 25.85 m
Draught .... 7.70 m
Power .... 11'620 kW

Container capacity .... 1300 TEU
Main engine .... Wärtsilä 7RT-flex50
Speed .... 19.8 kt

SCHIFFKO CV 1800 Container vessel

Length overall .... 194.65 m
Breadth .... 27.80 m
Draught .... 10.50 m
Power .... 19'360 kW

Container capacity .... 1800 TEU
Main engine .... Wärtsilä 8RT-flex60C
Speed .... 21 kt



PRODUCT TANKER SK 4119 3E Tankers – Environment, Economy, Efficiency

Length overall .... 130.00 m	Power .... 2 x 2400 kW
Breadth .... 22.00 m	Main engine .... Wärtsilä 8L26
Draught .... 11.70 m	Speed .... 13.5 kt

REEFER SK 3110 Refrigerated Cargo Carriers

Length overall .... 164.70 m	Power .... 16,949 kW
Breadth .... 27.00 m	Main engine .... Wärtsilä 7RT-flex60C
Draught .... 9.50 m	Speed .... 20.5 kt

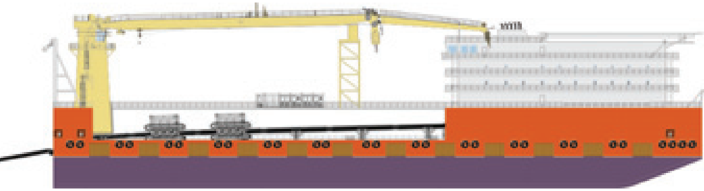
VS 491 CD AHTS Anchor Handling vessel

Length overall .... 91 m	Bollard pull .... 300 tonnes
Breadth .... 22.00 m	Power .... 2 x 8000 kW
Depth to 1st deck .... 9.60 m	Main engine .... Wärtsilä 16V32

VS4240 PLV Pipe laying vessel

Length overall................................ 194.5 m
Breadth.. 31.00 m
Speed .... 20.5 knots
Generators.............................. 6 x 4320 kW

Reel capacity..................... 2 x 2500 tonnes
Tension capacity........................ 450 tonnes
Main engines .... 6 x Wärtsilä 9L32



C4157 Accommodation / Derrick/ Pipelay barge

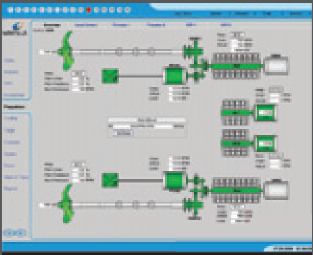
Length overall.................................. 120 m
Breadth.. 37.70 m
Depth .... 9.00 m

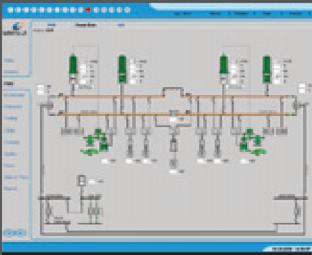
Draft designed......................... 6.00 tonnes
Complement................................ 300 Men
Generators.............................. 7 x 591 ekW

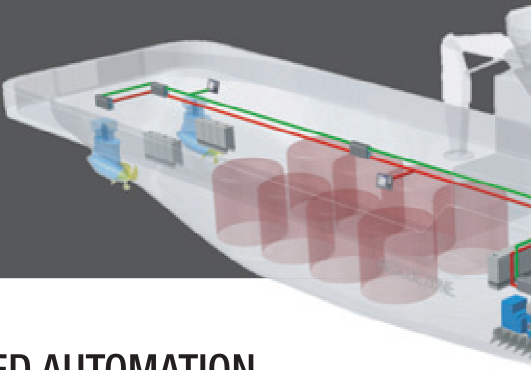
C4571 Offshore Support Vessel

Length over all............................... 59.2 m
Breadth.. 15.00 m
Depth.. 6.75 m

Draft designed................................... 5.0 m
Complement.................................. 28 men
Speed .... 12.5 knots


Propulsion optimization


Power management

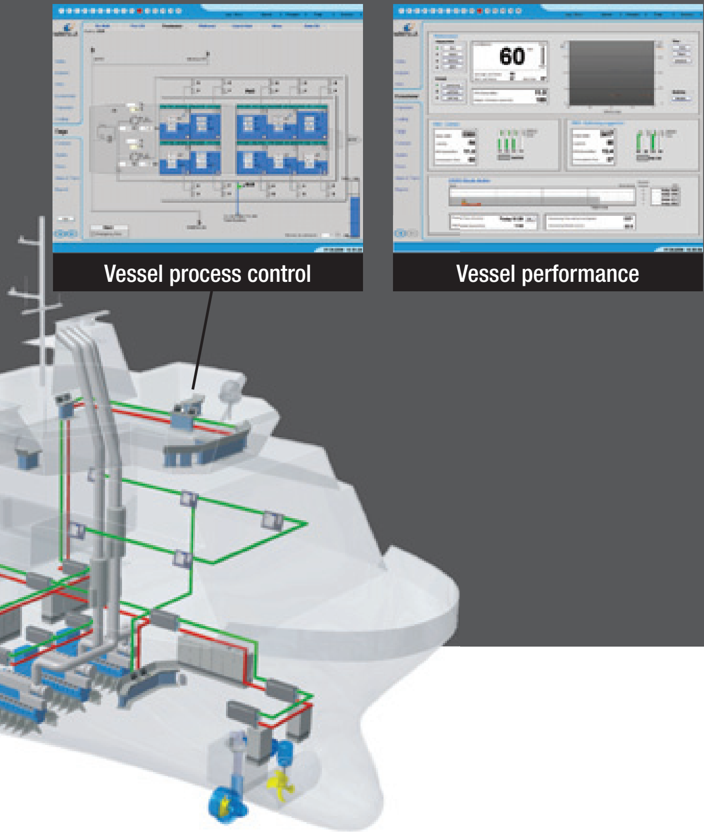


WÄRTSILÄ INTEGRATED AUTOMATION

The Wärtsilä integrated automation system is a new-generation vessel automation system based on a distributed architecture and transparent integration with the Wärtsilä engine control and propulsion system. It also covers all third-party systems onboard.

Wärtsilä offers scaleable systems from small alarm and monitoring systems to advanced integrated automation systems.

The integrated automation system is easy to install and has a number of enhanced applications: ● Alarm and Monitoring ● Power generation ● Propulsion ● HVAC ● Utilities ● Ballast ● Power distribution ● Thrusters ● Engines ● Cargo ● Power management.



The complexity of the integrated automation system reflects the type of vessel and the functionality onboard. We offer a wide range of configurations for various needs.

The integrated automation system has an easy, standardized interface with other systems onboard. Both shipowners and shipyards are ensured full lifecycle support from design, installation and commissioning to operation throughout the lifespan of the vessel.

Based on data from all essential vessel systems we can offer a performance estimator integrated in the control system, that enables ship owners and operators to manage the vessel more economical and environmental friendly. Includes fuel- and power optimization and reporting based on hull performance, power production, cargo- and navigational data.

WÄRTSILÄ POWER MANAGEMENT

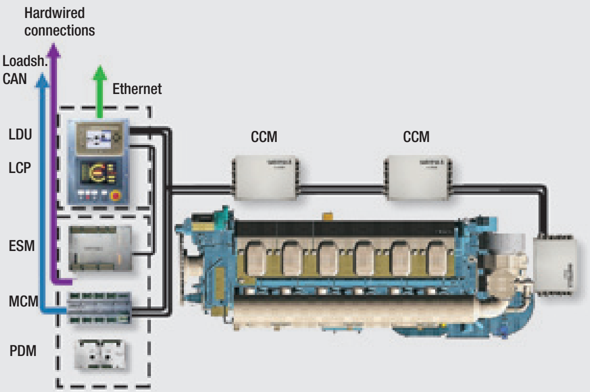
The Wärtsilä power management system provides effective control and monitoring of the power plant and power consumption. Power management covers the entire chain from the power generating units, switchgear, power distribution network and variable speed units to the power users.

The complexity of the power distribution control is built into the system so as to achieve the maximum efficiency performance. Each installation is therefore configured individually.

WÄRTSILÄ CONTROL SYSTEMS

UNIFIED CONTROLS

Wärtsilä unified controls, UNIC, introduce a flexible and fully scalable control system for large reciprocating diesel and gas engines.



UNIC

HIGH RELIABILITY AND EFFICIENT DESIGN

The UNIC system is designed to fulfil the long lifetime expectations for large marine diesel and gas engines operating in the toughest of conditions. The system is based on a high degree of commonalities and standard interfaces, covering different engine sizes and fuel systems in a modular way. A modular, standardized interface provides the designer of the off-engine automation systems with easily reusable design. It allows conversion of for example diesel engines to dual fuel or common rail with a minimum of modifications. Due to the pre-tested configuration, the engine or generating set is operational with a minimum of commissioning and installation work.

The critical parts of the UNIC system are either redundant or very fault-tolerant to guarantee high safety and availability in all circumstances. In particular, parts like the communication and power supply are fully redundant to allow single failures without interruptions in engine operation.

Thanks to the electronic control, the engine can be adapted to different operating conditions.

Key features of the UNIC system are complete engine safety system, local monitoring, speed control with loadsharing, fuel injection-, timing control, knock detection, alarm signal aquisition, start/stop sequencing, load reduction request, system diagnostics and fieldbus interface as applicable for each engine configuration.

WÄRTSILÄ PROPULSION CONTROLS

OPTIMISED CONTROL OF THE PROPULSION MACHINERY

The Wärtsilä Propulsion Controls are computer based, designed to monitor and control all components in a modern propulsion system with high accuracy, tailored to the individual applications.

REMOTE CONTROL FOR CONTROLLABLE PITCH PROPELLERS

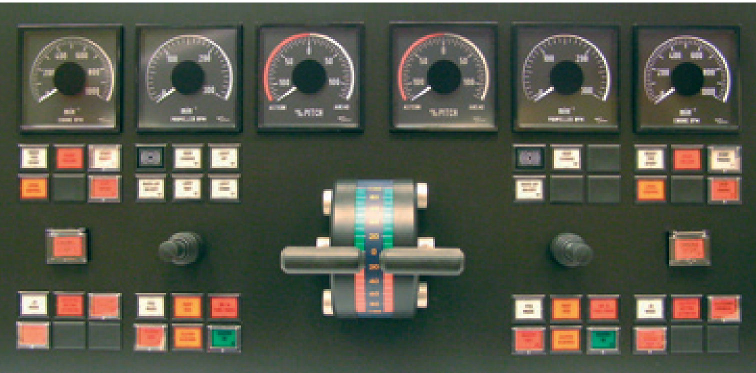
The Wärtsilä Propulsion Controls are designed to optimise the control of any propulsion machinery. The system exists in two versions, basic and advanced.

The Wärtsilä Propulsion Controls basic is a cost effective standardised system to meet most of the demands in the market for propulsion control. This system is applicable for single engine configurations (including twin screw).

The Wärtsilä Propulsion Controls advanced introduces a modular designed system with communication on a two-wire field bus. This gives high flexibility and multi functionality. This system is equaly suitable for single and twin engine configurations.

The system controls the propeller pitch position and engine speed either combined or in split modes. Included is a propeller and engine load control system developed on the basis of research and experience over many years. A large amount of special functions to optimise ship operations are available.

A user-friendly operator panel is supplied. This gives information of the propulsion plant and is used for calibrating of the system.



Main bridge panel for CPP Propulsion Controls.

SPECIAL FUNCTIONS AS:

- Pitch reduction zone – reduces propeller wear
- Windmilling prevention
- PTI/PTO functions
- Multiple combinator modes
- Frequency variation mode
- Cruise control
- Fine tuning pitch
- Electric shaft levers

REMOTE CONTROL FOR JETS:

These systems are similar to the one used for controllable pitch propellers, except for the integrated joystick system which is an option for catamarans and monohulls. For monohulls with joystick control a bow thruster is also required.

The joystick is a single lever system for enhancing manoeuvring.

REMOTE CONTROL FOR AZIMUTHING THRUSTERS:

For vessels such as harbour tugs an integrated control concept similar to that for jets is available.

For large off-shore platforms, individual controls for propulsion and steering are available. These include standardised interfaces with third party DP-systems.

Main bridge panel for Waterjet Controls.

WÄRTSILÄ JOYSTICK

CO-ORDINATING CONTROL SYSTEM:

The Wärtsilä Joystick concept is a co-ordinating control system for offshore supply vessels, cable-layers and other ships which require manoeuvring enhancing systems.

For vessels equipped with podded propulsors a dedicated Wärtsilä Joystick is available, including features such as a simplex DP-mode and anchoring mode.

CONTROLS

Cost effective universal controls for any propulsion system

- Robust design with type approval
- Joystick available for small and large vessels
- Field bus application available

WÄRTSILÄ VARIABLE SPEED DRIVE

The variable speed drive is specially designed for lifetime operation in a maritime environment. It is the world's most compact low voltage (690V) variable speed drive with excellent performance in control of propulsion motors, pump applications, compressors, mooring and winches, and drilling operations. The drive is water cooled and can be directly connected to the ship's cooling water system. Other important features are the redundant design and interchangeable power modules which gives an easy and efficient service concept.

WÄRTSILÄ PASSIVE RECTIFIER

The variable speed drive can be delivered with a diode rectifier in a 12 pulse or 24 pulse configuration, very well suited to either a Wärtsilä LLC system or a standard transformer solution.

WÄRTSILÄ ACTIVE FRONT END RECTIFIER

The variable speed drive can also be delivered with an active rectifier front end which allows for energy flow in both directions, eliminating the need for transformers and braking resistors. Direct Current Control and network filter gives small ripple currents and very low harmonic distortion.

Wärtsilä Passive Rectifier Drive – LV				
Power (kW)	Length (mm)	Depth (mm)	Height (mm)	Weight (kg)
880	900	1000	2051	800
1500	900	1000	2051	900
2700	1500	1000	2051	1400
3800	2100	1000	2051	1900
5000	2700	1000	2051	2300

Wärtsilä Active Rectifier Drive – LV				
Power (kW)	Length (mm)	Depth (mm)	Height (mm)	Weight (kg)
880	900	1000	2051	1500
1500	1500	1000	2051	2300
2700	3000	1000	2051	4500
3800	5100	1000	2051	6800
5000	6600	1000	2051	8500

MULTIDRIVE SYSTEMS, DC SOURCES

The variable speed drive can also be delivered as a multidrive system, where the inverters are connected to the same DC-link. Combined with own patented electronic DC breakers these work independently. The multidrive system can be connected to the main grid through either active or diode rectifiers, and also allows for DC-sources such as batteries and fuel cells.

WÄRTSILÄ SWITCHBOARS

Wärtsilä low and medium voltage switchboard systems are optimized for marine use.

When developing our switchboard systems, the need for easy installation and maintenance is a key consideration. The system is module-based and, therefore, very flexible. Later extensions can also be easily added.

WÄRTSILÄ MARINE SWITCHBOARD – LV

Technical data

Rated voltage (V) .... ≤ 690
Short circuit test IEC 439–1
  Surge current (peak) kA 176
  Prospective current (RMS) kA 80
  Thermal rated current (1s) 80
  Bus bar (A) 4000

WÄRTSILÄ MSS36 SWITCHBOARD – LV

Technical data

Rated voltage (V)	≤ 690
Short circuit test IEC 439–1	
Surge current (peak) kA	220
Prospective current (RMS) kA	87
Thermal rated current (1s)	87
Rated current	
Bus bar (A)	4000
Lead-down bar MCC (A)	1100
Enclosure IEC 529/947–1	
Doors closed	IP 4L2
All doors open	IP 20
Air and creepage current distances IEC	664
Flame arc test IEC 298 prospective current (RMS) kA	87

WÄRTSILÄ OPERA SWITCHBOARD – MV

Technical data

Rated voltage (kV)	7.2	12	17.5
Insulation level			
50 Hz/1 min (kV RMS)	20	28	38
1.2/50 ms(kV peak)	60	75	75
Rated current			
Bus bars (A)			3150
Droppers (A)			2500
Short circuit current			
Thermal (kA)			42 (1 sec)
Dynamic (kA)			106 (peak)
Flame Arc test aac. to IEC 298			40 kA 0.15 sec 31.5 kA 1 sec

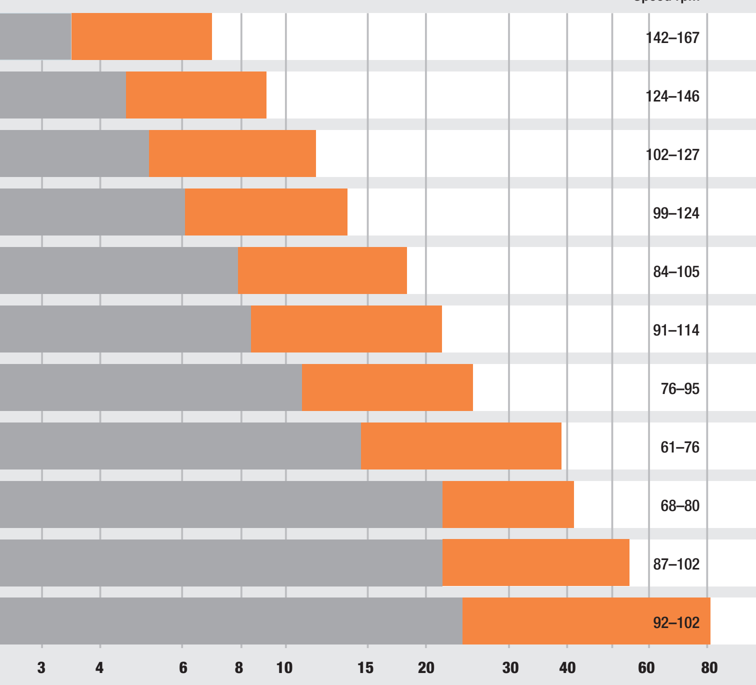
WÄRTSILÄ LOW-SPEED ENGINES

Wärtsilä RT-flex engines are low-speed two-stroke engines that provide optimum prime movers for the propulsion of ships of all sizes with direct drive of propellers and high overall economy.

The Wärtsilä RT-flex engines are based on the Wärtsilä RTA series but have fully electronically-controlled common-rail systems for fuel injection, exhaust valve actuation and starting. Their benefits to shipowners and operators may be summarized as:

- Optimum powers and speeds to match ship requirements
- Competitive first cost

POWER RANGE FOR WÄRTSILÄ LOW-SPEED ENGINES



- Lowest possible fuel consumption over the whole operating range, especially in part-load range
- Special tuning for even better part-load fuel consumption
- Low cylinder oil feed rate
- Three years' time between overhauls
- Low maintenance costs through reliability and durability
- Full compliance with NO_X emissions control regulations
- Smokeless operation at all running speeds
- Lower steady running speeds
- Reduced maintenance requirements with simpler engine setting

WÄRTSILÄ RT-flex35

IMO Tier II only

Main data:

Cylinder bore .... 350 mm
Piston stroke................................ 1550 mm
Speed .... 142–167 rpm
Mean effective pressure at R1........21.0 bar
Piston speed.................................. 8.6 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

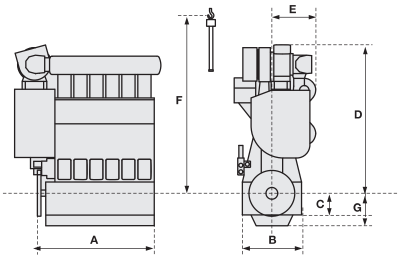
Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	167 rpm		142 rpm			
	R1	R2	R3	R4		
5	4 350	3 475	3 700	3 475	4 434	69
6	5 220	4 170	4 440	4 170	5 046	80
7	6 090	4 865	5 180	4 865	5 658	90
8	6 960	5 560	5 920	5 560	6 270	98
Dimensions mm	B	C	D	E	F*	G
	2 264	830	5 556	1 220	6 850	1 326

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			21.0	16.8	21.0	19.8
IMO Tier II	RT-flex	Standard Tuning	176	170	176	174

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier II	172.8	172.0	172.1	170.5	169.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex40

IMO Tier II only

Main data:

Cylinder bore .... 400 mm
Piston stroke................................ 1770 mm
Speed .... 124–146 rpm
Mean effective pressure at R1........ 21.0 bar
Piston speed.................................. 8.6 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	146 rpm		124 rpm			
	R1	R2	R3	R4		
5	5 675	4 550	4 825	4 550	5 050	109
6	6 810	5 460	5 790	5 460	5 750	125
7	7 945	6 370	6 755	6 370	6 450	140
8	9 080	7 280	7 720	7 280	7 150	153

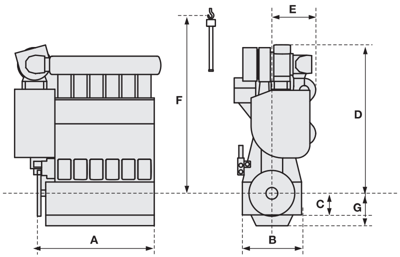
Dimensions mm	B	C	D	E	F*	G
	2 590	950	6 335	1 660	7 700	1 425

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			21.0	16.8	21.0	19.8
IMO Tier II	RT-flex	Standard Tuning	175	169	175	173

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier II	171.8	171.0	171.1	169.5	169.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex48T

IMO Tier I and Tier II

Main data: Version D, also available as traditional RTA type

Cylinder bore .... 480 mm
Piston stroke................................ 2000 mm
Speed .... 102–127 rpm
Mean effective pressure at R1........ 19.0 bar
Piston speed.................................. 8.5 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	127 rpm		102 rpm			
	R1	R2	R3	R4		
5	7 275	5 100	5 825	5 100	5 314	171
6	8 730	6 120	6 990	6 120	6 148	205
7	10 185	7 140	8 155	7 140	6 982	225
8	11 640	8 160	9 320	8 160	7 816	250

Dimensions mm	B	C	D	E	F*	G
	3 170	1 085	7 334	3 253	9 030	1 700

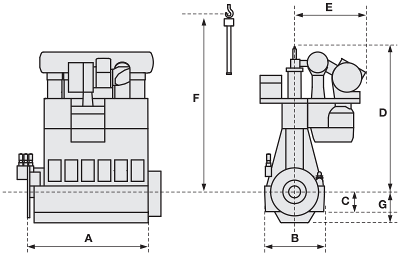
Brake specific fuel consumption (BSFC) in g/kWh

Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			19.0	13.3	19.0	16.6
IMO Tier I	RTA		169	161	169	165
IMO Tier II	RTA		173	167	173	169
	RT-flex	Standard Tuning	171	165	171	167

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier II	167.8	167.0	167.1	165.5	164.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex48T IMO Tier I and Tier II

Main data: Version D, also available as traditional RTA type

Economy Ratings

Rated power, principal dimensions and weights

Cyl.	Output in kW at 127 rpm		Length A mm	Weight tonnes
	ER1	ER2		
5	6 900	6 550	5 314	171
6	8 280	7 860	6 148	205
7	9 660	13 125	6 982	225
8	11 040	10 480	7 816	250

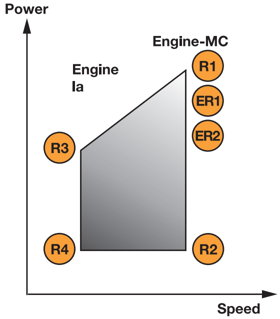
Dimensions mm	B	C	D	E	F*	G
	3 170	1 085	7 334	3 253	9 030	1 700

Brake specific fuel consumption (BSFC) in g/kWh

Rating point		Tuning variant	Load	ER1	ER2
BMEP, bar				18.0	17.1
IMO Tier I	RTA		100%	167.0	166.0
IMO Tier II	RTA		100%	171.5	170.0
	RT-flex	Standard Tuning	100%	169.5	168.0
	RT-flex	Standard Tuning	85%	166.3	164.8
	RT-flex	Standard Tuning	70%	165.5	164.0
	RT-flex	Delta Tuning	85%	165.8	164.5
	RT-flex	Delta Tuning	70%	164.4	163.3
	RT-flex	Low-Load Tuning	60%	163.4	162.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RTA48T

IMO Tier I only

Main data: Version B

Cylinder bore .... 480 mm
Piston stroke................................ 2000 mm
Speed .... 102–127 rpm
Mean effective pressure at R1........ 19.0 bar
Piston speed.................................. 8.5 m/s

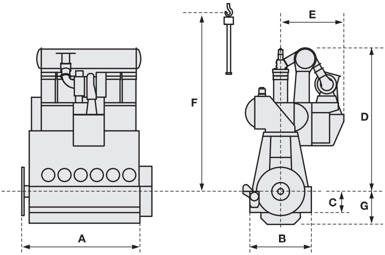
Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	127 rpm		102 rpm			
	R1	R2	R3	R4		
5	7 275	5 100	5 825	5 100	5 314	171
6	8 730	6 120	6 990	6 120	6 148	205
7	10 185	7 140	8 155	7 140	6 982	225
8	11 640	8 160	9 320	8 160	7 816	250
Dimensions mm	B	C	D	E	F*	G
	3 170	1 085	7 334	3 253	9 030	1 700

