NATURAL GAS USE FOR ON-SEA TRANSPORT

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Abstract

Norway has some obligations to reduce emission of pollution gases. And NOx emissions are increasing every year from transport sector and industry. NOx emission just from coastal traffic and fishing reached in 2002 the amount of 80,000 tonnes which is almost 37 % of total emission in Norway. Three ships in Norway are powered by natural gas. This thesis discusses the possibility of converting eleven Norwegian Coastal Voyage ships and two Coastal Express boats in order to reduce emission to comply with current regulations and obligations. This thesis provides an overview of the potential of converting ships and boats to natural gas in Norway. Calculations for the eleven ships and two boats show that reduction of nitrogen oxides will be about 9,500 tonnes per year which represents 4.5 % of the total NOx emission in Norway. That result is significant for the purpose of this thesis.

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Abbreviations

BSFC	- Break Specific Fuel Consumption
CNG	- Compressed Natural Gas
CO	- Carbon Monoxide
DF	- Dual Fuel
GCV	- Gross Calorific Value
HC	- Hydrocarbon
HFO	- Heavy Fuel Oil
IMO	- International Maritime Organization
LNG	- Liquefied Natural Gas
MDO	- Marine Diesel Oil
NSC	- Norwegian Continental Shelf
NG	- Natural Gas
NGL	- Natural Gas Liquids
NMD	- Norwegian Maritime Directorate
NMVOCs	- Non-Methane Volatile Organic Compounds
NO_x	- Nitrogen Oxides
NPD	- Norwegian Petroleum Directorate
o.e.	- Oil Equivalents
OVDS	- Ofotens og Vesteraalens Dampskibsselskab
PM	- Particulate Matter
RPM	- Revolutions Per Minute
SO_x	- Sulfur Oxides
TFDS	- Troms Fylkes Dampskibsselskap
VOCs	- Volatile Organic Compounds

1. Introduction

Increasing environmental requirements and restrictions force ship owners to consider new possibilities in vessel propulsion. Using natural gas as a main fuel for engines in marine industry is not a new idea but the new advances in gas engine technology have made natural gas more attractive than earlier. The potential of marine industry for using gas as a main fuel is no longer limited owning to the lack of infrastructure or regulation concerning gas-fuelled engine installations in ships but now cover an increasing variety of applications.

There are several environmental documents concerning reduction of nitrogen oxides emission. One of them is the MARPOL Convention which sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances. Another one is the Gothenburg protocol signed in 1999 and it is regarding four pollutant gases emissions in Norway. This thesis will contain calculations about environmental benefit of conversion Norwegian Coastal Voyages ships and Coastal Express boats to use natural gas as a main fuel.

Natural gas as fuel is well established in the urban transport and power generation sectors and that technology will transfer to the marine industry via availability of engines, systems and technical assistance. There are already several vessels operating on natural gas and three of them are Norwegian: ferry “Glutra” and supply/cargo vessels “Viking Energy” and “Stril Pioner”.

Passengers, cars and trucks are often transported over short distances by sea in environmentally sensitive areas and trips are frequent. For this reason many ferry fleet owners, and also local authorities should consider conversion to natural gas in order to reduce emission. The conversion to natural gas of Norwegian Coastal Voyage ships and Coastal Express boats might be a first step before gas becomes a main fuel at global scale.

2. Natural Gas in Norway

2.1 Natural Gas

Natural gas is a combustible mixture of hydrocarbon gases. While it is formed primarily of methane, it can also include ethane, propane, butane and pentane. The **Tables with typical composition of natural gas in Norway** are showed in the **Appendix A.** Natural gas is the cleanest of all fossil fuels and is the same gas as used in the home for cooking and heating. As an internal combustion engine fuel it produces the lowest level of carbon dioxide of all hydrocarbon fuels and is virtually free of sooty particles (particulates), lead and aromatic hydrocarbons like benzene.

2.2 Norwegian Resources of Natural Gas

The Norwegian Petroleum Directorate's resource account gives a survey of the recoverable petroleum resources on the Norwegian continental shelf. It covers quantities that have been sold and delivered, discovered remaining recoverable petroleum resources, and undiscovered resources which are assumed to be recoverable. The total petroleum resources are the sum of discovered and undiscovered recoverable resources, and include volumes that have already been produced. The resources split as 6.1 billion Sm^3 o.e. oil, 6.0 billion Sm^3 o.e. gas, 0.4 billion Sm^3 o.e. NGL and 0.3 billion Sm^3 o.e. condensate. The remaining recoverable resources are calculated to be 9.2 billion Sm^3 o.e. Total recoverable petroleum resources on the Norwegian continental shelf per 31 December 2002 are showed in Appendix A [1].

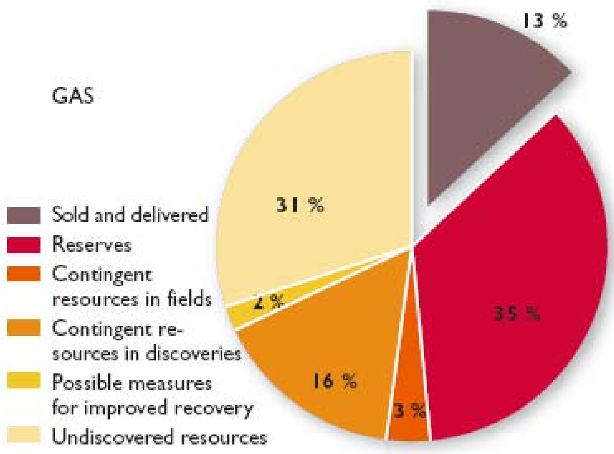

Figure 2.1 - Distribution of the recoverable gas resources, 6.0 billion Sm^3 o.e. [1].

The breakdown of the recoverable gas resources shows that more than about 13 per cent, of the total volume of the gas resources has been produced and 35 per cent fall into approved projects. Estimated undiscovered resources account for 31 per cent (Figure 2.1). So far, 796 billion Sm^3 of gas have been sold and delivered from the Norwegian shelf. By 31 December 2002, 25 per cent of the recoverable resources of gas had been sold and delivered (Figure 2.2) [1].

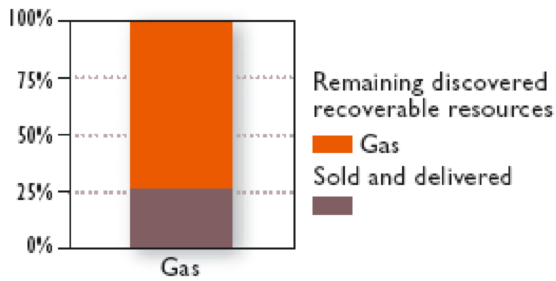

Figure 2.2 - Sold and remaining volumes of gas [1].

2.3 Forecasts

Forecasts have been made for how the resources are expected to be recovered, for costs and for discharges and emissions to the environment. These are based on data from the operators and evaluations on the part of the authorities. Production is continuing to rise and is expected to peak in 2006 at about 275 million Sm^3 o.e. Figure 2.3 shows h**istorical production and forecasts for the total production on the Norwegian continental shelf** [1].

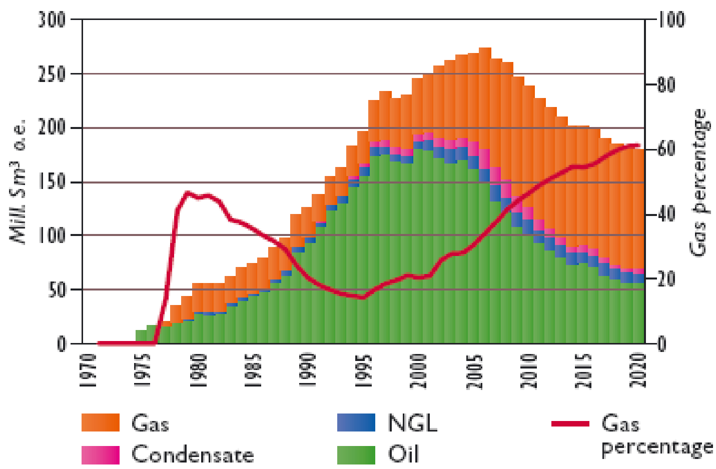

Figure 2.3 - Historical production and forecasts for the total production on the Norwegian continental shelf [1].

According to the forecast, the gas market will rise from the current level of gas sales, approximately 65 billion Sm^3 of gas a year, to 110 billion Sm^3 in 2010. The proportion of gas in the total production will rise to 50 per cent in 2012 or 2013 (Figure 2.4) [1].

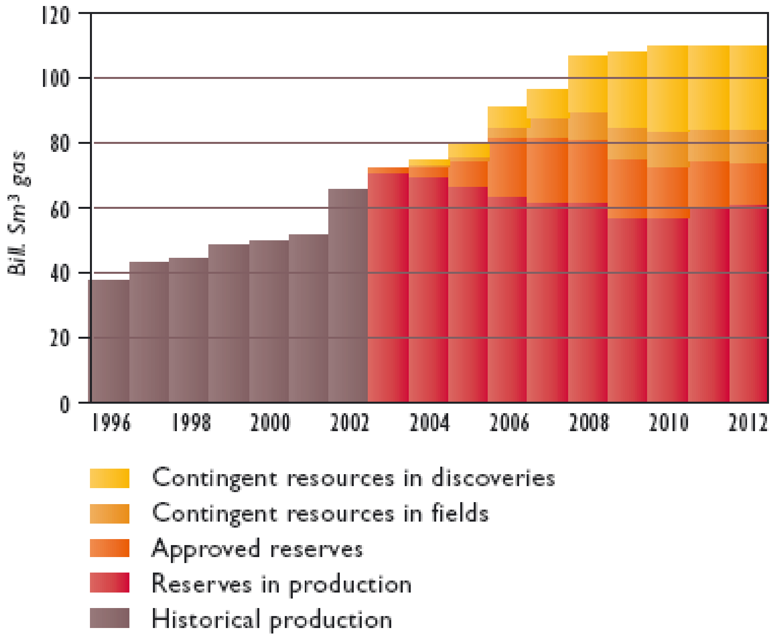

Figure 2.4 - Historical gas production from 1996 and forecast 2012 [1].

2.4 Norwegian Gas Sales

Europe is the main market for Norwegian gas. Today, Norwegian gas sales amount to 14 percent of the European gas consumption. Most of the gas from the NCS is sold on long term contracts. However, it is expected that this share will decline as the gas markets in Europe continue to open up for competition and the short term markets for gas evolve further. Due to the proximity to the European markets, gas field developments in Norway have been based on pipeline transportation. This has been the most cost-efficient way of bringing gas from the NCS to Europe, also for gas from the Norwegian Sea located relatively far from the European end users. The newest pipeline to be developed, Langeled, from the Ormen Lange development to the east coast of the UK, has a total pipeline length of approximately 745 miles (1,200 km). This will be the world's longest subsea gas pipeline [2].

New estimates show that Great Britain will become the biggest and most important customer for Norwegian natural gas in the near future. The planned gas export volume to the UK amounts to about 20 per cent of Norway's gas exports and 20 per cent of UK gas market demand [3].

3. Environmental Regulations

3.1 Environmental Regulations for Marine Industry

In 1997, the International Maritime Organization (IMO) adopted the new Annex VI (Prevention of Air Pollution from Ships) to the MARPOL Convention concerning harmful emissions of nitrogen oxides, NOx, and oxides of sulphur, SOx, from shipboard machinery to air. The regulations in this annex, set limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibit deliberate emissions of ozone depleting substances. Thus, since January 1, 2000, all incinerators and diesel engines over 130 kW (174 hp) fitted on ships and offshore installations had to comply with the new emission controls. Figure 3.1 shows relation between limit of NO_X emission and engine rated crankshaft speed [4].

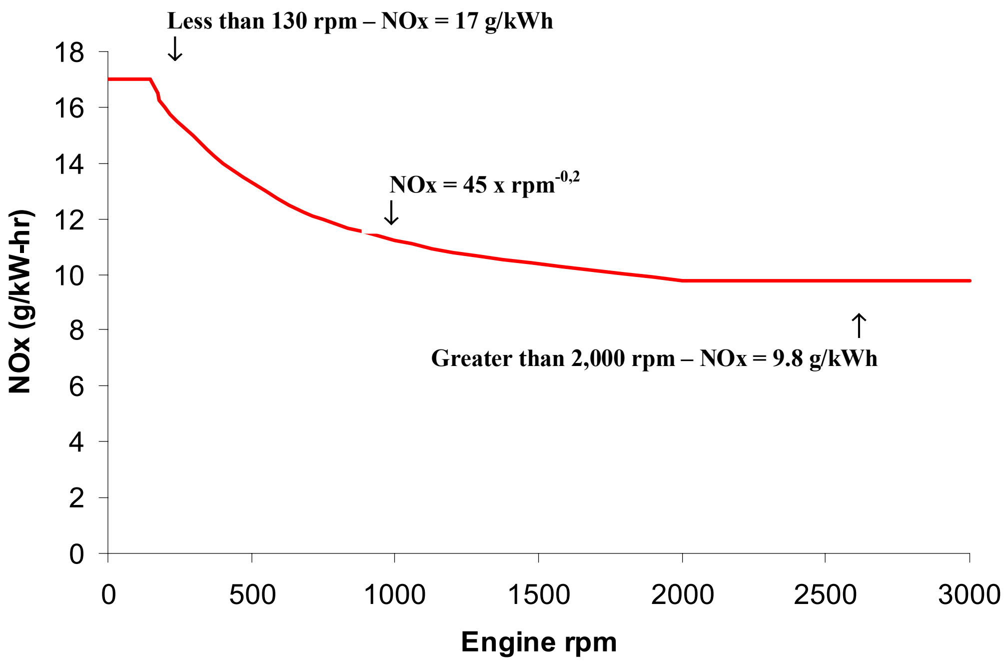

Figure 3.1 - IMO NOx emission standard – MARPOL Annex VI [5].

These requirements in few years time will impose wider and tighter controls and regulations on marine exhaust emissions. At the moment requirements are mainly directed to NOx and SOx restriction but there will be increasing pressure on marine propulsion regarding reduction of carbon monoxide (CO), hydrocarbons (HC) and particulates (PM) or smoke. Natural gas if compared with diesel fuel produces significantly lower emission than the IMO's Annex VI requirements.

Due to the proprieties of natural gas (it is lighter than air and any leaks will not accumulate in the bulges) it is the only gas accepted for use in machinery spaces. More information about MARPOL 73/78 Annex VI is accounted for in the Appendix B.

3.2 Environmental Regulations for Norway

In December 1999 Norway signed the Gothenburg protocol regarding pollutant gases emissions. Norway is to reduce emissions of four pollutant gases from current emission levels by 2010: sulphur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3) and non-methane volatile organic compounds (NMVOCs). The most cost-effective measures are in the shipping, offshore, industrial and agricultural sectors [6].

Table 3.1 - National commitments of Norway under the Gothenburg protocol. Emissions in tonnes SO_2, NOx, NH_3 or NMVOCs [7].

	Emissions in base year 1990	**Commitments under the Gothenburg protocol (2010)**	**Percentage reduction by 2010 in relation to 1990**
SO_2	53,000	22,000	58 %
NO_X	219,000	156,000	29 %
NH_3	23,000	23,000	0 %
NMVOC	300,000	195,000	35 %

According to Statistics Norway, emissions in 2003 of nitrogen oxides increased by 3 per cent compared to 2002 (Figure 3.2). Particularly emissions from sea transport, oil and gas extraction and heating were increasing. The growth took place in spite of Norway's obligation to reduce emissions considerably; according to the Gothenburg protocol emissions in 2010 should be reduced by 29 per cent from the present level. In 2003, 220,000 tonnes NO_X were emitted in Norway which is almost 7,000 tonnes more then in 2002. The source distribution of emissions in 2003 is uncertain, thus necessitating a reference to 2002 figures however the growth reminds that something needs to be done in Norway [8].

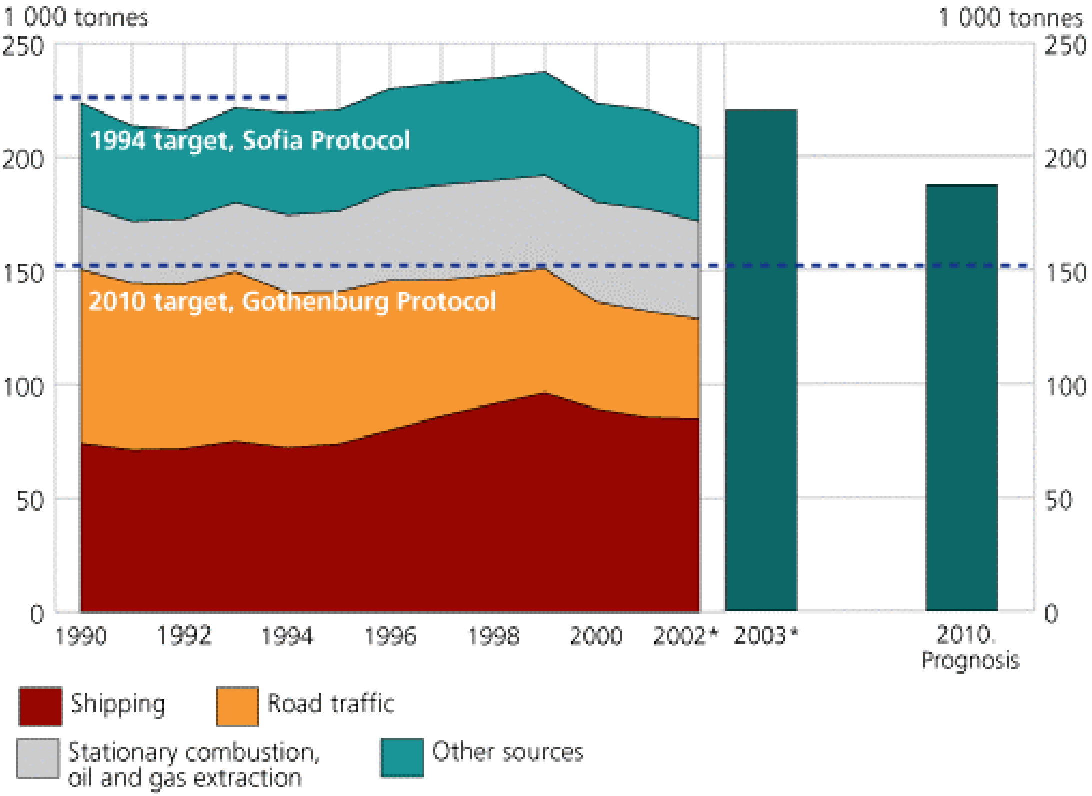

Figure 3.2 - Emissions of NOx by source, 1990-2003 [8].