Brake specific fuel consumption (BSFC) in g/kWh					
Full load					
Rating point		R1	R2	R3	R4
BMEP, bar		19.0	13.3	19.0	16.6
IMO Tier I	RTA	171	163	171	167

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex50

IMO Tier I and Tier II

Main data: Version D

Cylinder bore .... 500 mm
Piston stroke .... 2050 mm
Speed .... 99–124 rpm
Mean effective pressure at R1 .... 21.0 bar
Piston speed .... 8.5 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

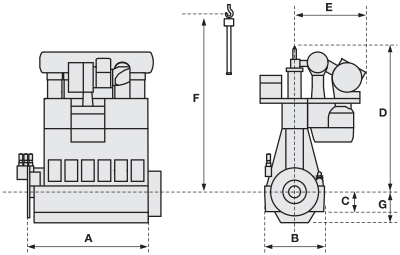
Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	124 rpm		99 rpm			
	R1	R2	R3	R4		
5	8 725	6 100	6 975	6 100	5 582	200
6	10 470	7 320	8 370	7 320	6 462	225
7	12 215	8 540	9 765	8 540	7 342	255
8	13 960	9 760	11 160	9 760	8 222	280
Dimensions mm	B	C	D	E	F*	G
	3 150	1 088	7 646	3 300	9 270	1 636

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			21.0	14.7	21.0	18.4
IMO Tier I	RT-flex	Standard Tuning	169	163	169	165
IMO Tier II	RT-flex	Standard Tuning	171	165	171	167

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	165.0	164.7	164.7	164.0	–
IMO Tier II	167.8	167.0	167.1	165.5	164.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex50

IMO Tier I and Tier II

Main data: Version B

Cylinder bore .... 500 mm
Piston stroke................................ 2050 mm
Speed .... 99–124 rpm
Mean effective pressure at R1........ 20.0 bar
Piston speed.................................. 8.5 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

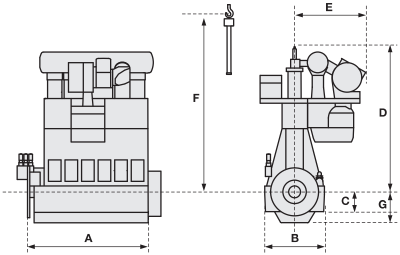
Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	124 rpm		99 rpm			
	R1	R2	R3	R4		
5	8 300	5 800	6 650	5 800	5 582	200
6	9 960	6 960	7 980	6 960	6 462	225
7	11 620	8 120	9 310	8 120	7 342	255
8	13 280	9 280	10 640	9 280	8 222	280
Dimensions mm	B	C	D	E	F*	G
	3 150	1 088	7 646	3 300	9 270	1 636

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			20.0	13.9	20.0	17.5
IMO Tier I	RT-flex	Standard Tuning	171	165	171	167
IMO Tier II	RT-flex	Standard Tuning	173	167	173	169

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	167.0	166.7	166.7	166.0	–
IMO Tier II	169.8	169.0	169.1	167.5	166.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex50

IMO Tier I only

Main data

Cylinder bore .... 500 mm
Piston stroke................................ 2050 mm
Speed .... 99–124 rpm
Mean effective pressure at R1........ 19.5 bar
Piston speed.................................. 8.5 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	124 rpm		99 rpm			
	R1	R2	R3	R4		
5	8 100	5 650	6 500	5 650	5 582	200
6	9 720	6 780	7 800	6 780	6 462	225
7	11 340	7 910	9 100	7 910	7 342	255
8	12 960	9 040	10 400	9 040	8 222	280

Dimensions mm	B	C	D	E	F*	G
	3 150	1 088	7 646	3 300	9 270	1 636

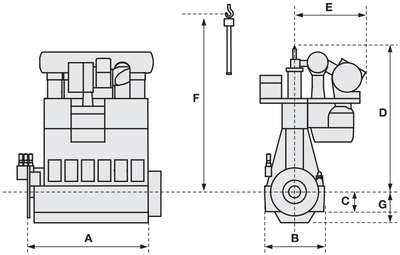
Brake specific fuel consumption (BSFC) in g/kWh

Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			19.5	13.6	19.5	17.1
IMO Tier I	RT-flex	Standard Tuning	171	165	171	167

Part load, % of R1	85	70	85	70
RT-flex tuning variant	Standard	Standard	Delta	Delta
IMO Tier I	167.0	166.7	166.7	166.0

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex58T IMO Tier I and Tier II

Main data: Version D, also available as traditional RTA type

Cylinder bore .... 580 mm
Piston stroke................................ 2416 mm
Speed .... 84–105 rpm
Mean effective pressure at R1........ 20.2 bar
Piston speed.................................. 8.5 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	105 rpm		84 rpm			
	R1	R2	R3	R4		
5	11 300	7 900	9 050	7 900	6 381	281
6	13 560	9 480	10 860	9 480	7 387	322
7	15 820	11 060	12 670	11 060	8 393	377
8	18 080	12 640	14 480	12 640	9 399	418

Dimensions mm	B	C	D	E	F*	G
	3 820	1 300	8 822	3 475	10 880	2 000

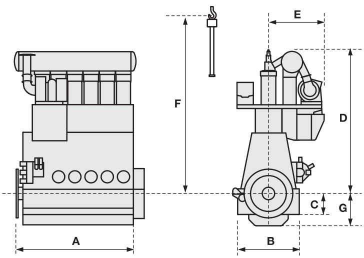
Brake specific fuel consumption (BSFC) in g/kWh

Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			20.2	14.1	20.2	17.7
IMO Tier I	RTA		170	162	170	166
	RT-flex	Standard Tuning	170	162	170	166
IMO Tier II	RTA		174	168	174	170
	RT-flex	Standard Tuning	171	165	171	167

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	166.0	166.5	165.6	165.0	–
IMO Tier II	167.8	167.0	167.1	165.5	164.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex58T

IMO Tier I only

Main data: Version B, also available as traditional RTA type

Cylinder bore .... 580 mm
Piston stroke................................ 2416 mm
Speed .... 84–105 rpm
Mean effective pressure at R1........ 19.5 bar
Piston speed.................................. 8.5 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	105 rpm		84 rpm			
	R1	R2	R3	R4		
5	10 900	7 650	8 700	7 650	6 381	281
6	13 080	9 180	10 440	9 180	7 387	322
7	15 260	10 710	12 180	10 710	8 393	377
8	17 440	12 240	13 920	12 240	9 399	418

Dimensions mm	B	C	D	E	F*	G
	3 820	1 300	8 822	3 475	10 880	2 000

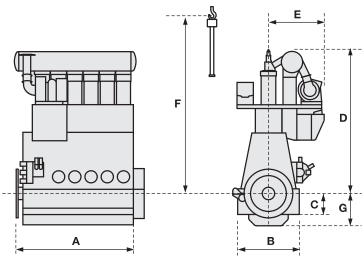
Brake specific fuel consumption (BSFC) in g/kWh

Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			19.5	13.7	19.5	17.1
IMO Tier I	RTA		170	162	170	166
	RT-flex	Standard Tuning	170	162	170	166

Part load, % of R1	85	70	85	70
RT-flex tuning variant	Standard	Standard	Delta	Delta
IMO Tier I	166.0	166.5	165.6	165.0

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex60C

IMO Tier I and Tier II

Main data: Version B

Cylinder bore .... 600 mm
Piston stroke................................ 2250 mm
Speed .... 91–114 rpm
Mean effective pressure at R1........ 20.0 bar
Piston speed.................................. 8.6 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

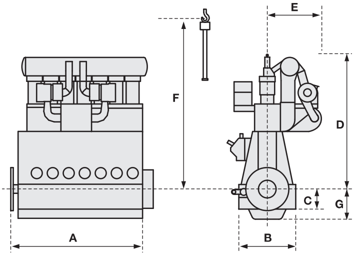
Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	114 rpm		91 rpm			
	R1	R2	R3	R4		
5	12 100	8 450	9 650	8 450	6 638	268
6	14 520	10 140	11 580	10 140	7 678	322
7	16 940	11 830	13 510	11 830	8 718	377
8	19 360	13 520	15 440	13 520	9 758	428
9	21 780	15 210	17 370	15 210	10 798	480
Dimensions mm	B	C	D	E	F*	G
	3 700	1 300	8 570	3 660	10 500	1 955

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			20.0	14.0	20.0	17.5
IMO Tier I	RT-flex	Standard Tuning	170	164	170	166
IMO Tier II	RT-flex	Standard Tuning	171	165	171	167

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	167.0	167.1	166.3	165.0	–
IMO Tier II	167.8	167.0	167.1	165.5	164.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex60C

IMO Tier I only

Main data

Cylinder bore .... 600 mm
Piston stroke................................ 2250 mm
Speed .... 91–114 rpm
Mean effective pressure at R1........ 19.5 bar
Piston speed.................................. 8.6 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	114 rpm		91 rpm			
	R1	R2	R3	R4		
5	11 800	8 250	9 400	8 250	6 638	268
6	14 160	9 900	11 280	9 900	7 678	322
7	16 520	11 550	13 160	11 550	8 718	377
8	18 880	13 200	15 040	13 200	9 758	428
9	21 240	14 850	16 920	14 850	10 798	480
Dimensions mm	B	C	D	E	F*	G
	3 700	1 300	8 570	3 660	10 500	1 955

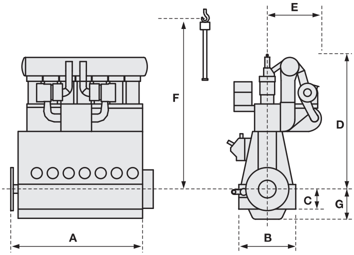
Brake specific fuel consumption (BSFC) in g/kWh

Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			19.5	13.7	19.5	17.0
IMO Tier I	RT-flex	Standard Tuning	170	164	170	166

Part load, % of R1	85	70	85	70
RT-flex tuning variant	Standard	Standard	Delta	Delta
IMO Tier I	167.0	167.1	166.3	165.0

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex68 IMO Tier I and Tier II

Main data: Version D, also available as traditional RTA type

Cylinder bore .... 680 mm
Piston stroke................................ 2720 mm
Speed .... 76–95 rpm
Mean effective pressure at R1........ 20.0 bar
Piston speed.................................. 8.6 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	95 rpm		76 rpm			
	R1	R2	R3	R4		
5	15 650	10 950	12 500	10 950	7 530	412
6	18 780	13 140	15 000	13 140	8 710	472
7	21 910	15 330	17 500	15 330	9 890	533
8	25 040	17 520	20 000	17 520	11 070	593

Dimensions mm	B	C	D	E	F*	G
	4 300	1 520	10 400	4 490	12 545	2 340

Brake specific fuel consumption (BSFC) in g/kWh

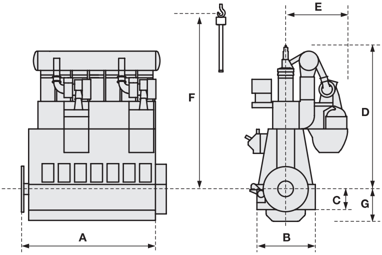
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			20.0	14.0	20.0	17.5
IMO Tier I	RTA		169	161	169	165
	RT-flex	Standard Tuning	169	161	169	165
IMO Tier II	RTA		174	168	174	170
	RT-flex	Standard Tuning**	170	164	170	166

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	165.0	165.3	164.6	164.0	–
IMO Tier II**	166.8	166.0	166.1	164.5	163.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.
** These BSFC values are for engines equipped with the latest high-efficiency turbochargers. Application of the previous generation of turbochargers leads to BSFC values that are 2g/kWh higher.

Delta Tuning and Low-Load Tuning are only available with the high-efficiency turbochargers.

For definitions see page 53.



WÄRTSILÄ RT-flex68

IMO Tier I only

Main data: Version B, also available as traditional RTA type

Cylinder bore .... 680 mm
Piston stroke................................ 2720 mm
Speed .... 76–95 rpm
Mean effective pressure at R1........ 19.6 bar
Piston speed................................... 8.6 m/s

Fuel specification:
Fuel oil ....700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

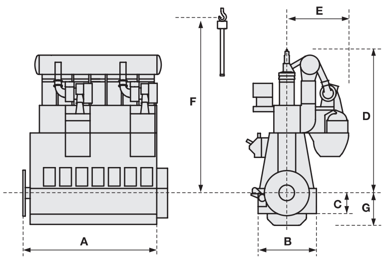
Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	95 rpm		76 rpm			
	R1	R2	R3	R4		
5	15 350	10 750	12 250	10 750	7 530	412
6	18 420	12 900	14 700	12 900	8 710	472
7	21 490	15 050	17 150	15 050	9 890	533
8	24 560	17 200	19 600	17 200	11 070	593
Dimensions mm	B	C	D	E	F*	G
	4 300	1 520	10 400	4 490	12 545	2 340

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			19.6	13.7	19.6	17.2
IMO Tier I	RTA		169	161	169	165
	RT-flex	Standard Tuning	169	161	169	165

Part load, % of R1	85	70	85	70
RT-flex tuning variant	Standard	Standard	Delta	Delta
IMO Tier I	165.0	165.3	164.6	164.0

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex82C

IMO Tier I and Tier II

Main data: Also available as traditional RTA type

Cylinder bore .... 820 mm
Piston stroke................................ 2646 mm
Speed .... 87–102 rpm
Mean effective pressure
at R1/R1+ .... 20.0/19.0 bar
Piston speed at R1/R1+ .... 8.6/9.0 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	97 / 102 rpm		87 rpm			
	R1 / R1+	R2 / R2+	R3	R4		
6	27 120	21 720	24 300	21 720	11 045	745
7	31 640	25 340	28 350	25 340	12 550	840
8	36 160	28 960	32 400	28 960	14 055	935
9	40 680	32 580	36 450	32 580	16 500	1 005
10	45 200	36 200	40 500	36 200	18 005	1 145
11	49 720	39 820	44 550	39 820	19 510	1 230
12	54 240	43 440	48 600	43 440	21 015	1 335

Dimensions mm	B	C	D	E	F*	G
	4 570	1 600	10 930	5 400	12 700	2 310

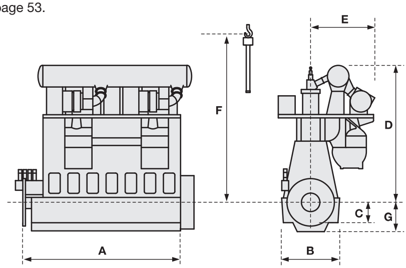
Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1/R1+	R2/R2+	R3	R4
BMEP, bar			20.0/19.0	16.0/15.2	20.0	17.9
IMO Tier I	RTA		171/169	165	171	167
	RT-flex	Standard Tuning	171/169	165	171	167
IMO Tier II	RTA		177/175	171	177	174
	RT-flex	Standard Tuning**	173/171	167	173	170

Part load, % of R1/R1+	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	168.1/166.1	168.1/166.1	167.1/165.1	166.0/165.0	164.5/162.5
IMO Tier II**	169.8/167.8	169.0/167.0	169.1/167.1	167.5/165.5	166.5/164.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.
** These BSFC values are for engines equipped with the latest high-efficiency turbochargers. Application of the previous generation of turbochargers leads to BSFC values that are 2g/kWh higher.

Delta Tuning and Low-Load Tuning are only available with the high-efficiency turbochargers.

For definitions see page 53.



WÄRTSILÄ RT-flex82T

IMO Tier I and Tier II

Main data: Also available as traditional RTA type

Cylinder bore .... 820 mm
Piston stroke................................. 3375 mm
Speed .... 68–80 rpm
Mean effective pressure
at R1/R1+ .... 20.0/19.0 bar
Piston speed at R1/R1+ .... 8.6/9.0 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	76 / 80 rpm		68 rpm			
	R1 / R1+	R2 / R2+	R3	R4		
6	27 120	21 720	24 300	21 720	11 045	785
7	31 640	25 340	28 350	25 340	12 550	880
8	36 160	28 960	32 400	28 960	14 055	975
9	40 680	32 580	36 450	32 580	16 500	1 090
Dimensions mm	B	C	D	E	F*	G
	5 320	1 800	12 250	5 400	14 750	2 700

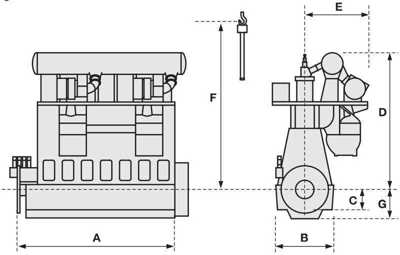
Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1/R1+	R2/R2+	R3	R4
BMEP, bar			20.0/19.0	16.0/15.2	20.0	17.9
IMO Tier I	RTA		167/165	162	167	164
	RT-flex	Standard Tuning	167/165	162	167	164
IMO Tier II	RTA		173/171	167	173	170
	RT-flex	Standard Tuning**	169/167	163	169	166

Part load, % of R1/R1+	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	163.7/161.7	162.5/161.0	162.8/161.0	161.5/160.2	159.7/158.3
IMO Tier II**	165.8/163.8	165.0/163.0	165.1/163.1	163.5/161.5	162.5/160.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.
** These BSFC values are for engines equipped with the latest high-efficiency turbochargers. Application of the previous generation of turbochargers leads to BSFC values that are 2g/kWh higher.

Delta Tuning and Low-Load Tuning are only available with the high-efficiency turbochargers.

For definitions see page 53.



WÄRTSILÄ RT-flex84T

IMO Tier I and Tier II

Main data: Version D, also available as traditional RTA type

Cylinder bore .... 840 mm
Piston stroke................................ 3150 mm
Speed .... 61–76 rpm
Mean effective pressure at R1........ 19.0 bar
Piston speed.................................. 8.0 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights

Cyl.	Output in kW at				Length A mm	Weight tonnes
	76 rpm		61 rpm			
	R1	R2	R3	R4		
5	21 000	14 700	16 850	14 700	9 695	740
6	25 200	17 640	20 220	17 640	11 195	870
7	29 400	20 580	23 590	20 580	12 695	990
8	33 600	23 520	26 960	23 520	15 195	1 140
9	37 800	26 460	30 330	26 460	16 695	1 260

Dimensions mm	B	C	D	E	F*	G
	5 000	1 800	12 150	5 105	14 500	2 700

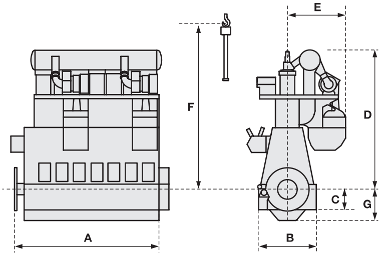
Brake specific fuel consumption (BSFC) in g/kWh

Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			19.0	13.3	19.0	16.6
IMO Tier I	RTA		167	160	167	164
	RT-flex	Standard Tuning	167	160	167	164
IMO Tier II	RTA		173	167	173	169
	RT-flex	Standard Tuning	171	165	171	167

Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	163.7	162.5	163.3	162.0	–
IMO Tier II	167.8	167.0	167.1	165.5	164.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

For definitions see page 53.



WÄRTSILÄ RT-flex96C IMO Tier I and Tier II

Main data: Version B, also available as traditional RTA type

Cylinder bore .... 960 mm
Piston stroke .... 2500 mm
Speed .... 92 - 102 rpm
Mean effective pressure at R1 .... 18.6 bar
Piston speed .... 8.5 m/s

Fuel specification:
Fuel oil .... 700 cSt/50°C
ISO-F 8217:2005,
category ISO-RMK700

Rated power, principal dimensions and weights						
Cyl.	Output in kW at				Length A mm	Weight tonnes
	102 rpm		92 rpm			
	R1	R2	R3	R4		
6	34 320	24 000	30 960	24 000	12 240	1 160
7	40 040	28 000	36 120	28 000	13 920	1 290
8	45 760	32 000	41 280	32 000	16 510	1 470
9	51 480	36 000	46 440	36 000	18 190	1 620
10	57 200	40 000	51 600	40 000	19 870	1 760
11	62 920	44 000	56 760	44 000	21 550	1 910
12	68 640	48 000	61 920	48 000	23 230	2 050
13	74 360	52 000	67 080	52 000	24 910	2 160
14	80 080	56 000	72 240	56 000	26 590	2 300
Dimensions mm	B	C	D	E	F*	G
	4 480	1 800	10 925	5 380	12 950	2 594

Brake specific fuel consumption (BSFC) in g/kWh						
Full load						
Rating point			R1	R2	R3	R4
BMEP, bar			18.6	13.0	18.6	14.4
IMO Tier I	RTA		171	163	171	164
	RT-flex	Standard Tuning	171	163	171	164
IMO Tier II	RTA		177	171	177	171
	RT-flex	Standard Tuning**	173	167	173	167

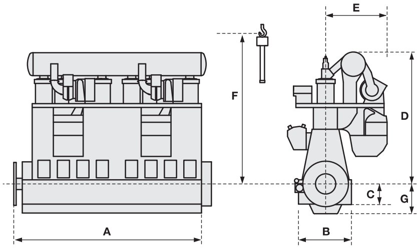
Part load, % of R1	85	70	85	70	60
RT-flex tuning variant	Standard	Standard	Delta	Delta	Low-Load
IMO Tier I	165.9	165.2	165.2	163.0	160.3
IMO Tier II**	169.8	169.0	169.1	167.5	166.5

* Standard piston dismantling height, can be reduced with tilted piston withdrawal.

** These BSFC values are for engines equipped with the latest high-efficiency turbochargers. Application of the previous generation of turbochargers leads to BSFC values that are 2g/kWh higher.

Delta Tuning and Low-Load Tuning are only available with the high-efficiency turbochargers.

13- and 14-cylinder engines are only available in RT-flex versions, and not in RTA versions.
For definitions see page 53.



DEFINITIONS AND NOTES FOR LOW-SPEED ENGINES

DIMENSIONS AND WEIGHTS

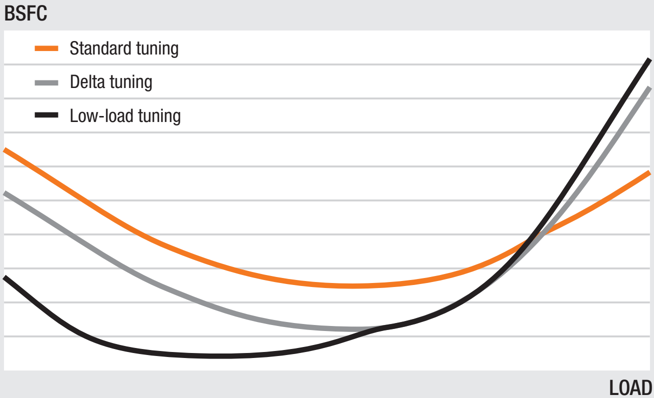
- All dimensions are in millimetres and are not binding.
- The engine weight is net in metric tonnes (t), without oil and water, and is not binding.

FUEL CONSUMPTION

All brake specific fuel consumptions (BSFC) are quoted for fuel of lower calorific value 42.7 MJ/kg, and for ISO standard reference conditions (ISO 15550 and 3046).

The BSFC figures for Wärtsilä engines are given with a tolerance of +5%.

Wärtsilä RT-flex engines have a lower part-load fuel consumption than the corresponding Wärtsilä RTA engines. Wärtsilä RT-flex engines are also available with Delta Tuning and the RT-flex82C and RT-flex96C also with Low-Load Tuning for even lower part-load fuel consumptions (see chart). Low-Load Tuning will be introduced also to the other RT-flex engines in the portfolio. Delta Tuning and Low-Load Tuning both take advantage of the complete flexibility in engine setting provided by the RT-flex common-rail system to optimize fuel injection pressures and timing at all loads. Delta Tuning focuses on reducing BSFC in the operating range below 90% engine load. Low-Load



Typical BSFC curves to illustrate Standard Tuning Delta Tuning and Low-Load Tuning.

Tuning further reduces BSFC in the operating range below 75% engine load by means of a modified turbocharging system layout in combination with appropriately adjusted RT-flex system parameters.

ISO STANDARD REFERENCE CONDITIONS

Total barometric pressure at R1 .... 1.0 bar
Suction air temperature .... 25 °C
Relative humidity 30%
Scavenge air cooling water temperature............................... 25 °C

IMO NO_X EMISSIONS

All Wärtsilä low-speed engines included in this booklet comply with the NO_X limits specified in Annex VI of the MARPOL 73/78 convention. For the amended regulations under IMO Tier II and Tier III, please see page 6.

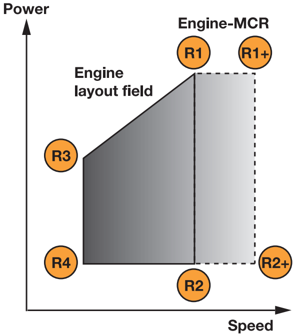
The latest versions of these engine types are available either complying with the amended regulations under IMO Tier II, or complying with the existing IMO Tier I regulations. Previous versions of these engine types comply only with existing IMO Tier I regulations.

Compliance with the IMO Tier II NO_X emissions limits involves a small increase in fuel consumption compared with the BSFC with the Tier I limits. Wärtsilä RT-flex electronically-controlled common-rail low-speed engines will comply with the Tier II NO_X emissions limits with a smaller increase in fuel consumption than Wärtsilä RTA low-speed engines.

Provisions for compliance with IMO Tier III NO_X emissions limits will be announced at a later date but in ample time for the implementation date.

RATING POINTS FOR WÄRTSILÄ LOW-SPEED ENGINES

The engine layout fields for Wärtsilä low-speed engines are defined by the power/speed rating points R1, R2, R3 and R4 (see diagram right). In certain engines, the layout field is extended to the points R1+ and R2+. R1, or R1+ instead if applicable, is the nominal maximum continuous rating (MCR). Any power and speed within the respective engine layout field may be selected as the Contract-MCR (CMCR) point for an engine.



CYLINDER LUBRICATION

The load-dependent accumulator cylinder lubricating system has proven reliable in operation since its introduction in the 1970s. It is employed as standard on Wärtsilä RTA low-speed engines of smaller bore.

To enable lubricating oil feed rates to be reduced the accumulator system has been further developed in recent years. The new Pulse Lubricating System with electronic control of lubrication timing has been developed. It is available for all Wärtsilä RT-flex low-speed engines and for selected RTA engines. The guide lubricating oil feed rate with the Pulse Lubricating System is 0.7–0.8 g/kWh. This allows important savings in engine operating costs.

For further information on this subject, please consult your nearest Wärtsilä company.

WÄRTSILÄ MEDIUM-SPEED ENGINES

DIESEL ENGINES

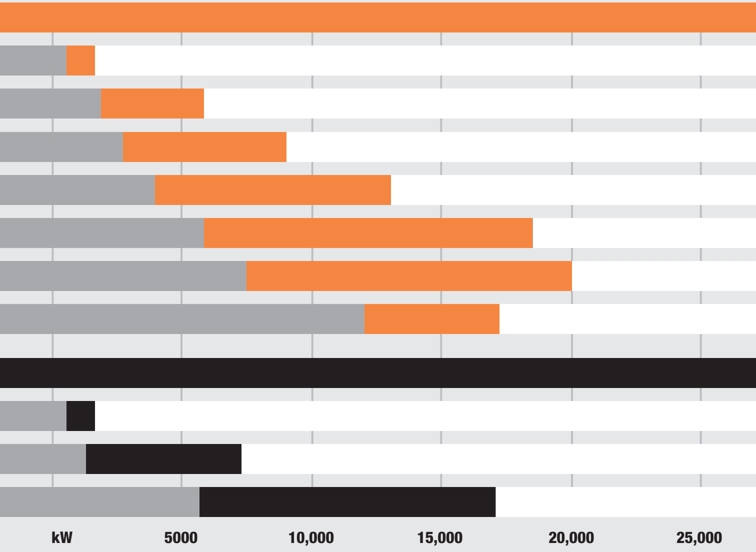
The design of the Wärtsilä medium-speed engine range is based on the vast amount of knowledge accumulated over years of successful operation.

Robust engines derived from pioneering heavy fuel technology have been engineered to provide unquestionable benefits for the owners and operators of Wärtsilä engines and generating sets:

- Proven reliability
- Low emissions
- Low operating costs
- Fuel flexibility

Benefits for the shipyard include installation friendliness, embedded automation system, and built-on modularized auxiliary systems.

POWER RANGE FOR WÄRTSILÄ MEDIUM-SPEED ENGINES



DUAL-FUEL ENGINES

Wärtsilä is continuously developing its portfolio of gas and multi-fuel engines to suit different marine applications, be they offshore oil and gas installation where gaseous fuel is available from the process, or a merchant vessel operating in environmentally sensitive areas. The Wärtsilä engines offer high efficiency, low exhaust gas emissions and safe operation. The innovative multi-fuel technology allows flexibility to choose between gas or liquid fuel. When necessary, the engines are capable of switching from one fuel to the other without an interruption in power generation.

WÄRTSILÄ 20

IMO Tier II

Main data

Cylinder bore .... 200 mm
Piston stroke.................................. 280 mm
Cylinder output......................... 200 kW/cyl
Speed .... 1000 rpm
Mean effective pressure .... 27.3 bar
Piston speed.................................. 9.3 m/s

Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 186 g/kWh
at ISO condition

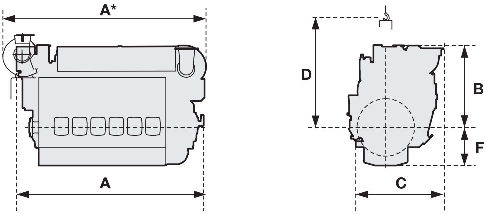
Option: Common rail fuel injection.

Rated power	
Engine type	kW
4L20	800
6L20	1 200
8L20	1 600
9L20	1 800

Dimensions (mm) and weights (tonnes)

Engine type	A*	A	B*	B	C*	C	D	F	Weight
4L20	–	2 510	–	1 348	–	1 483	1 800	725	7.2
6L20	3 254	3 108	1 528	1 348	1 580	1 579	1 800	624	9.3
8L20	3 973	3 783	1 614	1 465	1 756	1 713	1 800	624	11.0
9L20	4 261	4 076	1 614	1 449	1 756	1 713	1 800	624	11.6

*Turbocharger at flywheel end.
For definitions see page 68.



WÄRTSILÄ 26

IMO Tier II

Main data

Cylinder bore .... 260 mm
Piston stroke.................................. 320 mm
Cylinder output......................... 340 kW/cyl
Speed .... 1000 rpm
Mean effective pressure .... 25.5 bar
Piston speed................................ 10.7 m/s

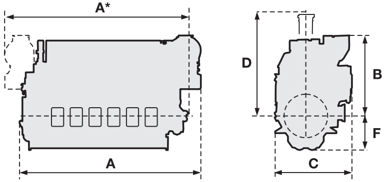
Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 183 g/kWh
at ISO condition

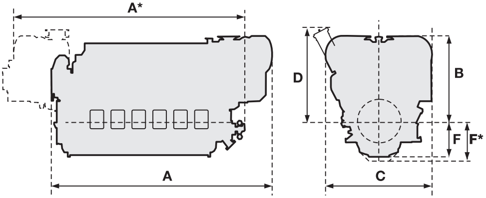
Rated power	
Engine type	kW
6L26	2 040
8L26	2 720
9L26	3 060
12V26	4 080
16V26	5 440

Dimensions (mm) and weights (tonnes)

Engine type	A*	A	B*	B	C*	C	D	F dry sump	F wet sump	Weight dry sump	Weight wet sump
6L26	4 258	4 110	1 881	1 802	1 912	1 883	2 430	818	950	16.9	18.4
8L26	5 117	4 890	2 019	1 825	1 912	1 979	2 430	818	950	21.0	22.9
9L26	5 507	5 280	2 019	1 825	1 912	1 979	2 430	818	950	22.7	24.8
12V26	5 218	4 968	2 074	2 074	2 453	2 453	2 060	800	1 110	29.2	31.9
16V26	6 223	5 973	2 151	2 151	2 489	2 489	2 060	800	1 110	33.0	36.5

*Turbocharger at flywheel end.
For definitions see page 68.





WÄRTSILÄ 32

IMO Tier II

Main data

Cylinder bore .... 320 mm
Piston stroke.................................. 400 mm
Cylinder output......................... 500 kW/cyl
Speed .... 750 rpm
Mean effective pressure .... 24.9 bar
Piston speed................................ 10.0 m/s

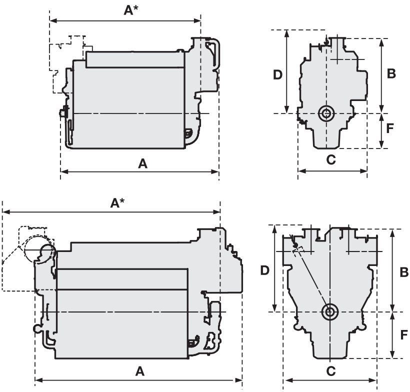
Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 176 g/kWh
at ISO condition

Option: Common rail fuel injection.

Rated power	
Engine type	kW
6L32	3 000
7L32	3 500
8L32	4 000
9L32	4 500
12V32	6 000
16V32	8 000
18V32	9 000

Dimensions (mm) and weights (tonnes)								
Engine type	A*	A	B*	B	C	D	F	Weight
6L32	4 980	5 260	2 560	2 490	2 305	2 345	1 155	33.3
7L32	5 470	5 750	2 560	2 490	2 305	2 345	1 155	39.0
8L32	5 960	6 245	2 360	2 295	2 305	2 345	1 155	43.4
9L32	6 450	6 730	2 360	2 295	2 305	2 345	1 155	46.8
12V32	6 935	6 615	2 715	2 665	3 020	2 120	1 475	58.7
16V32	8 060	7 735	2 480	2 430	3 020	2 120	1 475	74.1
18V32	8 620	8 295	2 480	2 430	3 020	2 120	1 475	81.2

*Turbocharger at flywheel end.
For definitions see page 68.



WÄRTSILÄ 38

IMO Tier II

Main data

Cylinder bore .... 380 mm
Piston stroke.................................. 475 mm
Cylinder output......................... 725 kW/cyl
Speed .... 600 rpm
Mean effective pressure .... 26.9 bar
Piston speed.................................. 9.5 m/s

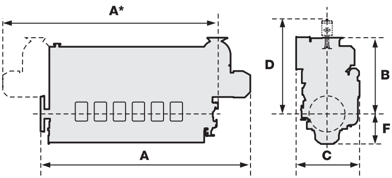
Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 173 g/kWh
at ISO condition

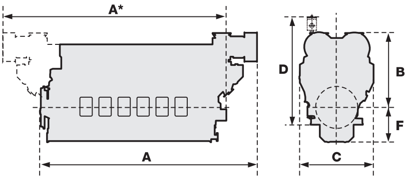
Rated power	
Engine type	kW
6L38	4 350
8L38	5 800
9L38	6 525
12V38	8 700
16V38	11 600

Dimensions (mm) and weights (tonnes)

Engine type	A*	A	B*	B	C	D	F	Weight
6L38	6 345	6 220	2 830	2 830	2 190 (2 210*)	3 135	1 115	51
8L38	7 925 (7 875**)	7 545 (7 495**)	2 820 (2 735**)	2 770 (2 690**)	2 445 (2 445**)	3 135	1 115	63 (62**)
9L38	8 525	8 145	2 820	2 770	2 445	3 135	1 115	72
12V38	7 615	7 385	2 930	2 930	3 030	2 855	1 435	88
16V38	9 130	8 945	3 105	3 105	3 030	2 855	1 435	110

* Turbocharger at flywheel end. ** Dimension valid for 8L, FPP application only.
For definitions see page 68.





WÄRTSILÄ 46

IMO Tier II

Main data

Cylinder bore .... 460 mm
Piston stroke.................................. 580 mm
Cylinder output....................... 1000 kW/cyl
Speed .... 500-514 rpm
Mean effective pressure .... 24.2-24.9 bar
Piston speed........................... 9.7, 9.9 m/s

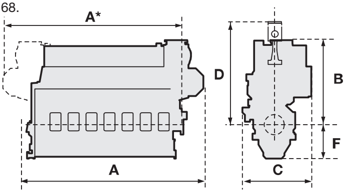
Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 172 g/kWh
at ISO condition

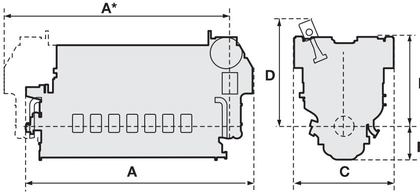
Common rail fuel injection.

Rated power	
Engine type	kW
12V46	12 000
16V46	16 000

Dimensions (mm) and weights (tonnes)							
Engine type	A*	A	B	C	D	F	Weight
12V46	10 540	10 420	3 890	4 055	3600	1 500	175
16V46	13 185	13 060	4 400	4 730	3600	1 500	220

* Turbocharger at flywheel end.
For definitions see page 68.





WÄRTSILÄ 46F

IMO Tier II

Main data

Cylinder bore .... 460 mm
Piston stroke.................................. 580 mm
Cylinder output...................... 1200 kW/cyl
Speed .... 600 rpm
Mean effective pressure .... 24.9 bar
Piston speed............................... 11.6 m/s

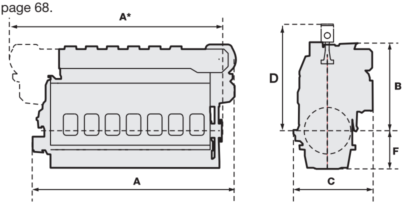
Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 171 g/kWh
at ISO condition

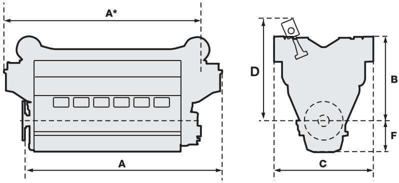
Options: Lubricating oil Module integrated on engine, Common Rail fuel injection.

Rated power	
Engine type	kW
6L46F	7 200
7L46F	8 400
8L46F	9 600
9L46F	10 800
12V46F	14 400

Dimensions (mm) and weights (tonnes)							
Engine type	A*	A	B	C	D	F	Weight
6L46F	8 430	8 620	3 500	2 930	3 750	1 430	97
7L46F	9 260	9 440	3 800	2 950	3 750	1 430	113
8L46F	10 080	10 260	3 800	2 950	3 750	1 430	124
9L46F	10 900	11 080	3 800	2 950	3 750	1 430	140
12V46F	11 080	11 150	3 820	4 050	3 800	1 620	178

* Turbocharger at flywheel end.
For definitions see page 68.





WÄRTSILÄ 64

IMO Tier II

Main data

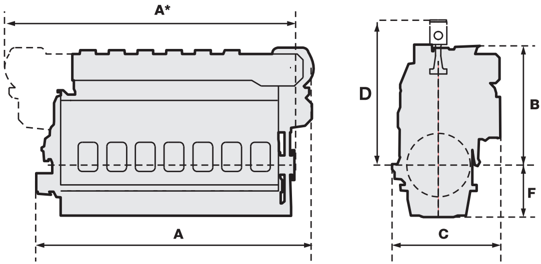
Cylinder bore .... 640 mm
Piston stroke.................................. 900 mm
Cylinder output....................... 2150 kW/cyl
Speed ....327.3, 333.3 rpm
Mean effective pressure ....25.0, 27.2 bar
Piston speed.............................. 9.8, 10 m/s

Fuel oil specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-RMK 700
SFOC 167 g/kWh
at ISO condition

Rated power	
Engine type	kW
6L64	12 900
7L64	15 050
8L64	17 200

Dimensions (mm) and weights (tonnes)							
Engine type	A*	A	B	C	D	F	Weight
6L64	10 250	10 540	4 395	4 065	5 345	1 905	233
7L64	11 300	11 690	4 510	4 165	5 345	1 905	265
8L64	12 350	12 740	4 510	4 165	5 345	1 905	295

* Turbocharger at flywheel end.
For definitions see page 68.



WÄRTSILÄ 20DF

IMO Tier II

Main data

Cylinder bore .... 200 mm
Piston stroke................................. 280 mm
Cylinder output........................ 176 kW/cyl
Speed .... 1200 rpm
Mean effective pressure .... 20.0 bar
Piston speed............................... 11.2 m/s

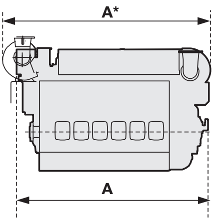
Fuel oil specification:
ISO-F-DMX, DMA and DMB
ISO 8217:2005(E)

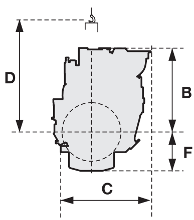
SFOC 199 g/kWh at ISO conditions
Natural gas
Methane number: 80

Rated power	
Engine type	kW
6L20DF	1 056
8L20DF	1 408
9L20DF	1 584

Engine dimensions (mm) and weights (tonnes)							
Engine type	A*	A	B	C	D	F	Weight
6L20DF	3 254	3 108	1 698	1 829	1 800	624	9.5
8L20DF	3 973	3 783	1 815	1 963	1 800	624	11.2
9L20DF	4 261	4 076	1 799	1 963	1 800	624	11.8

For definitions see page 68.





WÄRTSILÄ 34DF

IMO Tier II

Main data

Cylinder bore ....340 mm
Piston stroke..................................400 mm
Cylinder output......................... 450 kW/cyl
Speed ....750 rpm
Mean effective pressure ....19.8 bar
Piston speed................................ 10.0 m/s

Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-DMX,
DMA and DMB

Natural gas
Methane number: 80
LHV: min. 28 MJ/Nm³, 4.5 bar
BSEC 7700 kJ/kWh

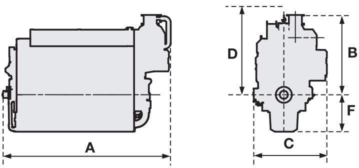
Rated power

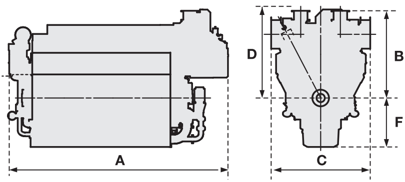
Engine type	kW
6L34DF	2 700
9L34DF	4 050
12V34DF	5 400
16V34DF	7 200

Engine dimensions (mm) and weights (tonnes)

Engine type	A	B	C	D	F	Weight
6L34DF	5 280	2 550	2 305	2 345	1 155	34
9L34DF	6 750	2 550	2 305	2 345	1 155	47
12V34DF	6 615	2 665	3 020	2 120	1 475	59
16V34DF	7 735	2 430	3 020	2 120	1 475	75

For definitions see page 68.





WÄRTSILÄ 50DF

IMO Tier II

Main data

Cylinder bore .... 500 mm
Piston stroke................................. 580 mm
Cylinder output.................. 950, 975 kW/cyl
Speed ....500, 514 rpm
Mean effective pressure ....20.0 bar
Piston speed............................ 9.7, 9.9 m/s

Fuel specification:
Fuel oil .... 700 cSt/50 °C
7200 sR1/100 °F
ISO 8217, category ISO-F-DMX, DMA and DMB

Natural gas
Methane number: 80
LHV: min. 28 MJ/nm³, 5.5 bar
BSEC 7410 kJ/kWh

Rated power

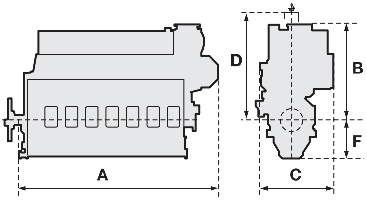
Engine type	50 Hz		60 Hz	
	Engine kW	Gen. kW	Engine kW	Gen. kW
6L50DF	5 700	5 500	5 850	5 650
8L50DF	7 600	7 330	7 800	7 530
9L50DF	8 550	8 250	8 775	8 470
12V50DF	11 400	11 000	11 700	11 290
16V50DF	15 200	14 670	15 600	15 050
18V50DF	17 100	16 500	17 550	16 940

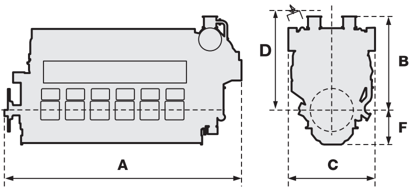
Generator output based on a generator efficiency of 96.5%.

Engine dimensions (mm) and weights (tonnes)

Engine type	A	B	C	D	F	Weight
6L50DF	8 115	3 580	2 850	3 820	1 455	96
8L50DF	9 950	3 600	3 100	3 820	1 455	128
9L50DF	10 800	3 600	3 100	3 820	1 455	148
12V50DF	10 465	4 055	3 810	3 600	1 500	175
16V50DF	12 665	4 055	4 530	3 600	1 500	220
18V50DF	13 725	4 280	4 530	3 600	1 500	240

For definitions see page 68.





DEFINITIONS AND NOTES FOR MEDIUM-SPEED ENGINES

ENGINE DIMENSIONS

A* Total length of the engine when the turbocharger is located at the flywheel end.

A Total length of the engine when the turbocharger is located at the free end.

B Height from the crankshaft centreline to the highest point.

B* Height from the crankshaft centreline to the highest point when the turbocharger is located at the flywheel end.

C Total width of the engine.

C* Total width of the engine when the turbocharger is located at the flywheel end.

D Minimum height from the crankshaft centerline when removing a piston.

F Distance from the crankshaft centreline to the bottom of the oil sump.

DIMENSIONS AND WEIGHTS

- Dimensions are in millimetres and weights are in metric tonnes. Indicated values are for guidance only and are not binding.
- Cylinder configurations: L = in-line and V = v-form.

SPECIFIC FUEL OIL CONSUMPTION

At ISO standard reference conditions
Lower calorific value of fuel 42 700 kJ/kg
Tolerance 5%
Without engine driven pumps
At 85% load.

ISO STANDARD REFERENCE CONDITIONS

Total barometric pressure	1.0 bar
Suction air temperature	25 °C
Charge air, or scavenge air, cooling water temperature	25 °C
Relative humidity	30%

WÄRTSILÄ MECHANICAL PROPULSION

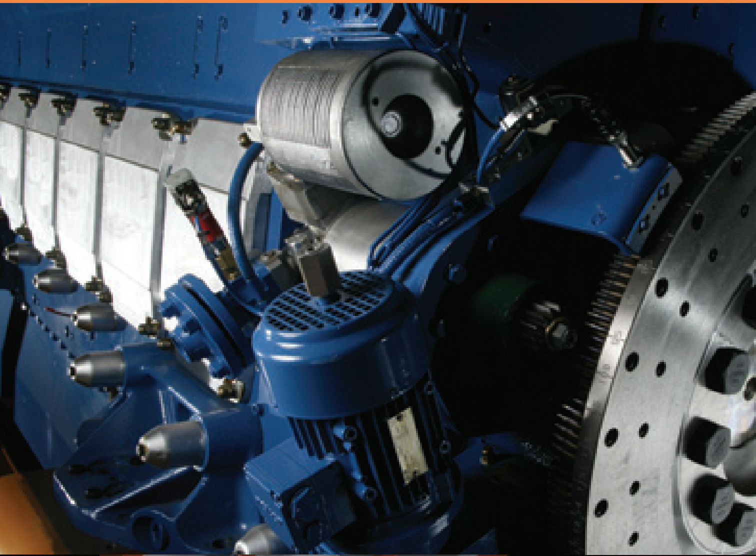
WÄRTSILÄ PROPAC ST

The comprehensive product portfolio places Wärtsilä in a unique position to offer a tailored and complete propulsion solution named Propac for practically any mechanical propulsion application. In-house design, manufacturing and project management ensure matching components and total responsibility, without forgetting lifetime support for the complete system from a single contact. Power range for medium-speed propulsion packages is 1080–19,360 kW.

To reduce implementation time and costs, Wärtsilä has developed a range of pre-engineered propulsion packages for two selected application types.

Wärtsilä Propac CP: medium-speed engine, controllable pitch propeller, reduction gear with built-in clutch, shaft, seals, bearings and integrated control system.

Wärtsilä Propac ST: medium-speed engine, steerable thruster with either fixed pitch or controllable pitch propeller, clutch, shafting, bearings and integrated control system.



Wärtsilä Propac CP	Wärtsilä Propac ST
CPP – 4-bladed D-hub – Built-in servo	Steerable thruster – Fixed pitch – Controllable pitch
Shafts, seals and bearings	High speed shafting
Reduction gearbox – PTO – Clutch	Nozzle
Flexible coupling	Slipping clutch and/or flexible coupling
Engine – 4-stroke, medium-speed	Engine – 4-stroke, medium-speed
Propulsion Control	Propulsion Control
Monitoring	Monitoring

WÄRTSILÄ PROPAC ST SELECTION TABLE

Engine type	MCR engine power [kW]	Thruster size	Propeller diameter [mm]	Propeller speed [rpm]	Bollard pull with twin thrusters [tonnes]
6L20	1080	175	1600	361	34
			1800		36
	1200	200	1900	290	41
			2100		43
8L20	1600	225	2100	274	53
			2300		55
9L20	1800	250	2400 2600	257	62
					64
6L26	2040	250	2400	257	68
			2600		70
8L26	2600	275	2600	245	84
	2720	300	2800	218	91
			3000		94
9L26	3060	300	2800	218	99
			3000		103

AVAILABLE OPTIONS PER THRUSTER TYPE:

- Controllable pitch propeller (CS) or fixed pitch propeller (FS).
- Propeller in nozzle or open propeller.
- Weld-in or can-mounted stem box.
- Soft on/off clutch or a modulating clutch for FS thrusters.