Natural gas as a fuel for ships is one of the ways to keep to the signed agreements. Transport produces 66 per cent (141,500 tonnes) of Norwegian NOx and conversions in this sector are the most reasonable (which shows Figure 3.3 and Appendix C). Figure 3.3 shows also that NOx emission is mainly form the shipping industry. One of the ways to reduce NOx emission below the settled limit is to convert that sector to use natural gas. Six years seems to be not sufficient for marine industry to make big changes however if new built ships used a natural gas and conversion were also supported by industry and other transport, Norway would have great chances. More information with exact numbers of emissions to air by sources in Norway is showed in the Appendix C.

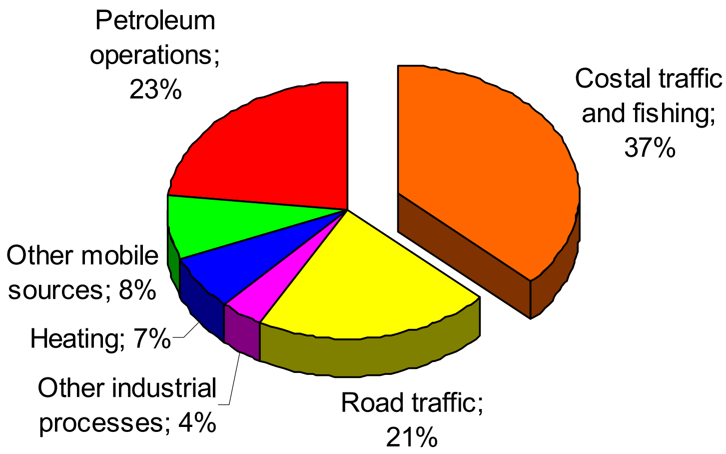

Figure 3.3 - Sources of Norwegian NO_x emissions, 2002 [9].

The Protocol sets emission ceilings for 2010 for four pollutants: sulphur, NOx, VOCs and ammonia. These ceilings were negotiated on the basis of scientific assessments of pollution effects and abatement options. Parties whose emissions have a more severe environmental or health impact and whose emissions are relatively cheap to reduce will have to make the biggest cuts. Once the Protocol is fully implemented, Europe's sulphur emissions should be cut by at least 63 %, its NOx emissions by 41 %, its VOC emissions by 40 % and its ammonia emissions by 17 % compared to 1990 [8]. There is more information regarding Gothenburg protocol in the Appendix D.

4. Benefits of Natural Gas as a Fuel

4.1 Safety Aspects of Natural Gas

Natural Gas is not explosive when it is in liquid state. When LNG is heated and becomes a gas, the gas is not explosive if it is unconfined. It is inherently less volatile than petrol or diesel. It is also lighter than air and in the event of a leakage and it will disperse upwards to the atmosphere rather than forming dangerous pools in confined depressions. The flammability of natural gas is only possible within a tight mixture range. If the natural gas content in air is less than 5 % the mixture is over-rich to burn and if it is higher than 15 % it is too lean (Figure 4.1) [4].

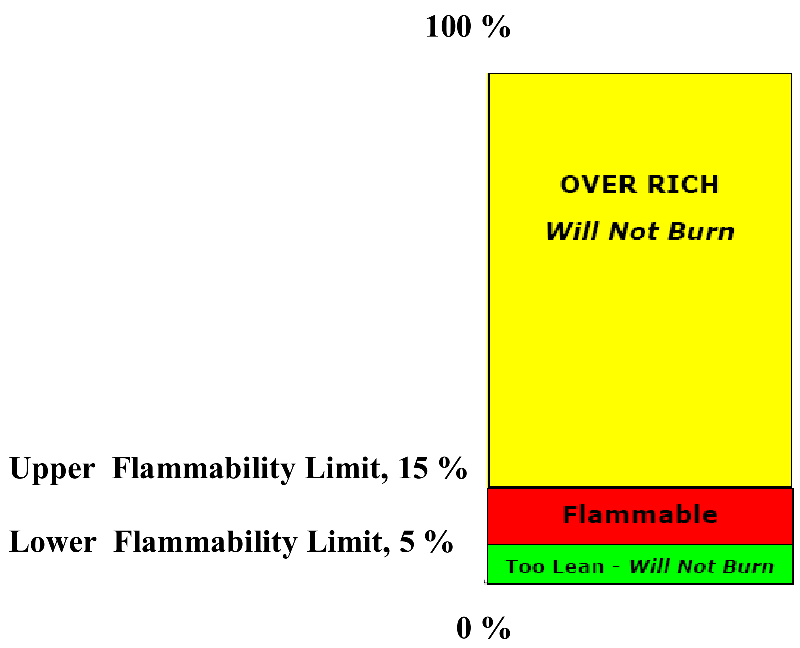

Figure 4.1 - Flammable range for natural gas [4].

When fuel concentration exceeds its upper flammability limit, it cannot burn because too little oxygen is present. When fuel concentration is below the lower flammability limit, it cannot burn because too little methane is present. Small spills of **Liquefied Natural Gas** present little fire risk. Evaporating LNG warms and floats away, in contrast to other liquid fuel vapors, which linger near the ground. LNG does not adhere to surfaces as diesel does. Therefore, a fire involving an LNG spill does not mean a fire on anything the LNG contacted [4].

Natural gas cannot detonate in unconfined spaces and its ignition temperature is higher than gasoline or diesel (a striking match will ignite it, but the coal of a cigarette will not). If ignition occurs, burning will take place only along the air/gas interface in which flammability requirements are met. In an unconfined space, pressure will not build, and flame speed will be relatively slow [4].

4.2 Environmental Benefits

The great benefit of the natural gas option is the clear reduction in CO_2 emissions, which cannot be achieved when burning oil-based fuels. Also the lack of sulphur in the natural gas fuel eliminates all SO_x emissions, while the clean burning properties of a lean-burn gas engine reduce the NO_x emissions to a fraction of those produced by conventional diesel engine (Figure 4.2) [11]

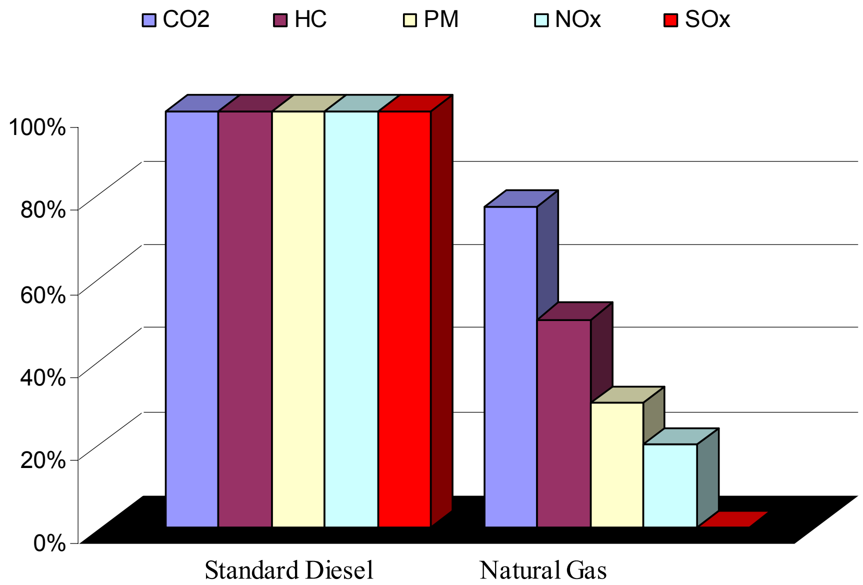

Figure 4.2 - Relative exhaust emission for entire machinery [11], [4].

The main environmental benefit of using natural gas instead of diesel fuel is a reduction of oxides of nitrogen (NOx) emission by approximately 80 %, particulate matter (PM) by 70 %, carbon dioxide CO_2 by 30 % and hydrocarbon by 50 %. Other environmental benefit of natural gas is elimination of potential soil and water contamination by spilled or leaking fuel.

5. Natural Gas Use in Ships

5.1 Natural Gas Use Today

Natural gas has been used as a marine fuel since the early 1980s. There is increasing worldwide demand for environmental consideration in all industries. The shipping industry is no exception and emissions regulations are getting stricter in many locations. The specifications are particularly tight in coastal and inland waters. Therefore, owners operating on short sea and inland routes have greater incentive to reduce emissions. The best way to reduce emissions is to generate the required propulsion power using natural gas. Hence the number of ferries and inland vessels with gas as bunkered fuel is expected to grow in the next few years. There is also evidence that in specific applications, natural gas may represent an economical alternative to diesel fuel [10]. There are already several vessels operating on natural gas which shows Table 5.1.

Table 5.1 - Some ships that use natural gas as a fuel [13].

Name	Location	Service	Fuel	Year
ACCOLADE II	Australia	Bulk Carrier	CNG dual fuel	1982
KLATAWA	Canada	Car/Passenger Ferry	CNG dual fuel	1985
KULLEET	Canada	Car/Passenger Ferry	CNG dual fuel	1988
VARIOUS	USA	Tourist Boats	CNG	1995
OSPREY	Canada	Car/Passenger Ferry	CNG dual fuel	2000
STRIL PIONER	Norway	Supply/Cargo Vessel	LNG dual fuel	2003
VIKING ENERGY	Norway	Supply/Cargo Vessel	LNG dual fuel	2003
GLUTRA	Norway	Car/Passenger Ferry	LNG dual fuel	2000

5.2 Comparison of CNG and LNG

Because of the gaseous nature of this fuel, it must be stored onboard a vessel in either a compressed gaseous state (CNG) or in a liquefied state (LNG). At the moment there are several vessels operate on compressed natural gas (Table 5.1). They use mainly dual fuel engines which need CNG and diesel fuel. Compressed Natural Gas (CNG) is natural gas pressurized up to 250 bar.

CNG consists mainly of methane with low percentages of other hydrocarbons like ethane, propane and butane. A **table with typical composition of Compressed Natural Gas is** accounted for in **Appendix A.** It has very low levels of pollution, does not materially restrict vessel performance and is more economical to use than diesel [12]. The drawback of this technology is the loss of efficiency caused by the energy required to pressure the fuel up to 250 bar. Also public opinion and the authorities are somewhat hesitant about installing high-pressure gas machinery on passenger vessels. On the other hand, lean-burn engine technology and also gas liquefaction techniques have advanced recently [10].

There are certain losses inherent in compressed gas systems. Compressing natural gas requires energy that must be taken into account when evaluating overall system economics. In addition, gas pressure tanks are heavy and take space that would otherwise be used for payload (according to Figure 5.1 approximately 5 times the volume of Diesel) therefore according to Dr. Ing. Tore A Torp from Statoil Research Centre in Trondheim the Compressed Natural Gas will not be use as a fuel for forthcoming ships in Norway.

Liquefied Natural Gas requires less tank space approximately twice that of diesel. CNG because of the lower density requires four times more space which makes it unacceptable due to the limit of space on board. LNG storage is only 50 % heavier than diesel. It has to be also taken on account that both CNG and LNG tank cannot be filled full. Approximately 85 % for LNG and 90 % for CNG. CNG tanks are about four times heavier than diesel tanks while LNG tanks only one and a half. If the pressure of storage LNG is higher the tanks demand less space but the relative weigh is higher due to the requirements for pressure tanks. These differences make that LNG is better solution for replacing diesel fuel then CNG [11].

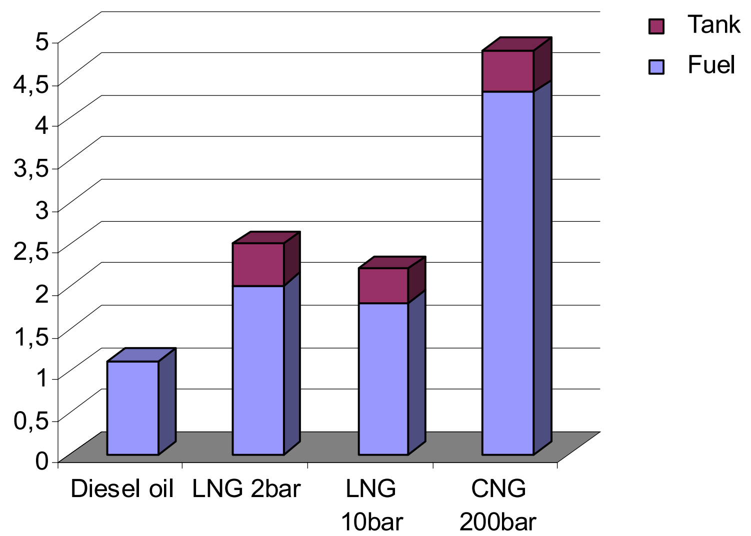

Figure 5.1 - Relative space demand for the storage of LNG compared to that of diesel fuels and CNG [11].

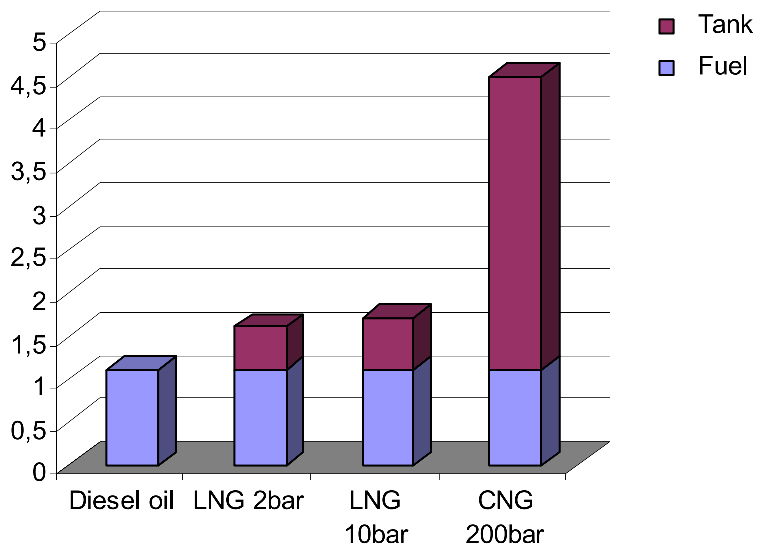

Figure 5.2 - Relative weight demand for the storage of LNG compared to that of diesel fuels and CNG [11].

LNG must be maintained cold to remain a liquid, independently of pressure. To fulfill that requirement the LNG could be stored at about -170°C as a boiling cryogen, and it will stay at near constant temperature if kept at constant pressure. The LNG vapor boil off produced during changes of state must be let out to allow the storage temperature to remain constant [13].

There are also legal aspects of gas storage and gas system on ships. From July 2002 the Norwegian Maritime Directorate and DNV (Det Norske Veritas) have regulations for gas-driven ships. The Norwegian Maritime Directorate's new regulatory requirements demand responsibility for internal control by shipping companies. Those regulations are accounted for in the Appendix E.

5.3 Viking Energy LNG-Fuelled Supply/Cargo Vessel

The support vessel Viking Energy has been built at the Kleven Maritime shipyard in Norway for its owners Eidesvik and started on a ten-year charter for Statoil in 2003. It is the world's first LNG-fuelled supply/cargo vessel, designed by Vik-Sandvik as a response to industry demands for minimizing greenhouse gas emissions [14].

Figure 5.3 - The Viking Energy is the world's first LNG-powered supply vessel [14].

The Viking Energy has an overall length of 94.9 m and a length between perpendiculars of 81.6m. It has a moulded breadth of 20.4 m. The depth to the second deck is 6.6 m and the depth to the first deck is 9.6m. The supply vessel has a maximum draft of 7.9 m and cargo deck area of 1,030 m^3. It has complement of 24 crew, accommodated in 12 single berths and five double cabins. The vessel can carry 1,300 m^3 of fuel oil, 2,000 m^3 of water ballast or drill water, 1,100 m^3 of potable water, 200 m^3 of methanol, 800 m^3 of brine, 900 m^3 of liquid mud and 450 m^3 of dry bulk.

The vessel has a gross tonnage of 5,073 tonnes and a net tonnage of 1,521 tonnes. Its deadweight is 2,886 tonnes at 5.9 m draught. The Viking Energy features dual fuel engines, with a consequence that it can run on both LNG and ordinary marine diesel oil in any proportion. Using LNG results in a 90 % reduction in the outlet of NOx (approx. 200 tonnes per year) as well as a 30 % reduction in CO_2 [14].

In order to use gas as a fuel, safety is a main priority and this has remained an important aspect in the design. The engine system is divided into fire-proof and explosion-proof zones and a number of constructive safety measures have been included. The storage of the LNG is in a vacuum insulated tank with a gross volume of 234 m^3. This is built as a pressure vessel and a vaporizer with a built-in coil pressurizing the tank [14].

The electric power for propulsion and other services is derived from four main gensets. The main engines are Wartsila 6032 DF 2,010 kW engines units, although there is also a Caterpillar 3304T 116 kW emergency genset. These gensets are linked to a pair of Rolls-Royce Contaz 25 contra-rotating 3000 kW stern thrusters and two Rolls-RoyceTT 2200 SS 1,000 kW tunnel thrusters in the bow. The vessel also has a Rolls-Royce ULE 1201 880 kW azimuthing retractable thruster for maneuvering. This complement gives the Viking Energy a top speed of 16 nm fully loaded [14].

In order to minimise fuel consumption, Kongsberg Simrad has used their new GreenDP system, which features predictive control logic instead of reactive control for an improved thruster use of 20 % as well as a reduction in fuel consumption and greenhouse gases. It also resulted in a 50 % to 80 % reduction in power variations [14].

5.4 Liquefied Natural Gas Fuel Ferry Glutra

In February 2000, the Norwegian ferry Glutra was put into operation as the world’s only LNG dual fuel ferry [15].

Figure 5.4 - Liquefied Natural Gas fuel ferry Glutra [15].

Ferry parameters:

Length OA... 94.8 m
Length BP... 85.2 m
Beam .... 15.7 m
Passengers 300
Automobiles.. 96
Engines .... 4 Mitsubishi GS 12R-PTk lean burn
Fuel Storage.. 2 x 27.2 m^3 LNG tanks

Four generator sets, 675 kW each, were put in separate engine rooms above the main deck. This was at the same tame an elegant way to meet this strict requirement regarding consequences of the engine room. An explosion analysis showed that in the worst case the two-sashed door of the engine room would burst and immediately release the pressure without affect the other engine rooms. The engine rooms are arranged two and two, with the main switchboard for the electric power, separating them [15].

In normal operation two engines gives sufficient power for propulsion and other energy consumers. The third generator set is backup or may be added to increase speed or higher energy demand due to weather conditions. The fourth generator set could then be available for maintenance. By this arrangement the ferry could be in operation 365 days a year in period of 2-3 years [15].

The LNG is stored onboard the vessel in two vacuum and perlite insulated, stainless cryogenic tanks are supplied by AGA Cryo AB in Gothenburgh. They have a maximum net LNG volume of 27.2 m^3 for each tank at the allowed maximum of 85 % filling. The cryogenic tanks, made of double walled stainless steel, are insulated by vacuum and perlite between the walls and are located under the main deck of the ferry in double walled, rockwool filled, sheet metal stainless steel containers [15].