REMARKS:

- Bollard pull is based on twin installation, 100% MCR power and 2% thrust deduction with the propellers designed for best performance at 0 knots
- Selections are for installations without ice class.
- A modulating clutch improves the manouverability for fixed pitch (FS) thrusters at low speeds.
- A floating shaft arrangement is applied for installations with the engine in-line with the thruster input shaft.

Main data of engines	**Wärtsilä 20**	**Wärtsilä 26**
Cylinder bore	200 mm	260 mm
Piston stroke	280 mm	320 mm
Cylinder output	200 kW/cyl	340 kW/cyl
Engine speed	1000 rpm	1000 rpm
Mean effective pressure	24.6, 28.0 bar	23.0, 24.0 bar
Piston speed	9.3 m/s	10.7 m/s

Fuel oil specification: 730 cSt/50°C
7200 sR1/100°F
ISO 8217, category ISO-F-RMK 55

<table>
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[mm]</th><th>B*
[mm]</th><th>C
[mm]</th><th>D
[mm]</th><th>F
[mm]</th><th>K
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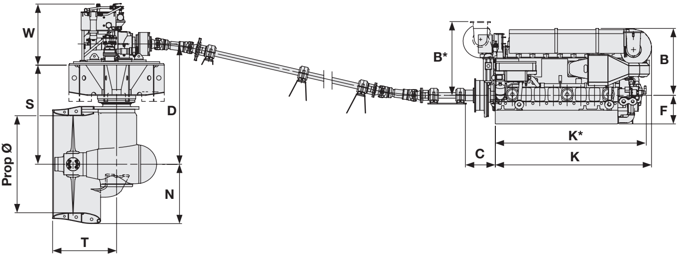


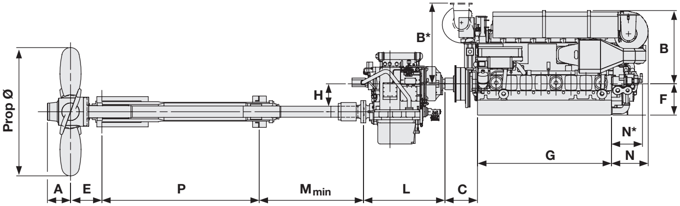
WÄRTSILÄ PROPAC CP SELECTION TABLE

Engine type	Propeller Ø [mm]	Gear size SCV	Hub size	Aft seal size	A [mm]	B [mm]	B *) [mm]
4L20	1900–2000	38	4D505	170	373	1348	N/A
	2100–2300	38	4D550	190	402	1348	N/A
	2400–2500	38	4D600	190	432	1348	N/A
6L20	2100–2400	42	4D600	200	432	1348	1528
	2500	46	4D600	220	432	1348	1528
	2600–2800	46	4D650	220	467	1348	1528
	2900	50	4D650	220	467	1348	1528
8L20	2200	46	4D600	220	432	1465	1614
	2300–2400	46	4D650	220	467	1465	1614
	2500–2600	50	4D650	240	467	1465	1614
9L20	2300–2500	50	4D650	240	467	1449	1614
	3200–3300	62	4D775	260	550	1449	1614
6L26	3000–3200	62	4D775	260	550	1801	1882
	3300–3400	62	4D845	280	574	1801	1882
	3500	68	4D845	280	574	1801	1882
8L26	2800–2900	62	4D775	280	550	1825	2020
	3000–3400	68	4D845	300	574	1825	2020
	3500–3900	75	4D920	330	631	1825	2020
	4000	85	4D920	330	631	1825	2020
9L26	3000–3200	68	4D845	300	574	1825	2020
	3300–3700	75	4D920	330	631	1825	2020
	3800	85	4D920	330	631	1825	2020
	3900–4000	85	4D1000	330	674	1825	2020

REMARKS:

- *) Turbocharger at flywheel end.
- **) 624 if dry sump.
- Coupling and flywheel length C and sterntube length P are project specific dimensions.
- Dimension M is project specific but a minimum service space Mmin must be respected.
- Selections based on propeller tip speed 32.5 m/s.
- Selections based on classification ABS, LRS or BV – no ice class. Note that DNV class (no ice) often allows for one size smaller reduction gear.
- Wärtsilä 20–200 kW/cylinder.
- Wärtsilä 26–340 kW/cylinder.

C [mm]	E [mm]	F [mm]	G [mm]	H [mm]	L [mm]	N [mm]	N *) [mm]
615	551	725	1480	380	990	665	N/A
615	574	725	1480	380	990	665	N/A
615	600	725	1480	380	990	665	N/A
685	600	824 **)	2080	420	1090	663	585
685	600	824 **)	2080	460	1195	663	585
685	627	824 **)	2080	460	1195	663	585
685	627	824 **)	2080	500	1505	663	585
685	600	824 **)	2680	460	1195	738	585
685	627	824 **)	2680	460	1195	738	585
685	642	824 **)	2680	500	1505	738	585
725	642	824 **)	2980	500	1505	731	585
725	714	824 **)	2980	620	1720	731	585
700	714	950	2866	620	1720	885	634
700	750	950	2866	620	1720	885	634
700	750	950	2866	680	1875	885	634
750	714	950	3646	620	1720	933	758
750	750	950	3646	680	1875	933	758
750	790	950	3646	750	1960	933	758
750	790	950	3646	850	2200	933	758
750	750	950	4036	680	1875	933	758
750	790	950	4036	750	1960	933	758
750	790	950	4036	850	2200	933	758
750	829	950	4036	850	2200	933	758



WÄRTSILÄ PROPAC LOW-SPEED ENGINES

Wärtsilä propulsion packages are available that combine low-speed engines and controllable or fixed pitch propellers. They are integrated mechanical propulsion system products with lifetime support. The packages are tailor engineered to suit individual project requirements.

The Wärtsilä low-speed propulsion packages are based on time-proven technological expertise, an unrivalled range of leading products and close customer support. Customer support extends from initial design to construction and operation.

Scope of low-speed propulsion packages

- Two-stroke, low-speed engine, designed for marine installation
- State-of-the-art controllable pitch or fixed pitch propeller
- Shafting with intermediate bearings
- Sterntube with bearings
- Shaft seals
- Integrated propulsion control systems

Benefits to shipowners and shipyards:

- Turnkey responsibility for complete package
- In-house design, manufacturing and project management
- Rapid implementation
- Highly reliable seaworthy low-speed main engine for unrestricted service
- Low fuel consumption with heavy fuel oil
- Easy installation - simple mechanical and automation interfaces
- Comprehensive documentation and user manuals
- Lifetime support – best worldwide service network

Engine type & application	Engine				
	Cyl.	Engine power [kW]	Engine rpm	E [mm]	D [mm]
Wärtsilä RT-flex35 (tankers and bulkers)	5	4 350	167	4 434	4 150–4 350
	6	5 220	167	5 046	4 350–4 550
	7	6 090	167	5 658	4 450–4 650
	8	6 960	167	6 270	4 600–4 800
Wärtsilä RT-flex35 (containers and roro)	5	4 350	167	4 434	3 900–4 100
	6	5 220	167	5 046	4 100–4 250
	7	6 090	167	5 658	4 200–4 400
	8	6 960	167	6 270	4 350–4 600
Wärtsilä RT-flex40 (tankers and bulkers)	5	5 675	146	5 050	4 850–5 000
	6	6 810	146	5 750	5 050–5 250
	7	7 945	146	6 450	5 250–5 400
	8	9 080	146	7150	5 350–5 600
Wärtsilä RT-flex40 (containers and roro)	5	5 675	146	5 050	4 600–4 800
	6	6 810	146	5 750	4 750–4 950
	7	7 945	146	6 450	4 950–5 150
	8	9 080	146	7 150	5 150–5 300
Wärtsilä RT-flex48T (tankers, bulk carriers)	5	7 275	127	5 917	5 400–5 600
	6	8 730	127	6 751	5 650–5 850
	7	10 185	127	7 585	5 850–6 050
	8	11 640	127	8 419	6 000–6 250
Wärtsilä RT-flex48T Wärtsilä RTA48T (containers and roro)	5	7 275	127	5 917	5 100–5 400
	6	8 730	127	6 751	5 300–5 600
	7	10 185	127	7 585	5 500–5 800
	8	11 640	127	8 419	5 700–6 000
Wärtsilä RT-flex50 (tankers, bulk carriers)	5	8 725	124	6 213	5 650–5 850
	6	10 470	124	7 093	5 900–6 100
	7	12 215	124	7 973	6 100–6 300
	8	13 960	124	8 853	6 250–6 500
Wärtsilä RT-flex50 (containers)	5	8 725	124	6 213	5 350–5 600
	6	10 470	124	7 093	5 550–5 800
	7	12 215	124	7 973	5 800–6 000
	8	13 960	124	8 853	5 950–6 200
Wärtsilä RT-flex58T Wärtsilä RTA58T (tankers, bulk carriers)	5	11 300	105	6 985	6 550–6 850
	6	13 560	105	7 991	6 850–7 100
	7	15 820	105	8 997	7 050–7 350
	8	18 080	105	10 003	7 250–7 550
Wärtsilä RT-flex60C (containers)	5	12 100	114	7 211	6 100–6 350
	6	14 520	114	8 251	6 350–6 600
	7	16 940	114	9 291	6 550–6 850
	8	19 360	114	10 331	6 800–7 050

NOTES: Above table provides rough guidance for a low-speed propulsion package; detailed engineering to be performed for specific project

CPP Standard four-bladed controllable-pitch propeller, for special applications five-bladed CPP on request.
Further details are given in this booklet, section 'Propulsors'

D Propeller diameter.
The diameter ranges are chosen for optimal propulsive efficiency, which includes the open water efficiency, but also the effect of the hull efficiency.
Tankers and bulkers have the following parameters: Vs = 15 knots, wake fraction = 0.3 and blade area ratio estimated at 0.55.

Container ships have the following parameters: Vs = 20 knots, wake fraction = 0.25 and blade area ratio estimated at 0.65.

E Length of engine

S Minimum length of shaft with oil distribution box

T Minimum length of sterntube in case of two sterntube bearing arrangement

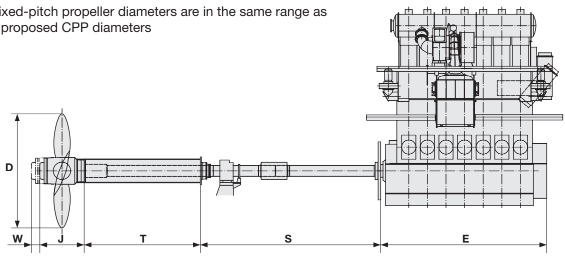
J Length of propeller hub

W Dismantling length

Weight The package weight is based on dry engine and 12 m shaftline.
The propellers are based on 'no ice' but are available up to the highest ice classes with related enforcement.

Controllable pitch propellers					Package weight (tonnes)
Hub	T [mm]	J [mm]	S [mm]	W [mm]	
4D1095	3 000	1 344	1 495	490	83
4D1190	3 100	1 457	1 495	525	97
4D1190	3 300	1 457	1 495	525	109
4D1415	3 500	1 767	1 640	610	122
4D1000	3 000	1 228	1 495	460	82
4D1095	3 100	1 344	1 495	490	95
4D1095	3 300	1 344	1 495	490	106
4D1190	3 500	1 457	1 640	525	117
4D1190	3 500	1 457	1 640	525	129
4D1300	3 600	1 574	1 640	575	148
4D1415	3 800	1 767	1 780	610	167
4D1540	4 000	1 916	1 950	655	185
4D1190	3 500	1 457	1 640	525	128
4D1300	3 600	1 574	1 640	575	146
4D1300	3 800	1 574	1 780	575	163
4D1415	4 000	6 050	1 950	610	180
4D1415	3 500	1 767	1 780	610	200
4D1540	3 700	1 916	1 950	655	241
4D1540	4 000	1 916	1 950	655	263
4E1540	4 200	2 321	2 160	345	296
4D1300	3 900	1 574	1 780	575	195
4D1415	4 100	1 767	1 950	610	234
4D1415	4 300	1 767	1 950	610	256
4D1540	4 500	1 916	2 160	655	287
4D1415	3 800	1 767	1 950	610	231
4D1540	3 900	1 916	1 950	655	263
4E1540	4 000	2 321	2 160	345	300
4E1680	4 200	2 514	2 335	375	334
4D1415	3 500	1 767	1 780	610	230
4D1415	3 900	1 767	1 950	610	258
4E1415	4 200	2 128	2 160	320	295
4E1540	4 200	2 321	2 335	345	327
4E1540	4 200	2 321	2 160	345	328
4E1680	4 400	2 514	2 335	375	379
4E1835	4 400	2 726	2 335	400	448
4E1835	5 000	2 726	2 505	400	493
4E1540	4 200	2 321	2 160	345	315
4E1540	4 300	2 321	2 335	345	372
4E1680	4 800	2 514	2 335	375	439
4E1835	5 100	2 726	2 505	400	502

FPP Fixed-pitch propeller diameters are in the same range as above proposed CPP diameters



WÄRTSILÄ ELECTRIC PROPULSION

The Wärtsilä electric propulsion system incorporates state-of-the-art technology in every integrated component and has a unique system configuration to maximize safety and efficiency.

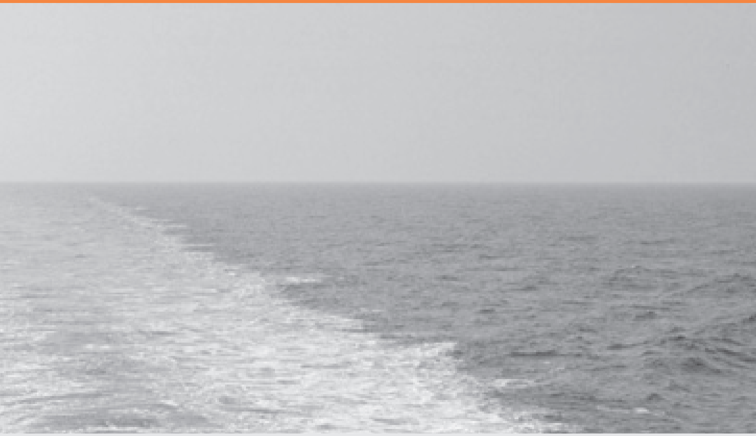
The Wärtsilä low loss concept is a patented solution developed to enhance redundancy and to reduce the number of components in the system. The concept is flexible and can be designed to fit any configuration of power generation units and propulsion units as well as other electric power consumers onboard.

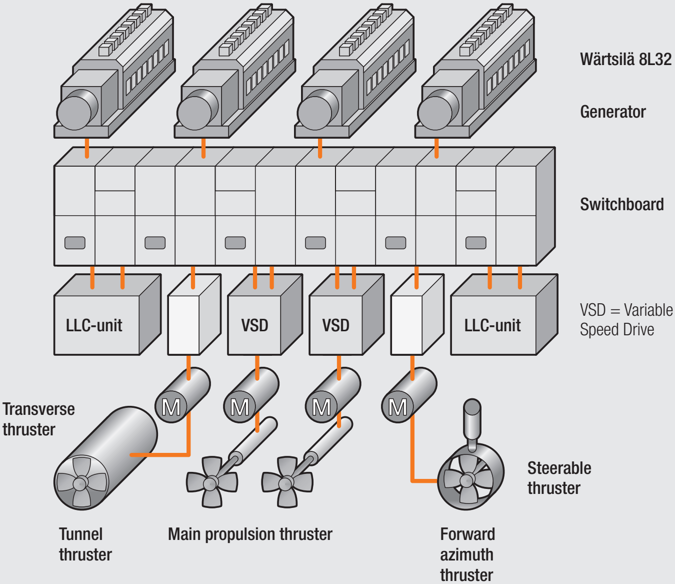
In addition to tailor made solutions the low loss concept is available in five standardized systems: Wärtsilä low loss concept 1500, 2700, 3800, 5000 and 10,000 indicating the maximum power of each of the two main propellers.

For vessels with large power generation and power consumption, a medium voltage system is available. The system can be combined with Wärtsilä's variable speed drives powering up to 10 MW propulsion units.

The system can be combined with any configuration of power generation units and can be tailor made to meet specific requirements for flexible power distribution in a variety of different applications.

A combination of a medium voltage system for power generation and a low voltage system for power distribution to the ship consumers and to special purposes will enhance the flexibility and increase the operability of the vessel.





Wärtsilä 8L32
Generator
Switchboard
LLC-unit
VSD
VSD
LLC-unit
VSD = Variable Speed Drive
M
M
M
M
Transverse thruster
Steerable thruster
Tunnel thruster
Main propulsion thruster
Forward azimuth thruster

WÄRTSILÄ AUXPAC

The Auxpac generating sets are available in a selected range as pre-engineered and pre-commissioned auxiliary generating sets. The common baseframe is optimized for the package, which together with the compact design of the engine and the selected generator, offers unmatched power-to-space and power-to-weight ratio. Other benefits of pre-engineering include readily available documentation, also including models in Tribon® format, and short lead-times. Auxpac generating sets are offered only as 400V/690V–50Hz and 450V/690V–60 Hz in the power range 500 kW to 2800 kW.

PRE-ENGINEERED MEDIUM-SPEED GENERATING SETS

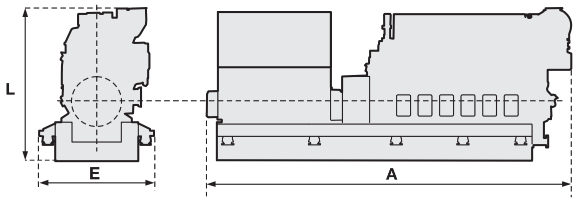
Main data of generators	**60 Hz**	**50 Hz**
Voltage	450, 690 V	400, 690 V
Protection class	IP 23, IP 44 *	IP 23, IP 44 *
Temperature rise and isolation	Class F	Class F
Cooling	Air, water *	Air, water *

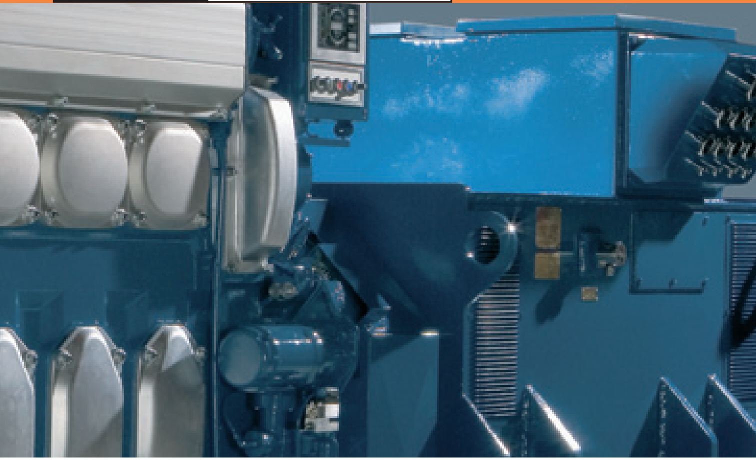
* Option

Fuel oil specification:
700 cSt/50°C, 7200 sR1/100°F, ISO 8217, category ISO-F-RMK 55

60 Hz						
	Output		Dimensions (mm) and weights (tonnes)			
Type	kWe	kVA	A	E	L	Weight
520W4L20	520	650	3 837	1 720	2 243	13.4
645W4L20	645	806	4 390	1 720	2 243	14.0
760W6L20	760	950	4 988	1 720	2 243	17.0
875W6L20	875	1 094	5 048	1 720	2 243	17.3
975W6L20	975	1 219	5 158	1 720	2 243	17.9
1050W6L20	1 050	1 313	5 083	1 920	2 243	19.1
1200W8L20	1 200	1 500	5 758	1 920	2 490	21.2
1400W8L20	1 400	1 750	5 900	1 920	2 474	21.5
1600W9L20	1 600	2 000	6 513	1 920	2 474	23.6
1800W6L26	1 800	2 250	6 422	2 246	2 938	31.7
2100W8L26	2 100	2 625	7 664	2 332	3 025	41.7
2400W8L26	2 400	3 000	7 744	2 332	3 025	42.3
2700W9L26	2 700	3 375	8 799	2 332	3 090	46.8

50 Hz						
	Output		Dimensions (mm) and weights (tonnes)			
Type	kWe	kVA	A	E	L	Weight
520W4L20	520	650	3 648	1 770	2 243	13.0
670W4L20	670	838	3 837	1 770	2 243	13.6
790W6L20	790	988	4 988	1 770	2 243	16.2
860W6L20	860	1 075	5 048	1 770	2 243	16.9
1000W6L20	1 000	1 250	5 158	1 770	2 243	17.5
1140W6L20	1 140	1 425	5 288	1 770	2 243	18.1
1350W8L20	1 350	1 688	5 758	1 920	2 490	21.7
1550W9L20	1 550	1 938	6 163	1 920	2 474	22.9
1700W9L20	1 700	2 125	6 513	1 920	2 474	24.4
1950W6L26	1 950	2 438	6 422	2 246	2 938	31.7
2250W8L26	2 250	2 813	7 644	2 332	3 025	41.7
2550W9L26	2 550	3 188	8 809	2 332	3 090	46.5
2850W9L26	2 850	3 563	8 809	2 332	3 090	46.5

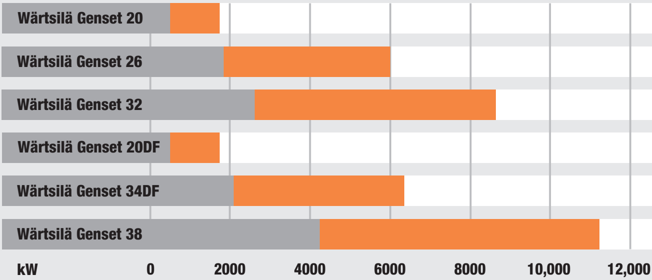




WÄRTSILÄ GENSETS

A wide range of generating sets, comprising generator and diesel engine mounted on a common baseframe, are available for both service power generation and for diesel-electric propulsion. All generating sets listed in this section are based on medium-speed diesel engines designed for operating on heavy fuel oil. The generating sets are resiliently mounted and the generator voltage can be selected in all cases except for the Auxpac generating sets, which are Low Voltage only. Larger diesel generators are delivered for separate mounting of the diesel engine and generator.

POWER RANGE FOR WÄRTSILÄ GENSETS



WÄRTSILÄ GENSET 20 IMO Tier II

Main data

Cylinder bore .... 200 mm
Piston stroke.................................. 280 mm
Cylinder output.................. 185, 200 kW/cyl
Engine speed........................ 900–1000 rpm
Mean effective pressure .... 27.3, 28.0 bar
Piston speed............................ 6.7, 9.3 m/s
Generator voltage..................... 0.4–13.8 kV
Generator efficiency 0.95–0.96

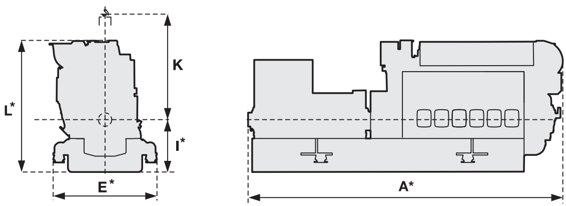
Fuel oil specification:
700 cSt/50°C
7200 sR1/100°F
ISO 8217, category ISO-F-RMK 700
SFOC 185 g/kWh
at ISO condition

Option: Common rail fuel injection.

Rated power				
	60 Hz		50 Hz	
Engine type	185 kW/cyl, 900 rpm		200 kW/cyl, 1000 rpm	
	Eng. kW	Gen. kW	Eng. kW	Gen. kW
4L20	740	700	800	760
6L20	1 110	1 055	1 200	1 140
8L20	1 480	1 405	1 600	1 520
9L20	1 665	1 580	1 800	1 710

Dimensions (mm) and weights (tonnes)						
Engine type	A*	E*	I*	K	L*	Weight*
4L20	4 910	1 770/1 920	990	1 800	2 338	14.0
6L20	5 325	1 770/1 920/2 070	895/975/1 025	1 800	2 243/2 323/2 373	16.8
8L20	6 030	1 920/2 070	1 025/1 075	1 800	2 474/2 524	20.7
9L20	6 535	2 070/2 300	1 075/1 125	1 800	2 524/2 574	23.8

* Dependent on generator type and size.
For definitions see page 91.