Refueling of the tanks takes place every five or six days, with the LNG being delivered by truck operated by Statoil. The LNG is produced at Tjeldbergodden Luftgassfabrikk DA owned by Statoil (50.9 %), AGA (37.8 %) and Conoco (11.3 %). At one of the docking stations (Sølsnes), there is a working bridge which is hydraulically lifted during the filling operation to ease the connecting operation of the LNG filling hose to the truck and to the receiving connector on the ferry [15].

It takes almost two hours to transfer 47 m^3 or 16 tonnes of LNG, the tanks being filled to the regulated 85 % of the tank total volume. The LNG is transferred to the ferry tanks by means of the pressure in the truck tank produced by an air-heated LNG evaporator on the truck. The LNG can either be filled straight into the bottom of the ferry tanks or it can be sprayed from the top of the tanks. The spraying option is usually chosen to condense gas in the gas “pillow” above the LNG and thus avoiding excessive pressure build-up in the LNG tanks during filling [15].

5.5 CNG Dual Fuel Ferries Klatawa

Two CNG fueled ferries, the MV Klatawa and MV Kulleet have been operating in British Columbia for over 15 years. The natural gas fuel is compressed and stored in pressure vessels. The fuel is delivered to the engine in gaseous form through pressure regulators [13].

Figure 5.5 - CNG dual fuel ferries Klatawa [13].

On December 16, 1985, the MV Klatawa became the first certificated vehicle/passenger vessel in the world to operate on natural gas. With the success of the dual fuel operation on the MV Klatawa, her sister ferry MV Kulleet which operates on the same route, was similarly converted to dual fuel operation in 1988. Originally the main propulsion engines were adjusted to a 80% / 20% natural gas/diesel mixture at 85% load but now operate on a 91% / 9% natural gas/diesel ratio at 85% load and a 35% / 65% natural gas/diesel ratio at an idle speed of 750 rpm. In addition to the main engine conversion, the generator engines were also converted to dual fuel on a 75% / 25% mixture of natural gas/diesel whilst the hot air furnace was modified to 100 per cent natural gas [13].

The converted units were four-stroke, turbo-charged, fresh water after-cooled Caterpillar diesel engines. Other than the addition of gas regulators, a carburetor and a modified Woodward governor, the engine is a standard Caterpillar Model 3406-B with the timing retarded only by two degrees [13].

This system is comprised of a fueling station, natural gas storage cylinders, pressure regulating valves, relief valves, gas detectors and alarms, ventilated hoods to capture and alarm leaks, double walled supply piping in the engine room and nitrogen protection for the engine crankcases [13].

The MV Klatawa main engines were first opened up at 30,000 hours and found to be in first class condition. Based on these results, the main engines in the MV Kulleet ran to 60,000 hours before requiring overhaul. This is four times longer than the average diesel fueled engine and roughly equates to running a highway truck 2.4 million kilometers between overhauls [13].

6. Conversion Options

6.1 Availability of Natural Gas Engines

Gas engines have been used since the 1930s and were mainly applied in land transport, propelled with town's gas, when liquid fuels where scarce. At present most world leading engine makers have sparked natural gas variations of diesel based models on their curriculum, with some versions Turbo-Aspirated. Some brands have embarked in research programs, aiming to optimize and refine their products for particular applications, inclusive of marine propulsion [4].

The majority of modern gas engines work according to the Otto principle. The fuel is premixed with the air before compression in the cylinders, next the mixture is ignited burning rapidly and relatively evenly in the combustion chamber. How the flame propagates is a function of many factors including combustion chamber shape, temperature, pressure, mixture preparation and mixture ignition [4].

Table 6.1 - Main characteristics for different gas engines [4].

	Designation	**Lean burn**	**Combustion principle**	**Spark ignition system**	**Prechamber**	**Only gas fuel**	**Main gas feed before turbo**
Open chamber spark ignited	SG	Yes	Otto	Yes	No	Yes	Yes
Prechamber spark ignited	SG	Yes	Otto	Yes	Yes	Yes	No
Carburetor pre-chamber ignited	SGC	Yes	Otto	Yes	Yes	Yes	Yes
Prechamber micro pilot	PG	Yes	Otto	No	Yes	No	No
Open chamber dual fuel	DF	Yes	Otto Diesel	No	No	No	No
Gas diesel	GD	No	Diesel	No	No	No	No
Stoichometric		No	Otto	Yes	No	Yes	No

When an engine works according to the diesel principle the gas fuel is injected after compression of the air in the cylinders, and the heat release is controlled through the combustion phase. The fuel pressure must have a magnitude of one to two thousand bars [4]. In Table 6.1 are showed main characteristics for different gas engines. Certain parameters of engines and their availability suggest using dual fuel engines for marine propulsion.

6.2 Dual-Fuel Engines

A dual fuel engine is able to operate on either 100 per cent diesel fuel, or alternatively, on a mixture of diesel fuel and natural gas. The engine is not able to operate on natural gas exclusively. It is also fully capable of switching over from gas to liquid fuel (marine diesel oil) automatically should the gas supply be interrupted, while continuing to deliver full power. When running on natural gas, ignition is triggered using a very small quantity of liquid fuel. Marine diesel oil can be used as a secondary fuel [16].

The typical dual fuel engine operates according to the lean-burn principle: the mixture of air and gas in the cylinder is lean, which means that there is more air than needed for complete combustion. Lean combustion increases engine efficiency by raising the compression ratio and reducing peak temperatures, and therefore also reducing NO_X emissions. A higher output is reached while avoiding knocking or preignition of gas in the cylinders. Combustion of the lean air-fuel mixture is initiated by injecting a small amount of Marine Diesel Fuel (pilot fuel) into the cylinder. The pilot fuel is ignited in a conventional diesel process, providing a high-efficiency ignition source for the main charge [16].

The fuel oil system on the engine is divided into two: one for pilot fuel oil and one for the main diesel oil forback-up fuel operation. The equipment used for diesel operation is similar to the conventional diesel engine, with camshaft-driven injection pumps at each cylinder. The engine is equipped with a twin-needle injection valve, one main needle used during diesel mode and one for pilot fuel oil. The pilot fuel is elevated to the required pressure by one common pump unit, including filters, pressure regulator and an engine-driven radial piston-type pump. The pilot fuel is distributed through common-rail type piping and injected at approximately 900 bar pressure into cylinders. Pilot fuel injection timing and duration are electronically controlled [16].

When running the engine in gas mode, the pilot fuel amounts to less than 1% of full-load consumption. The fuel gas system feeding the engine with fuel includes filters and the necessary shut-off and venting valves to ensure safe and trouble-free gas supply. The natural gas is supplied to the engine through a gas valve unit. The fuel gas feed pressure to the engine is controlled by a pressure regulating valve located on the gas valve unit. The fuel gas pressure is dependent on engine load and the fuel gas calorific value (lower heating value) [16].

The dual fuel engine during its operation has different NOx and CO_2 emission dependent on load level. If the load is higher the emission level is lower. Typical load use by ships and boats is between 75- 85 % [16].

Table 6.2 - Typical dual fuel engine emissions [16].

Engine in gas operating mode		
Typical emission levels*	**100 % load**	**75 % load**
NO_X (g/kWh)	1.4	2
CO_2 (g/kWh)	430	450
Engine in diesel operating mode		
Typical emission levels*	**100 % load**	**75 % load**
NO_X (g/kWh)	11.5	12
CO_2 (g/kWh)	630	630

* note that the emission level always depends on the gas composition and that these figures should be seen as indicative only.

The conversion of the system include modifications onboard the ferry and construction of a shore fueling station or method of fueling. Those changes include the modification of main and auxiliary engines, the addition of a onboard natural gas supply system including natural gas storage cylinders, supply piping and valves, gas detection units and alarms, exhaust ventilation system and others components.

6.3 Natural Gas Engines Manufacturers

The relative share of emissions from shipping has increased during the past years compared to land transportation and other industries. The high power requirements of a ships and ferries represent a serious challenge regarding emission from onboard diesel machinery. Many manufacturers have taken that challenge and emissions reduction claims in excess of IMO requirements are stated regularly in the marine press [4].

Natural gas technology offers remarkable achievement with only minimal emissions, hence prompting some leading engine manufacturers to start thinking about development of the natural gas engine for marine applications. Those development efforts benefit widely from the experience of light and heavy fuel oil engine technology.

There are few leading power plant makers with natural gas industry, such as:

- MAN B&W,
- Waukesha,
- Mitsubishi,
- Vickers-Ulstein,
- Jenbacher,
- Ruston –Alstom,
- Wärtsilla,
- Caterpillar.

To ensure that the engines comply with marine standards, it is required that they be extensively tested. The engines are tested either individually or divided into families or groups where only the parent engine is tested. The certificate of the member engine is then based on the test carried out for the parent engine. The actual test can usually be carried out in connection with normal workshop engine tests. After successful testing and approval of the documentation, the engine is supplied with an interim statement of compliance that is formalized at a later stage [17].

7. Norwegian Coastal Voyage

7.1 Background

The Norwegian Coastal Voyage (Hurtigruten) is one of the world's last remaining long haul waterborne transportation system for passenger and cargo. Nature and geology have provided Norway with a spectacular beauty, but its craggy, rocky and often isolated nature really never facilitated land links. So like most traditional steamship services, this route, worked for quite some time exclusively by motor ships. Beginning life in 1893, Norwegian Coastal Voyage, formerly known as Bergen Lines, served the isolated towns and villages sprinkled throughout the shoreline and fjords of Norway's western seacoast between Bergen on the south and Kirkenes, hundreds of miles above the Arctic Circle. Known as the coastal steamers or the mail boats, these vessels provided a vital lifeline to areas isolated from other forms of transportation. With the passage of time extra services have been offered and additional markets tapped [18].

A Norwegian Coastal cruise is likely to include a mix of traditional cruisers, along with passengers traveling point-to-point along the coast, and some ferrying their cars as well. The ships still carry freight, so a voyage on this line is comprised of a handful of extended port calls interspersed with several shorter stops each day, many just long enough to load and offload cargo. The service has run almost without interruption since its beginning, hardly stopping for war and German occupation [18].

7.2 Itineraries

Eleven Norwegian Coastal Voyage ships are committed year-round to Norwegian coastal itineraries. Passengers may choose seven-night northbound, six-night southbound or 12-night round trip sailings, calling at as many as thirty-five ports per one-way segment. In some places the ship stops only long enough to pick up or unload some cars and fish and people, and at other ports the ship stops long enough for passengers to take a stroll ashore or have several hours for sightseeing and shopping [18]. More information about ports that Norwegian Coastal Voyage ships stops, map and timetable are showed in the Appendix F.

Norwegian Coastal Voyage has also expanded the span of its cruising region to include, along with its signature fjord and coastal trips, expedition cruising to Spitsbergen, Greenland, and Antarctica & the Chilean Fjords [18].

7.3 Norwegian Coastal Voyage's fleet.

Norwegian Coastal Voyage has stabilized the number of ships in its fleet, constantly modernizing both amenities and technology with each new built, retiring an older, smaller, less sophisticated ship for each new one brought online. Norwegian Coastal Voyage's fleet is made up of eleven ships broken down into three different classes or categories and it is described in the Appendix F [18].

The newest is the "Millennium Class," in which there are currently three ships: MS Midnatsol, MS Trollfjord and MS Finnmarken. These ships, largest in the fleet, were built between 2002 and 2003, measure 15,000 tons, and carry between 822 and 1,000 passengers. The ships differ slightly from each other both externally and internally. MS Finnmarken continues the classic style of the Norwegian Coastal Voyage, while MS Midnatsol and MS Trollfjord are more modern in design. Six "Contemporary Ships," MS Nordnorge, MS Polarlys, MS Nordkapp, MS Nordlys, MS Richard With, and MS Kong Harald, were built between 1993 and 1997. They range from 11,000 to 12,000 tons and carry approximately 700 passengers. Two "Mid-Generation Ships" date from the early 1980s and include the MS Vesterålen and MS Narvik, each carrying a handful over 500 passengers and measuring about 6,250 tons [18].

8. Coastal Boats

8.1 Background

The roads in Fjord Norway are constantly interrupted by fjords - and ferry trips. coastal boats and ferries are a major form of transport in Norway. The service is efficient and the ride enjoyable. A far-reaching system of ferries and express boats link Norway's offshore islands, coastal towns and fjord districts.

Kystekspressen (the Coastal Express) is one of Norway's major express-boat routes operating among other things between Kristiansund and Trondheim. In the middle of XIX century the steamer “Nidelven” had a route around Trondheim’s fjord. Trip form Kristiansund to Trondheim used to take about one day, but time was not so important and ships and ferries used to spend few days in ports. Nowadays, ferries go three times par day and the trip takes only 3.5 hour [19]. Route map and timetable are accounted for in the Appendix G

8.2 Fast Ferries

Kystekspressen has operated between Kristiansund and Trondheim since 6 June 1994 as cooperation between Fosen Trafikklag ASA and Møre og Romsdal Fylkesbåtar. There are two fast ferries operating on this route: Ladejarl (Figure 8.1) and Mørejarld - 38 m catamarans [19].

Figure 8.1 - Ladejarl – one of the fast ferries belongs to Kystekspressen.

9. Analyses of Norwegian Coastal Voyage Ships

9.1 Fuel Consumption

Fuel consumption of the natural gas engines is higher than diesel and it is due the lower efficiency because of the engines where originally designed for diesel fuel. The Figure 9.1 shows approximately differences between these two engines. Typical load use by ships and boats is between 75 - 85 % dependent on current conditions. Therefore, calculation will be for 75 % load and estimated gas consumption for such load is about 23 % higher than diesel.

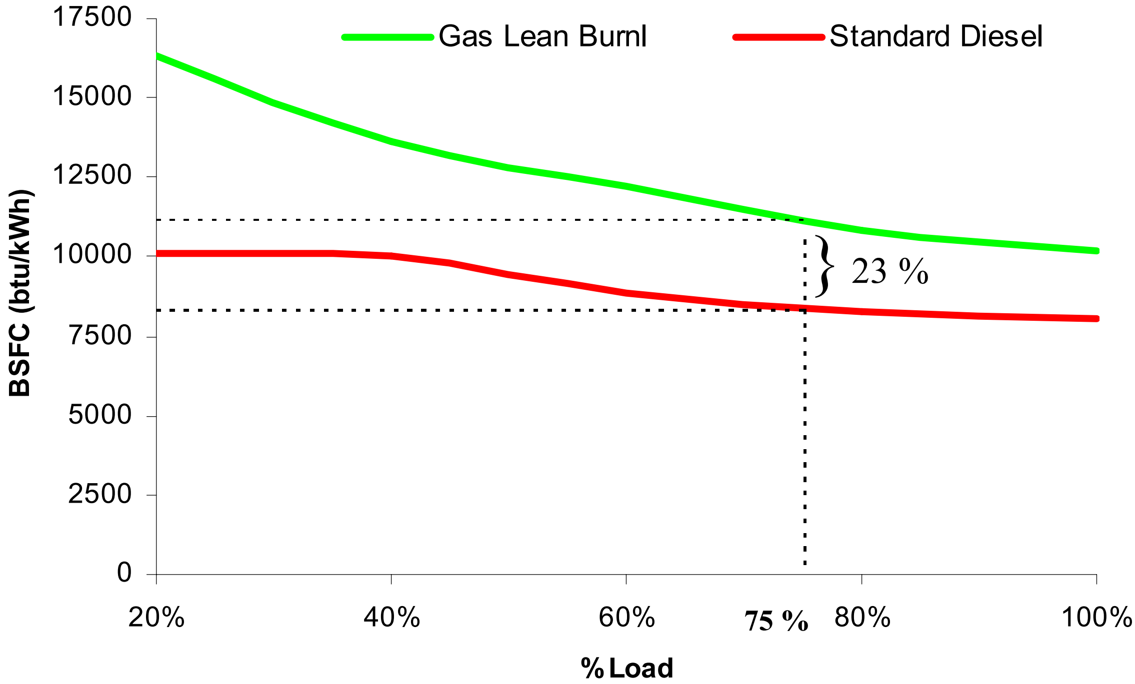

Figure 9.1 - Typical fuel consumption of combustion engine: Diesel and NG [4].

Comparison of gas engine consumption with diesel (according to Figure 9.1):

diesel consumption + 23 % = natural gas consumption

According to The European Natural Gas Supply–Demand Report, gross calorific value (GCV) for natural gas in Norway is 41.18 MJ/Sm^3 [20] and gross calorific value for diesel fuel in the thesis is assumed as 40 MJ/litre [21] (density is 0.87 kg/m^3).

The relation between natural gas and Diesel fuel:

- equivalent energy:

1 litre of Diesel = 971 litres of natural gas

- hence, the actual natural gas equivalent to 1 litres of Diesel is:

971 x 1.23 = 1,194 Sm^3 of natural gas

Due to the natural gas will be storage in liquid state the further calculation will be for LNG. Assume that 1 m^3 LNG gives 609 Sm^3 of natural gas and density of LNG is 450 kg/m^3 [22], the LNG equivalent to 1 litre of Diesel is:

1 litre of Diesel = 1.96 litres of LNG

Table 9.1 - The HFO fuel used by some of the Norwegian Coastal Voyage ships belonging to TFDS in 2003 [23] and equivalent LNG amount.

Ship	HFO [dm^3]	HFO [tonne]	Distance [nm]	LNG [m^3]	LNG [tonne]
MS "Kong Harald"	7,809,000	6,793.8	87,153	15,305.6	6,887.5
MS "Midnatsol"	5,889,000	5,123.4	66,754	11,542.4	5,194.0
MS "Nordlys"	7,373,563	6,415.0	89,940	14,452.1	6,503.4
MS "Polarlys"	6,814,138	5,928.3	86,583	13,355.7	6,010.0
MS "Trollfjord"	8,606,483	7,487.6	85,282	16,868.7	7,590.9

Table 9.1 includes the HFO fuel consumption and distance for 2003 year and equivalent consumption of LNG. HFO is the dominating marine fuel [32] with density about 870 kg/m^3 [23] and for LNG is 450 kg/m^3 [22]. The volume of LNG is about twice more, hence it is necessary to install bigger tankers or fill them more often.

The conversion from diesel engine to new dual fuel engine has to include calculations to determine the volume of natural gas required operating the vessel on dual fuel mode. Due to the variety of dual fuel engines on the market with different fuel consumption factors it is assumed in the thesis that the typical engine needs 95 % natural gas and 5 % of diesel fuel mixture under 75 % engine load.

Table 9.2 - Estyamted fuel consumption for TFDS' ferries if using dual fuel engines (95/5 % mixture of LNG and diesel fuel) in 2003.

Ship	Diesel [m^3]	Diesel [tonne]	LNG [m^3]	LNG [tonne]
MS "Kong Harald"	390.5	329.9	14,540.4	6,543.2
MS "Midnatsol"	294.5	248.8	10,965.3	4,934.4
MS "Nordlys"	368.7	311.5	13,729.6	6,178.3
MS "Polarlys"	340.7	287.9	12,687.9	5,709.6
MS "Trollfjord"	430.3	363.6	16,025.3	7,211.4

Table 9.2 includes approximately calculation concerning probable fuel consumption for the same of the Hurtigruten's ships, considering using dual fuel engines. Due to different technical requirements dual fuel engines operate on typical marine diesel oil (MDO) instead of using heavy fuels like HFO [16], [32]. Marine diesel oil has different parameters therefore based on information from Jan Brox (2004) from TFDS the density of marine diesel fuel is assumed as 845 kg/m^3.

The total gas consumption was estimated, assuming condition for all the Hurtigrutn ships have similar parameters of fuel consumption. The calculations are made for eleven ships during one year working (Table 9.3 and Table 9.4). First option includes equivalent consumption of LNG, while second shows calculation for dual fuel mode. In order to make these numbers assailable the total use was calculated of natural gas.

Table 9.3 - Estimations of gas consumption per year for all the Coastal Express boats.

	Total Use of LNG [m^3]	Total Use of LNG [tonne]	Total Use of Natural Gas [Sm^3]
Option 1. **100% LNG**	157,353	70,809	95,827,977
Option 2. **95% LNG and 5% Diesel Fuel**	149,486	67,296	91,036,974

Table 9.4 - Estimations of diesel consumption per year for all the Coastal Express boats.

	Total Use of Diesel Fuel [m^3]	Total Use of Diesel Fuel [tonne]
Option 2. **95% LNG and 5% Diesel**	4,014	3,392

Table 9.3 includes approximately calculation concerning probable LNG consumption for all the Coastal Express boats in two options. First option shows equivalent consumption of LNG and second shows LNG consumption considering using dual fuel engines. Table 9.4 shows approximately marine diesel oil for dual fuel engine option (95/5 % mixture of LNG and MDO).

9.2 Gas Storage and Filling Stations

New ships using LNG as a fuel require special designed tank rooms which have to be thermally isolated from the hull to prevent the cold LNG coming into contact with the steel structure in case of leakage and also vented upwards to a safe location.

Table 9.5 - The quantity of oil storage on the TFDS' ferries [23].

Ship	HFO [m^3]	HFO [tonne]
MS "Kong Harald"	620.0	539.4
MS "Midnatsol"	293.3	255.2
MS "Nordlys"	618.9	538.4
MS "Polarlys"	438.0	381.1
MS "Trollfjord"	293.3	255.2

Norwegian Coastal Voyage ships at the moment need to be refuel once per round trip and it is done in Bergen [23]. The quantity of HFO is showed in Table 9.5 and it should be enough for 12 - 16 days dependent on ship. The ships dispose of limited space however the LNG fuel might be storage in the same quantity. In order to reduce costs of filling stations the best solution is to build just one filling station and to install sufficient big tanks. Due to the higher consumption ships should posses about 1,000 m^3 of LNG tank which is enough for 15 days journey.

Norwegian Coastal Voyage ships during eleven days journey stop at the several ports. The most suitable place for refueling will be in Hammerfest due the distance form LNG plant on island Melkøya. The Snøhvit gas field is the first offshore petroleum project to be developed in the Norwegian sector of the southern Barents Sea. Three fields – Snøhvit, Askeladd and Albatross – make up the Snøhvit Area. Because of the long distance from existing gas export infrastructure, the Snøhvit partners lead by Statoil, plan to transport the gas through a multiphase pipeline to a single-train onshore LNG plant on Melkøya in Finnmark County, Norway. Statoil will operate the Melkøya LNG-plant with a production capacity of 6 billion m^3 LNG per year. The construction on Melkøya will start during the summer of 2002 and the plant will be in full production in 2006 [24].

The Norwegian Coastal Voyage ships stop for about one hour and half in Hammerfest and during this time vessels might be refuel. The short distance to Melkøya allows building pipeline to the filling place somewhere in Hammerfest. The place for filling station will be dependent on few factors such as costs, low regulations etc. (does not have to be in port). The annual demand of LNG for all the Norwegian Coastal Voyage ships is about 150,000 m^3 which is about 2.5 % of LNG production in Melkøya.

10. Analyses of Coastal Express Boats

10.1 Fuel Consumption

The route Trondheim - Kristiansund is served by two express boats, Ladejarl and Mørejarld. They are identical and run about 4,000 hours per year each. They have 2x2490 kW installed power each and are run at 85-90 % of power when at full speed. Average fuel consumption is about 710 litre per hour [25].

Annual diesel (density 870 kg/m^3 [23]) fuel consumption for two boats per year:

$$\text{Fuel consumption} = 5{,}680\ \text{m}^3 = 4{,}941\ \text{tonne}$$

Equivalent LNG consumption for express boats:

$$\text{Fuel consumption} = 11{,}132.8\ \text{m}^3 = 5{,}009.8\ \text{tonne}$$

Equivalent LNG consumption per year for express boats using dual fuel engines (95/5 % mixture, density of marine diesel oil (MDO) is the same as for calculation before 845 kg/m^3 [23], [16]):

$$\text{Diesel fuel consumption} = 284\ \text{m}^3 = 240\ \text{tonne}$$

$$\text{LNG fuel consumption} = 10{,}576\ \text{m}^3 = 4{,}759\ \text{tonne}$$

To make these numbers assimilable the LNG consumption is converted to the total use of natural gas of two ferries for one year working. First option includes equivalent consumption of LNG, while second shows calculation for dual fuel mode (Table 10.1).

Table 10.1 - Estimation of LNG consumption per year for all the coastal boats.

	Total Use of LNG [m^3]	**Total Use of LNG [tonne]**	**Total Use of Natural Gas [Sm^3]**
Option 1. **100% LNG**	11,132.8	5,009.8	6,779,875
Option 2. **95% LNG and 5% Diesel Fuel**	10,576	4,759	6,440,784

10.2 Filling Stations

The Coastal Express boats operate about twelve hours par day and refueling is quite flexible. There are few possible ports. Tjeldbergodden is suitable place due to existing industrial complex which has an annual production capacity of 10,000 tonnes of LNG per year which is about 50 % of annual demand for two Coastal Express boats [26].

There are several ferries operating around Kristiandsund and Trondheim area and refueling has to be different from that for Norwegian Coastal Voyage ships and also it must be planed for more ferries not only for two. One of the possibilities is to use trucks to transport LNG from the supply place (e.g. Tjeldbergodden Luftgassfabrikk DA) to certain ports. Depending on number of boats one or two tracks harmonious with time tables can operate for all the day. This method of refueling was successful with ferry Glutra. Another possibility is to use special designed LNG supply vessel which will be operating around this area. The converted coastal boats will be able to work about four or five days without refueling and that can be matched with LNG vessel route.

11. Benefits of Converting to Natural Gas

In order to make calculation easier it was assumed based on Wãrstilä graph and information about dual fuel engines (Table 6.2). The present NOx emission is 12 g/kWh for diesel engines and 2 g/kWh for dual fuel engine with 75 % load [16].

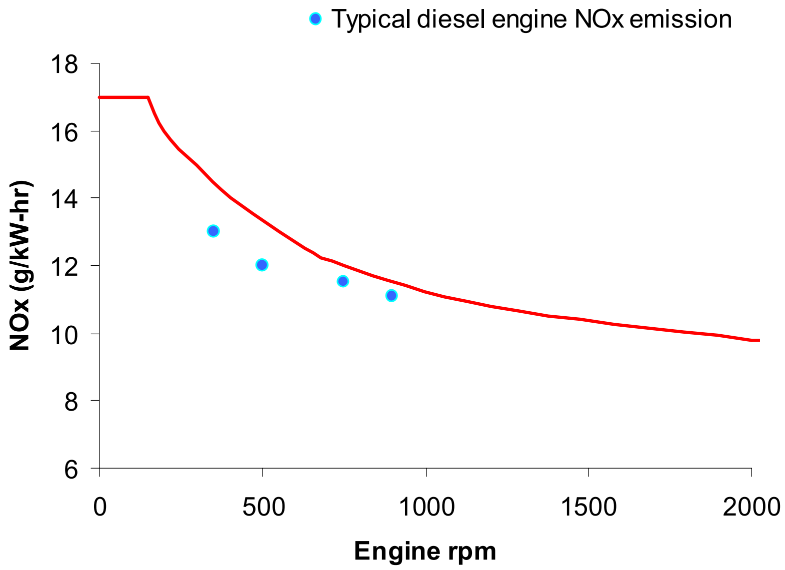

Figure 11.1 - Typical Wãrstilä diesel engine NOx emission and IMO NO_x emission standard

Based on information about annual fuel consumption by Norwegian Coastal Voyage ships [23], annual used power and emission of NOx were estimated and showed in Table 11.1.

Annual power for the Norwegian Coastal Voyage ships:

$$\text{annual power} = \text{annual fuel consumption} \cdot \text{diesel GCV} \cdot 8{,}000 \text{ houers}$$

Hence, NOx emission equals:

$$\text{NOx emission} = \text{annual power} \cdot \text{mass of NOx emission per kWh}$$

Table 11.1 - The NOx emission of the Norwegian Coastal Voyage ships belonging to TFDS.

Ship	Used Power in 2003 [MWh/year]	Present emission of NOx [tonnes/year]	Future emission of NOx [tonnes/year]
MS "Kong Harald"	86,766.7	1,041.2	173.5
MS "Midnatsol"	65,433.3	785.2	130.9
MS "Nordlys"	81,928.5	983.1	163.9
MS "Polarlys"	75,712.6	908.6	151.4
MS "Trollfjord"	95,627.6	1,147.5	191.3

If estimate that the other six Norwegian Coastal Voyage ships belonging to OVDS are similar the present NOx emission is 10,700 tonnes per year. The same ships with dual fuel engines in gas operating mode will use 1,790 tonnes per year therefore the NOx emission will be reduced to 8,910 tonnes per year. All the numbers are gathered and showed in Table 11.2.

The coastal boats have smaller engines with lower power. Power of engine is indirectly related to revolutions per minute (rpm). According to Wãrstilä, ship engines with higher revolutions per minute have lower NOx emission. It is assumed based on data that present NOx emission is about 10 g/kWh and 1,5 g/kWh for dual fuel engine with 75 % load [27]. The calculations are the same as for Norwegian Coastal Voyage ships besides that Coastal Express boats work 4,000 hours. The present NOx emission is about 796 tonnes per year and future emission for the same ferries with dual fuel engines in gas operating mode will use 126 tonnes per year therefore the NOx emission will be reduced about 631 tonnes per year (Table 11.2).

Table 11.2 - The NOx emission of the Norwegian Coastal Voyage ships and coastal boats.

	Present NOx emission [tonne/year]	Future NOx emission [tonne/year]	Reduction of NOx Emission [tonne/year]
Norwegian Coastal Voyage Ships	10,700	1,790	8,910
Coastal Boats	796	126	670
Total	11,457	1,916	9,580

The main benefit of that conversion is that NOx emission will be reduced about 9,541 tonnes per year which is about 4.5 % of total NOx emission in Norway and 11 % of emission from the shipping industry (tables with numbers of NOx emission in Norway are showed in Appendix C). Also the fact of possessing so big numbers of ships (which shows Appendix H) makes it very interesting. Conversion of Norwegian Coastal Voyage ships and Coastal Express boats to natural gas will reduce emission by 17 % of required reduction in Gothenburg Protocol.

11. Discussion

Norway possesses large resource of natural gas. Most of the gas is exported and only a small percentage is consumed in Norway. New discovered reserves and existent Liquefied Natural Gas plants in Norway make natural gas available and also give the opportunity for gas to become a main fuel in the transport sector.

The Annex VI which was adopted to the MARPOL Convention in 1997 by International Maritime Organization was created for ships with diesel engines. Current new diesel engines have lower gases emissions which are compliant with the requirements in this protocol. However, in future these regulations will be even tighter. Furthermore, the Gothenburg protocol signed in 1999 that obliges Norway to reduce considerably emission brings more challenges and efforts.

In this thesis calculations regarding nitrogen oxides and the possibility of its reduction were considered. The calculations show that conversion of Norwegian Coastal Voyage ships and Coastal Express boats to natural gas will reduce emission by 17 % of required reduction in Gothenburg Protocol. Therefore, something has to be done more but conversion of these few ships could be a good start. A conversion of 70 per cent of the Norwegian shipping industry to natural gas will reduce emission enough to be compliant with Gothenburg Protocol.

All the calculations were carried out for the existing diesel and dual fuel engines. Dual fuel engines for marine applications are not so developed as in other sectors such as power generators or urban transport. The efficiency is lower which means that gas consumption is higher and also emission is much higher than typical diesel engines. However, every year there are new dual fuel engines which require less diesel fuel as a pilot fuel which is also responsible for high greenhouse gases emission. For all this, it is possible to estimate that in future engines will be more advanced and with better parameters.

12. Conclusion

Recent Norwegian studies on emission of pollution gases show that there has not been any progress in reduction for the few last years. From all the gases, the NOx emission which is a serious problem for environment was reported to be approximately 213,000 tonnes in 2002. If nothing is done the NOx emission will established on this level. According to the Norwegian Statistics almost 37 % of total NOx emission in 2002 was emitted from coastal traffic and fishing vessels.

The environmental conscious causes global trends, which lead to reduction of greenhouse gases. There are several environmental protocols concerning the reduction of nitrogen oxides emission. One of them is the MARPOL Convention which sets the limits on sulphur oxide and nitrogen oxide emissions from ships exhausts and prohibits deliberate emissions of ozone depleting substances. Another one is the Gothenburg protocol, signed in 1999. According to this protocol Norway has to reduce the emissions of four pollutant gases from the current emission levels by 2010.

The carried out calculations regarding NOx emission from Norwegian Coastal Voyage ships and Coastal Express boats show that the reduction is significant for the Norwegian environment. The main benefit of that conversion is that NOx emission from these few vessels will be reduced by 83 per cent, which is 9,541 tonnes per year. This number represents about 4.5 per cent of total NOx emission in Norway and 11 per cent of emission from the shipping industry.

As stated in this thesis the conversion of engines to natural gas is not any more limited by lack of technology. There is a variety of dual fuel engines which are able to operate on either 100 per cent diesel fuel, or alternatively, on a mixture of diesel fuel and natural gas. Also storage of LNG does not represent any inconvenience and any big losses to the space and weight.

Norwegian Coastal Voyage ships and Coastal Express boats can be supplied with LNG from two plants located in Hammerfest and Tjeldbergodden. The annual LNG consumption will be about 150,000 m^3 for Norwegian Coastal Voyage ships which is about 2.5 % of the LNG production in Melkøya and 4,800 tonnes for Coastal Express boats which is about 50 % of annual production in the industrial complex in Tjeldbergodden. The LNG can be delivered to the vessels by trucks, boats or pipeline depending on demands and conditions.

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Appendixes

Appendix A. Natural Gas Compositions

Table A.1 - Examples of gas compositions [28].

Molecule \ Mole %	Troll (1)	Sleipner Fields (2)	Draugen (3)
Methane	**93,070**	**83,465**	**44,659**
Ethane	**3,720**	**8,653**	**13,640**
Propane	**0,582**	**3,004**	**22,825**
Iso-Butane	**0,346**	**0,250**	**4,875**
N-Butane	**0,083**	**0,327**	**9,466**
C5++	**0,203**	**0,105**	**3,078**
Nitrogen	**1,657**	**0,745**	**0,738**
Carbon-dioxide	**0,319**	**3,429**	**0,720**
Total	**100**	**100**	**100**

(1) After processing at Kollsnes (on-shore processing plant), average for Nov. 2000.

(2) After off-shore processing into off-shore pipelines, combination of Sleipner East and West, average Nov. 2000.

(3) After off-shore processing into pipeline Åsgard Transport to Kårstø (on –shore processing plant) for further processing, average for Dec. 2000.

Table A.2 - Typical composition of Compressed Natural Gas [12].

Methane	91.9 %
Ethane	3.7 %
Carbon di Oxide	2.0 %
Propane	1.2 %
i-Butane	0.4 %
i-Pentane	0.2 %
n-Pentane	0.2 %
Nitrogen	0.2 %
n-Butane	0.1 %

Appendix B. MARPOL 73/78 Annex VI - NOx and SOx Controls [5]

B.1 MARPOL 73/78 Annex VI

The International Maritime Organization, IMO, exists to develop a range of Conventions, Codes and Guidelines which member countries then incorporate into their domestic legislation. The fundamental principle underpinning this activity is the understanding that a uniform approach on a world-wide basis to such matters as maritime safety and environmental protection is essential to the smooth functioning of international trade. Pollution controls are primarily effected through the workings of the MARPOL Convention and its associated Annexes, the functioning of which is overseen by the IMO Maritime Environmental Protection Committee, MEPC.

MARPOL Annex VI, 'Regulations for the Prevention of Air Pollution from Ships', was adopted by the 1997 Conference of the Parties to the MARPOL Convention. The Annex will enter into force, for all MARPOL Convention signatories, 12 months after attaining the required level of ratification. This ratification requirement is a minimum of 15 states which control a combined merchant gross tonnage of not less than 50% of the world total. Ratification is currently expected to be achieved before the end of 2004.

In terms of exhaust emissions, the Annex VI controls will apply, to a greater or lesser extent, to the oxides of nitrogen (NOx) – Regulation 13 - and the oxides of sulphur (SOx) – Regulation 14. Furthermore, there are requirements, partly related to the SOx controls, which will cover certain aspects related to fuel oil quality and supply arrangements – Regulation 18. In addition, but outside the scope of this paper, the Annex also covers such aspects as the prohibition of new systems using certain ozone depleting substances (for example, halons and freons as used for firefighting and refrigeration), the design and operation of onboard incinerators and the design requirements for tanker vapour emission control systems.

Fixed and floating platforms, including drilling rigs and similar structures, are considered as ships for the purpose of this Annex, except in respect of those emissions to the atmosphere resulting directly from operations solely related to their drilling or processing functions. These controls are in addition to any imposed by the government which has jurisdiction over the waters in which they operate.

The basis of these Annex VI controls is, as with the other MARPOL Annexes, statutory. Compliance is therefore to be demonstrated to the Administration of the ship's Flag State which ultimately is the entity which will undertake the necessary approvals and issue of certification. Therefore, it is totally separate matter to the ship's classification.

However, where so authorised, the ship's classification society may undertake all or part of these statutory functions, but as a Recognised Organisation on behalf of the Flag State.

Due to the particular nature of the implementation of the NO_X and SO_X controls, consideration of these is divided into two sections; prior to and after the Annex entry into force date. In this, it is essential to recognise that Annex VI will apply to all merchant ships, except where specifically exempted, and will be a mandatory Annex. Consequently, compliance will not be optional for ships intending to trade on an international basis.

B.2 Annex VI, Prior to Entry into Force Date

Prior to the entry into force date, the various provisions of Annex VI cannot be enforced, except where a Flag State decides to enact those requirements on the ships under its control. However, in the case of the NOx controls, this initial 'voluntary' compliance over the intervening period will be an essential precursor to eventual mandatory compliance (in view of the extreme difficulty in obtaining post installation certification) and therefore, this must be seen as a highly qualified 'voluntary' compliance. A failure to take these steps now could render a ship uncertifiable in the future. In terms of the SOx controls, these too will not be enforceable over this period. Nevertheless, for those ships which will intend to operate on residual fuel oils on a world-wide basis, there are essential preparatory steps which will need to be taken in order to retain operational flexibility thereafter.