WÄRTSILÄ GENSET 26

IMO Tier II

Main data

Cylinder bore .... 260 mm
Piston stroke.................................. 320 mm
Cylinder output.................. 325, 340 kW/cyl
Engine speed........................ 900, 1000 rpm
Mean effective pressure .... 23.0, 25.5 bar
Piston speed........................... 9.6, 10.7 m/s
Generator voltage..................... 0.4–13.8 kV
Generator efficiency 0.95–0.96

Fuel oil specification:
700 cSt/50°C
7200 sR1/100°F
ISO 8217, category ISO-F-RMK 700
SFOC 184 g/kWh
at ISO condition

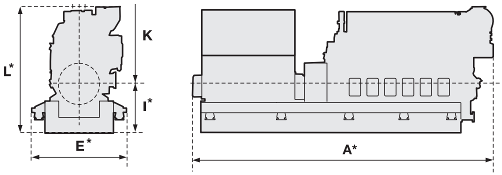
Rated power

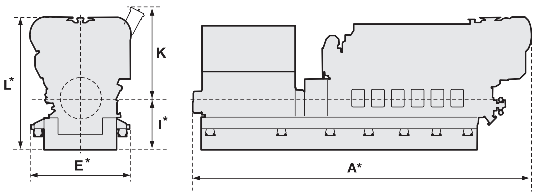
Engine type	60 Hz		50 Hz	
	325 kW/cyl, 900 rpm		340 kW/cyl, 1000 rpm	
	Eng. kW	Gen. kW	Eng. kW	Gen. kW
6L26	1 950	1 870	2 040	1 960
8L26	2 600	2 495	2 720	2 610
9L26	2 925	2 810	3 060	2 940
12V26	3 900	3 745	4 080	3 915
16V26	5 200	4 990	5 440	5 220

Dimensions (mm) and weights (tonnes)

Engine type	A*	E*	I*	K	L*	Weight*
6L26	7 500	2 300	1 200	2 430	3 081	40
8L26	8 000	2 300	1 200	2 430	3 219	45
9L26	8 500	2 300	1 200	2 430	3 219	50
12V26	8 400	2 700	1 560	2 765	3 634	60
16V26	9 700	2 700	1 560	2 765	3 711	70

* Dependent on generator type and size.
For definitions see page 91.





WÄRTSILÄ GENSET 32

IMO Tier II

Main data

Cylinder bore.................................320 mm
Piston stroke..................................400 mm
Cylinder output.................. 480, 500 kW/cyl
Engine speed..........................720, 750 rpm
Mean effective pressure ....24.9 bar
Piston speed..........................9.6, 10.0 m/s
Generator voltage................... 0.4 – 13.8 kV
Generator efficiency .... 0.95 – 0.97

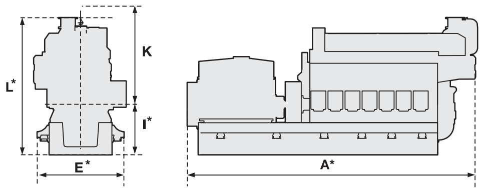
Fuel oil specification:
700 cSt/50°C
7200 sR1/100°F
ISO 8217, category ISO-F-RMK 700
SFOC 175 g/kWh
at ISO condition

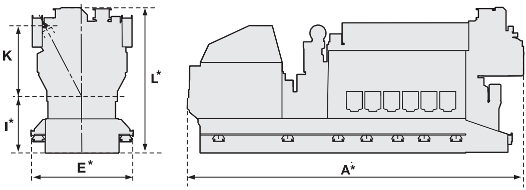
Options: Common rail fuel injection,crude oil.

Rated power				
Engine type	60 Hz		50 Hz	
	480 kW/cyl, 720 rpm		500 kW/cyl, 750 rpm	
	Engine kW	Gen. kW	Engine kW	Gen. kW
6L32	2 880	2 760	3 000	2 880
7L32	3 360	3 230	3 500	3 360
8L32	3 840	3 690	4 000	3 840
9L32	4 320	4 150	4 500	4 320
12V32	5 760	5 530	6 000	5 760
16V32	7 680	7 370	8 000	7 680
18V32	8 640	8 290	9 000	8 640

Dimensions (mm) and weights (tonnes)						
Engine type	A*	E*	I*	K	L*	Weight*
6L32	8 345	2 290	1 450	2 345	3 940	57
7L32	9 215	2 690	1 650	2 345	4 140	69
8L32	9 755	2 690	1 630	2 345	3 925	77
9L32	10 475	2 890	1 630	2 345	3 925	84
12V32	10 075	3 060	1 700	2 120	4 365	96
16V32	11 175	3 060	1 850	2 120	4 280	121
18V32	11 825	3 360	1 850	2 120	4 280	133

* Dependent on generator type and size.
Generator output based on a generator efficiency of 96%.
For definitions see page 91.





WÄRTSILÄ GENSET 38

IMO Tier II

Main data

Cylinder bore .... 380 mm
Piston stroke................................. 475 mm
Cylinder output......................... 725 kW/cyl
Engine speed................................600 rpm
Mean effective pressure ....26.9 bar
Piston speed.................................. 9.5 m/s
Generator voltage.................... 0.4–13.8 kV
Generator efficiency 0.96–0.98

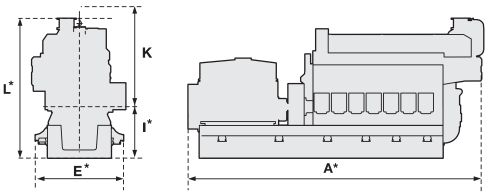
Fuel oil specification:
700 cSt/50°C
7200 sR1/100°F
ISO 8217, category ISO-F-RMK 700
SFOC 176 g/kWh
at ISO condition

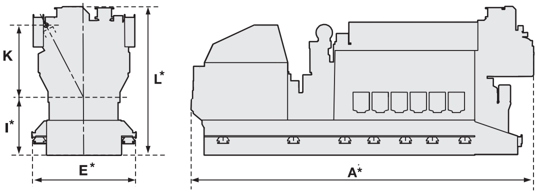
Rated power		
Engine type	50 Hz, 60 Hz	
	Eng. kW	Gen. kW
6L38	4 350	4 200
8L38	5 800	5 600
9L38	6 525	6 300
12V38	8 700	8 400
16V38	11 600	11 200

Dimensions (mm) and weights (tonnes)

Engine type	A*	E*	I*	K	L*	Weight*
6L38	9 600	2 900	1 655	3 135	4 485	90
8L38	12 000	2 900	1 705	3 135	4 475	110
9L38	12 300	3 100	1 805	3 135	4 575	130
12V38	11 900	3 600	2 015	2 855	4 945	160
16V38	13 300	3 800	2 015	2 855	5 120	200

* Dependent on generator type and size.
For definitions see page 91.





WÄRTSILÄ GENSET 20DF

IMO Tier II

Main data

Cylinder bore .... 200 mm
Piston stroke.................................. 280 mm
Cylinder output.................. 146/176 kW/cyl
Engine speed...................... 1000/1200 rpm
Mean effective pressure .... 20.0 bar
Piston speed........................... 9.3/11.2 m/s
Generator voltage..................... 0.4–13.8 kV
Generator efficiency 0.95–0.96

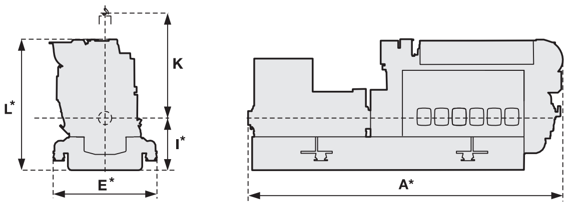
Fuel oil specification:
ISO-F-DMX, DMA and DMB
ISO 8217:2005(E)

SFOC 194/199 g/kWh at ISO conditions
Natural gas
Methane number: 80

Rated power				
Engine type	60 Hz		50 Hz	
	176 kW/cyl, 1200 rpm		146 kW/cyl, 1000 rpm	
	Engine kW	Gen. kW	Engine kW	Gen. kW
6L20DF	1 056	1 014	876	841
8L20DF	1 408	1 352	1 168	1 121
9L20DF	1 584	1 521	1 314	1 261

Dimensions (mm) and weights (tonnes)						
Engine type	A*	E	I*	K	L*	Weight
6L20DF	5 325	2 070	900/980/1 030	1 800	2 688	17
8L20DF	6 030	2 070	1 030/1 080	1 800	2 824	20.9
9L20DF	6 535	2 300	1 080/1 130	1 800	2 874	24

For definitions see page 91.



WÄRTSILÄ GENSET 34DF

IMO Tier II

Main data

Cylinder bore ....340 mm
Piston stroke..................................400 mm
Cylinder output.................. 435, 450 kW/cyl
Engine speed..........................720, 750 rpm
Mean effective pressure ....20.0, 19.8 bar
Piston speed..........................9.6, 10.0 m/s
Generator voltage................... 0.4 – 13.8 kV
Generator efficiency .... 0.95 – 0.97

Fuel oil specification:
700 cSt/50°C
7200 sR1/100°F
ISO 8217, category ISO-F-DMX, DMA and DMB

Natural gas
Methane number: 80
LHV: min. 28 MJ/Nm³, 4.5 bar
BSEC 7700 kJ/kWh

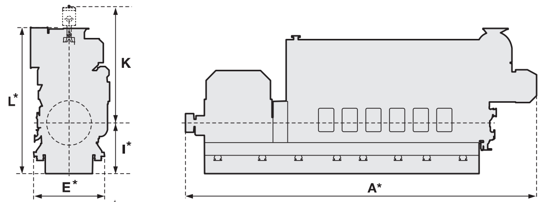
Rated power

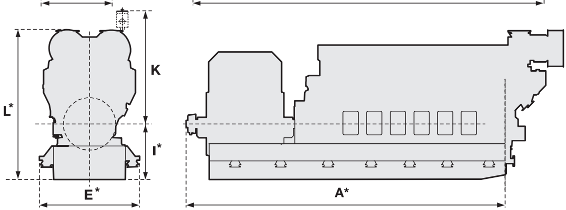
Engine type	60 Hz		50 Hz	
	435 kW/cyl, 720 rpm		450 kW/cyl, 750 rpm	
	Engine kW	Gen. kW	Engine kW	Gen. kW
6L34DF	2 610	2 510	2 700	2 600
9L34DF	3 915	3 760	4 050	3 890
12V34DF	5 220	5 010	5 400	5 190
16V34DF	6 960	6 680	7 200	6 920

Dimensions (mm) and weights (tonnes)

Engine type	A*	E*	I*	K	L*	Weight
6L34DF	8 345	2 290	1 450	2 345	3 940	57
9L34DF	10 475	2 890	1 630	2 345	3 925	84
12V34DF	10 075	3 060	1 700	2 120	4 365	96
16V34DF	11 175	3 060	1 850	2 120	4 280	121

* Dependent on generator type.
Generator output based on a generator efficiency of 96%.
For definitions see page 91.





DEFINITIONS AND NOTES FOR GENERATING SETS

GENERATING SET DIMENSIONS

A Total length of the generating set.

E Total width of the generating set.

I Distance from the bottom of the common baseframe to the crankshaft centreline.

K Minimum height from the crankshaft centreline when removing a piston.

L Total height of the generating set.

DIMENSIONS AND WEIGHTS

Dimensions are in millimetres and weights are in metric tonnes.
Indicated values are for guidance only and are not binding.
Cylinder configurations: L = in-line, and V = V-form.

SPECIFIC FUEL OIL CONSUMPTION

At ISO standard reference conditions
Lower calorific value of fuel 42 700 kJ/kg
Tolerance 5%
Without engine driven pumps
At 85% load.

ISO STANDARD REFERENCE CONDITIONS

Total barometric pressure	.... 1.0 bar
Suction air temperature	.... 25 °C
Charge air, or scavenge air, cooling water temperature	.... 25 °C
Relative humidity	.... 30%

ENGINE AUXILIARY SYSTEMS

All auxiliary equipment needed for the diesel engines can be delivered by Wärtsilä. Some equipment can be built on the engine, and the rest can be delivered loose or grouped in modules.

Depending on the engine type and application, lubricating oil pump, HT- and LT-cooling water pumps, fuel pump, oil filters and coolers, pre-lubricating oil pump and thermostatic valves can be built on the engine.

Stand by pumps, seawater pumps, central coolers, starting air vessels, lubricating oil automatic filters, exhaust gas silencers and boilers are typically delivered for separate mounting.

STANDARDIZED MODULAR AUXILIARY UNITS

- Fuel oil booster
- Fuel oil separating
- Lubricating oil separating
- Cooling water preheating
- Starting air compressors
- Oil mist separator
- Oily water bilge separator

Maximum compatibility is ensured when auxiliary systems are delivered together with the main propulsion engines and diesel generator sets. Whenever necessary, the auxiliary systems are tailored to optimize the operating performance for a specific trade. The systems are specified to minimise building costs and operating costs for a specific combination of main and auxiliary engines.

Fuel booster unit.

Tailor made modular auxiliary units are available on request.

Module consisting of preheater, cooling water thermostatic valves, lubricating oil automatic filter, pre-lubricating oil pump and fuel oil booster unit.

Fuel oil transfer pump module with heater.

Oil mist separator module.

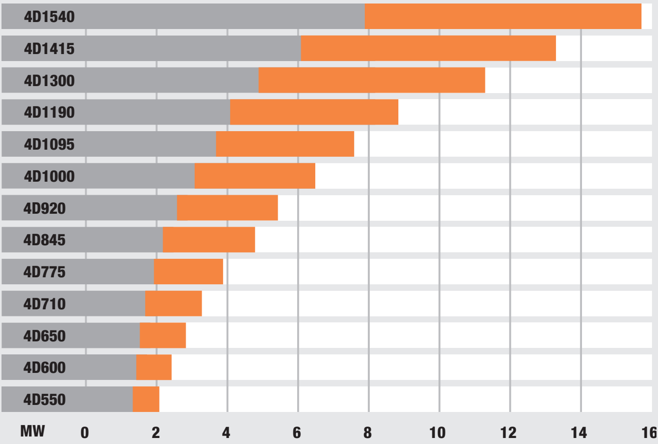
WÄRTSILÄ CONTROLLABLE PITCH PROPELLERS

Wärtsilä controllable pitch propellers offer excellent manoeuvrability, saving ship time and docking costs. For ships with frequent port calls, Wärtsilä CP propellers are the ideal choice for diesel mechanical plants with medium-speed engines.

Full power is available in heavy and light conditions through automatic pitch adjustment. Engine overload is avoided in all conditions. CP propellers permit high skew angles to minimize noise and vibrations.The combinator curve can be shaped to avoid ship and machinery resonances, and to assure optimum operation of the complete propulsion system.

- Compact, well proven, strong hub designs
- Few components, robust design
- Small overhang weight
- Accurate stepless hydraulic pitch control
- Reduced hydraulic power requirement
- Easy to install, delivered as pre-assembled complete system
- Under water replacement of blades

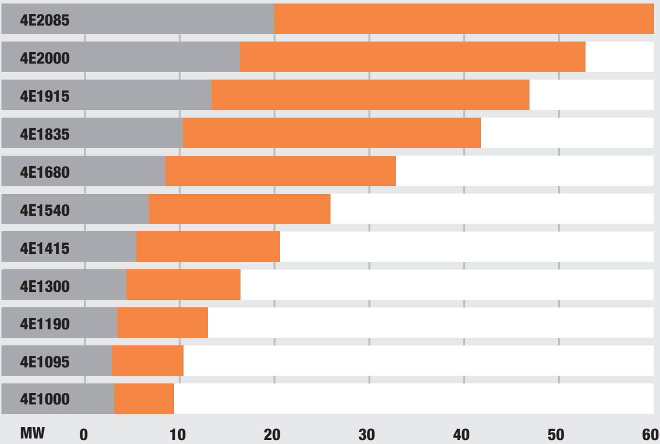
PROPELLER HUB RANGE FOR WÄRTSILÄ D-HUB



Wärtsilä CP propellers are all of standard hub design, customised to suit the customer's needs by applying wake-adapted propeller designs and ship-construction related shaft designs. CP propellers are manufactured in the following hub types:

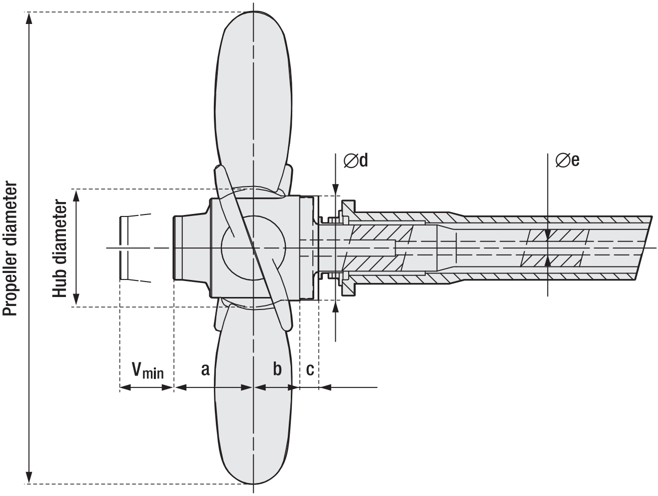
Type	Material	Hub diameter	Special features
Wärtsilä D-hub	CuNiAl Bronze	550–1540 mm	One piece hub casting with integrated hub-cover for extra rigidity. Available for all applications.
Wärtsilä E-hub	CuNiAl Bronze	1000–2085 mm	Exceptionally well-suited for heavy duty applications.
Specific application	CuNiAl Bronze or stainless steel	330–2800 mm	Navy installations 5-bladed propeller Feathering propellers

PROPELLER HUB RANGE FOR WÄRTSILÄ E-HUB



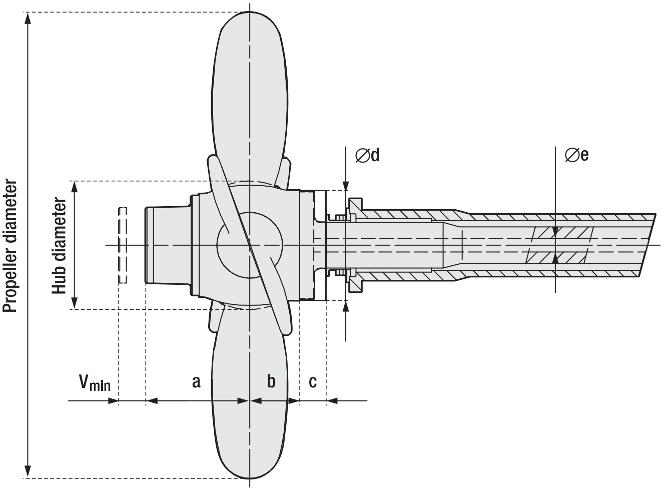
DIMENSIONS OF WÄRTSILÄ D-HUB (IN MM)

Type	Hub diameter	Dimensions					
		a	b	c	d	e	v_{min}
4D550	550	402	219	100	506	65	320
4D600	600	432	238	107	546	65	335
4D650	650	467	258	114	586	65	365
4D650	650	467	258	114	586	100	365
4D710	710	506	280	120	636	100	385
4D775	775	550	304	135	690	100	405
4D845	845	574	332	143	745	100	410
4D920	920	631	361	154	824	100	435
4D1000	1000	674	392	162	884	115	460
4D1095	1095	735	427	182	963	115	490
4D1190	1190	798	465	194	1052	115	525
4D1300	1300	859	508	207	1137	130	575
4D1415	1415	933	551	283	1229	130	610
4D1540	1540	1016	600	300	1332	130	655



DIMENSIONS OF WÄRTSILÄ E-HUB (IN MM)

Type	Hub diameter	Dimensions					
		a	b	c	d	e	V_{min}
4E1000	1000	884	433	236	926	115	245
4E1095	1095	961	470	256	1014	115	260
4E1190	1190	1043	502	272	1096	115	275
4E1300	1300	1127	548	295	1201	130	295
4E1415	1415	1225	589	314	1298	130	320
4E1540	1540	1346	638	337	1415	160	345
4E1680	1680	1466	686	362	1544	160	375
4E1835	1835	1584	745	397	1679	160	400
4E1915	1915	1650	777	412	1752	160	415
4E2000	2000	1724	810	430	1825	190 (160)	435
4E2085	2085	1785	846	454	1907	190 (160)	450



WÄRTSILÄ FIXED PITCH PROPELLERS

Each ship's hull has its own characteristics. In order to achieve the highest possible total efficiency of the vessel, the propeller must be a perfect match with the engine and the hull. A fixed pitch propeller is the choice when optimum efficiency, reliability and robustness are required. Fixed pitch propellers are usually installed for ocean sailing vessels, for example

- Container vessels
- Tankers
- Bulk carriers
- Dry cargo vessels

Wärtsilä FP propellers for all ship types guarantee maximum efficiency and minimum noise and vibration levels due to tailor-made designs with the latest available technology.

MATERIAL

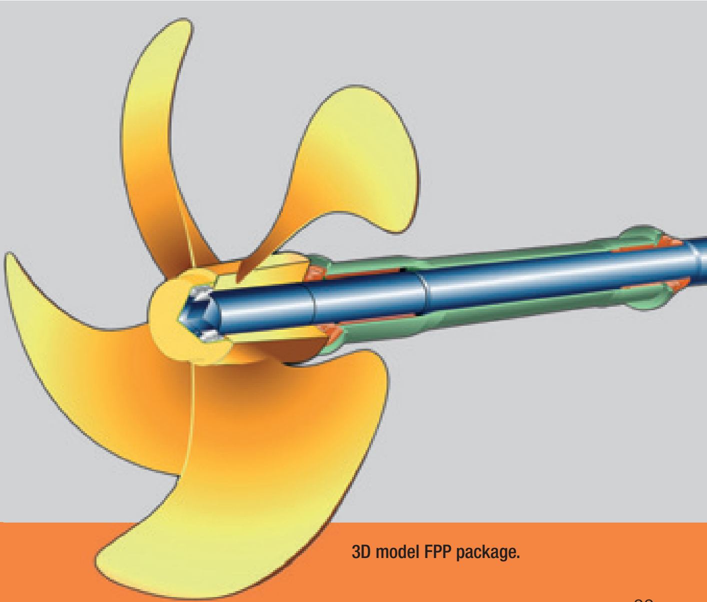
Wärtsilä patented Cunial material provides excellent casting, machining and fatigue properties. An additional advantage is the good repairability.

Wärtsilä FP propellers can be made to meet all requirements for the number and size of the blades, from 3.5 m upwards (for smaller sizes,see chapter on Wärtsilä CIPS).

FP PROPELLER PACKAGE

The propeller following items can also be included in the package supplied

- Hydrodynamic consultancy
- Alignment calculations
- Jackload calculations
- Whirling calculations
- Build-up propellers
- Propeller caps
- Hydraulic nut/ring
- Hydraulic mounting tools
- Ropeguard
- Netcutters
- Sterntubes
- Torque measurement device
- Turning device
- Thrust bearing
- Earthing device
- Shaft locking device
- Shaft brake



3D model FPP package.

WÄRTSILÄ COASTAL AND INLAND PROPULSION SYSTEMS

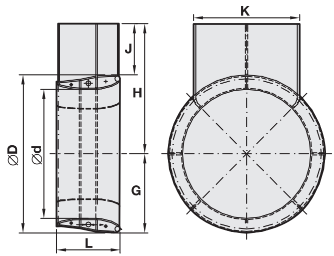
Coastal and Inland Propulsion Systems (CIPS) specializes in propulsion systems for vessels operating in local waterways, and for coastal and fishing vessels. We are also experts in designing propulsion systems for large luxury yachts and government owned ships with propeller diameters up to 3500 mm, as well as a variety of special vessels all with their original characteristics.