B.3 NOx Controls

The NOx controls as given within the Annex will apply to diesel engines (boilers and gas turbines are not covered) over 130 kW which are not used solely for emergency purposes and which are:

(a) installed on ships built (i.e. keel laid) on or after 1 January 2000, or

(b) subject to 'major conversions', as defined, on or after 1 January 2000.For the purpose of this regulation a 'major conversion' is where an engine:

- is replaced by a new engine built on or after 1 January 2000
- output of an engine is increased by more than 10%
- is 'substantially modified', as defined

The 'major conversion' clause is extremely significant, since it potentially extends the scope of these controls to engines which would otherwise be exempt, i.e. those installed on ships built prior to 1 January 2000. In the case of engines installed on ships built before 1 January 2000, 'substantially modified' means any operational or technical modifications which are made after that date which could increase NOx emissions, as defined. Such modifications may include changes to fuel injection timing, fuel injection equipment, the charge / scavenge air systems or combustion chamber profile. The onus would be on the shipowner to demonstrate to the responsible Administration that any changes to such operational or technical features did not result in an unacceptable increase in emissions.

The NO_X emission limits are related to engine rated crankshaft speed:

Engine Speed (n) rpm	NO_x Emission Limit g/kWh
Less than 130	17.0
130 – 1999	$45 \times n^{-0.2}$
2000 and above	9.8

An engine's duty cycle weighed emission values (since it could be rated for more than one cycle) are given at reference conditions (covering such aspects as fuel type, inlet air temperature and humidity and primary coolant temperature). Consequently, these controls focus on engine design rather than 'end of stack' emission rates.

There are four duty cycles for marine engines:

- E2 Main propulsion, constant speed (including engines driving variable pitch propellers)
- E3 Main propulsion or auxiliaries operating on the propeller law speed curve
- D2 Auxiliary engines, constant speed
- C1 Auxiliary engines not covered by D2 or E3

In this it is important to recognise that, in terms of NOx certification, an engine is specifically approved only for those duty cycles and rating (power and speed) which are given in its certification.

Underpinning the whole of these NOx emission controls is the NOx Technical Code which, as a mandatory document, defines the procedures and means by which an engine is to be certified and compliance demonstrated over its service life.

Over this interim period between 1 January 2000 and the entry into force date, the essential points in respect of those engines which will fall within the scope of Annex VI are:

- Engines, either installed on new buildings or supplied new, are to be in compliance with the NOx Technical Code – as indicated by a Statement of Compliance or similar, normally issued by, or on behalf of, the Flag State of the ship on which they are installed. It will usually be the responsibilty of the engine builder to have obtained the appropriate certification.
- For all engines, where changes to duty, ratings, restrictions, components or settings which could affect NOx emissions are undertaken, the necessary steps are taken to demonstrate either:
  - that those changes do not affect the status of the subject engine relative to the Annex requirements and any existing NOx certification; or
  - that the engine as modified is, and will thereafter be, demonstrably compliant with the relevant emission limit and is so certified. These changes would need to be approved by, or on behalf of, the Flag State of the ship on which the engine is installed. In the case of previously certified engines those changes could only be approved by the entity which issued the original Statement of Compliance with the NOx Technical Code.
- An original copy of the Technical File as approved by, or on behalf of, the Flag State of the ship on which the engine is installed is to be supplied with the engine. This document is to be retained onboard and is not to be subject to unauthorised amendments. The Technical File is the key document in demonstrating compliance; consequently, it is to be kept with the engine throughout its service life. The Technical File, which is engine specific, defines the engine in terms of rating, application, performance, limitations and NOx critical components and settings, the emission test report relevant to that engine and the means by which that engine is to be subsequently surveyed in order to demonstrate compliance. Three survey options, the Onboard NOx Verification Procedures, are given in the NOx Technical Code:

  (a) Parameter Check

  (b) Simplified Measurement

  (c) Direct NOX Monitoring

The outlines of the first two of these options are defined in the NOx Technical Code. The Guidelines for the Direct Monitoring Method were developed later and were finalised at MEPC 49 in July 2003 as Resolution MEPC.103(49).

- Engines are installed in accordance with the application and restrictions as given within the Technical File. This covers such matters as rated power, speed and duty (main engine; constant or propeller law speed, auxiliary engines; constant or variable speed). The design requirement is that the engine is to be compliant when operating with 25°C sea water temperature. Therefore, where engines have intermediate, for example fresh water, cooled charge, or scavenge, air coolers, it will be necessary to ensure that they are installed with an adequate cooling capacity to achieve charge / scavenge air temperatures no higher than the reference charge air temperatures ('Tsc ref') as given in the Technical File corresponding to operation with a sea water temperature of 25°C.
- Although the Statement of Compliance with the NOx Technical Code for an engine demonstrates that it was in a compliant condition as manufactured, shipowners may require that a survey be undertaken following installation to confirm that the status of the engine has not been compromised. While such surveys would be voluntary, they are strongly recommended in order to ensure that it will subsequently be possible to complete the mandatory Initial Survey, see next section, when required.
- Over the period up to the Annex VI entry into force date, those engines to which this regulation applies will either need to be maintained in a (voluntary) compliant condition (including the ongoing completion of the Engine Record Book, for those intending to demonstrate compliance by means of the Parameter Check method, in which all changes to NOx critical components or settings are to be recorded) or capable of being put back into such a condition when compliance becomes mandatory. These points in particular must be considered where a change of Flag or ownership is contemplated.

Over this period, shipowners should also consider whether:

- the Onboard NOx Verification Procedure as given within the Technical File is compatible with their operating requirements
- can the engine survey, when required following the entry into force, be undertaken along with other statutory and classification surveys
- will the given survey regime require specialist services to be provided
- the implications in respect to the supply of spare parts are acceptable

In this, it must be remembered that, while the engine builder will have developed the Technical File supplied with the engine as manufactured, the Code fully allows for other parties, such as the shipowner, with or without the cooperation of the engine builder, to also develop new Engine Groups - which would of course need to be approved. Additionally, shipowners may seek to have alternative options added to existing Technical Files in order to give greater operating flexibility. Again those amendments would need to be approved. It would be seen that such alterations would primarily affect the Onboard NOx Verification procedures, either to adopt a form of the Parameter Check Method which was not tied to the original equipment supplier or the utilisation of the Direct Monitoring option.

B.4 SOx Controls

In order to limit SOx emissions Annex VI will introduce a maximum limit of 4.5 % m/m sulphur for all marine fuel oils, irrespective of fuel grade or the type of combustion machinery in which they are to be used. From the MEPC sulphur monitoring programme, which has operated since 1999, covering some 232,000 fuel deliveries to date, the number of deliveries of residual fuel oils to ships with sulphur contents in excess of 4.5 % m/m has been less than 1.0 % each year, the overall average sulphur value being 2.6 / 2.7 % m/m.

Consequently, while this 4.5 % m/m limit does not represent any significant restriction on current fuel supplies, a yet lower limit will apply within designated SOx Emission Control Areas (SECA) which inevitably will have a much wider effect.

The Baltic Sea (as defined in MARPOL Annex I) was the first SECA. At MEPC 44 in March 2000, it was further agreed that the North Sea (as defined in MARPOL Annex V) had met the necessary criteria to be declared a SECA after the entry into force of the Annex. Furthermore, there may be other areas (i.e. areas to the west of the British Isles, west of continental Europe, US coastal waters or the Mediterranean, in total or in part) which may be expected to be proposed as SECAs.

Within a SECA, the requirement will be either a maximum limit of 1.5 % m/m sulphur content to the fuel oil as used or 6.0 g / kWh maximum SOx content of the exhaust gas stream. In practice, it is expected that the majority of ships will seek to comply with the SECA requirements by means of the primary control option of limiting fuel oil sulphur content. Whether in practice this will be achieved by the use of low sulphur residual fuel oils or gas oils (which inherently have sulphur contents below the limit value) will depend on such factors as ship's projected operating profile, bunker tank and transfer systems and the price differentials between the various grades.

Consequently, there will be those ships which will never enter, or alternatively never leave, a SECA. For those ships, the future situation will be relatively straight forward; the respective fuel oil sulphur content limit will apply without exception. The complication arises for ships which use residual fuel oil and operate, or may operate, for only a portion of their time within a SECA, since outside the SECA, such ships will utilise fuel oils of sulphur content typically around 1.5 – 3.5 % m/m. In these instances, it will be necessary to ensure that those ships will have both the necessary segregated bunker capacity and the means to change over to the lower sulphur content fuel prior to entry into a SECA.

Obviously, the effect of this change over requirement is going to differ from ship to ship, but certainly, it can be seen that some ships will require substantial low sulphur fuel oil bunker capacity. In those instances, shipowners will need to consider their options prior to the entry into force of these requirements and take the necessary steps at forthcoming dockings or other opportunities to arrange for the necessary sub-division or addition and segregation of bunker, settling and service tanks and associated piping systems. Ships using residual fuel oil which intend to enter a SECA, but which do not have the capability for two segregated fuel oil grades, will therefore need to operate continuously on the lower sulphur fuel oil with a detrimental effect on fuel costs.

Additionally, where ships are to operate on fuel oils of substantially different sulphur contents, i.e. within and without SECAs, the possible need to change over the engine lubricants will need to be considered. Apart from requiring a further subdivision of the lubricant storage capacity, duplicate service tank systems may also be required.

B.5 Annex VI, After Entry into Force Date

From the entry into force date, compliance in terms of both the equipment and operational requirements of Annex VI will be mandatory for all ships engaged on international voyages and to which the MARPOL Convention applies. In the case of ships of 400 gross tonnage (GT) and above, compliance will be indicated by the issue of an International Air Pollution Prevention Certificate (IAPPC) following an Initial Survey by, or on behalf of, the responsible Flag State. For ships under this tonnage limit, it is for the individual Administrations to set up schemes appropriate to such vessels to ensure compliance.

For ships completed after the entry into force date, the IAPPC will need to be issued prior to entering into service. However, for ships in service at the entry into force date, the IAPPC Initial Survey is to be undertaken no later than the first scheduled drydocking thereafter, although in all cases, it must be satisfactorily completed within three years of the entry into force date.

Thereafter, a system of annual, or intermediate and unscheduled, surveys will apply with a periodic (renewal) survey every five years. These statutory surveys will be undertaken by, or on behalf of, the relevant Flag State and are to be harmonised with the other MARPOL Annex surveys. Additionally, there will be Port State inspections, which may be either random or targeted in terms of the particular ships checked.

In addition to the specific Annex VI requirements, shipowners will also need to ensure that the various operational requirements of the Annex are implemented and verifiable. Consequently, those ISM procedures covering refrigeration, firefighting systems, incineration and bunkering will need to have been updated, as necessary, in addition to those required to cover aspects of the NOx and SOx controls.

The one fundamental point which shipowners must bear in mind is that for ships in service at the entry into force date, and for all ships thereafter, it will be for them to ensure that the necessary valid certification exists and that compliance can be demonstrated at the various scheduled and unscheduled survey stages. While certain aspects of the certification procedure may normally be undertaken by other parties, i.e. the engine builder in the case of the certification of new engines at the manufacturing stage, ultimately that responsibility will rest solely with the shipowner. Any lack of certification or failure to be able to demonstrate the necessary compliance, will effectively bar a ship from international trade.

B.6 NOx Controls

The NOx controls within Regulation 13 form the major part of Annex VI in terms of complexity, implications for the shipowner and survey.

The IAPPC survey scheme with regard to NOx compliance verification is shown in Figure 1.

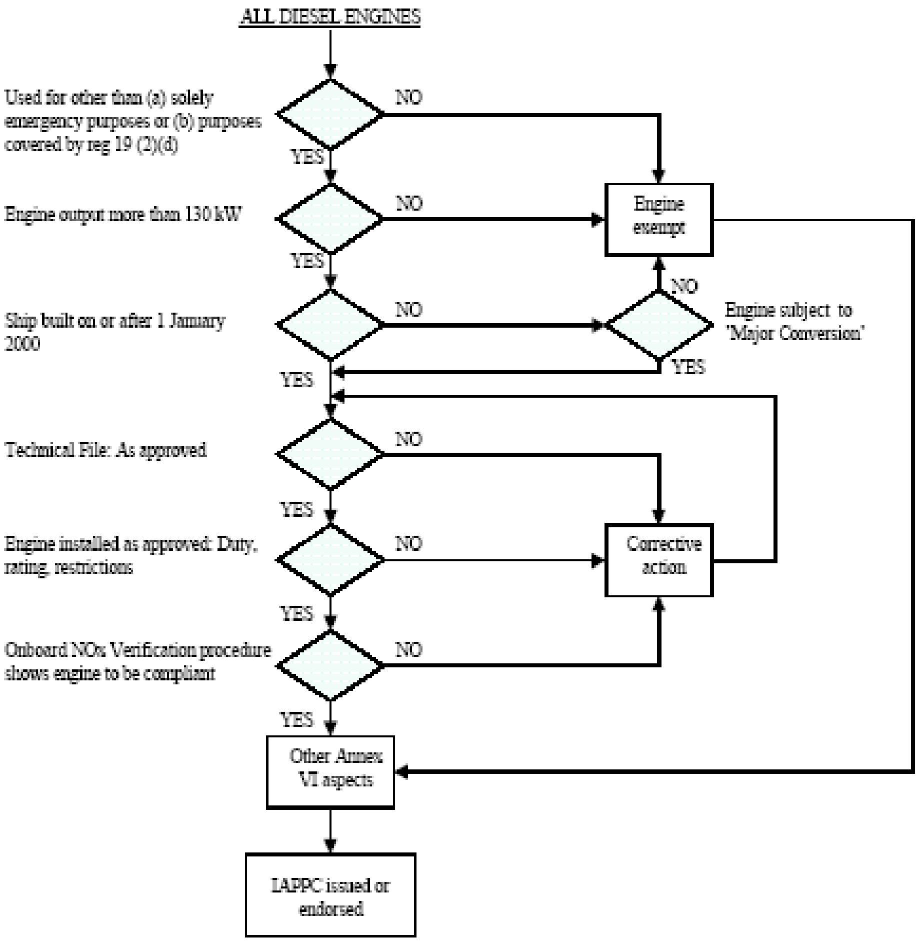

Figure B.1 - NOx Emission Survey Flowsheet.

Any diesel engine falling within the scope of these requirements will need:

- Valid engine certification. Following the entry into force date, Administrations, or organisations acting on their behalf, will issue Engine International Air Pollution Prevention Certificates (EIAPPC) to signify the initial compliance of an engine. For engines already issued with Statements of Compliance with the NOx Technical Code, it would be for the responsible Administration to decide whether or not it would require those Statements to be changed to EIAPPCs – a purely administrative task, no re-survey of the engine would be required.
- Technical File, as approved by, or on behalf of, the ship's Flag State, including any associated approved Technical File 'Change Sheets' reflecting modifications (amendments, additions or deletions). As in the previous section, it will be necessary that this document is retained, in good order, onboard with the engine to which it relates. Where amendments, additions or deletions are necessary, these will need to be duly approved by, or on behalf of, the relevant Flag State.
- Installed in accordance with the duty, rating and restrictions as given in the Technical File.
- In the case where the Onboard NOx Verification procedure is to be based on the Parameter Check method, the Engine Record Book will need to be accurately maintained. This document, as required by the NOx Technical Code, is to provide a chronological record of any changes to NOx critical components or settings, including adjustments, part replacements and implementation of approved modifications. As with the Technical File, this record is to be retained with the engine to which it refers and must be available, and complete, at the time of scheduled or unscheduled (i.e. Port State) surveys. However, unlike the Technical File, this record will be completed by the ship's staff.
- To be in a demonstrably (i.e. surveyable) compliant condition.

Consequently, any engines installed between 1 January 2000 and the entry into force date, which were modified from their initial NOx compliant condition or to which spare parts have been fitted, which do not enable the Onboard NOx Verification procedure, as given in the Technical File, to be applied, will need to be re-instated to their ‘as approved’ condition.

With the need to actually implement the Onboard NOx Verification procedures as given within the Technical Files, it is to be expected that there will be a greater tendency for shipowners to take action to ensure that such procedures can be applied without undue delay, or specialist services, while retaining the flexibility of component supply to which the industry has been accustomed. Shipowners may also seek to influence the engine builders as to the nature of the verification procedures contained within the Technical Files as supplied, or may take a more direct form in proposing to the responsible Administration alternative survey schemes.

B.7 SOx Controls

All fuel oils for use onboard will need to be ordered, and verified from the bunker receipt on delivery, as having a maximum sulphur content of 4.5 % m/m. The exception to this is where ships are to operate within a SECA with compliance through primary, rather than secondary controls. In those instances, the fuel oils to be used within a SECA are to be ordered, and verified, to have a maximum sulphur content of 1.5 % m/m.

Where a ship enters a SECA it will be necessary that the fuel oil service system is fully changed over and flushed of all fuel oils exceeding 1.5 % m/m prior to that entry into the SECA. Consequently, it will be necessary to have onboard, prior to entering such an area, an adequate quantity of 1.5 % m/m maximum sulphur fuel oil. However, this requirement will not be applied to vessels operating in a SECA during the first year after the entry into force date or, where such areas are declared after that date, the first year after their designation.

Obviously, the accurate completion of the mandatory (MARPOL Annex I) Oil Record Book will be an essential element in keeping track of the different fuel oil grades (in terms of sulphur content) onboard. Additionally, under the Annex VI requirements, it will be necessary to record the date, time and position when this change over was completed into the ship’s log-book, together with the quantities of low sulphur fuels in each tank (storage, settling or service). Although departure from a SECA is not specifically mentioned within the regulation, these requirements should be considered to be equally applicable on exit from a SECA.

Consequently, the date, time and position at which that change over process back to a higher sulphur fuel oil (4.5% m/m maximum) was commenced, of course after exiting a SECA, will therefore also need to be recorded entry in the log-book.

B.8 Fuel Oil Quality

Although entitled fuel oil quality, the relevant requirements only cover some of the commercial aspects which so often affect supply. These requirements are essentially operational in nature. From the entry into force date, it will be necessary to ensure that:

- Marine fuel oils are only supplied by companies registered with the appropriate authority of the country in which they operate.
- Bunker receipts are only accepted from the supplier if they are fully in accordance with the required scope (given in Appendix V of Annex VI), particularly the statement as to the actual sulphur content. Additionally, the bunker receipt must include the required composition clause in order to indicate that the fuel is free of certain deleterious materials.
- For ships of 400 GT and above, the bunker receipt is to be kept onboard for a minimum period of 3 years from the date of delivery. Individual Administrations may extend this requirement to ships below that tonnage limit.
- For those ships which are required to keep their bunker receipts onboard, as above, a retained sample of all fuel oils as supplied is drawn in accordance with defined Guidelines, MEPC.96(47), at the ship's receiving manifold, sealed and signed on behalf of the supplier and the Master or ship's officer in charge of the bunkering operation.