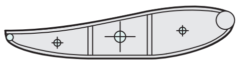
- Tailor made propellers with 3, 4, 5, 6 and 7 blades in ISO class II, I and S accuracy.
- Standard and custom-made nozzles
- Shaft installations complete with sterntube and seals & bearings

WÄRTSILÄ NOZZLES FOR CIPS

Nozzle	Ød	ØD	G	H	J	K	L
HR 1000	1010	1238	619*	1019*	400*	840*	500
HR 1050	1060	1300	650*	1050*	400*	900*	525
HR 1100	1110	1360	680*	1080*	400*	970*	550
HR 1150	1160	1422	711*	1111*	400*	960*	575
HR 1200	1210	1483	742*	1142*	400*	1200*	600
HR 1250	1260	1545	772*	1172*	400*	1012*	625
HR 1300	1310	1606	803*	1203*	400*	1064*	650
HR 1350	1360	1667	834*	1234*	400*	1104*	675
HR 1400	1410	1730	865*	1265*	400*	1144*	700
HR 1450	1460	1790	895*	1295*	400*	1186*	725
HR 1500	1510	1852	926*	1326*	400*	1226*	750
HR 1550	1560	1913	957*	1357*	400*	1264*	775
HR 1600	1610	1974	987*	1387*	400*	1306*	800
HR 1650	1660	2032	1016*	1416*	400*	1344*	825
HR 1700	1710	2098	1049*	1449*	400*	1380*	850
HR 1750	1760	2158	1079*	1479*	400*	1420*	875
HR 1800	1810	2220	1110*	1510*	400*	1680*	900
HR 1850	1860	2282	1141*	1541*	400*	1502*	925
HR 1900	1910	2342	1171*	1571*	400*	1542*	950
HR 1950	1960	2404	1202*	1602*	400*	1582*	975
HR 2000	2010	2465	1233*	1633*	400*	1620*	1000

* = Dimensions can be adjusted according to ship's hull.





Cross section HR-profile.

A headbox
B aft seal

C bearing
D sterntube

E coupling
F forward seal

G propeller shaft
H bearing

I nozzle
J propeller

Two Wärtsilä FP propellers in HR nozzles.

WÄRTSILÄ HIGH EFFICIENCY NOZZLE

Fitting a nozzle increases the thrust at relatively low ship speeds. Significant savings can be achieved in terms of fuel consumption, depending on the number of revolutions and the capacity of the motor.

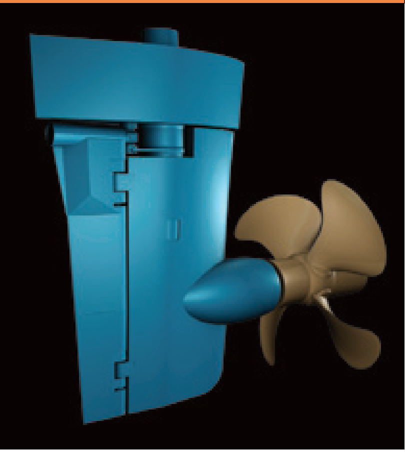
The improved Wärtsilä high efficiency nozzle, type HR, combined with a Wärtsilä propeller, can produce up to 10% more thrust than conventional nozzles, both in bollard pull and in free sailing condition. The nozzle profile offers a double profiled cross section (outside and innerside). This sophisticated shape improves the water flow both into and out of the nozzle, increasing thrust performance.

ENERGOPAC

Energopac is the optimised propulsion and manoeuvring solution for coastal and sea going vessels. The key objective is to reduce the vessel's fuel consumption by integrating both propeller and rudder design. Each Energopac is designed to fit the vessel and to meet its specific requirements; this allows Energopac to be optimised fully for energy efficiency, whilst not compromising on either manoeuvrability or comfort levels.

FUEL SAVINGS

Energopac reduces fuel consumption because it reduces flow separation behind the propeller hub in an effective way. Extended studies show that for



the same course-keeping capabilities, Energopac will create less drag than conventional rudder systems. Especially when using small – corrective – steering forces to keep your vessel on course, the difference in rudder resistance is significant. The high-lift performance of Energopac requires smaller steering angles and consequently reduces the rudder resistance.

DESIGN SPACE

The application of Energopac gives more freedom to optimise between conflicting requirements. High performance propeller designs are often a compromise between increased efficiency and reduced vibration levels. Energopac allows for a propeller design, that gives the optimal balance between these requirements.

TYPICAL APPLICATIONS

Energopac will effectively reduce the operational costs for any vessel with a considerable share of free sailing time in its operational profile. Additionally it will work very well for propellers with a relatively large propeller hub.
The potential savings are large for vessels with highly loaded controllable pitch propeller systems such as RoRo-vessels, ferries, container / multipurpose vessels and vessels with an ice class notation.

MONEY SAVINGS DUE TO ENERGOPAC

The reduction in fuel consumption depends very much on the vessel type, the operational profile of the vessel and also on the reference propeller and rudder. For any application the power savings can be estimated by Wärtsilä. The estimate is based on the vessel design, operational profile and other requirements.
Proven savings in required power for a vessel's trial speed vary between 2–9% due to Energopac.

WÄRTSILÄ STEERABLE THRUSTERS

With steerable thrusters thrust can be applied in any direction, resulting in superior manoeuvrability. Wärtsilä steerable thrusters are durable and reliable.

- High thrust-to-power ratio
- Modular flexible design or compact standard design
- Fixed pitch propeller or controllable pitch propeller
- With or without nozzle
- Variable propeller diameter
- Maintenance friendly
- Low operating costs

WÄRTSILÄ COMPACT THRUSTERS

- Easy mounting by welding
- Robust design
- High thrust-to-power ratio
- Standardized Z- or L-drive design
- Diesel or electric driven up to 3000 kW
- Maintenance friendly
- Optional mounting can

Wärtsilä modular thruster range:

WÄRTSILÄ MODULAR STEERABLE THRUSTERS

- Flexible design, L-drive and Z-drive
- Various shaft arrangements
- Diesel or electric driven up to 7000 kW
- Optional mounting can available

WÄRTSILÄ RETRACTABLE STEERABLE THRUSTERS

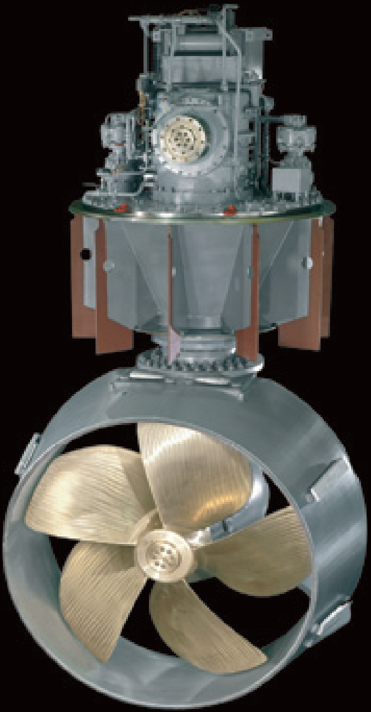
- L-drive and Z-drive
- Retraction system with cylinders or spindles
- Electric driven up to 7000 kW

WÄRTSILÄ UNDERWATER DEMOUNTABLE STEERABLE THRUSTERS

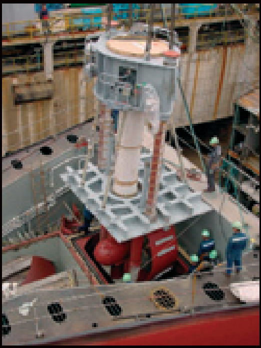
- L-drive and Z-drive
- Stable three-wire handling
- Electric driven up to 7000 kW

WÄRTSILÄ CONTAINERIZED STEERABLE THRUSTERS

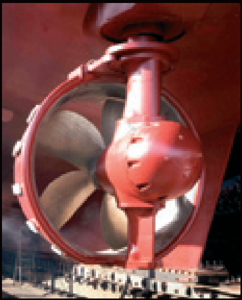
- L-drive
- Customized container
- Electric driven up to 7000 kW
- Retractable option
- Retrievable option



Wärtsilä compact thruster.



Wärtsilä retractable steerable thruster.



Wärtsilä modular steerable thruster.

Wärtsilä underwater demountable steerable thrusters.

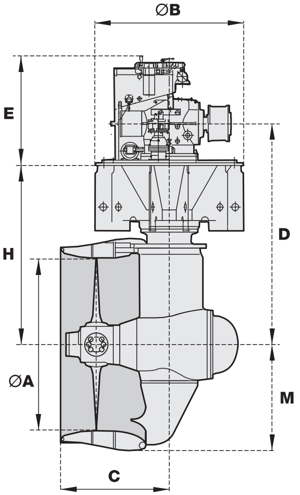
Wärtsilä containerized steerable thrusters.

WÄRTSILÄ ENGINES CONNECTED TO WÄRTSILÄ COMPACT THRUSTERS

Engine type	MCR engine power (kW)	MCR engine speed (rpm)	Thruster type	Reduction ratio	Propeller speed (rpm)	Propeller diameter (mm)	Bollard pull based on two installations, In nozzle (tonnes)
6L20	1080	1000	175	2.770	361	1600	34
						1800	36
	1200	1000	200	3.448	290	1900	41
						2100	43
8L20	1600	1000	225	3.650	274	2100	53
						2300	55
9L20	1800	1000	250	3. 895	257	2400	62
						2600	64
6L26	2040	1000	250	3.895	257	2400	68
						2600	70
8L26	2600	1000	275	4.084	245	2600	84
	2720	1000	300	4.592	218	2800	91
						3000	94
9L26	3060	1000	300	4.592	218	2800	99
						3000	103

Variations per type

- Two different propeller diameters.
- Controllable pitch propeller (CS) or fixed pitch propeller (FS).
- Propellers in nozzle or open propeller.
- Reduction ratios optimised for application.
- Weld-in stembox or can-mounted.
- Soft on/off clutch or modulating clutch.



Remarks

- The propellers are designed for bollard pull condition in tug boat application.
- Bollard pull calculations are based on two installations, 100% MCR power and 2% thrust deduction.
- Selections are valid for classification without ice class; final selection is subjected to rules of classification societies.
- Thrusters with controllable pitch propellers improve manoeuverability and efficiency over the complete speed range, and protect the engine against overload.
- Thrusters with controllable pitch propellers are very suitable for constant speed operation.
- The weld-in stembox provides easy installation and maximum stiffness of the construction in the vessel.
- The can-mounted thruster provides the possibility to install or remove the thruster while the ship is afloat.
- Modulating clutches (MCD) improve manoeuverability for thrusters with fixed pitch propellers at low speeds.
- Low duty (LD) modulates between 0 and idle engine speed. Heavy duty (HD) modulates between 0 and maximum engine speed.

WÄRTSILÄ COMPACT THRUSTER DIMENSIONS

Thruster type fs/cs	A mm	B mm	C mm	D mm	E mm	H mm	M mm
175	1600	1600	1200	2100	910	1743	985
	1800		1230	2200		1843	1110
200	1900	1900	1300	2500	1200	2048	1180
	2100		1350	2600		2148	1305
225	2100	2100	1400	2630	1210	2168	1305
	2300		1450	2830		2368	1425
250	2400	2100	1525	3100	1435	2512	1485
	2600		1575	3200		2612	1615
275	2600	2850	1665	3500	1465	2890	1615
	2800		1765	3620		3010	1735
300	2800	2850	1770	3700	1465	3090	1735
	3000		1870	3850		3090	1860

WÄRTSILÄ RETRACTABLE THRUSTER SELECTION UP TO 2000 KW

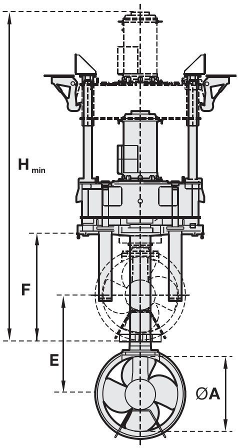
Electric motor									
MCR motor power	kW	1000		1200		1600		2000	
	HP	1360		1632		2176		2720	
Frequency	Hz	50	60	50	60	50	60	50	60
Nominal motor speed	rpm	1000	1200	1000	900	1000	900	750	720
Thruster type		**175**		**200**		**225**		**250**	
Propeller diameter	mm	1700		1900		2100		2400	
Reduction ratio		2.643	3.154	2.929	2.929	3.308	2.929	2.714	2.714
Propeller speed	rpm	378	380	341	307	302	307	276	265
Thrust at zero knots									
in nozzle	kN	165		200		260		320	

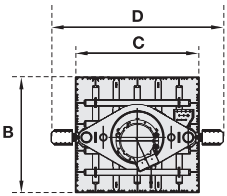
Variations per type
Fixed pitch propeller (FS) or controllable pitch propeller (CS). Reduction ratios optimized for application.
L-drive and Z-drive are available.

Remarks
Above information is for vertical e-drive only. For information only, subject to change without prior notice. The propellers are designed for bollard pull condition at 100% MCR power in DP application. Final selection is subjected to classification societies rules. Selections are not valid for classification with iceclass.

WÄRTSILÄ RETRACTABLE THRUSTERS DIMENSIONS

Thruster type		A mm	B mm	C mm	D mm	E mm	F mm	H_{min} mm	Estimated motor height mm	Weight unit kg	Weight auxiliaries kg
175	FS CS	1700	2700 2850	2950	4050	2200	2400	7700	1850	18000 19000	2000 2500
200	FS CS	1900	2850 3000	3050	4160	2450	2700	8600	1900	20000 21000	2000 2500
225	FS CS	2100	3300 3450	3590	4625	2650	3000	9000	2000	22000 23000	2000 2500
250	FS CS	2400	3710 3710	3666	4625	3000	3370	10000	2200	34000 32000	2000 2500





NOTES
For information only, subject to change without prior notice.
Minimum total height of the thruster unit is depending on selected electric motor.
Weight of unit is empty and without electric motor.
Dimensions can be changed for better fit in the vessel's structure.

WÄRTSILÄ MODULAR THRUSTERS FOR OVER 2000 KW

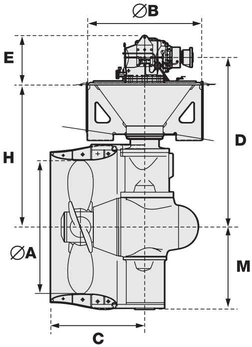
Thruster type			1510	2500	2510	3500	5000
Maximum allowable power	kW		2300	3200	3500	5500	7000
Maximum allowable input speed	rpm	Z-drive	1200	1200	1200	900	900
	rpm	L-drive	1000	900	900	750	750
Propeller diameter in nozzle	mm	Maximum	2900	3200	3400	3800	4400
	mm	Standard	2700	3000	3200	3600	4200

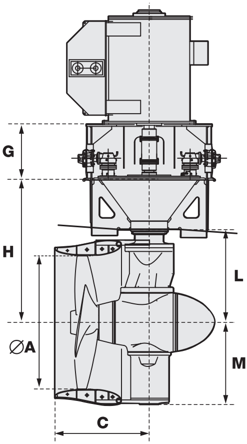
Remarks
Mentioned power and input speed do not necessarily coincide. Actual maximum power depends on application and class rules. These units are also applied for underwaterdemountable thrusters, pulling thrusters and large retractabe thrusters.

STEERABLE THRUSTERS DIMENSIONS

Thruster type CPP or FPP	A mm. standard	B mm.	C mm.	D min. (PAL) mm.	E mm.	G mm. (L-Drive)	H min. mm.	L mm.	M mm.
1510	2700	2850	1900	3500	1470	3800	2890	2100	1620
2500	3000	3100	2000	3900	1250	4500	3900	2300	1880
2510	3200	3100	2035	4000	1250	4860	4000	2410	1910
3500	3600	3100	2550	4300	1340	5000	3500	2510	2225
5000	4200	3540	3000	5300	1519	5450	4500	3200	2720

Remarks
Dimensions are based on thrusters with nozzle.





WÄRTSILÄ TRANSVERSE THRUSTERS

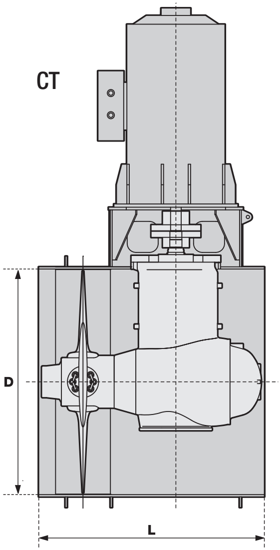
Bevel-gear driven propeller in a transverse tunnel.

- Controllable or fixed pitch propeller
- Maximum thrust with small diameter
- Robust reliable design
- Easy installation
- Standard and demountable versions available
- Applications for dynamic positioning and manoeuvring purposes

WÄRTSILÄ CT/FT 125-CT/FT 300 M TYPES

Type	Electr. freq.	Rational frequency		Max. power (kW) [1]		D	L	Mass[2]
	(Hz)	Input (rpm)	Output (rpm)	Manoeuv-ring	Dynamic positioning	(mm)	(mm)	(kg)
CT/FT125 H	60	1755	519	614	404	1250	1550	2800
	50	1465	433	516	341			
CT/FT150 H	60	1755	430	880	589	1500	1800	4200
	50	1465	359	735	492			
CT/FT175 H	60	1755	379	1025	713	1750	2000	5900
	50	1465	316	900	595			
CT/FT175 M	60	1170	371	995	995	1750	1926	5600
	50	975	309	829	829			
CT/FT200 H	60	1170	263	1115	742	2000	2250	8100
	50	1465	329	1394	928			
CT/FT200 M	60	1170	324	1515	1227	2000	2181	7550
	50	975	270	1262	1022			
CT/FT225 H	60	1170	287	1785	1201	2250	2350	11500
	50	975	239	1487	1001			
CT/FT225 M	60	880	266	1649	1478	2250	2285	10600
	50	975	295	1827	1502			
CT/FT250 H	60	1170	265	2175	1458	2500	2550	13800
	50	975	221	1813	1215			
CT/FT250 M	60	880	233	1998	1599	2500	2482	12700
	50	975	259	2213	1754			
CT/FT275 H	60	880	216	2532	1735	2750	2800	17800
	50	975	239	2805	1923			
CT/FT275 M	60	880	238	2569	2241	2750	2704	15600
	50	735	199	2145	1858			
CT/FT300 H	60	880	216	3145	2454	3000	3000	22700
	50	735	180	2625	2035			
CT/FT300 M	60	705	210	3405	2657	3000	2916	22500
	50	735	219	3550	2771			

1) Max. power is dependent on sailing pofile and classification society requirements.
2) Includes a standad tunnel with e-motor support.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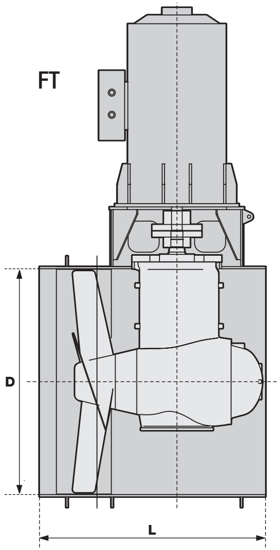
FT
D
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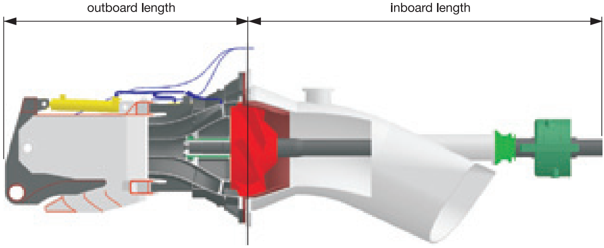
WÄRTSILÄ JETS

Waterjet propulsion is the most successful and efficient method of propulsion for high-speed applications. The advantages are not only higher efficiency, but also lower vessel resistance due to the absence of underwater appendages like shafts, rudders and shaftstruts. The absence of any parts below the waterline also makes waterjets an ideal solution for shallow water operation. The unique design features of the Wärtsilä jet will ensure access to even the smallest ports. Hybrid propulsion systems – the use of two fixed or controllable pitch propellers in combination with a centre waterjet – combine the best of both worlds. The propellers are used for normal cruising while the combination of the propellers with the centre waterjet is used to achieve the top speed. Hybrid systems allow optimization of the propellers for normal cruising conditions, resulting in improved efficiency, low noise and vibration and a smaller propeller diameter.

WÄRTSILÄ JET E-SERIES, 6-BLADED WATERJETS

GENERIC WEIGHTS AND DIMENSIONS FOR THE MOST OFTEN USED WATERJET SIZES



Waterjet size[1]	Outboard length [mm][2]	Inboard length [mm][3]	Transom flange[4]	Weight steering [kg][5]	Weight booster [kg][5]	Entrained water [ltr][6]
LJ43E	1175 (1260)	1870	725	475	330	250
LJ47E	1275 (1370)	2040	795	615	435	330
LJ51E	1395 (1490)	2210	860	780	545	420
LJ55E	1505 (1620)	2380	930	995	695	530
LJ60E	1635 (1760)	2600	1015	1290	910	690
LJ65E	1780 (1910)	2810	1100	1635	1155	880
LJ71E	1935 (2070)	3070	1200	2070	1465	1150
LJ77E	2110 (2250)	3330	1300	2690	1890	1460
LJ84E	2290 (2450)	3630	1420	3400	2420	1900
LJ91E	2490 (2660)	3940	1535	4470	3160	2410
LJ99E	2705 (2890)	4280	1670	5510	3915	3100
LJ108E	2945 (3140)	4670	1825	5730 ~ 6860	4085 ~ 4730	4030
LJ114E	3100 (3320)	4930	1925	6720 ~ 8100	4755 ~ 5535	4740
LJ120E	3270 (3500)	5190	2025	7805 ~ 9635	5605 ~ 6570	5530
LJ127E	3465 (3700)	5490	2145	9415 ~ 11170	6625 ~ 7630	6550
LJ135E	3685 (3930)	5830	2280	11160 ~ 13160	7925 ~ 9065	7870
LJ142E	3880 (4140)	6140	2400	13100 ~ 15390	9395 ~ 10725	9160
LJ150E	4095 (4370)	6480	2535	15630 ~ 18560	11195 ~ 12765	10800
LJ157E	4285 (4570)	6780	2650	18120 ~ 21170	12985 ~ 14755	12380
LJ164E	4475 (4770)	7090	2770	20505 ~ 23815	14715 ~ 16635	14120
LJ171E	4665 (4980)	7390	2890	23205 ~ 27815	16745 ~ 19255	16000
LJ179E	4880 (5210)	7730	3025	26410 ~ 31605	19320 ~ 21940	18350
LJ190E	5185 (5530)	8210	3210	32805 ~ 37240	23671 ~ 26075	21950
LJ200E	5460 (5830)	8640	3380	38100 ~ 43870	27900 ~ 30255	25600

Notes

1) The waterjets defined in the above table are the most frequently used waterjet sizes. Intermediate sizes for the above range like a LJ160E or LJ175E size and the data for the range up to the LJ400E size are available on request.

2) The data in brackets is the maximum outboard length in full reverse and steering.

3) Inboard length may vary depending on the optimized shape of the inlet duct.

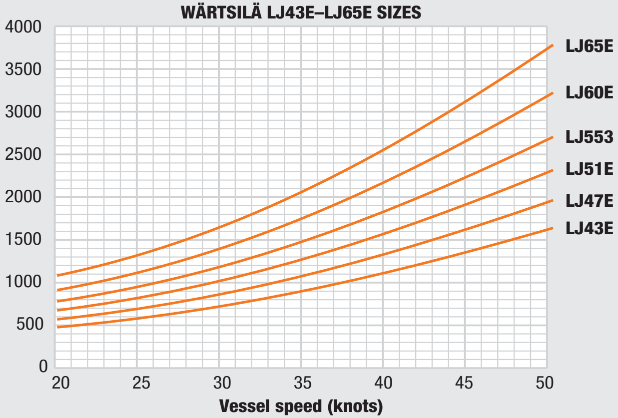
4) Transom flange connections can be custom designed. Smaller transom flange diameters are possible if the requirements for the interface with the hull are met.

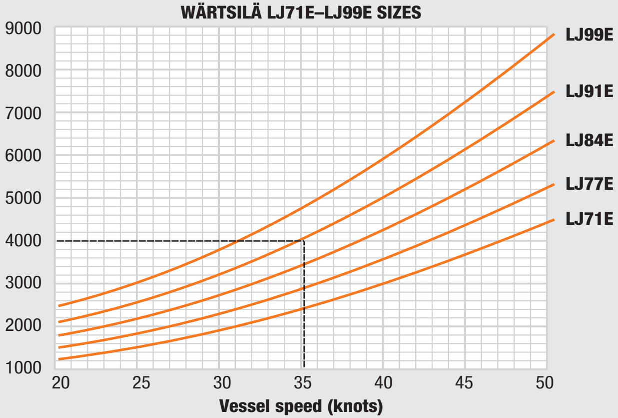
5) Weights are calculated based on jet power density. Please contact us for the weights of the jet sizes above the LJ99E based on the power density of your design. Weights include an inboard bearing, but exclude hydraulic powerpacks and oil lubrication sets.

6) Water in the inlet duct is calculated to the transom and based on the standard shaft height.

WÄRTSILÄ JET E-SERIES, 6-BLADED WATERJETS

RELATION BETWEEN POWER AND VESSEL SPEED FOR THE MOST FREQUENTLY USED WATERJET SIZES

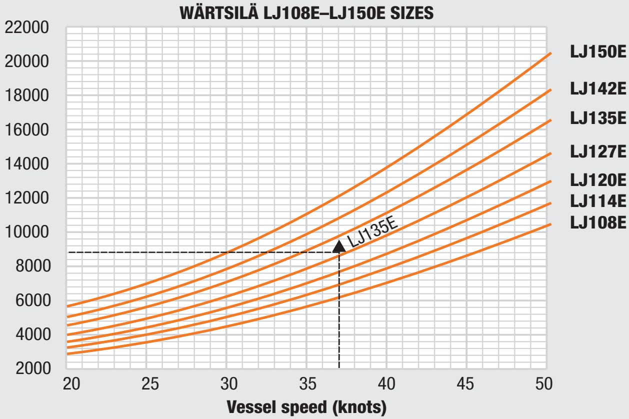


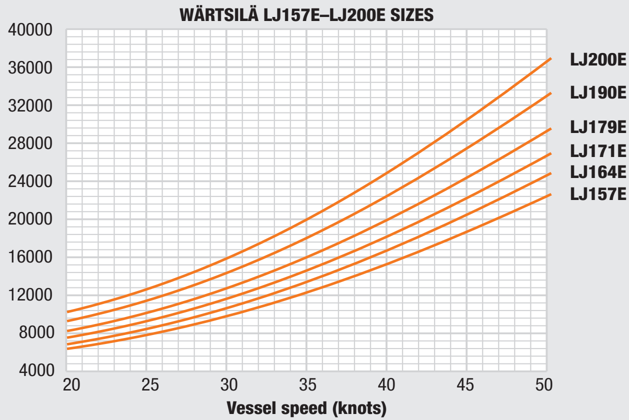


WATERJET SELECTION

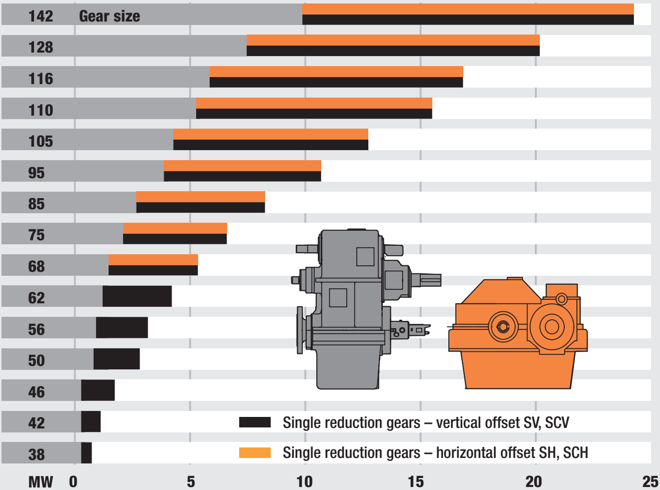
The graphs below indicate the jet size required based on the relation between the engine power and the design speed of the vessel. For instance a ship with four 4000 kW engines and a corresponding design speed of 35 knots will need four LJ91E jets. A ship with three 9000 kW engines and 37 knots will need three LJ135E jets. The correct jet size is thus indicated by the line above the intersection of the power and the design speed (see examples in graphs below).

The size range below is not complete but represents the most frequently-used waterjet sizes up to 50 knots. We are available from the earliest design stages of the vessel to work with you on an optimized propulsion system. Please contact us for an accurate jet selection based on the specific vessel design parameters, or for details of waterjets for speeds above 50 knots and 40,000 kW. DXF / DWG format general arrangement drawings of the most often used sizes are available.





WÄRTSILÄ REDUCTION GEARS – OUTPUT RANGE



WÄRTSILÄ REDUCTION GEARS

The core function of a reduction gearbox is to reduce the main engine speed to the optimum propeller speed. The Wärtsilä gears have been designed to meet the highest standards of operational efficiency, reliability and low noise and vibration.

GEAR CONFIGURATIONS

The gears can be supplied with built in multidisc clutches. Single input, single output gears are available with vertical or horizontal offsets of the shafts. Twin input single output gears can be delivered with up to 3.8 m horizontal offsets.

POWER TAKE-OFF (PTO)

All Wärtsilä gears can be supplied with one or more PTOs for driving the shaft alternator, compressor or pump. For single vertical- and horizontal gears, the standard PTO is primary driven. For twin input-single output gears the PTO is optionally primary or secondary driven.

- A primary driven PTO is rotating whenever the engine is rotating.
- A secondary driven PTO is rotating whenever the propeller shaft is rotating.

Two speed PTOs are available for geartypes SCV75-SCV142.

Wärtsilä gear type TCH350-S58.

POWER TAKE-IN (PTI)

Most Wärtsilä gears can be supplied with a combined PTO/PTI. In PTI mode the shaft alternator can also be used as an electric motor.

PTI is normally used for the following operation modes:

- PTI "Booster" mode is used when the main power of the engine is too small, in order to increase the total propulsion power. For this mode, no clutches are required on the gear.
- PTI "Take me home" mode is used in case of emergency, if the prime mover is out of operation. For this mode a minimum of 2 clutches are required on the gear.

Two speed PTO/PTIs are available for geartypes SCV75-SCV142.

INTEGRATED OR SEPARATE HYDRAULIC SYSTEM FOR GEAR AND CP PROPELLER

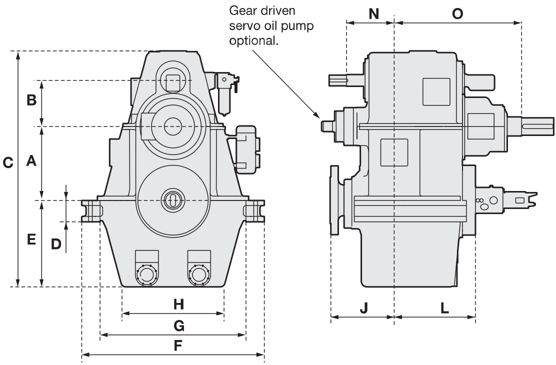
Most Wärtsilä gears are purposely-designed with an integrated hydraulic system for both the gear and the CP propeller. As the separate hydraulic power unit for the CP propeller is superfluous, both installation costs for the yard and operational costs for the owner are reduced. For safety reasons the gear mechanically drives the main pump for the propeller. All gears can also be interfaced to a separate hydraulic power unit.

WÄRTSILÄ SINGLE INPUT REDUCTION GEARS

WÄRTSILÄ VERTICAL OFFSET GEARS – DIMENSIONS

SV/SCV size	A	B Std-Max	C	D	E	F	G	H	J	L	N	O SCV/SV	Weight tonnes*
SCV38	380	290	1305	115	465	1000	750	530	340	538	230	650	2.1
SCV42	420	320	1435	125	510	1500	830	585	530	558	255	715	2.7
SCV46	460	350	1570	140	560	1580	910	640	570	595	280	785	3.4
SCV50	500	380	1724	150	590	1340	1024	720	470	592	420	1035	4.2
SCV56	560	410	1848	160	645	1500	1110	800	530	650	450	1100	6.0
SCV62	620	440-470	2210	180	740	1580	1240	880	570	662	350	1150	7.0
SCV68	680	460-510	2370	200	800	1720	1360	960	625	720	370	1250	8.5
SCV75	750	480-530	2460	220	880	1850	1480	1040	660	800	450	1300/1095	10.0
SCV85	850	510-560	2720	250	1000	2100	1680	1178	730	915	550	1470/1220	14.5
SCV95	950	580-630	3025	280	1145	2350	1880	1327	800	1025	450	1640/1350	20.0
SCV105	1050	630	3302	300	1265	2600	2100	1487	880	1125	500	1700/1400	31.0
SCV110	1010	650	3025	65	1150	2600	2140	1822	1405	550	1100	1615	33.0
SCV116	1160	650	3525	150	1400	2580	2300	1800	1535	765	885	1800/1025	37.0
SCV128	1280	800	3970	275	1536	3160	2645	1815	1700	840	900	2270/1120	40.0
SCV142	1420	1000	4520	305	1704	3505	2645	2012	1885	928	910	2270/1320	55.0

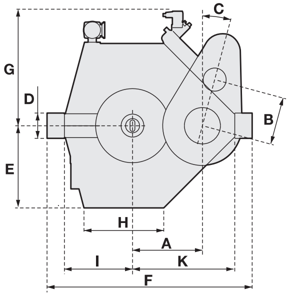
* Not binding

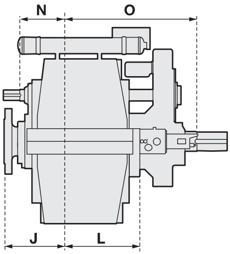


WÄRTSILÄ HORIZONTAL OFFSET GEARS – DIMENSIONS

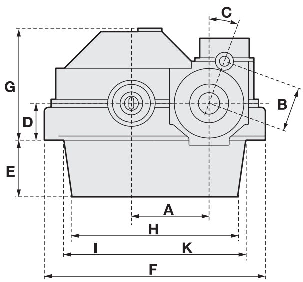
SH/SCH size	A	B	C	D	E	F	G	H	I	J	K	L	N	O SCH/SH	Weight tonnes*
SCH68	680	510	0	100	700	2000	840	650	515	570	1095	730	500	1245	10
SCH75	750	530	15	280	885	2230	1220	865	735	660	1115	800	515	1670	12.5
SCH85	850	580	15	320	1000	2495	1440	970	830	730	1245	915	550	1800	16.5
SCH95	950	580	15	450	750	2710	1520	2250	830	1215	1420	540	700	1640	21
SCH105	1050	630	20	500	771	2995	1658	2195	910	1405	1545	560	750	1700/ 1510	30
SCH110	1100	670	20	500	810	3150	1850	2320	950	1450	1630	610	790	1750	33
SCH116	1160	670	20	550	850	3300	2240	2500	1015	1535	1715	725	830	1100/ 1800	40
SCH128	1280	740	20	590	1550	3640	1960	2675	1090	1600	1870		915	1915	50
SCH142	1420	820	20	620	1720	4040	2180	2970	1380	1700	2240		1015	2100	55

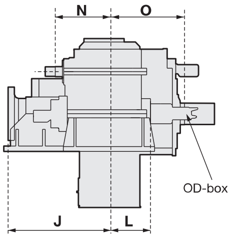
* Not binding





SH/SCH 75–85



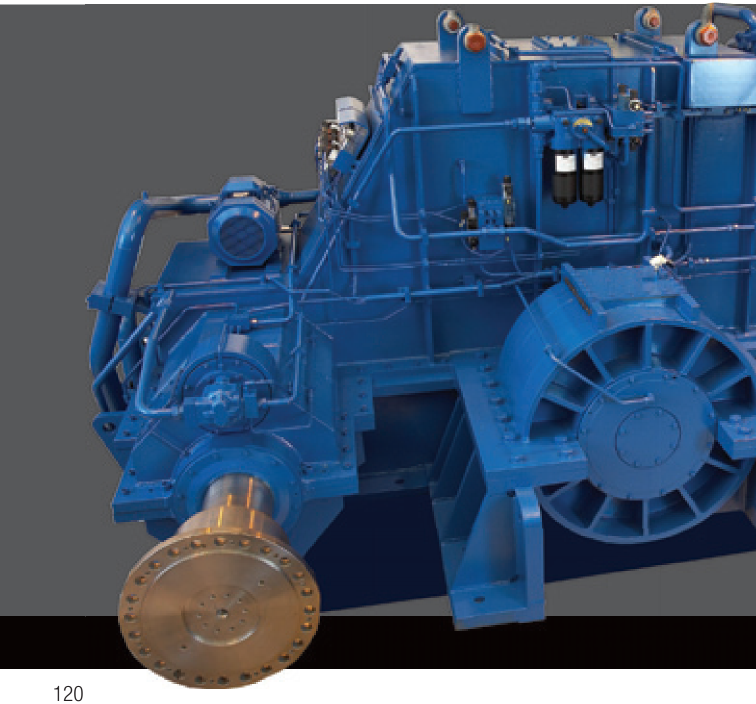


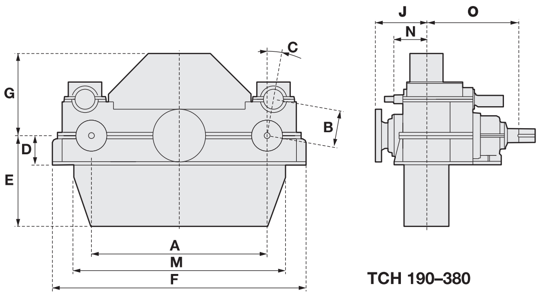
SH/SCH 95–142

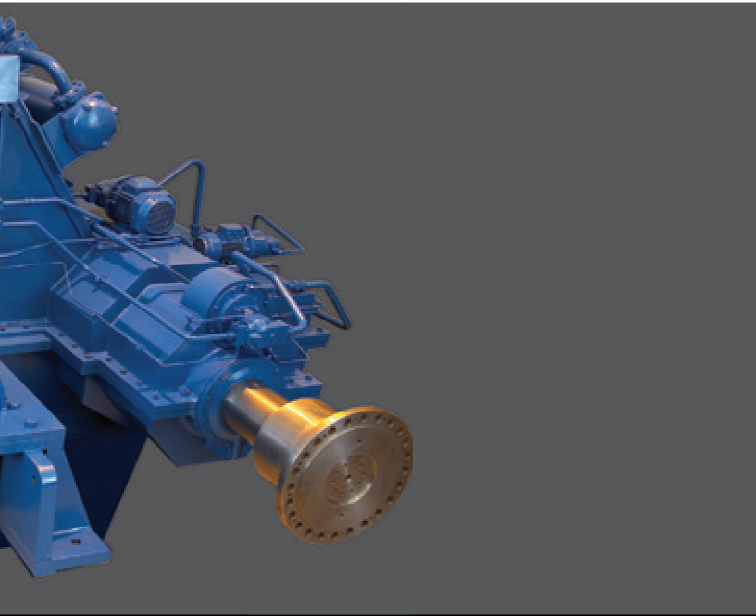
WÄRTSILÄ TWIN INPUT-SINGLE OUTPUT REDUCTION GEARS

DIMENSIONS

* Not binding







Wärtsilä gear type TCH370-S63.

Wärtsilä is the world's leading supplier of marine engineered sealing, bearing and sterntube systems. Wärtsilä and is the only supplier in the world to offer a full range of both radial and axial seal types, commonly known as face and lip seals for any type and size of ship, whether naval or commercial.

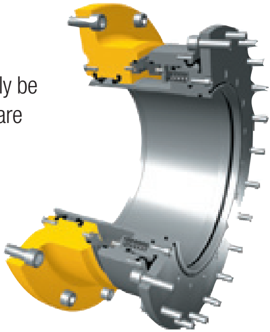
The products are reliable, efficient and easy to maintain through Wärtsilä's global service network. The range of seals, bearings and sterntubes is unequalled in the market.

Product group	Product type	Product	Shaft size (mm)	Special features/ Applications
Seals	Oil lubricated lip seals	Airguard	315–1172	Anti-polluting; ideal for use on LNG carriers, containers, bulkers, pods etc.
		Sandguard	315–1172	Sand eliminating anti-polluting seal; ideal for use on dredgers
		Sternguard	56–1172	Standard seal for use in sterntubes, thrusters, pods, stabilisers & rudderstocks
	Oil lubricated face seals	Oceanguard	400–750	Pollution free combination face & lip type seals; ideal for use on cruise ships & ferries
		Worksafe	70–355	Outboard seal for use in aggressive environments; ideal for sterntubes & thrusters
		Manebar	50–330	Seal ideal for use in stabilisers & rudderstocks
		A-Series	50–1000	Seal ideal for use in thrusters & specialist applications
	Water lubricated face seals	Manejet	70–400	Seal ideal for use in waterjets
		Maneseal	161–1040	Pollution free sterntube seal for use in multiple vessel types
		Manedive	150–800	Pollution free sterntube seal ideal for use in submarines
		Maneguard	80–330	Pollution free seal ideal for use in sterntubes & pods
		Manebar	50–330	Seals ideal for use in stabilisers & rudderstocks
	Bulkhead seals	Manesafe	50–1000	Bi-directional non wearing diaphragm seal
Bearings	Oil lubricated white metal bearings	STB / LSB	100–1172	Bearing ideal for use in sterntube & line shaft applications
	Oil lubricated composite bearings	Worksafe	70–325	Bearing ideal for use in oil lubricated sterntubes
		Sternsafe	325–1200	Bearing ideal for use in oil lubricated sterntubes
	Water lubricated composite bearings	Maneguard	70–325	Pollution free water lubricated sterntube bearing
		Ecosafe	200–1200	Pollution free water lubricated sterntube bearing
	Dry operation composite bearings	Steersafe	700–1200	High pressure laminate, low bearing wear; ideal for use in rudderstocks
Stern tubes	Oil lubricated stern tubes	Sterntube	>140	Suitable for all types of oil lubricated applications
	Water lubricated stern tubes	Sterntube	>140	Suitable for all types of water lubricated applications

WÄRTSILÄ SEALS

ENVIROMENTAL SEALS

OCEANGUARD AND AIRGUARD

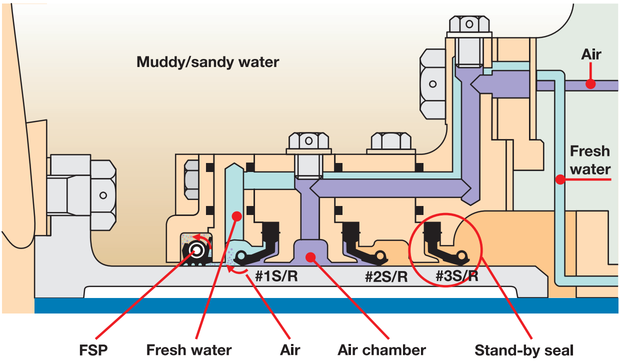


Oceanguard

Genuine anti-pollution sterntube sealing can only be achieved if the seawater and the stern tube oil are completely separated from each other.

Wärtsilä Environmental sealing systems are now in use on cruise ships, LNG carriers, containers, bulk carriers and many other vessel types to ensure continuous operation between planned maintenance periods, with no unplanned dry dockings for emergency repairs. The Oceanguard system itself is unique in that it enables all potentially polluting oil to be contained within the vessel, using a double barrier seal separated by a vent space at atmospheric pressure and a very low sterntube pressure of no more than 0.2 bars.

The Airguard system operates by separating the oil and water seals by a pressurised air space that is drained and monitored inboard. The oil pressure in the sterntube and air pressure in the air chamber is changing everytime the draft of the vessel changes, giving the seal optimum performance and increased life. Modified versions of the airguard seal have been designed specifically for dredger applications.

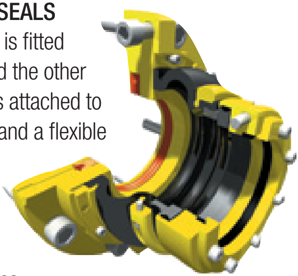


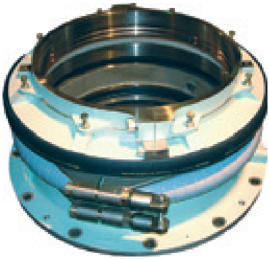
Airguard

WATER LUBRICATED SEAL SOLUTIONS

MANEGUARD & MANESEAL FACE TYPE SEALS

These seals consist of two assemblies. One is fitted to and rotates with the propeller or shaft and the other is stationary. The stationary main seal unit is attached to the sterntube by means of a mounting ring and a flexible bellows assembly. This allows the seal to accept normal ship and machinery movements whilst ensuring sustained and uniform face contact between the sealing elements. The design of these seals facilitates complete inspection of the seal face without the need to disturb either the propeller or the shaft.


Maneguard FSE/PSE.


Maneseal.

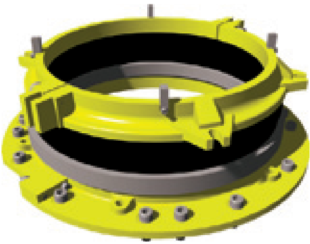
SPECIALISED APPLICATIONS

BULKHEAD SEALS

Manesafe bulkhead seals ensure the integrity of watertight bulkheads that are penetrated by any rotating shaft. The seal is bi-directional and can be fitted on whichever side of the bulkhead is more convenient.

RUDDERSTOCK SEALS

These seals are available in both axial and radial solutions, in both cases they are derived from either Manebar or Sternguard (MKII) seals.


ER type manebar seal.


ND type bulkhead seal.

OIL LUBRICATED SEAL SOLUTIONS

WORKSAFE FACE TYPE SEAL

The Worksafe outboard face seal incorporates very hard wearing mating surfaces, corrosion resistant metal components and rubber bellows with a flexible design. The excellent design and use of high quality materials ensure improved performance and extended service life. Further security can be offered with the optional rope/net protection device.

STERNGUARD LIP TYPE SEAL

The Sternguard range of seals comprises the MKII, MKIIM and 4BL Seals. The MKII and MKIIM seals are made up of three lip seals, manufactured from either NBR or Viton to offer high resistance to wear and attack by either seawater or oil. The 4BL type seal has an extra oil lip in the seal that is a standby lip offering redundency to the seal and if any leakage of oil to the sea occurs, this standby by lip seal can be activated to overcome the leakage.

Sternguard MKII (M).

Seal 4BL.

WÄRTSILÄ BEARINGS

OIL LUBRICATED BEARINGS

WORKSAFE & STERNSAFE

Wärtsilä supplies ready-to-fit bearing systems that utilise lightweight composite materials and come with the most technologically advanced bearing surface available on the market. The bearings have high stability and a very low degree of swell.

STERNTUBE BEARING

The white metal lined sterntube bearings are designed for trouble-free service throughout the lifetime of the vessel

WATER LUBRICATED BEARINGS

MANEGUARD & ECOSAFE

These bearings are composite non-polluting bearing systems designed for water-lubricated sterntubes for all vessel types and are suited to abrasive laden water conditions. A water lubrication system ensures that there will be no negative impact on the environment.

Composite bearings.

WÄRTSILÄ STERNTUBES

Wärtsilä's supplies sterntubes suitable for all sizes and types of vessel, both water & oil lubricated.

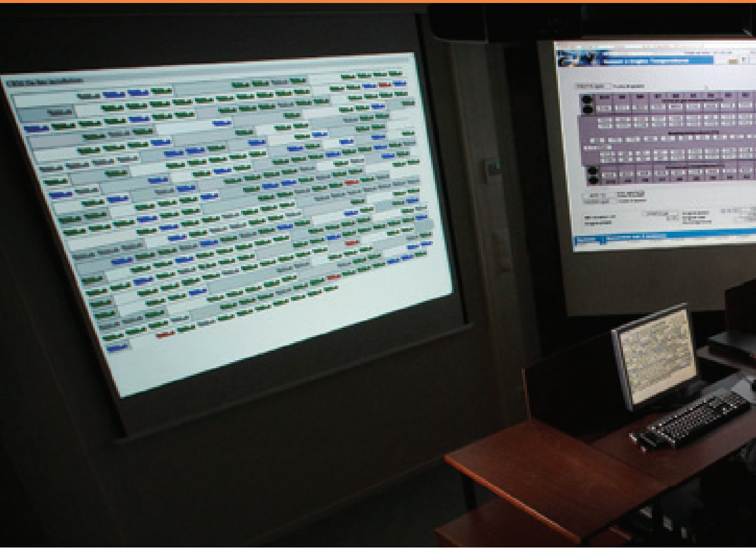
Sterntubes

SELF-ALIGNING TYPE LINE SHAFT BEARING

Spherical seated line shaft bearings closely follow the dynamic change in the shaft alignment and at the same time provide better weight distribution across each bearing surface.

STEERSAFE RUDDER BEARING

Steersafe is a bearing system designed for rudders and steering gear for all types of vessels; it is suited to water lubrication or to dry operation.



SERVICES

Several customers have recognized us as their preferred service supplier to ensure the availability and cost-efficient operation of their installations. They benefit from having their entire power system fully serviced by one global supplier. Wärtsilä Services provides full service throughout the product lifecycle for both marine and power plant customers, and is constantly developing our network worldwide.

Additionally we are continually broadening our range of services by adding valuable products and specialist services to our portfolio. In this way we also support equipment on board of your vessel or at your installation and in our numerous workshops around the globe and in key ports, regardless of your equipment make.

We offer lifecycle efficiency solutions in the following services:

- Engine Services
- Propulsion Services
- Electrical & Automation Services
- Boiler Services
- Operations & Management
- Training Services
- Environmental Services

These services cover everything from basic support with parts, field service and technical support to service agreements and condition based maintenance; from installation and commissioning, performance optimization, including upgrades and conversions, to environmental solutions, technical information and online support.

The choice available to you extends from parts and maintenance services to a variety of comprehensive, customized long-term service agreements, including performance and operations & management agreements. Our Services organization currently features more than 11,000 dedicated professionals in 70 countries.