  This retained sample is to be kept under the ship's control until the subject fuel oil has been substantially consumed, but in any case, for at least 12 months from the date of delivery.

From the above, it is evident that, at change of owner or management, it will be vital for the incoming organisation to ensure the availability of the documentation (i.e. Technical File, Engine Record Book and bunker receipts), together with the representative fuel oil samples required to demonstrate compliance as necessary (American Bureau of Shipping).

Appendix C. Emissions to Air in Norway

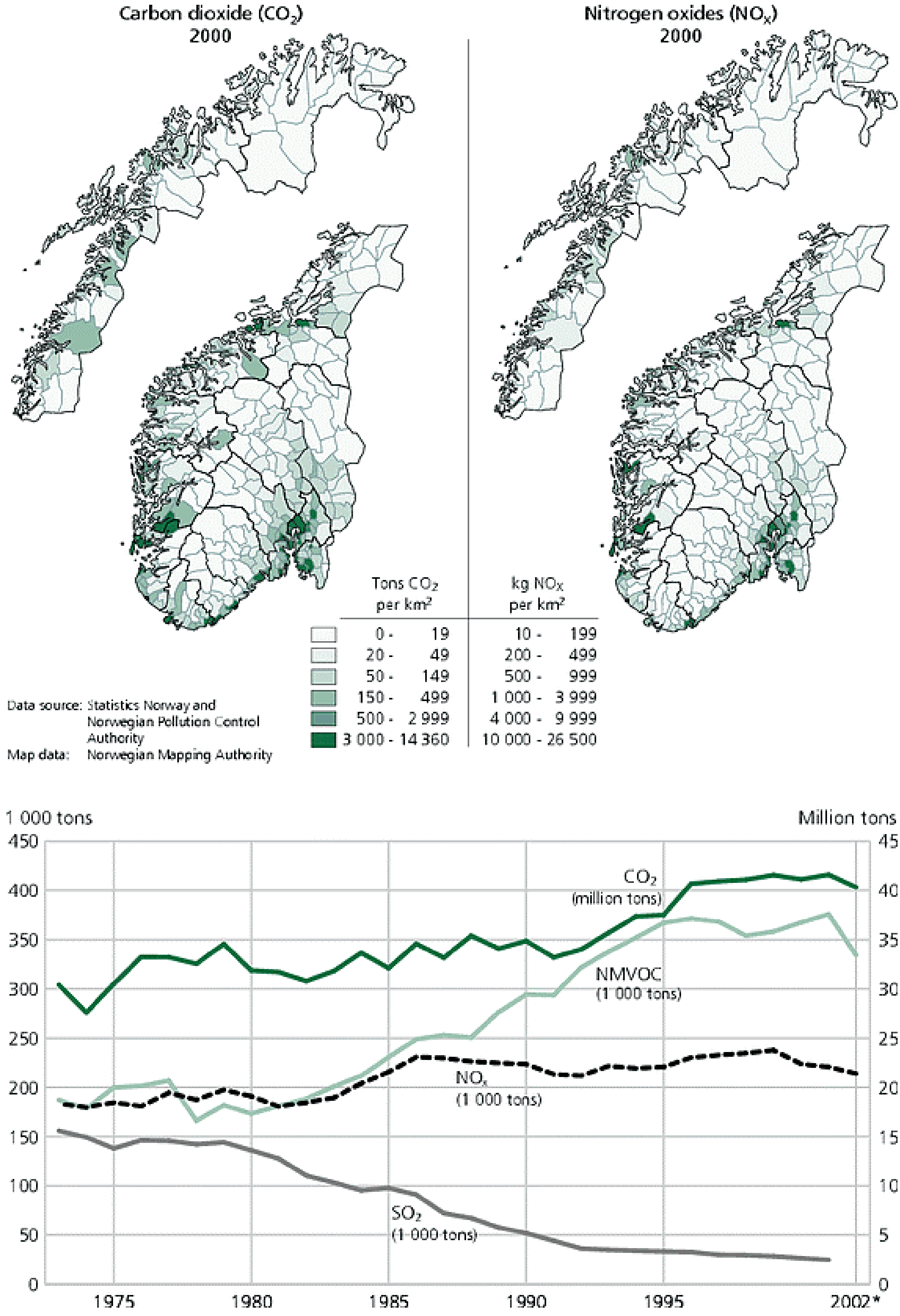

Figure C.1 - Emissions to air in Norway [29].

Table C.1 - Emissions to air (1000 tonnes) by source in 2002 (does not include international sea traffic) [29].

	CO_2	CH_4	N_2O	SO_2	NO_X	NH_3	NMVOC	CO	PM
Total	40900.0	327.4	18.8	22.1	213.0	22.2	344.9	529.6	61.6
Stationary combustion	17600.0	11.7	0.3	5.5	56.7	0.1	12.4	193.2	43.8
Process emissions	7800.0	312.8	15.8	13.3	9.6	20.2	278.0	30.1	12.9
Mobile combustion	15600.0	2.9	2.6	3.3	146.7	1.9	54.5	306.3	4.9

Table C.2 - Emissions to air (1000 tonnes) by source in 2002 (does not include international sea traffic) [29].

	CO_2	CH_4	N_2O	SO_2	NO_X	NH_3	NMVOC	CO	PM
Road traffic	9500.0	2.1	2.1	0.5	44.1	1.9	35.5	239.8	2.4
Shipping	3800.0	0.4	0.1	2.5	84.7	-	2.6	6.0	0.7
Coastal traffic, etc.	2100.0	0.2	0.1	1.5	45.8	-	1.6	1.7	0.5
Fishing vessels	1500.0	0.1	0.0	0.9	33.7	-	0.7	3.7	0.2
Mobile oil rigs, etc.	200.0	0.1	0.0	0.1	5.2	-	0.4	0.5	0.0
Other transport[1]	1300.0	0.4	0.2	0.3	17.9	-	16.4	60.5	1.8

[1] Other transport - snow scooters, small boats, railways, air traffic, motorized equipment.

Appendix D. Gothenburg Protocol

PROTOCOL TO THE 1979 CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION TO ABATE ACIDIFICATION, EUTROPHICATION AND GROUND-LEVEL OZONE - selected articles.

Article 2

OBJECTIVE

The objective of the present Protocol is to control and reduce emissions of sulphur, nitrogen oxides, ammonia and volatile organic compounds that are caused by anthropogenic activities and are likely to cause adverse effects on human health, natural ecosystems, materials and crops, due to acidification, eutrophication or ground-level ozone as a result of long-range transboundary atmospheric transport, and to ensure, as far as possible, that in the long term and in a stepwise approach, taking into account advances in scientific knowledge, atmospheric depositions or concentrations do not exceed:

(a) For Parties within the geographical scope of EMEP (EMEP means the Cooperative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe) and Canada, the critical loads of acidity, as described in annex I;

(b) For Parties within the geographical scope of EMEP, the critical loads of nutrient nitrogen, as described in annex I; and

(c) For ozone:

(i) For Parties within the geographical scope of EMEP, the critical levels of ozone, as given in annex I;

(ii) For Canada, the Canada-wide Standard for ozone; and

(iii) For the United States of America, the National Ambient Air Quality Standard for ozone.

Article 3

BASIC OBLIGATIONS

1. Each Party having an emission ceiling in any table in annex II shall reduce and maintain the reduction in its annual emissions in accordance with that ceiling and the timescales specified in that annex. Each Party shall, as a minimum, control its annual emissions of polluting compounds in accordance with the obligations in annex II.

2. Each Party shall apply the limit values specified in annexes IV, V and VI to each new stationary source within a stationary source category as identified in those annexes, no later than the timescales specified in annex VII. As an alternative, a Party may apply different emission reduction strategies that achieve equivalent overall emission levels for all source categories together.
3. Each Party shall, in so far as it is technically and economically feasible and taking into consideration the costs and advantages, apply the limit values specified in annexes IV, V and VI to each existing stationary source within a stationary source category as identified in those annexes, no later than the timescales specified in annex VII. As an alternative, a Party may apply different emission reduction strategies that achieve equivalent overall emission levels for all source categories together or, for Parties outside the geographical scope of EMEP, that are necessary to achieve national or regional goals for acidification abatement and to meet national air quality standards.
4. Limit values for new and existing boilers and process heaters with a rated thermal input exceeding 50 MWth and new heavy-duty vehicles shall be evaluated by the Parties at a session of the Executive Body with a view to amending annexes IV, V and VIII no later than two years after the date of entry into force of the present Protocol.
5. Each Party shall apply the limit values for the fuels and new mobile sources identified in annex VIII, no later than the timescales specified in annex VII.
6. Each Party should apply best available techniques to mobile sources and to each new or existing stationary source, taking into account guidance documents I to V adopted by the Executive Body at its seventeenth session (decision 1999/1) and any amendments thereto.
7. Each Party shall take appropriate measures based, *inter alia*, on scientific and economic criteria to reduce emissions of volatile organic compounds associated with the use of products not included in annex VI or VIII. The Parties shall, no later than at the second session of the Executive Body after the entry into force of the present Protocol, consider with a view to adopting an annex on products, including criteria for the selection of such products, limit values for the volatile organic compound content of products not included in annex VI or VIII, as well as timescales for the application of the limit values.
8. Each Party shall, subject to paragraph 10:

(a) Apply, as a minimum, the ammonia control measures specified in annex IX; and

(b) Apply, where it considers it appropriate, best available techniques for preventing and reducing ammonia emissions, as listed in guidance document V adopted by the Executive Body at its seventeenth session (decision 1999/1) and any amendments thereto.

9. Paragraph 10 shall apply to any Party:

(a) Whose total land area is greater than 2 million square kilometres;

(b) Whose annual emissions of sulphur, nitrogen oxides, ammonia and/or volatile organic compounds contributing to acidification, eutrophication or ozone formation in areas under the jurisdiction of one or more other Parties originate predominantly from within an area under its jurisdiction that is listed as a PEMA in annex III, and which has presented documentation in accordance with subparagraph

(c) to this effect;

(c) Which has submitted upon signature, ratification, acceptance or approval of, or accession to, the present Protocol a description of the geographical scope of one or more PEMAs for one or more pollutants, with supporting documentation, for inclusion in annex III; and

(d) Which has specified upon signature, ratification, acceptance or approval of, or accession to, the present Protocol its intention to act in accordance with this paragraph.

10. A Party to which this paragraph applies shall:

(a) If within the geographical scope of EMEP, be required to comply with the provisions of this article and annex II only within the relevant PEMA for each pollutant for which a PEMA within its jurisdiction is included in annex III; or

(b) If not within the geographical scope of EMEP, be required to comply with the provisions of paragraphs 1, 2, 3, 5, 6 and 7 and annex II, only within the relevant PEMA for each pollutant (nitrogen oxides, sulphur and/or volatile organic compounds) for which a PEMA within its jurisdiction is included in annex III, and shall not be required to comply with paragraph 8 anywhere within its jurisdiction.

11. Canada and the United States of America shall, upon their ratification, acceptance or approval of, or accession to, the present Protocol, submit to the Executive Body their respective emission reduction commitments with respect to sulphur, nitrogen oxides and volatile organic compounds for automatic incorporation into annex II.

12. The Parties shall, subject to the outcome of the first review provided for under article 10, paragraph 2, and no later than one year after completion of that review, commence negotiations on further obligations to reduce emissions.

Annex II

EMISSION CEILINGS

The emission ceilings listed in the tables below relate to the provisions of article 3, paragraphs 1 and 10, of the present Protocol. The 1980 and 1990 emission levels and the percentage emission reductions listed are given for information purposes only.

Table D.1 - Emission ceilings for sulphur (thousands of tonnes of SO_2 per year).

Party	Emission level		Emission ceilings for 2010	Percentage emission reductions for 2010 (base year 1990)
	1980	1990		
Armenia	141	73	73	0 %
Austria	400	91	39	-57 %
Belarus	740	637	480	-25 %
Belgium	828	372	106	-72 %
Bulgaria	2050	2008	856	-57 %
Canada national a/	4643	3236		
PEMA (SOMA)	3135	1873		
Croatia	150	180	70	-61 %
Czech Republic	2257	1876	283	-85 %
Denmark	450	182	55	-70 %
Finland	584	260	116	-55 %
France	3208	1269	400	-68 %
Germany	7514	5313	550	-90 %
Greece	400	509	546	7 %
Hungary	1633	1010	550	-46 %
Ireland	222	178	42	-76 %
Italy	3757	1651	500	-70 %
Latvia	-	119	107	-10 %
Liechtenstein	0.39	0.15	0.11	-27 %
Lithuania	311	222	145	-35 %
Luxembourg	24	15	4	-73 %
Netherlands	490	202	50	-75 %
Norway	137	53	22	-58 %
Poland	4100	3210	1397	-56 %
Portugal	266	362	170	-53 %
Republic of Moldova	308	265	135	-49 %
Romania	1055	1311	918	-30 %
Russian Federation b/	7161	4460		
PEMA	1062	1133	635	-44 %
Slovakia	780	543	110	-80 %
Slovenia	235	194	27	-86 %
Spain b/	2959	2182	774	-65 %
Sweden	491	119	67	-44 %
Switzerland	116	43	26	-40 %
Ukraine	3849	2782	1457	-48 %
United Kingdom	4863	3731	625	-83 %
United States of America				
European Community	26456	16436	4059	-75 %

a/ Upon ratification, acceptance or approval of, or accession to, the present Protocol, Canada shall submit an emission ceiling for sulphur, either at a national level or for its PEMA (Pollutant emissions management area), and will endeavour to provide a ceiling for 2010. The PEMA for sulphur will be the sulphur oxides management area (SOMA) that was designated pursuant to annex III to the Protocol on Further Reduction of Sulphur Emissions adopted at Oslo on 14 June 1994 as the South-east Canada SOMA. This is an area of 1 million km^2 which includes all the territory of the provinces of Prince Edward Island, Nova Scotia and New Brunswick, all the territory of the province of Quebec south of a straight line between Havre-St. Pierre on the north coast of the Gulf of Saint Lawrence and the point where the Quebec-Ontario boundary intersects the James Bay coastline, and all the territory of the province of Ontario south of a straight line between the point where the Ontario-Quebec boundary intersects the James Bay coastline and Nipigon River near the north shore of Lake Superior.

b/ Figures apply to the European part within the EMEP area.

c/ Upon ratification, acceptance or approval of, or accession to, the present Protocol, the United States of America shall provide for inclusion in this annex: (a) specific emission reduction measures applicable to mobile and stationary sources of sulphur to be applied either nationally or within a PEMA if it has submitted a PEMA for sulphur for inclusion in annex III; (b) a value for total estimated sulphur emission levels for 1990, either national or for the PEMA; (c) an indicative value for total sulphur emission levels for 2010, either national or for the PEMA; and (d) associated estimates of the percentage reduction in sulphur emissions. Item (b) will be included in the table and items (a), (c) and (d) will be included in a footnote to the table.

Table D.2 - Emission ceilings for nitrogen oxides (thousands of tonnes of NO_2 per year).

Party	Emission level 1990	Emission ceilings for 2010	Percentage emission reductions for 2010 (base year 1990)
Armenia	46	46	0 %
Austria	194	107	-45 %
Belarus	285	255	-11 %
Belgium	339	181	-47 %
Bulgaria	361	266	-26 %
Canada a1/	2104		
Croatia	87	87	0 %
Czech Republic	742	286	-61 %
Denmark	282	127	-55 %
Finland	300	170	-43 %
France	1882	860	-54 %
Germany	2693	1081	-60 %
Greece	343	344	0 %
Hungary	238	198	-17 %
Ireland	115	65	-43 %
Italy	1938	1000	-48 %
Latvia	93	84	-10 %
Liechtenstein	0.63	0.37	-41 %
Lithuania	158	110	-30 %
Luxembourg	23	11	-52 %
Netherlands	580	266	-54 %
Norway	218	156	-28 %
Poland	1280	879	-31 %
Portugal	348	260	-25 %
Republic of Moldova	100	90	-10 %
Romania	546	437	-20 %
Russian Federation b1/	3600		
PEMA	360	265	-26 %
Slovakia	225	130	-42 %
Slovenia	62	45	-27 %
Spain b/	1113	847	-24 %
Sweden	338	148	-56 %
Switzerland	166	79	-52 %
Ukraine	1888	1222	-35 %
United Kingdom	2673	1181	-56 %
United States of America c1/			
European Community	13161	6671	-49 %

a1/ Upon ratification, acceptance or approval of, or accession to, the present Protocol, Canada shall submit 1990 emission levels and 2010 emission ceilings for nitrogen oxides, either at a national level or for its PEMA for nitrogen oxides, if it has submitted one.

b1/ Figures apply to the European part within the EMEP area.

c1/ Upon ratification, acceptance or approval of, or accession to, the present Protocol, the United States of America shall provide for inclusion in this annex: (a) specific emission reduction measures applicable to mobile and stationary sources of nitrogen oxides to be applied either nationally or within a PEMA if it has submitted a PEMA for nitrogen oxides for inclusion in annex III; (b) a value for total estimated nitrogen oxide emission levels for 1990, either national or for the PEMA; (c) an indicative value for total nitrogen oxide emission levels for 2010, either national or for the PEMA; and (d) associated estimates of the percentage reduction in nitrogen oxide emissions. Item (b) will be included in the table and items (a), (c) and (d) will be included in a footnote to the table (United Nations Economic Commission for Europe).

Table D.3 - Emission ceilings for ammonia (thousands of tonnes of NH_3 per year).

Party	Emission level 1990	Emission ceilings for 2010	Percentage emission reductions for 2010 (base year 1990)
Armenia	25	25	0 %
Austria	81	66	-19 %
Belarus	219	158	-28 %
Belgium	107	74	-31 %
Bulgaria	144	108	-25 %
Croatia	37	30	-19 %
Czech Republic	156	101	-35 %
Denmark	122	69	-43 %
Finland	35	31	-11 %
France	814	780	-4 %
Germany	764	550	-28 %
Greece	80	73	-9 %
Hungary	124	90	-27 %
Ireland	126	116	-8 %
Italy	466	419	-10 %
Latvia	44	44	0 %
Liechtenstein	0.15	0.15	0 %
Lithuania	84	84	0 %
Luxembourg	7	7	0 %
Netherlands	226	128	-43 %
Norway	23	23	0 %
Poland	508	468	-8 %
Portugal	98	108	10 %
Republic of Moldova	49	42	-14 %
Romania	300	210	-30 %
Russian Federation a2/	1191		
PEMA	61	49	-20 %
Slovakia	62	39	-37 %
Slovenia	24	20	-17 %
Spain a2/	351	353	1 %
Sweden	61	57	-7 %
Switzerland	72	63	-13 %
Ukraine	729	592	-19 %
United Kingdom	333	297	-11 %
European Community	3671	3129	-15 %

a2/ Figures apply to the European part within the EMEP area.

Table D.4 - Emission ceilings for volatile organic compounds (thousands of tonnes of VOC per year).

Party	Emission level 1990	Emission ceilings for 2010	Percentage emission reductions for 2010 (base year 1990)
Armenia	81	81	0 %
Austria	351	156	-55 %
Belarus	533	309	-42 %
Belgium	324	144	-56 %
Bulgaria	217	185	-15 %
Canada a3/	2880		
Croatia	105	90	-14 %
Czech Republic	435	220	-49 %
Denmark	178	85	-52 %
Finland	209	130	-38 %
France	2957	1100	-63 %
Germany	3195	995	-69 %
Greece	373	261	-30 %
Hungary	205	137	-33 %
Ireland	197	55	-72 %
Italy	2213	1159	-48 %
Latvia	152	136	-11 %
Liechtenstein	1.56	0.86	-45 %
Lithuania	103	92	-11 %
Luxembourg	20	9	-55 %
Netherlands	502	191	-62 %
Norway	310	195	-37 %
Poland	831	800	-4 %
Portugal	640	202	-68 %
Republic of Moldova	157	100	-36 %
Romania	616	523	-15 %
Russian Federation b3/	3566		
PEMA	203	165	19 %
Slovakia	149	140	-6 %
Slovenia	42	40	-5 %
Spain b3/	1094	669	-39 %
Sweden	526	241	-54 %
Switzerland	292	144	-51 %
Ukraine	1396	797	-42%
United Kingdom	2555	1200	-53 %
United States of America c3/			
European Community	15353	6600	-57 %

a3/ Upon ratification, acceptance or approval of, or accession to, the present Protocol, Kanada shall submit 1990 emission levels and 2010 emission ceilings for volatile organic compounds, either at a national level or for its PEMA for volatile organic compounds, if it has submitted one.

b3/ Figures apply to the European part within the EMEP area.

c3/ Upon ratification, acceptance or approval of, or accession to, the present Protocol, the United States of America shall provide for inclusion in this annex: (a) specific emission reduction measures applicable to mobile and stationary sources of volatile organic compounds to be applied either nationally or within a PEMA if it has submitted a PEMA for volatile organic compounds for inclusion in annex III; (b) a value for total estimated volatile organic compound emission levels for 1990, either national or for the PEMA; (c) an indicative value for total volatile organic compound emission levels for 2010, either national or for the PEMA; and (d) associated estimates of the percentage reduction in volatile organic compound emissions. Item (b) will be included in the table and items (a), (c) and (d) will be included in a footnote to the table.

Appendix E. Draft Regulation Concerning Gas-Fuelled Engine Installations in Cargo Ships

Laid down by the Norwegian Maritime Directorate on …………… pursuant to the Act of 9 June 1903 No. 7 relating to Public Control of the Seaworthiness of Ships, etc, § 41, § 41a first paragraph, subparagraph a), § 42 first paragraph, subparagraphs c), d), g) and h), and third paragraph, subparagraph a).

Chapter 1
General provisions

§ 1
Scope of application

This regulation applies to:

a) cargo ships with an internal combustion engine installation fuelled by liquefied natural gas (LNG). The regulation may, insofar as it is appropriate, also be made applicable to LNG carriers where the cargo is used as bunker fuel.
b) cargo ships with a low-pressure systems plant in which the pressure is less than 10 bars.

§ 2
Relation to classification society rules

Matters which are not regulated herein shall comply with the DNV rules contained in *Gas fuelled engine installations* of January 2001 or the equivalent rules of any other recognized classification society upon the approval of the Norwegian Maritime Directorate.

§ 3
Relations with bodies etc. concerned

Matters which concern bodies or authorities etc. outside the area of responsibility of the maritime administration shall not be submitted to the Norwegian Maritime Directorate, but to the body etc. concerned for consideration and, where appropriate, approval in accordance with the requirements of that body.

§ 4
Definitions

For the purpose of this regulation, the following definitions shall apply:

a) *Recognized classification society:* Any classification society with which the Ministry has entered into an agreement pursuant to § 9 of the Seaworthiness Act:

1. Det Norske Veritas (DNV).
2. Lloyd's Register of Shipping (LRS).
3. Bureau Veritas (BV).
4. Germanischer Lloyd (GL).
5. American Bureau of Shipping (ABS).

b) *A-60 fire integrity:* Class A-60 fire-resistant division, ref. chapter II-2 of the SOLAS Convention.
c) *Semi-enclosed space:* Any area where natural conditions of ventilation are notably different from those on open decks due the presence of structures such as deck, floor, wind breakers or bulkheads which are so arranged that there may be accumulation of gas.
d) *Dual-fuel engine:* An internal combustion engine which can burn gaseous and liquid fuel simultaneously and in a variety of proportions.
e) *Formal safety assessment:* An analysis which is in accordance with the resolution currently in force concerning *Formal Safety Assessment* (FSA) developed by the IMO *(International Maritime Organization)*.
f) *Gas-dangerous space:* An enclosed or semi-enclosed space containing a gas source or sources or arranged with direct access or openings into any other gas-dangerous area.
g) *Gas-dangerous zones:* Zones on open decks or semi-enclosed spaces on open decks within:
- 3 metres of the gas tank pressure relief valve exhaust outlets.
- 3 metres of gas tank openings, gas pipe flanges, or openings to gas-dangerous spaces containing gas sources.
- 3 metres of ventilation exhaust openings from spaces where any gas compressors, pumps or similar equipment are present and of ventilation exhaust openings from pipe ducting and gas-fuelled engine or valve installation spaces.
- 2.4 metres of the outer surface of a gas containment system where such surface is exposed to the weather.

h) *Gas source:* Any valve, detachable pipe joint, pipe packing, compressor or pump seal in the gas fuel system.
i) *Gas-safe areas:* Spaces or zones not being gas dangerous.
j) *Gas machinery spaces:* Spaces where internal combustion engines fuelled by gas and any generators are located.
k) *Gas lock:* An enclosed space for passage between gas-dangerous and gas-safe areas to prevent the ingress of gas to a gas-safe area.
l) *Classed vessel:* A ship/barge assigned class in a recognized classification society.
m) *Control station:* A space defined as a control station in the SOLAS Convention, chapter II-2.
n) *Cargo ship:* Any ship that is not a passenger ship, fishing vessel, mobile offshore unit, barge or pleasure craft.
o) *LNG:* Liquefied natural gas.
p) *LNG carrier:* Cargo ship constructed or equipped for the carriage of LNG in bulk, ref. the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).
q) *SOLAS Convention:* International Convention for the Safety of Life at Sea, 1974, as amended.
r) *Tank space:* A space in which a gas storage tank with its associated and necessary equipment is fitted.
s) *Valve installation space:* A space in which necessary gas control equipment for gas-fuelled engines is fitted.

§ 5

Responsibility

The company and the master are responsible for ensuring compliance with the provisions of this regulation.

§ 6

Exemptions

The Norwegian Maritime Directorate may, in individual cases and upon written application, grant exemptions from the requirements of this regulation. There must be special reasons that make an exemption necessary and it must be justifiable in terms of safety. Exemptions must not contravene international agreements to which Norway has acceded.

Chapter 2
Approval, etc.

§ 7

Approval - Verification

(1) For classed vessels, a written statement shall be submitted by the classification society declaring that the vessel complies with this regulation prior to any initial survey report, trading certificate, or safety construction certificate being issued.
(2) Prior to the initial issue of certificates and at subsequent renewals, the Norwegian Maritime Directorate may demand verification of compliance with the requirements of this regulation.
(3) The Norwegian Maritime Directorate may demand that practical tests be conducted to document correspondence between rules, regulations and preconditions.
(4) The company shall ensure that for every construction project a responsible coordinator is designated who is charged with ensuring compatibility between components from subvendors, designing a testing and control programme, as well as ensuring the right combination of all control and regulation arrangements in connection with propulsion and power generation, including the associated emergency arrangement.
(5) Conditions or incidents which may affect the vessel's surroundings are not considered by the Norwegian Maritime Directorate, but shall be submitted to the competent authority for consideration and, where appropriate, approval.

Chapter 3
Documentation and general construction requirements

§ 8

Documentation

(1) All matters contained in this regulation shall be documentable but the documentation shall be submitted to the Norwegian Maritime Directorate only as required by the Directorate.
(2) A formal safety assessment shall be undertaken for any new or altered concept, which is required to document a safety level which is at least equivalent to a new, comparable diesel-engine vessel. Such assessments shall be made of the final concept and shall comprise all relevant risks, including such conditions as are exterior to the vessel itself, such as densely populated areas, ports, terminals, and oil installations.
(3) An explosion assessment shall be made to ascertain the design overpressure for gas machinery spaces, valve installation spaces or any similar gas-dangerous space with bulkhead, hull, deck, ventilation ducts, and any blowdown installations and/or relief spaces. The assessment shall be based on a stochiometric mixture of gas and made by an institution that is recognized for this type of assessment.

§ 9

Passive safety

(1) The following requirements shall be complied with in respect of passive safety and redundancy in the event of failure of operational or fitted technical active safety arrangements:
   a) The gas machinery and valve installation spaces shall be located at least 0.1L aft of the collision bulkhead,
   b) the gas tank(s) shall be fitted at least L/3 aft of the collision bulkhead,
   c) the gas machinery, tank and valve installation spaces shall contain only a minimum of such necessary equipment, components and systems as are required to ensure that any piece of equipment in each individual space shall maintain its principal function,
   d) the internal combustion engines for propulsion, associated control systems and engines and power generation systems with appurtenant distribution and wiring shall be located in at least two redundant zones so separated that fire or explosion in any one space does not:
      1. cause damage to any space other than that in which the incident occurs,
      2. disrupt the proper functioning of other zones,
      3. open the ship in such a way that there is flooding of water below the main deck or any other progressive flooding,
      4. damage the deck or accommodation in such a way that people who stay in such areas under normal operating conditions are injured,
      5. disrupt the proper functioning of control stations and switchboard rooms for necessary power distribution,
      6. damage life-saving equipment or associated launching arrangements,
      7. disrupt the proper functioning of fire-fighting equipment located outside the explosion-damaged space, and
      8. affect other areas in the vessel in such a way that chain reactions involving, *inter alia*, cargo, gas and bunker oil may arise.

§ 10

Arrangement

(1) For the arrangement of spaces, accesses, etc., the following shall apply:
   a) A gas machinery space shall under normal conditions not be considered to be gas dangerous unless there is gas leakage, in which case the space shall be considered to be a gas-dangerous space.
   b) In the event of gas detection, the following shall be shut down automatically[1]:
      1. Gas supply to the gas machinery space concerned,
      2. fuel oil supply where a dual fuel engine is used, and
      3. non-ex-proof equipment or installations.
   c) There shall be no direct access from the accommodation to gas machinery spaces, gas-dangerous spaces or gas-dangerous zones. Gas locks are accepted as indirect accesses. Tank spaces and collection arrangements shall be so secured that access will not be possible during normal operation.
   d) Where gas is stored below deck, the gas storage tank with associated and necessary equipment shall be located in a space arranged as a secondary barrier with a collection arrangement in the event of gas leakage.

(2) Gas supply to internal combustion engines shall be by dual pipes as far as practicable.

(3) There shall be a separate earth cable between the tank wagon or tank ashore and the bunkering station on board whenever flammable gas or liquid is transferred. Additionally, the bunkering system shall meet any requirements laid down by the shore plant and the competent authority.

(4) The bunkering station shall be located on the open deck and be physically shielded from accommodation, cargo/working deck and control stations. Connections and piping shall be so positioned and arranged that any damage to the gas piping does not cause damage to the vessel's gas storage tank arrangement leading to uncontrolled gas discharge.
(5) The following ventilation requirements shall apply:
  a) Ventilation shall give lower pressure in gas machinery spaces below deck than in adjacent spaces.
  b) Combustion air to engines shall be supplied in a separate system from an open-air gas-safe area. Where this is not possible, air ducts shall be provided with dampers which close automatically when gas is drawn into the system.
  c) Generators in gas machinery spaces shall be arranged with overpressure ventilation from a gas-safe area.
  d) Every valve installation space shall be provided with separate ventilation with the same number of air exchanges as tank spaces.
(6) The following structural fire safety requirements shall apply:
  a) Bulkheads and decks surrounding gas storage tank spaces and associated ventilation ducts shall have an A-60 fire integrity, unless bounded by tanks with substances that are neither combustible nor dangerous. The use of cofferdams does not influence the A-60 requirement.
  b) Bulkheads and decks between contiguous machinery space zones shall have an A-60 fire integrity.
(7) Gas machinery spaces shall be provided with fixed and appropriate fire-fighting equipment.
(8) The following strength requirements shall apply:
  a) Gas storage tanks, generators and other heavy components of the gas-fuel system shall have such foundations as to withstand a longitudinal retardation of 2g. Other critical components of the gas and control system shall be dimensioned and constructed to withstand the same load.
  b) Gas storage tanks shall be so arranged that they do not float free in the event of flooding of water into the tank space, and
  c) Gas storage tanks which are fitted in or below an area for cargo-handling operations involving the use of a crane shall be protected by a structure dimensioned to withstand potential falling cargo.

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[1] Refer to DNV's rules of January 2001 for *Gas fuelled engine installations* concerning *ESD (Emergency shutdown).*

Operational and training requirements

§ 11
Operational conditions

(1) Procedures shall be developed to take care of the safety aspects of the vessel's ordinary operation, for instance during navigation, in ports, at bases, oil installations, oil fields, and repair yards.
(2) No other operations are permitted on deck simultaneously with a bunkering operation. Operational aspects of the machinery and gas-dangerous spaces and areas shall be specially considered.

§ 12
Training

(1) The whole operational crew of a gas-fuelled cargo ship shall have necessary training in gas-related safety, operation and maintenance prior to the commencement of work on board.
(2) Additionally, crew members with a direct responsibility for the operation of gas-related equipment on board shall receive special training. The company shall document that the personnel have acquired the necessary knowledge and that this knowledge is maintained at all times.
(3) Gas-related emergency exercises shall be conducted at regular intervals. Safety and response systems for the handling of defined hazards and accidents shall be reviewed and tested.
(4) A training manual shall be developed and a training programme and exercises shall be specially designed for each individual vessel and its gas installations.

Chapter 5
Concluding provisions

§ 13
Penalty

Wilful or negligent violation of these regulations is punishable by fines pursuant to the General Civil Penal Code of 22 May 1902 No. 10, § 339 subsection 2, ref. § 48a and § 48b, unless a more severe penalty is applicable pursuant to any other statutory provision.

§ 14
Entry into force

Appendix F. Route of Norwegian Coastal Voyage

F.1 Route of Norwegian Coastal Voyage

Figure F.1 - Route Map of Norwegian Coastal Voyage [30].

Table F.1 - Timetable of Norwegian Coastal Voyage ferries –Northbound [30].

Northbound		Summer	Winter
		16/4-11/9	**1/10-15/4** **12/9-30/9**
From	Bergen	20:00	22:30
	Florø	02:15	04:45
	Måløy	04:30	07:30
	Torvik	07:30	10:45
To	Ålesund	08:45	12:00
From	Ålesund	09:30	/
From	Geiranger*	13:30	/
From	Ålesund	18:45	15:00
	Molde	22:00	18:30
	Kristiansund	01:45	23:00
To	Trondheim	08:15	06:00
From	Trondheim	12:00	12:00
	Rørvik	21:15	21:15
	Brønnøysund	01:00	01:00
	Sandnessjøen	04:15	04:15
	Nesna	05:30	05:30
	Ørnes	09:30	09:30
To	Bodø	12:30	12:30
From	Bodø	15:00	15:00
	Stamsund	19:30	19:30
To	Svolvær	21:00	21:00
From	Svolvær	22:00	22:00
	Stokmarknes	01:00	01:00
	Sortland	03:00	03:00
	Risøyhamn	04:30	04:30
To	Harstad	06:45	06:45
From	Harstad	08:00	08:00
	Finnsnes	11:45	11:45
To	Tromsø	14:30	14:30
From	Tromsø	18:30	18:30
	Skjervøy	22:45	22:45
	Øksfjord	02:15	02:15
To	Hammerfest	05:15	05:15
From	Hammerfest	06:45	06:45
	Havøysund	09:45	09:45
To	Honningsvåg	11:45	11:45
From	Honningsvåg	15:15	15:15
	Kjøllefjord	17:45	17:45
	Mehamn	20:00	20:00
	Berlevåg	22:45	22:45
	Båtsfjord	01:00	01:00
To	Vardø	04:00	04:00
From	Vardø	04:15	04:15
	Vadsø	08:15	08:15
To	Kirkenes	10:00	10:00

* Hurtigruten calls at Geiranger in the period 17 April - 12 September.

Table F.2 -. Timetable of Norwegian Coastal Voyage ferries –Southbound [30].

Southbound		Summer	Winter
		16/4-11/9	1/10-15/4
			12/9-30/9
From	Kirkenes	12:45	12:45
	Vadsø	/	/
To	Vardø	16:00	16:00
From	Vardø	17:00	17:00
	Båtsfjord	20:30	20:30
	Berlevåg	22:30	22:30
	Mehamn	01:15	01:15
	Kjøllefjord	03:30	03:30
	Honningsvåg	06:15	06:15
	Havøysund	08:30	08:30
To	Hammerfest	11:15	11:15
From	Hammerfest	12:45	12:45
	Øksfjord	15:45	15:45
	Skjervøy	19:45	19:45
To	Tromsø	23:45	23:45
From	Tromsø	01:30	01:30
	Finnsnes	04:45	04:45
To	Harstad	08:00	08:00
From	Harstad	08:30	08:30
	Risøyhamn	11:00	11:00
	Sortland	13:00	13:00
	Stokmarknes	15:15	15:15
To	Svolvær	18:30	18:30
From	Svolvær	19:30	19:30
	Stamsund	21:30	21:30
To	Bodø	01:30	01:30
From	Bodø	04:00	04:00
	Ørnes	07:15	07:15
	Nesna	11:15	11:15
	Sandnessjøen	13:30	13:30
	Brønnøysund	17:00	17:00
	Rørvik	21:30	21:30
To	Trondheim	06:30	06:30
From	Trondheim	10:00	10:00
	Kristiansund	17:00	17:00
	Molde	21:30	21:30
To	Ålesund	24:00	24:00
From	Ålesund	00:45	00:45
	Torvik	02:15	02:15
	Måløy	05:45	05:45
	Florø	08:15	08:15
To	Bergen	14:30	14:30

Table F.3 - Time and distance [30].