Wärtsilä adds value to your business at every stage in the lifecycle of your installations. With us as your service partner, you receive many measurable benefits such as availability and performance, productivity gains and cost benefits. Above all, peace of mind in the knowledge that your installation is being serviced by the most experienced partner you could have – Wärtsilä.

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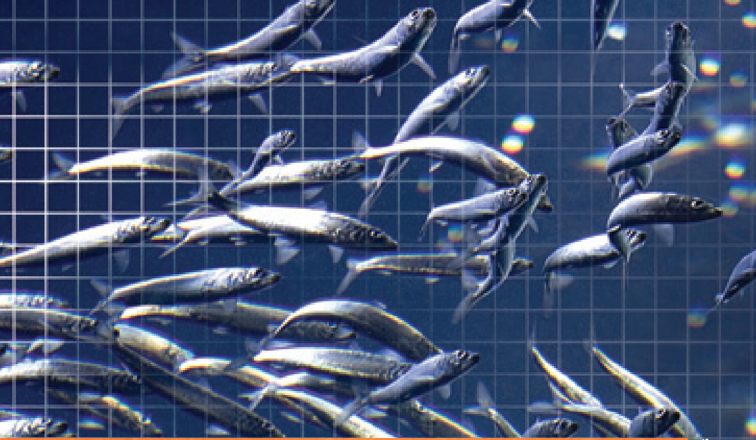

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Appendix IV

Fig. 1 - New container vessel design with dual-fuel auxiliary engines running on LNG.

LNG auxiliary power in port for container vessels

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Large ships running their auxiliary engines whilst in port create local emissions that are increasingly creating problems. One alternative is to connect to shore power; another is to switch to clean LNG fuel when near shore.

The basic idea of the alternative fuel concept is to use dual-fuel (DF) auxiliary engines and run them on heavy fuel oil (HFO) at sea, and switch the electric power production to LNG (liquefied natural gas) operation when approaching the coastline. With this solution the local emissions of NO_X and SO_X can be reduced to the same or lower level as when using a shore power connection. The new solution can also be economically more attractive than shore power.

Shore power

Shore power, or “cold ironing”, simply means connecting the ships electric network to the shore grid. This procedure will of course reduce the exhaust emissions locally around the ship, however, it does not necessarily mean that the emissions go down on a global scale as the power still needs to be generated somewhere.

Shipowners in general are not happy with the idea of shore connections for a variety of reasons, including the following:

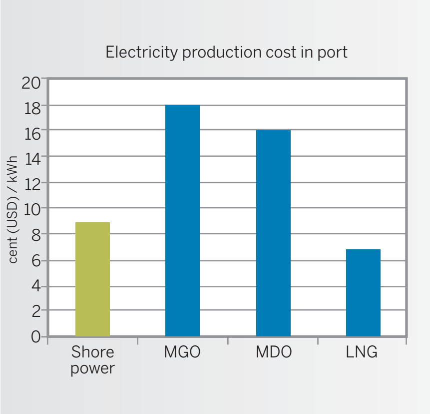
- The electric power can be expensive compared to producing power using the ships own generating sets.
- Investment costs are needed for ship installations to facilitate a shore connection.
- Port investments.
- The solution is not globally available in all ports.
- Voltages and frequencies are not standardized.
- Connectors are not standardized for high voltages.
- Local power distribution network limitations.
- Risk of power loss during changeover.
- Risk of spikes in the electric network during switch-over. These can damage sensitive equipment onboard.

Alternatives to shore power

Basically there are three ways to cut emissions while continuing the use of auxiliary engines in port:

- Continue running on heavy fuel oil and clean the exhaust gas with additional systems
- switch to distillate fuels like marine gas oil
- apply DF-engines and run on natural gas.

All three alternatives are technically possible with today's technology. In the first option, the SO_X emissions can be cleaned with exhaust gas scrubbers, which are installed in the exhaust line. Scrubbers will also give a reduction in particle emissions. The benefit of this system is that the exhaust can be cleaned during ocean crossings as well. Switching to distillate fuels is the easiest solution since it does not require additional equipment. However, the operating costs will be the highest of the alternatives. It should also be noted that the use of scrubbers and distillate fuels give mainly a reduction in SO_X emissions only, with no actual reduction in the NO_X count. Lower NO_X emissions might also be required in port in the future, which means that SCR units will have to be installed as well. Furthermore, some port authorities might require particle emissions to be reduced more than that achieved using scrubbers or distillate fuels.



- Fig. 2 – Typical electricity production costs for a ship. Shore power price is estimated.

Dual-fuel auxiliary engines

The best alternative to shore power would be to reduce ships' generating set emissions to the same level as those of shore power. This can be achieved by using dual-fuel generating sets that can run on gas whilst in port and coastal areas, whereby the emissions are significantly reduced. When the ship is out at sea, and where the need for clean exhaust is not as apparent, the same engines can switch to diesel (HFO) or marine diesel oil (MDO) operation. This allows for extended range operation, including ocean crossings, without a need for large onboard LNG storage tanks.

To illustrate the principle, a machinery concept using dual-fuel auxiliary engines has been designed for a large container vessel. The emissions and costs have been calculated for a typical route across the Pacific Ocean.

7300 TEU container vessel with dual-fuel auxiliary engines

The design of an efficient container vessel, the Resolute 7300 by the former SCHIFFKO (today Wärtsilä Ship Design Germany GmbH), has been converted to feature gas burning auxiliary engines. The ship particulars are given below:

- Length overall 322 m
- Breadth 40 m
- Draught 14 m
- Deadweight 84,500 ton
- Main engine Wärtsilä 11RT-flex96C
- Propulsion power 62,920 kW
- Speed (trial) 25.5 kn
- Cargo capacity 7300 TEU
- Reefer plugs 1300 FEU

The ship has a relatively high number of reefer plugs, which means that the electric power demand, around 8 MW in port and up to 12 MW when manoeuvring with the bow thruster engaged, is substantially high.

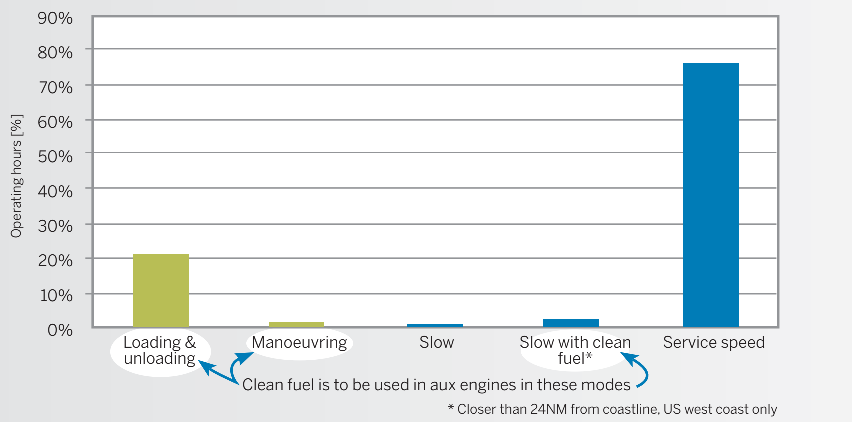
Machinery

The conventional Resolute 7300 Container vessel has a machinery configuration consisting of one Wärtsilä 11RT-flex96C main engine and four Wärtsilä 32 auxiliary generating sets. The installed main engine power is 62,920 kW and the →

- Fig. 3 - 7300 TEU container vessel.

■ Fig. 4 – The operating route used for the comparison:
Los Angeles – Oakland – Dalian – Busan – Nagoya – Yokohama – Los Angeles.

■ Fig. 5 – The 24 nautical mile "Clean fuel" zone along the US west coast (max. sulphur content 0.5%, after 2010: 0.1%).



■ Fig. 6 – The operating profile. The modes in which clean fuel is used are circled.

auxiliary power is 14,400 kW.

In the new design based on running on LNG whilst in port, the normal diesel generating sets are replaced by dual-fuel engines. Four Wärtsilä 9L34DF engines give a combined power of 15,040 kW. These engines can operate on HFO, MDO or LNG.

Machinery evaluation

The new concept has been evaluated for a typical route transiting the Pacific Ocean as shown in Figure 4. The corresponding operating profile is given in Figure 6. The fuel consumption has been calculated based on the assumption that the ship is using LNG for the auxiliary power when operating inside the 24 nautical zone of the US coastline. Otherwise, the vessel is running on HFO. This gives an LNG consumption of 110 tons per trip, equalling approximately 250 m^3 of LNG. If the ship were to use LNG in all ports throughout the voyage, then the consumption would be 240 tons or about 530 m^3.

LNG storage

The LNG can be stored in different ways. The basic alternative would be to use one or more fixed LNG tanks inside the hull. An example with two tanks of 190 m^3 each is shown in Figure 7. An alternative approach would be to use containerized LNG tanks for storing the fuel. The ship could then be bunkered by lifting the tanks onboard with container cranes. Since a 40 ft LNG container can have a capacity of 31.5 m^3, it means that 8 containers would be needed to facilitate the LNG used along the US West Coast. These tanks could be stored in a special hold inside the vessel, or more ideally, outdoors on deck as seen in Figure 8.

Operating and investment costs

The operating costs of the auxiliary engines have been calculated according to the profile and the result is shown in Figure 9. The DF engines running on LNG give an annual reduction of 1.5 MEUR in fuel costs compared to the diesel (MGO) alternative. The shore power alternative has, of course, the lowest fuel costs as the engines are not being used in port. However, this alternative will have to pay a large sum for the electricity used instead. The assumed fuel prices used in the comparison are shown in Table 1.

	USD/ton	EUR/ton	USD/MBtu
LSHFO	580	370	15.1
MDO	1100	705	27.2
MGO	1200	770	29.6
LNG	513	330	11.0

Table 1 – Estimated fuel prices used in the comparison. The assumed exchange rate is 1 EUR=1.56 USD.

The investment cost varies between the alternatives. The DF-concept investment cost includes the DF-engines with related equipment and gas tanks, plus fuel bunkering and the feed system. With fixed tanks, the difference between this and the "standard" diesel solution will be about 3.5 MEUR. For the shore power connection, an estimated 1 MEUR is added for the connection/cabling and the switchboard/control system. One should note that the land side part of the shore power connection is not included as it depends a lot on the port in question. No additional exhaust cleaning device is included for the diesel option either. The prices of the main equipment related to auxiliary power production are shown in Figure 10.

The total annual costs for the auxiliary power production are shown in Figure 11. The capital cost is divided to annuity for a 15-year period at an interest rate of 8%. It can be seen that the DF option offers the most competitive solution of the three alternatives. When comparing DF to the diesel alternative, the payback time for the concept without interest will be approximately 3 years only. For the shore power alternative, an electricity price of 0.11 USD/kWh is assumed.

Emissions

The emissions of the three alternatives have been calculated for the operating modes close to shore, and are shown in Figure 12. It can be seen that the DF engine and the shore power offer clear reductions in local emissions. When looking at the total emission levels, including the shore based power plant, the DF machinery offers the lowest emission levels of CO_2, NO_X and SO_X. →

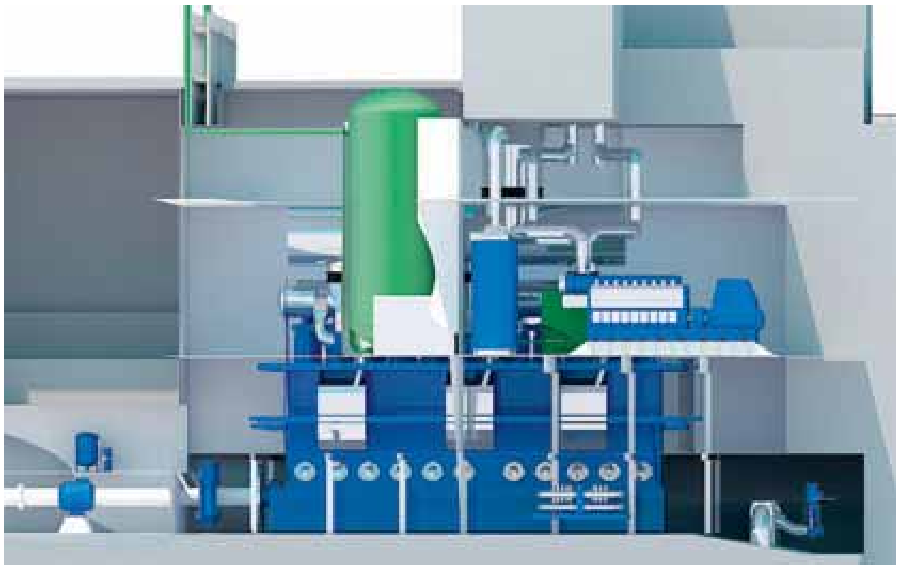


Fig. 7 – Machinery space with fixed LNG storage tank.

Fig. 8 – Containerized LNG storage tanks located outdoors on top of the deckhouse.

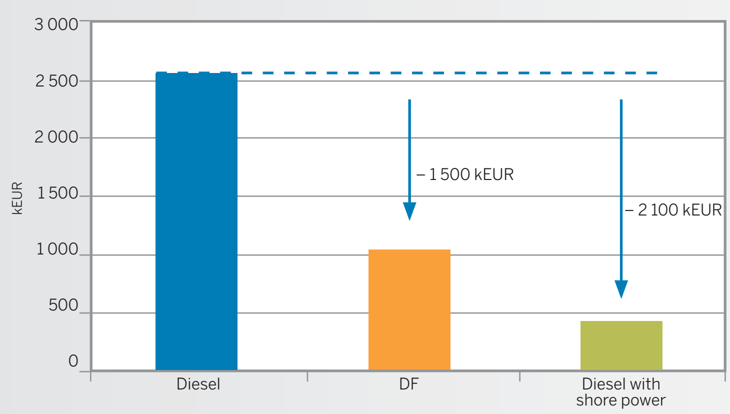


Fig. 9 – Annual fuel costs of auxiliary engines in selected modes. Shore power electricity cost not included.

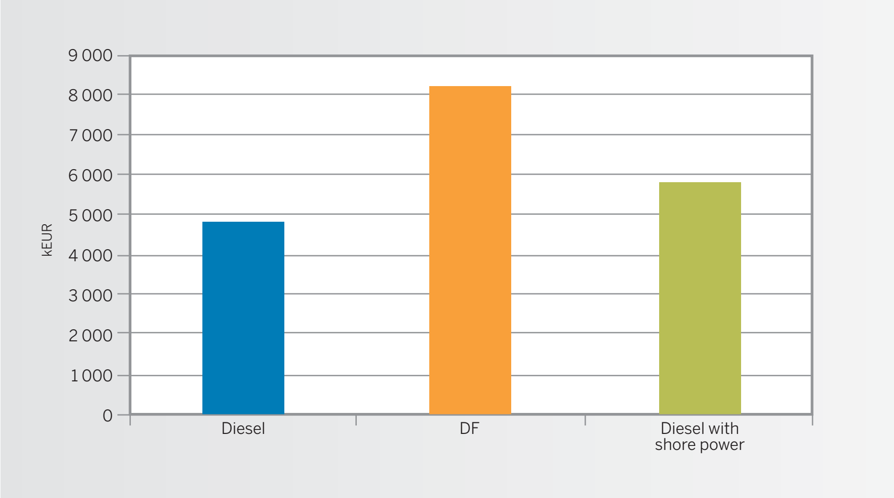
[MARINE / IN DETAIL]

It can of course be discussed how the shore based electric power is produced. However, one can safely assume that when a ship connects to the power grid and power consumption is increased, it will not be renewable energy power plants that are started up. All available renewable energy production will of course be in use already, and the extra power is covered by power stations burning fossil fuels. The emissions for the power plant in Figure 12 are calculated assuming a natural gas driven gas turbine, and a single cycle peak load power plant.

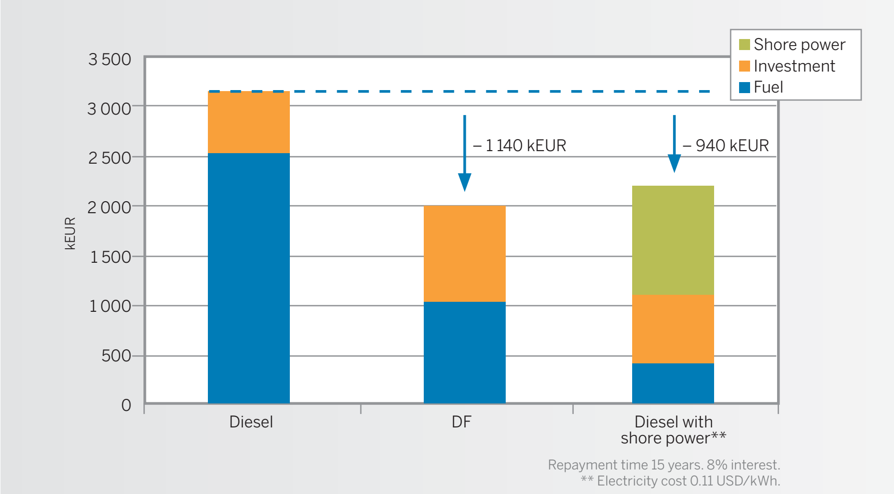
Even when looking at local emissions in port and assuming a zero contribution from the shore based power, the DF engines offer similar or lower levels of NO_X or SO_X compared to the shore power option. This might seem odd, but the reason for it is that the shore power is not connected while the ship is sailing close to shore, during manoeuvring, or during the beginning and end of berthing. During these modes the shore power concept is burning diesel, while the DF machinery is running on clean LNG.

CONCLUSION

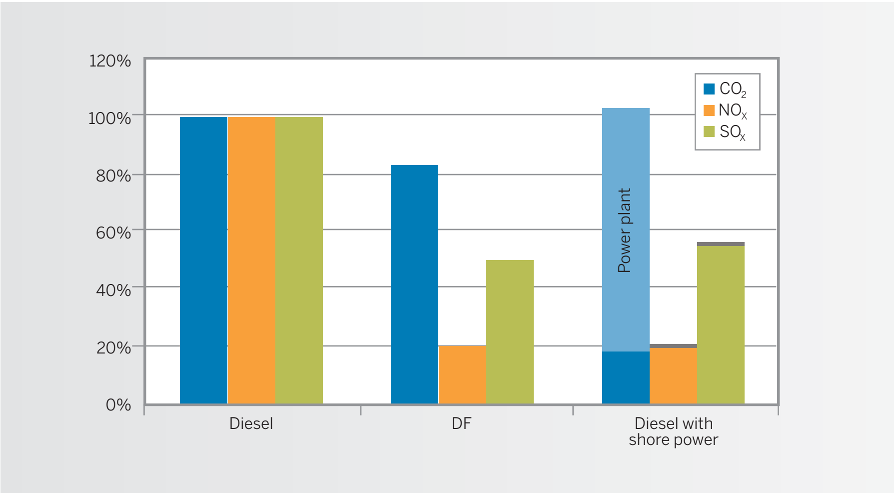
LNG offers a very attractive means for reducing the total, and especially the local, environmental impact of ships. This novel auxiliary power concept can drastically reduce the exhaust emissions in port areas, which is a matter of great interest and concern today. The concept also seems to be economically and environmentally competitive compared to the rather controversial shore power alternative, and offers huge fuel cost savings compared to distillate fuel operation. Furthermore, with the exception of LNG bunkering, the system is not dependent on port facilities, so low-emission gas operation can be used in all ports at which the ship calls.



■ **Fig. 10 – Estimated investment costs of auxiliary engines and related equipment (engines, generators, LNG system and tanks, shore power connection).**



■ **Fig. 11 – Estimated annual costs for the auxiliary power and related equipment (engines, generators, LNG system and tanks, shore power connection).**



■ **Fig. 12 – Calculated emissions in selected operating modes (close to shore).**

INCREASING ENVIRONMENTAL CONCERN

Ship propulsion development is today mainly driven by two challenges: to reduce the environmental impact from shipping, and to keep fuel costs reasonable in a world of sky rocketing oil prices. These two targets sometimes go hand in hand when striving to make ships more efficient.

Society is becoming ever more aware of climate change, and pressure on the maritime industry to contribute to the effort to reduce emissions is building. There are both new international regulations as well as local requirements setting stricter exhaust emission standards. The IMO is in the process of tightening the limits on NO_x and SO_x emissions from ships. In addition, there are national and even more local regulations stipulating stricter limits on exhaust gases. However, most of these rules target NO_x and SO_x emissions while society is more focused on greenhouse emissions. This means that we can soon expect more attention being given to the CO_2 emissions from ships. In addition, there is also an increasing awareness of the relationship between particle emissions and health-related issues. This has resulted in increased focus on emissions from coastal shipping and port operations. Ports are often located close to densely populated areas, so the emissions from ships whilst in port are coming under increasing scrutiny.

LNG AS A MARINE FUEL

Switching from diesel to natural gas (NG) will significantly reduce all important exhaust gas emissions from a ship, including a 25% reduction in CO_2 emissions. The main reason for this reduction is the fact that the main component of natural gas (NG) is methane (CH_4), which in turn is the most efficient hydrocarbon when measuring energy content against carbon content. The molecular structure of natural gas has the highest number of bonds to hydrogen of all the hydrocarbons. Essentially this results in the lowest emissions of carbon during energy release.

Except for the primary component, methane, natural gas can have minor concentrations of heavier hydrocarbons like ethane and propane. Natural gas is colourless, odourless, non-toxic, and lighter than air. In normal ambient conditions natural gas is in gas form, but can be liquefied by cooling it down to -162 °C at atmospheric pressure. In liquid form, the specific volume is reduced about 600 times compared to the gaseous state. This allows for storage tanks to be of a reasonable size relative to the energy content.

In dual-fuel engines, the natural gas burns with low emissions of NO_x due to the lean burn concept. Sulphur emissions are negligible, as the sulphur is removed from the fuel during the liquefaction process of LNG. Additionally, very low particle emissions, with no visible smoke or sludge deposits make this fuel an appealing choice for built up areas such as ports. LNG can also have a highly competitive market price, which also makes this fuel a very interesting choice for ships.

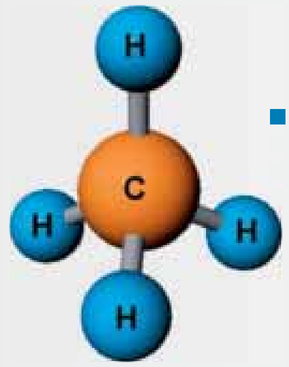


Fig. 13 – Methane molecule with four hydrogen atoms for each carbon atom.

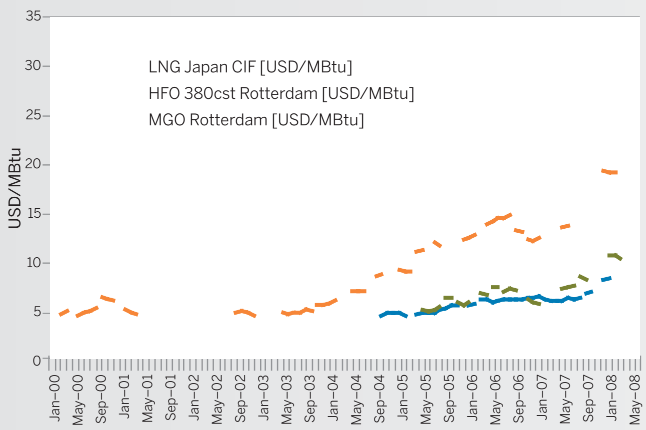


Fig. 14 – Market prices for LNG, HFO and MGO.

STORAGE OF GAS

The most feasible way to store NG in ships is in liquid form. In existing ship installations (other than LNG-carriers) LNG is stored in cylindrical, double-walled, insulated stainless steel tanks. The tank pressure is defined by the requirement of the engines burning the gas and is typically less than 5 bar. A higher (typically 10 bar) tank design pressure is selected due to the natural boil-off phenomenon. This means that the heat flow through the tank insulation boils the LNG, which increases the pressure in the tank. In the case of long lay-up periods (>2 weeks), the gas must be released or burned. However, most ships will not go this long without any need for power, or gas consumption, so this will never occur in normal operation.

The main problem with using LNG in ships is the relatively large amount of space required for the LNG tanks. Compared to marine diesel oil (MDO), an equal energy content of LNG requires about 1.8 times more volume. When adding the tank insulation and bearing in mind the maximum filling ratio of 95%, the required volume is increased to about 2.3 times. The practical space required in the ship becomes about 4 times higher when also taking into account the squared space around the cylindrical LNG tank. This comparison does not take into account the fact that nowadays diesel tanks are not located in the double bottom anymore, (the space next to the shell plating), so there will be some space lost around/on top of the diesel tanks as well.