City		Time [h]	Distance [nm]
From	To		
Bergen		**5:30**	—
Bergen	Florø	6:15	90
Florø	Måløy	2:15	25
Måløy	Torvik	3:00	36
Torvik	Ålesund	1:15	16
Ålesund		**0:45**	—
Ålesund	Geiranger	4:00	54
Geiranger	Ålesund	5:15	54
Ålesund	Molde	3:15	36
Molde	Kristiansund	3:45	45
Kristiansund	Trondheim	6:30	90
Trondheim		**3:45**	—
Trondheim	Rørvik	9:15	124
Rørvik	Brønnøysund	3:45	43
Brønnøysund	Sandenessjøen	3:15	36
Sandenessjøen	Nesna	1:15	16
Nesna	Ørnes	4:00	50
Ørnes	Bodø	3:00	39
Bodø		**2:30**	—
Bodø	Stamsund	4:30	55
Stamsund	Svolvær	1:30	17
Svolvær		**1:00**	—
Svolvær	Stokmarknes	3:00	33
Stokmarknes	Sortland	2:00	14
Sortland	Risøyhamn	1:30	16
Risøyhamn	Harstad	2:15	26
Harstad		**1:15**	—
Harstad	Finnsens	3:45	37
Finnsens	Tromsø	2:45	35
Tromsø		**4:00**	—
Tromsø	Skjervøy	4:15	55
Skjervøy	Øksford	3:30	46
Øksford	Hammerfest	3:00	39
Hammerfest		**1:30**	—
Hammerfest	Havøysund	3:00	35
Havøysund	Honningsvåg	2:00	32
Honningsvåg		**3:30**	—
Honningsvåg	Kjøllefjord	2:30	43
Kjøllefjord	Mehamn	2:15	24
Mehamn	Berlevåg	2:45	35
Berlevåg	Båtsfjord	2:15	23
Båtsfjord	Vardø	3:00	40
Vardø		**2:15**	—
Vardø	Vadsø	4:00	40
Vadsø	Kirkenes	5:15	25
Kirkenes		**2:45**	—

F.2 Statistics

Table F.4 - Number of passengers by port 2002-2003 [29].

Port	2002		2003	
	From	To	From	To
Totalt	**547 407**	**547 407**	**528 543**	**528 543**
Bergen	83 454	69 283	87 659	71 458
Florø	4 620	2 877	4 458	2 579
Måløy	1 396	2 822	1 192	2 487
Torvik	3 827	3 912	2 886	3 335
Ålesund	21 013	15 158	17 395	13 128
Geiranger	3 979	2 772	4 212	3 224
Ålesund	3 128	10 645	3 145	8 132
Molde	10 492	10 229	8 239	9 141
Kristiansund	6 994	9 910	5 670	10 222
Trondheim	41 615	52 033	41 185	50 286
Rørvik	12 884	12 774	11 696	12 062
Brønnøysund	8 787	12 258	7 668	10 349
Sandnessjøen	10 231	7 998	9 131	6 620
Nesna	6 989	4 621	5 984	3 946
Ørnes	5 713	4 173	5 258	3 999
Bodø	45 557	29 985	43 173	28 316
Stamsund	20 708	27 672	18 959	25 934
Svolvær	24 708	40 586	23 945	40 482
Stokmarknes	13 554	9 543	13 683	8 138
Sortland	9 657	8 611	8 284	7 653
Risøyhamn	4 406	4 109	3 701	3 121
Harstad	22 346	15 237	23 700	14 747
Finnsnes	10 286	7 327	10 023	6 324
Tromsø	43 316	54 415	41 315	55 465
Skjervøy	10 616	7 518	10 125	6 511
Øksfjord	4 113	4 513	3 600	3 837
Hammerfest	16 205	14 901	15 390	14 283
Havøysund	3 652	3 575	3 148	3 115
Honningsvåg	11 382	12 385	10 087	11 430
Kjøllefjord	4 623	4 040	3 677	3 597
Mehamn	2 181	2 865	1 844	2 229
Berlevåg	1 799	2 550	1 666	1 914
Båtsfjord	2 721	2 640	2 385	2 276
Vardø	4 187	5 012	4 140	4 460
Vadsø	10 602	1 498	8 806	1 421
Kirkenes	55 666	66 960	61 114	72 322

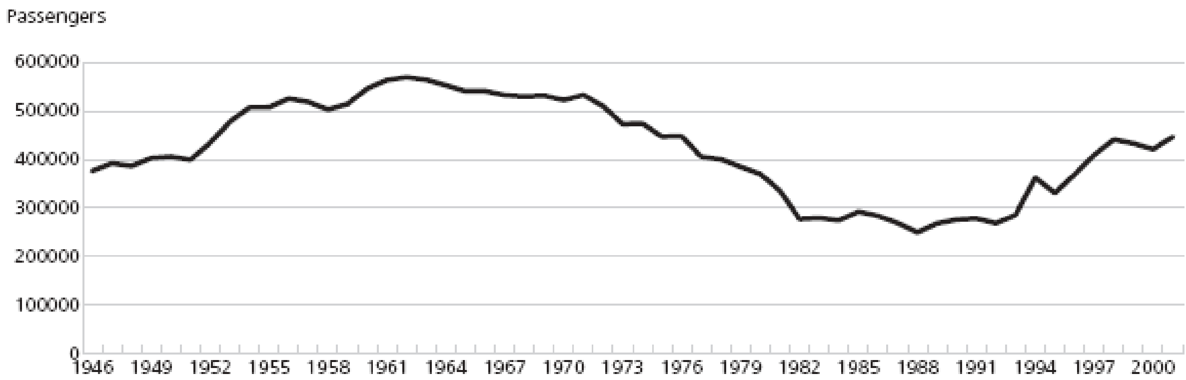

Figure F.2 - Number of passengers total 1946-2001 [29].

F.2 Ports that Hurtigruten Visits [29].

Bergen - is an old town, with some remaining buildings from the 12th and 13th centuries. With 213000 inhabitants it is one of the largest towns in Norway. The population is even larger considering the students at the University. The ships begin here their twelve day long journey to Kirkenes, and back - one ship leaving Bergen almost every day of the year.

Florø - is a relatively new town, founded in 1860. The town developed around the fishing of herring, but the herring stocks along the norwegian coast has fluctuated drastically over the years. Today the main industries are fish farming and food for fish farming, and the supply base for one of the large oil fields outside the coast. About 5.000 inhabitants live in Florø, and another 5000 lives in the rest of the municipality.

Måløy - is one of the largest fishing ports in Norway. Every year 180000-200000 tones of fish are landed here. The industri deep-freezes, dries or preserves fish in cans, and exports large quantities abroad. In Måløy lives just 2500 inhabitants.

Torvik - is the name of the port Hurtigruten visits in Hærøy municipality, an area with some 8000 inhabitants. The main industries are fishing and boat building.

Ålesund - In the capital of Sunnmøre lives 35000 inhabitants. The main industries are fishing and industries related to fishing, ships and oil.

Molde - is a very nice town situated in Romsdalsfjorden. Sheltered from the Norwegian Sea, the mild climate with green vegetation and rose gardens has given the town its nickname - "the Town of Roses". It is an administrative and trade centre with 22000 inhabitants, with several industries and education facilities up to university level and it is also a tourist town.

Kristiansund - in 1992 the town was linked to the mainland with two long bridges and a subsea tunnel of 5,2 kilometers. This increased the possibilities for traffic, together with the airport. Today 17000 inhabitants live here. Beside the traditional industries such as fishing and herring industry Kristiansund also has become involved in the oil business.

Trondheim - This town in the middle of Norway is constantly changing and developing. In Norway it is a well known centre for commerce, administration and education. Trondheim has 154000 inhabitants and a large number of students, probably 15000–20000.It is also known for an active winter sports scene.

Rørvik - with 2500 inhabitants, is the capital of the island group Vikna consisting of almost 6000 islets, skerries and islands. The town lies in a sound between Vikna and the mainland, and all coastal traffic passes. This makes Rørvik a trading and shopping centre. It is one of the ports where the northbound and the southbound Hurtigruten ships meet.

Brønnøysund - was founded in 1923 as a reloading place for sea and land traffic. Today 3000 persons live in the town.

Sandnessjøen - has been a trade centre for more than 300 years in 'modern time'. In 1891 the town became a port of Hurtigruten, which gave it an even greater importance.

Nesna - is a small village with 950 inhabitants, located near the opening of Ranafjorden which stretches 70 kilometers inland to the town of 'Mo i Rana'.

Ørnes - became a place of trade since 1794, and although several fires have ravaged the town there are still houses left from the early 1800s. Today 1500 inhabitants live here.

Bodø - is a large town, with 38000 inhabitants, and more than 1 000 students attending the colleges of higher education. Bodø is also a young town. It became a trading centre in 1816, and grew rapidly during the 1860s and 1870s when there were plenty of herring off the coast. Meanwhile various fishing-related industries were established, but also more independent industries.

Stamsund - is the southernmost port for Hurtigruten on the Lofoten Islands. It is a new village, with the construction of it begun in the first half of the 1900s. Today it is Lofotens largest fishing village, with 1300 inhabitants. The main products are cod liver oil, dried cod and guano.

Svolvær - is seen as the capital of Lofoten, nowadays a centre for three main interests: fishing, mountain and winter sports, and painters. The town has 4000 inhabitants, the municipality 9.000 inhabitants. In Svolvær the industries handle fishing and related products, although the amount of the fishing has decreased since the 1940s. Today there are less than 3000 fishermen, catching about 20 million kilograms of cod.

Stokmarknes - has been a trading post since 1776. In 1881 the steamship company Vesteraalens Dampskibsselskap was founded in Stokmarknes, with captain and tradesman Richard With - the initiator - as the companys first captain. The company began in 1893 the traffic in what today has become Hurtigruten. Today the town has 3500 inhabitants, living of fish and shrimp processing facilities among others.

Sortland - is a town with 4000 inhabitants. Beside the fishing industries the island has agricultural land. Strategically located Sortland has been a trading place for ages.

Risøyhamn - is the small port Hurtigruten visits on the fascinating island Andøya. The village, a trading post from 1777, today has around 350 inhabitants.

Harstad - is a large town with 23000 inhabitants, and a wide spectrum of industries. Fishing and shipping industries, of course, but also dairy and meat processing industries.

Finnsnes – it is one of the most important trading centers in the district, with 5000 inhabitants in the town and another 6 000 in the rest of the municipality. Among the industries is a banana ripening facility.

Tromsø - is situated at one of the main routes along the Norwegian coast. Today the town has 52000 inhabitants, and schools and colleges catering for 13000 pupils. Beside the fishing and trade industries Tromsø is an administrative centre and one of the northernmost brewery.

Skjervøy – is a small town which has 2300 inhabitants. The main industries are concentrated around fishing

Øksfjord - is a small town, with 800 inhabitants. It is the administrative centre for the municipality Loppa, where 1600 inhabitants live. Local industries are related to fishing and shipping.

Hammerfest - today has 7000 inhabitants, and the municipality has a total of 10000 inhabitants. The main industries are fishing, shipping, tourism and commerce.

Havøysund – is a fishing village and has 1500 inhabitants. The majority of the inhabitants have moved to the village from the islands lying further out in the ocean.

Honningsvåg - is a small but very important fishing village. The municipality has 4.000 inhabitants, of which 2800 lives in the village. But 4000-5000 ships enters the harbour each year, for trade, industrial transports and to bunker. And the local airport has 20000 passengers a year.

Kjøllefjord – is a fishing village on the centre of the municipality Lebesby, which has a population of 1700 persons. The village is situated at the end of the fjord.

Mehamn - is a 'newer' fishing village at the north of the peninsula Nordkynhalvøya. The municipality has 1400 inhabitants.

Berlevåg - lies open to the ocean, with a port that has no natural protection. The 1300 peoples living in Berlevåg are mainly occupied in fishing and shipyard industries.

Båtsfjord - is one of the major catch landing centers in Norway. Here are a number of industries related to fishing and shipping, such as a freezing plant and a filleting factory. The town lies in a fjord, and the harbour is sheltered from the waves. Today the municipality has 2300 inhabitants. Båtsfjord has an airport handling 8000 passengers yearly.

Vardø - is the easternmost town in Norway. It became a trading centre in 1789. The towns location on the doorstep to the Barents Sea makes it an important fishing port. About 3000 inhabitants live in Vardø today.

Vadsø - is the administrative centre in the area. The population of 6000 works mainly in the fishing industry and the administration.

Kirkenes - is close to Finland and Russia. The main industry during the 20th century has been iron ore mining. Exports began in 1910 and lasted until 1997. The open air mine got too expensive to use when they had to get deeper to extract ore. Other industries include saw mills handling timber from the forest in the Pasvik Valley, and a ship yard for the fishing fleet. Kirkenes has 5000 inhabitants, and the municipality 9900. The E6 highway ends here, as do the Norwegian domestic flights - and it is the turning-point of Hurtigruten.

F.3 Norwegian Coastal Voyage Ships [30]

MS Midnatsol

- company: TFDS, Tromsø
- year built: 2003
- length: 135,75 m
- width: 21,5 m
- GRT: 16140
- passengers: 1000

MS Trollifjord

- company: TFDS, Tromsø
- year built: 2002
- length: 135,75 m
- width: 21,5 m
- GRT: 16151
- passengers: 822

MS Finnmarken

- company: OVDS, Narvik
- year built: 2002
- length: 138,5 m
- width: 21,5 m
- GRT: 15000
- passengers: 1000

.

MS Nordnorge

- company: OVDS, Narvik
- year built: 1997
- length: 123,5 m
- width: 19,5 m
- GRT: 11380
- passengers: 691

MS Polaryls

- company: TFDS, Tromsø
- year built: 1996
- length: 123 m
- width: 19,5 m
- GRT: 11341
- passengers: 737

MS Nordkapp

- company: OVDS, Narvik
- year built: 1996
- length: 123,3 m
- width: 19,5 m
- GRT: 11386
- passengers: 691

MS Nordlys

- company: TFDS, Tromsø
- year built: 1994
- length: 121,8 m
- width: 19,2 m
- GRT: 11204
- passengers: 691

MS Richard With

- company: OVDS, Narvik
- year built: 1993
- length: 121,8 m
- width: 19,2 m
- GRT: 11205
- passengers: 691

MS Kong Harald

- company: TFDS, Tromsø
- year built: 1993
- length: 121,8 m
- width: 19,2 m
- GRT: 11204
- passengers: 691

MS Vesterålen

- company: OVDS, Narvik
- year built: 1983
- length: 108,6 m
- width: 16,5 m
- GRT: 6261
- passengers: 560

MS Narvik

- company: OVDS, Narvik
- year built: 1982
- length: 108,6 m
- width: 16,5 m
- GRT: 6257
- passengers: 500

Appendix G. Route of Coastal Boats

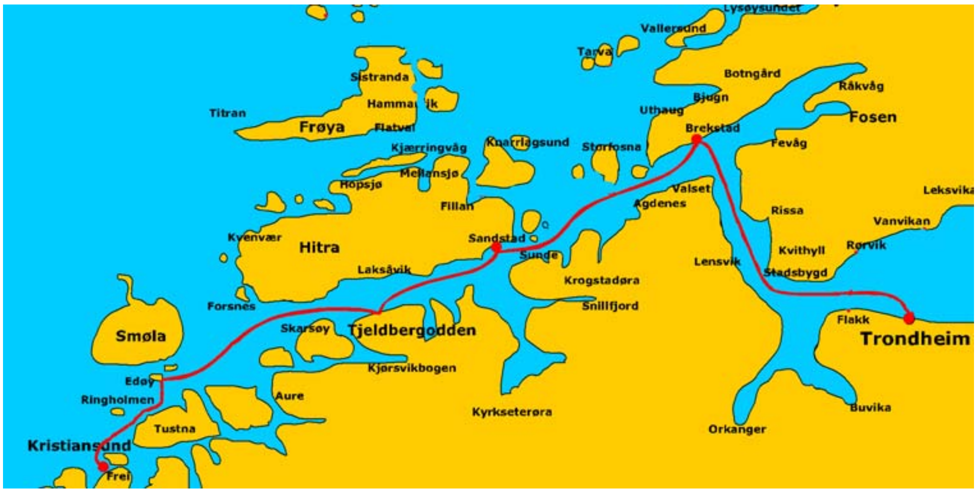

Figure G.1 - Route map of coastal boats between Kristiansund and Trondheim [19].

Table G.1 - Timetable of coastal boats Kristiansund and Trondheim [19].

Kystekspressen
Kristiansund - Trondheim

Fra	Dx67				6	7		
Kristiansund	**0800**	**1140**	**1630**	**2000**	**1400**	**1215**	**1600**	**2000**
Ringholmen	c	c	c	c	c	c	c	c
Edøy	0835h	1215h	1705h	2035	1435h	1250	1635	2035h
Kjørsvikbugen(g)	0910	1250	1740		1510	1325	1710	
Sandstad (x)	**0940**	**1320**	**1810**		**1540**	**1355**	**1740**	
Leksa	0950b						1750	
Brekstad	**1020**	**1400**	**1850**		**1620**	**1435**	**1820**	
Lensvik		1425					1845	
Kvithyll			1910					
Trondheim	**1115**	**1500**	**1945**		**1715**	**1530**	**1920**	

Table G.2 - Timetable of coastal boats Trondheim and Kristiansund [19].

Kystekspressen
Trondheim - Kristiansund

Fra	Dx67				6		7	
Trondheim		**0800**	**1150**	**1630**		**1400**	**1215**	**1600**
Kvithyll		0830						
Lensvik				1700d		1430		1630
Brekstad		**0855**	**1245**	**1730**		**1500**	**1310**	**1700**
Leksa			1305	1750a				
Sandstad (x)		**0935**	**1320**	**1805**		**1530**	**1345**	**1735**
Kjørsvikbugen (g)		1005	1350	1835		1600	1415	1805
Edøy	0705h	1040h	1425h	1910	0900h	1635	1450	1840h
Ringholmen		c	c	c	c	c	c	c
Kristiansund	**0740**	**1120**	**1505**	**1950**	**0935**	**1715**	**1530**	**1920**

Appendix H. Maritime Transport in Norway

Table H.1 - Domestic maritime transportation in 2001. Passengers transported by vessels operating domestically Vessels registered in the Norwegian Ordinary Ship Register [29].

Vessel group	Number of passengers	Number of operating vessels
Total	49 557 379	415
Norwegian Coastal Voyage Vessels	446 684	11
Car ferries	36 220 310	196
Other passenger ships and ferries[1]	12 890 385	208

Table H.2 - The merchant fleet. Norwegian Ordinary Ship Register[2]. The number of vessels by type of vessel in1999 [29].

Type of vessel	Number of vessels
Total	954
Tankers, total	50
Gas carriers	-
Chemical tankers	2
Other tankers	48
Dry cargo vessels, total	904
Combined carriers[3]	6
Bulk carriers[4],[5]	1
Refrigerator vessels and freezing vessels	9
Passenger vessels and ferries	404
Supply vessels for oil activity	112
Other dry cargo vessels[5]	372

[1] Comprises all vessels in local service traffic registered in Norwegian Ordinary Ship Register above 50 gross tons.

[2] Vessels of 100 gross tons and over for transport of passengers and goods.

[3] Including ore/oil carriers, bulk/oil carriers and ore/bulk/oil carriers.

[4] Including ore carriers.

[5] Bulk carriers less than 6 000 gross tons are included in other dry cargo vessels.